GA no 282826

Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction

Deliverable No. D1.3

Final report based on Conference Proceedings of Final Project Conference

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Nature		
R	Report	x
O	Other	

Deliverable Details		
Due date:	31.05.2015	
Submission date:	31.07.2015	
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Involved participants:	All SECTOR Participants	
WP no. and title:	WP 01 Project Management	
WP leader:	DBFZ	
Task no. and title:	1.2 Reporting and Contact to EC	
Task leader:	DBFZ	
Draft/Final:	FINAL	
Keywords:	Torrefaction, Final Project Meeting, Presentations, Project Management	

Table of Contents

1 Summary

The SECTOR Final Project Meeting took place from 6th to 7th May 2015 at the coordinator´s site, Deutsches Biomasseforschungszentrum (DBFZ) in Leipzig, Germany. Nearly 50 participants from different European countries came to attend the meeting and to learn about the improvements achieved in torrefaction, to which the EU-funded project SECTOR has considerably contributed during the last 3.5 years. Next to the project partners, the public part of the meeting was attended by members of the IBTC (International Biomass Torrefaction Council) from different states, industry, various universities and other stakeholders interested in torrefaction, e.g. from Japan, France and Germany. A visit of the DBFZ facilities gave an insight into the various research activities and facilities of the project coordinator including a visit of the technical centre, the laboratories and combustion test facilities, which also have been used for tests during the project.

Figure 1: SECTOR-partners during the visit of the DBFZ facilities

The detailed results based on the presentations annexed to this report will be published in a separate paper.

2 Agenda

The meeting was divided into two parts: a public meeting and a project internal meeting. The public meeting aimed to inform all interested stakeholders about the progress, findings and results of the SECTOR project. The public meeting commenced with a presentation giving a general overview about the project background and its objectives. For more detailed information the project partners presented objectives, the most important results achieved in their work packages and gave an outlook about further research required in four different sessions. Following the main findings about the improvements of the torrefaction technology, the strategy and perspectives for market implementation of this technology and its possible products was presented and discussed. After every presentation meeting participants had time for questioning and commenting. Table 1 gives an overview of the sessions and their presentations given during the public part of the meeting.

Table 1: Overview of the sessions and presentations of the public SECTOR meeting on 06.05.2015

Sessions	Presentations	Speaker/Partner
I “Torrefied fuels”	Torrefaction	Michiel Carbo / ECN
	Densification	Wolfgang Stelte / DTI
	Demonstration	Alex Adell / Topell
II “Logistics”	Handling and Logistics	Michiel Carbo / ECN
III “End-use”	Co-milling	Collins Ndibe / USTUTT
	Co-firing	Jaap Koppejan / Procede
	Co-gasification	Linda Pommer / UmU
	Small-to-medium scale combustion	Fritz Biedermann / BIOS
IV “Value-chains, sustainability and standardization”	GHG Emission Value Chains	Stefan Majer / DBFZ
	Environmental Assessment	Markus Meyer / UFZ
	Standardization	Eija Alakangas / VTT
V “Strategy and perspectives for market implementation”	Market Perspectives	Janet Witt / DBFZ

On the second day, all meeting participants were invited to visit DBFZ to get an insight into its research activities and facilities, e.g. the technical centre, the densification unit, the combustion test system and the biogas research plant. The second part of the final meeting was exclusively foreseen for the project partners. Partners were informed about details of the 3rd amendment, the schedule for the upcoming reporting and the dissemination activities by DBFZ. During the second part of the internal meeting, WP leaders presented the impacts achieved through the participation in the SECTOR project, which were summarized for the topics technology, end-use and framework conditions. Regarding technology, SECTOR has considerably contributed to identify stable process conditions and recipes to meet end user requirements and contribute to an increasing confidence levels amongst relevant stakeholders and thus reducing the risks of implementing torrefaction. For the end use of torrefied pellets in co-firing and co-gasification as well as in small and medium scale combustion has been proven. End-user requirements and logistic demands regarding REACH and MSDS have been investigated, hereby supporting market implementation. The main impact of the tasks related to framework condition was the development of new test methods and the validation of existing ones for standardization (fuel specification and analysis), based on a broad data set from the project research. Value chains and sustainability have been assessed with a new developed tool (BioChainS), which can be used in future. These are based on real data from extensive tests and research, thus providing a new quality of research results.

3 Presentations

Please refer to Annex I for the presentations of the public final SECTOR project meeting.

4 Conclusions and Outlook

The aim of the SECTOR project to support the market introduction of torrefaction-based bioenergy carriers as a commodity renewable solid fuel has been achieved by technology optimization through extensive testing. During SECTOR, project partners have been able to produce more than 150 tons of torrefied biomass of a better and more constant quality which resulted in dedicated recipes for the torrefaction and densification of various feedstocks. The properties of pellets have been tested in various end-use applications, outside storage and handling. Furthermore, new analysis methods of fuel properties and parameters have been successfully tested in more than 50 labs worldwide using the torrefied pellets from the SECTOR project. Based on this assessment, the new standard ISO 17225-8 "Solid biofuels - Fuel specifications and classes - Graded thermally treated densified biomass” was proposed. Lastly, a methodology has been developed for both the life-cycle-assessment and socio-economic assessment of the torrefaction-based value chains; the environmental assessment has been done in the form of case studies for specific focus regions.

Project results were disseminated at more than 50 conferences, two public workshops and to standardization committees and platforms through the memberships of different SECTOR partners. In the next months, the project objectives will be finalized by fulfilling the co-firing tests in Finland, transfer all assessment results into safeguards for sustainability and development of a standard.

The SECTOR partners developed a torrefaction-based bioenergy carrier ready for the market. Caused by changing market conditions, the next steps of market implementation require a coordinated approach. This is initiated in a policy and technology workshop in June 2015 in Brussels, jointly organized by the projects SECTOR and BioBoost.

There is still some work to be done in torrefaction, which has to be carried out step by step, stated by Michael Wild, director of the International Biomass Torrefaction Council (IBTC), at the final project meeting. The SECTOR project comes to an end, however he confirmed that the market is still highly interested in further research.

SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SECTOR - FINAL PROJECT MEETING

Date: 06.05.2015

Place: Leipzig, Germany

Project Partner: DBFZ (Coordinator), VTT, ECN, DTI, EON, USTUTT, OFI, UmU, CENER, Topell, Vattenfall, DB, Procede, IEN, TFZ, BIOS, BE2020, TU Wien, UFZ, SLU






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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SECTOR - Background and Overview

Final Project Meeting, 06.05.2015 in Leipzig

Daniela Thrän
Janet Witt
Kay Schaubach
Marlen Ristola
Virginie Bellmann






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Welcome to Leipzig,

welcome to the final meeting of SECTOR!

Leipzig in the middle of Germany celebrates its 1,000th city jubilee

Source: Leipzig.de

and SECTOR as a large-scale European project with a consortium of 21 partners from industry and science is close of being finalized.

SECTOR
Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Source: openstreetmap.de

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Welcome to Leipzig,

welcome to the final meeting of SECTOR!

We are here at Mediencampus Villa Ida , the place of the „Leipzig School of Media« ".

… hosted by DBFZ

- Mission: applied research for efficient integration of biomass into sustainable energy supply
- About 200 employees working in 4 research departments

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DBFZ - short introduction

- **Development:**
  - Founded on 28th February 2008 in Berlin as non-profit limited company
  - Sole shareholder: Federal Republic of Germany, represented by the Federal Ministry of Food and Agriculture (BMEL)
- **Mission:**
  - The key scientific mission of the DBFZ is to provide wide-ranging support for the efficient integration of biomass as a valuable resource for sustainable energy supply based on applied scientific research.
- **Structure:**
  - About 200 employees are working in the administration and the four research departments.

Source: DBFZ

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06.05.2015 - agenda for today

08:30 - 09:00	*Welcome Coffee + Registration*
09:00 - 09:45	**Welcome & Introduction** Objectives of the EU, objectives of SECTOR
09:45 - 11:15	**Session I "Torrefied fuels" (each 20 min presentation + 10 min discussion)** (torrefaction, densification, demonstration)
11:15 - 11:45	**Session II "Logistics" (20 min presentation + 10 min discussion)** (storage and handling)
11:45 -13:00	*Lunch Break*
13:00 - 14:30	**Session III "End-use" (each 20 min presentation + 10 min discussion)** (co-firing, co-gasification, small-to-medium-scale combustion)
14:30 - 16:00	**Session IV "Value-chains, sustainability and standardisation" (each 20 min presentation + 10 min discussion)**
16:00 - 16:30	*Coffee Break*
16:30 - 17:30	**Session V "Strategy and perspectives for market implementation"**
19:00 - …	*Get-together/Dinner*

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The SECTOR project - Facts

...a pan European consortium

Source: DBFZ

Project start:	01.01.2012
Duration:	42 months (+6)
Total budget:	10 Mio. Euro
Participants:	21 from 9 EU-countries
Coordinator:	DBFZ

Midterm Project Meeting October 2013 in Pamplona/Spain

Source: DBFZ

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Partners

University of Stuttgart Germany

DANISH TECHNOLOGICAL INSTITUTE

Deutsches Biomasseforschungszentrum gemeinnützige GmbH DBFZ

e·on

SLU Swedish University of Agricultural Sciences

ECN

VATTENFALL

ofi

VTT

JEN

Topell Energy

UMEÅ UNIVERSITET

cener centro nacional de energías renovables FUNDACIÓN CENER CIEMAT

PROCEDE BIOMASS B.V.

DOOSAN Doosan Power Systems

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

TU WIEN

Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe

bioenergy2020+

BIOS BIOENERGIESYSTEME GmbH

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Daniela Thrän

PROJECT BACKGROUND AND OBJECTIVES

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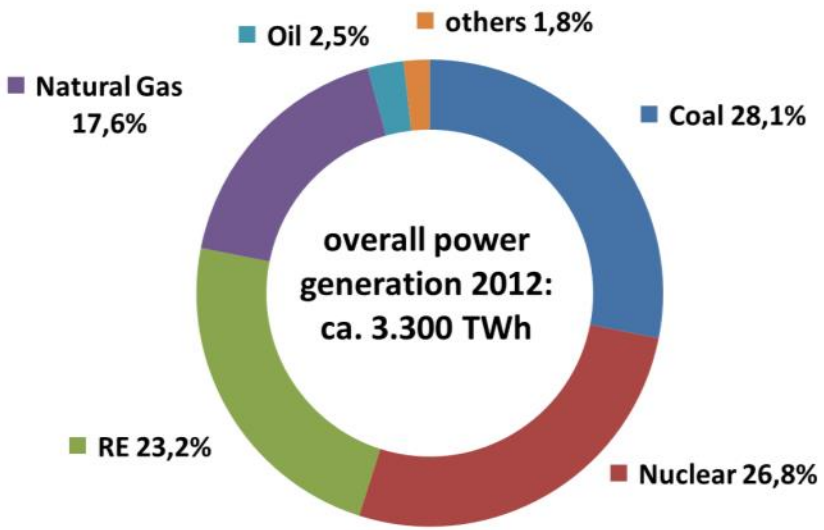
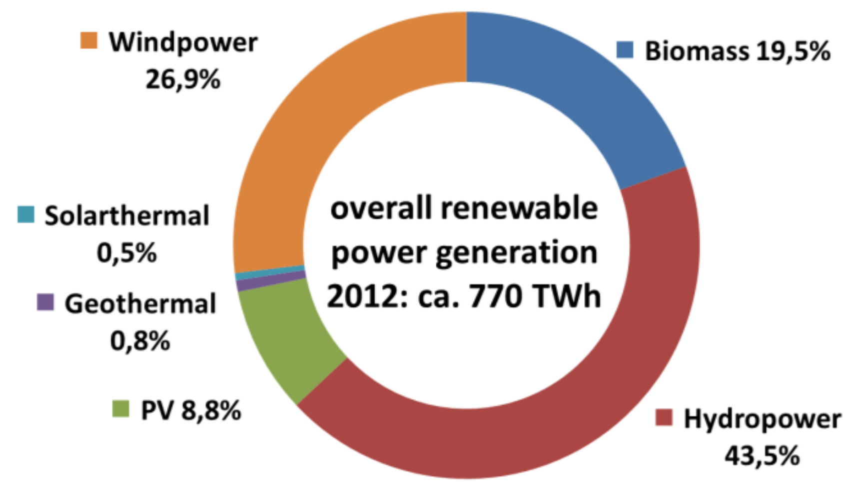
Status Quo: power generation in the EU 2012





Others: industrial residues, not renewable municipal waste, pump storage etc.

Source: DBFZ, based on ZSW and Eurostat

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The way ahead: R&D focus areas - EC goals

- 20-20-20 goals defined for 2020
  - CO_2 emission reduction of 20% compared to 1990
  - Energy efficiency increase of 20%
  - Renewable energy share of 20% in the overall energy consumption
- Targets for 2030 of the EC
  - CO_2 emission reduction of 40% compared to 1990
  - Renewable energy share of 27% in the overall energy consumption
  - 30% improvement in energy efficiency (compared to projections)

https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

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The way ahead: EC policies to achieve the targets

- A reformed EU emissions trading scheme (ETS)
- New indicators for the competitiveness and security of the energy system, such as price differences with major trading partners, diversification of supply, and interconnection capacity between EU countries
- First ideas on a new governance system based on national plans for competitive, secure, and sustainable energy. These plans will follow a common EU approach. They will ensure stronger investor certainty, greater transparency, enhanced policy coherence and improved coordination across the EU.

https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

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The role of torrefaction

- Large scale implementation of bioenergy
- Improvement in long-distance transport, storage, handling
- Superior properties for major end-use applications
  - Coal cofiring: existing equipment may be used
  - Gasifiers: meeting the stringent fuel requirement
  - Pellet boilers: higher energy density, possibly lower emissions
- Done properly, it can reduce costs and emissions
- Exploitation of residues
- Besides energy, starting point for biorefinery routes

→ Part of the Implementation Plan and Technology Roadmap of the European Industrial Bioenergy Initiative (EIBI) and
→ Strategic Energy Technology Plan (SET plan)

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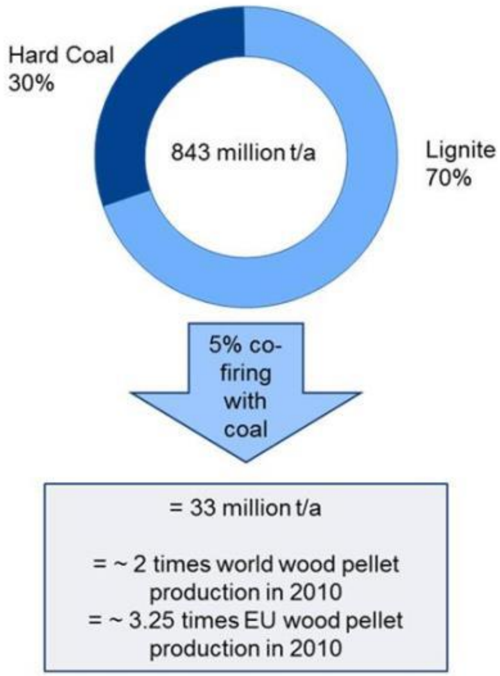
Estimated biomass pellet demand and Cofiring potential of torrefied pellets in Europe

Wood pellet cofiring potential (5% with coal) in more than 100 existing pulverised coal-fired plants in Europe



- Total coal use was 772 million tons in Europe in 2012.
- Biggest coal users in Europe are Germany, Poland, Ukraine, United Kingdom and Czech Republic.
- By torrefied pellets replacement could be as high as 50%*, this makes European market hugely significant.

2013: worldwide wood pellet production about 23 Mio. t
2014: EU production approximately 20 Mio. t wood pellets

source: Pöyry, pelletforum

*source: *Wilén, C., Jukola, P., Järvinen, T., Sipilä, K. Verhoeff, F. & Kiel, J. 2013.* Wood torrefaction – pilot tests and utilisation prospects, VTT Technology 122, 73 p.

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Biomass potentials and availability

- **Biomass resources are limited** and an **increasing competition** with material use is seen about high quality fractions (especially round wood)
- The energetic **use of large potentials is often very inefficient** (especially in non-developed countries)
- The **cultivation of energetic biomass plants (e.g. SRC) is limited according to the area potential** (→food & fodder cultivation, natural protection etc.) and expensive
- New market actors compete about available amounts (Bioeconomy)
- **However:** Worldwide are still available biomass potentials, especially in the sector of agricultural and forestry residues as well as organic waste
- **But:** Biomass qualities and risks/benefits are often unknown
  - Agro-biomass contains higher amounts of chlorine, potassium and sodium (corrosion, emission and ash problems must be solved) → torrefaction process does influence such incredience rarely)
  - Experiences with untreated agro-biomass showed that cofiring ratio 10 to 20% should be possible
  - fuel prices can become competitive by efficient logistic concepts

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What is Biomass Torrefaction?

... destruction of hemicellulose, depolymerisation of cellulose and lignin (but it should keep its binding capacity (for pelletisation))

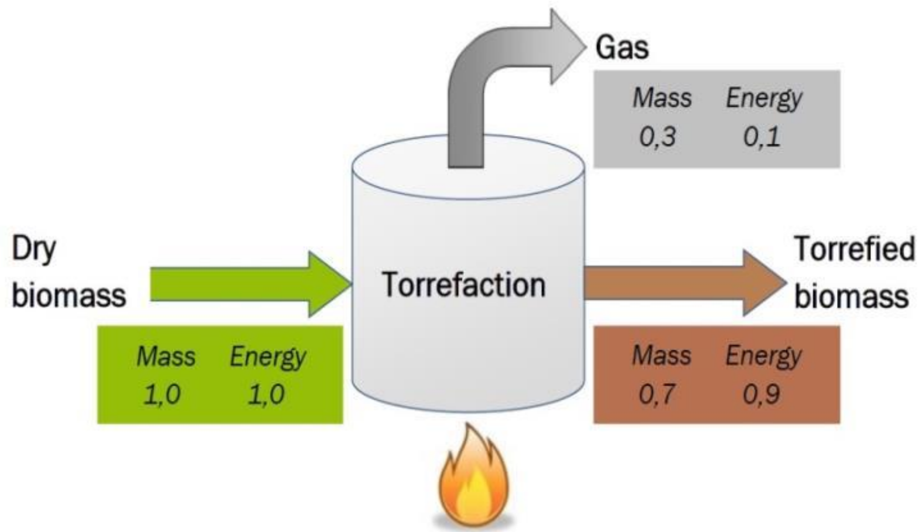
... a mild form of pyrolysis at temperatures typically ranging between 200-320°C

... thermal upgrading process of solid biofuels

...a dry, fat-free heating of plants (foodstuff) up to 300°C - extension for biofuels: in the absence of oxygen

... controlled carbonisation of biomass

Simplified mass and energy streams of the torrefaction process



© Masse- und Energiebilanz (DBFZ-Darstellung in Anlehnung an Basu, P., S. 94)

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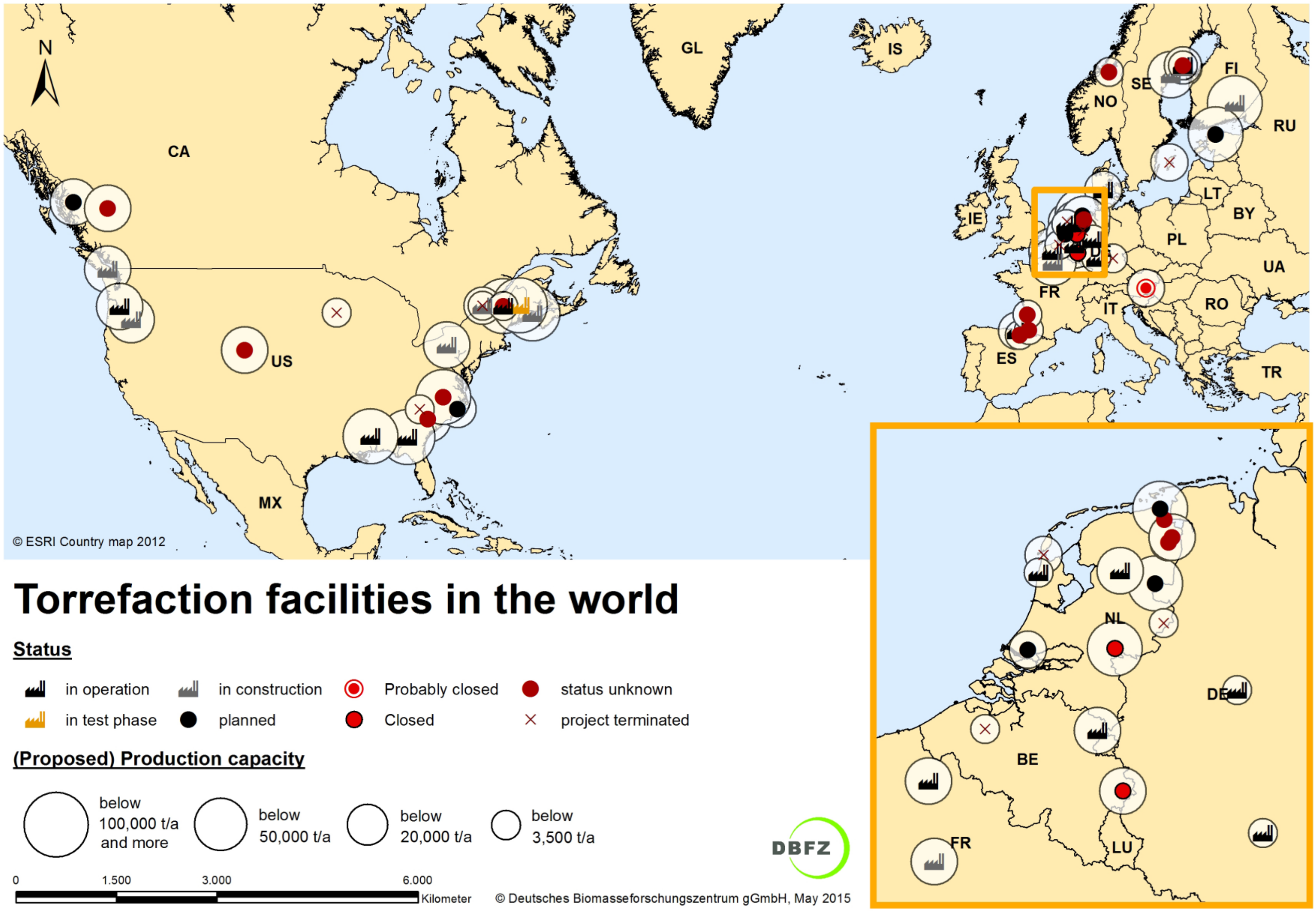
Distribution of (soon) operational torrefaction plants



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Where we stand today

Capacity		5-10 kg/h	30-200 kg/h	20-50 kton/a	60-200 kton/a
Woody biomass	Proof-of-principle	Proof-of-concept	Prototype (pilot-scale)	Technical demonstration	Commercial role out

Time	2002	2004	2006	2008	2010	2012	2014	2016	2018

Non-woody biomass residues	Proof-of-principle	Proof-of-concept	Prototype (pilot-scale)	Technical demonstration	Commercial role out

SECTOR

source: ECN

Proof-of-concept
- Experimentally based process designs
- Technology identification
- Knowledge base torrefaction
- Experimental infrastructures torrefaction
- Economic evaluations full-scale (study estimate 30%)
- Set-up pilot phase of development

Prototype (pilot-scale evaluation)
- Pilot plants / prototype technology
- Demonstration technical feasibility
- Process & product characterization (design)
- Economic evaluations full-scale (preliminary estimate 20%)
- Business plan(s) (technical demo, semi-commercial)

Technical demonstration
- Demonstration plants (semi-commercial)
- Technical optimization (refined design)
- Product applications (logistics & end-use)
- Economic evaluations full-scale (definite estimate <10%)
- Business plan(s) (commercial operation)

Commercial role out
- Commercial plants (full-operation)
- Quality control (product)
- Quality assurance (product)
- Best practice for sustainability
- Standardization (product)
- Purchase agreements (from energy & chemical sector)

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SECTOR Objectives I

- Further **development of torrefaction-based technologies** (up to pilot-plant scale and beyond) for production of solid bioenergy carriers from broad range of feedstock (domestic and imported biomass) including forestry residues and agro-residues
- Development of **specific production recipes**, validated through extensive lab-to-industrial-scale logistics and end-use performance testing
- Development and **standardisation** of dedicated analysis and testing methods for assessment of transport, storage, handling logistics and end-use performance

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SECTOR Objectives II

- **Assessment** of the role of torrefaction-based solid bioenergy carriers in **bioenergy value chains** – including bio-products – and their contribution to the development of the bioenergy market in Europe, including the development of deployment strategies and scenarios
- Full **sustainability assessment** of the major torrefaction-based biomass-to-end-use value chains, including:
  - socio-economic assessment
  - life cycle assessment (energy and GHG balances)
  - full environmental assessment
- **Dissemination** of project results to industry and into international forums (e.g. EIBI, EERA, CEN/ISO, IEA and sustainability round tables)

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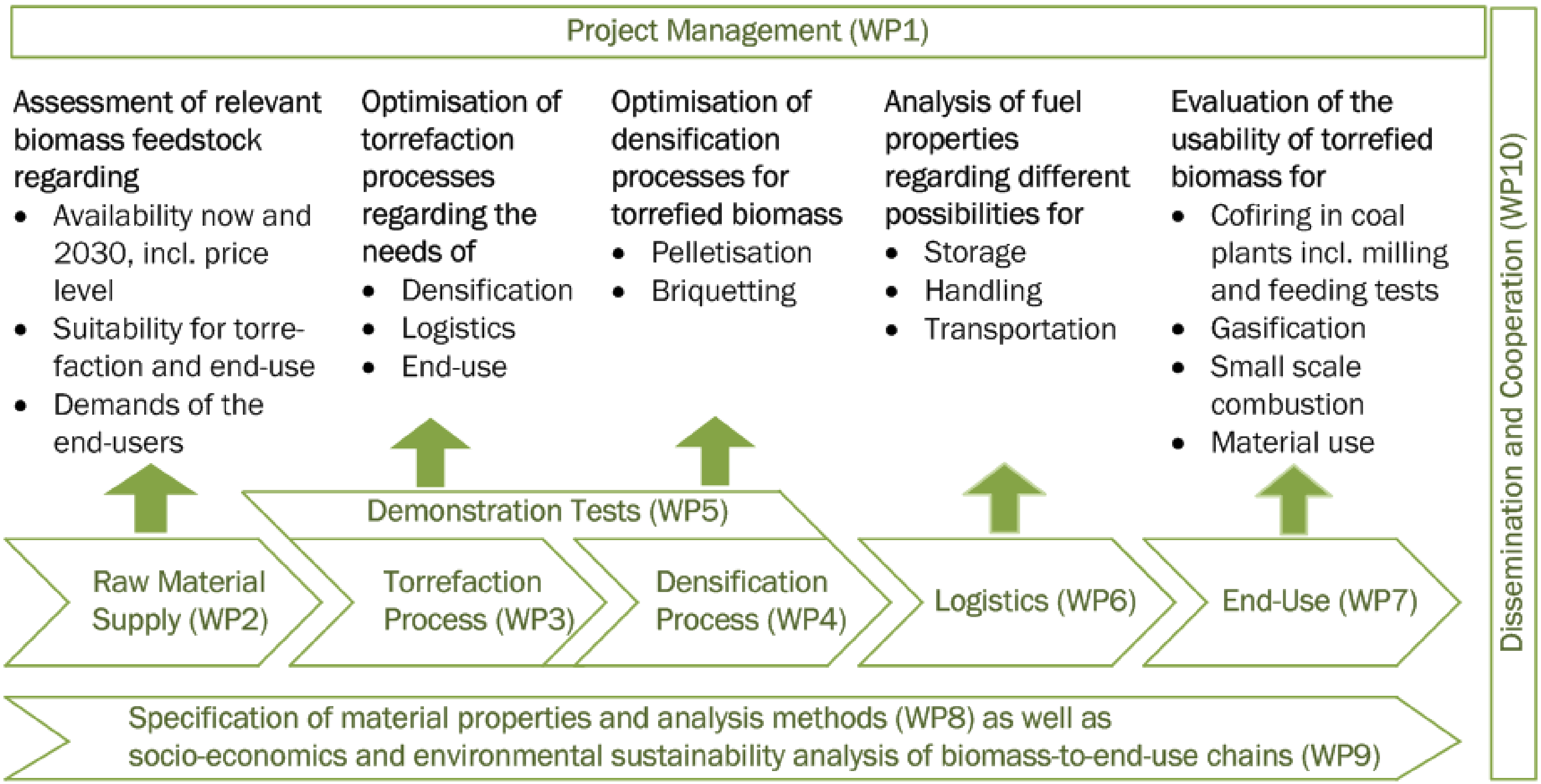
Project structure



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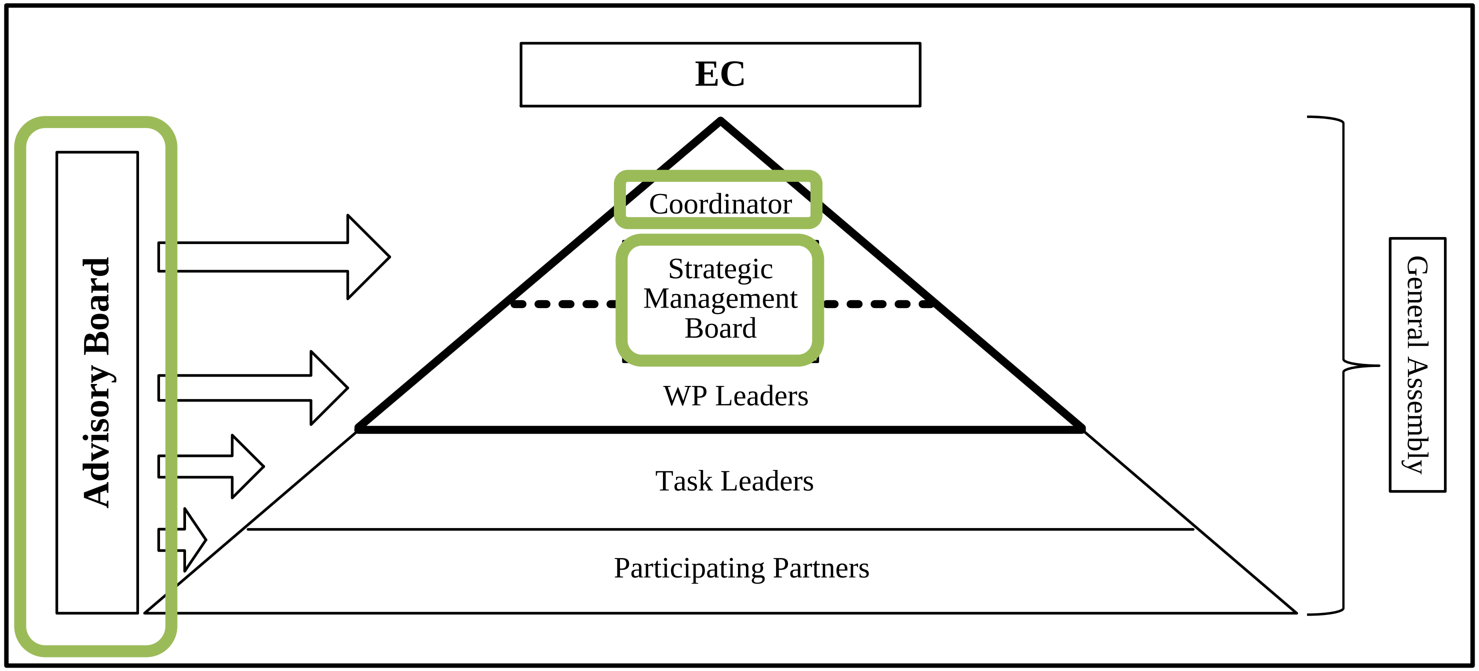
Management aspects: Project Management

- Main bodies are: Coordinator, Strategic Management Board (SMB) and Advisory Board (AB)
- WP- and Task leaders complete this structure
- All other partners are managed by their WP/Task leaders



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Project Management

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Former Project Management

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Strategic Management Board (SMB)

DBFZ	• Coordination & Assessment
ECN	• Technology
OFI	• Sampling/Analysis

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Advisory Board

Representative	Country	Company/Institution	Expertise
Panagiotis Grammelis	GR	CERTH	Greek research institute for research on indigenous solid fuels
Staffan Melin	CA	Wood Pellet Association of Canada	Representing the Canadian pellet industry, Active in ISO/TC 238/248
Hubert Röder	DE	University of Applied Sciences Weihenstephan-Triesdorf	Research on sustainable resources
Christian Rakos	BE	European Pellet Council	Expert in European pellet sector
Stefan Döring	DE	Plant Engineering	Expert and consultant for energy technology
Mieke Vandewal	NL	Peterson Control Union Group	Logistics, quality, certification and risk management
Michael Deutmeyer	DE	Green Resources AS	Expert for international biomass market
Michael Wild	AT	Wild&Partner	active in IEA Bioenergy Task 40, AEBIOM and President of IBTC

3-4 members of Advisory Board have taken part in both major project meetings with very valuable input and guidance

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Cooperation with Project "BioBoost"

Karlsruhe Institute of Technology

BioBoost

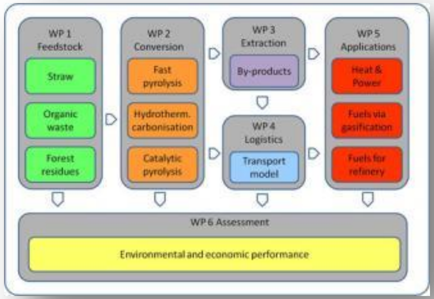
Extension of BioBoost logistics model with SECTOR results

Joint Policy Workshop in Brussels June 2015

Scenario development

Cross fertilization

REACH registration of products



pictures: bioboost.eu

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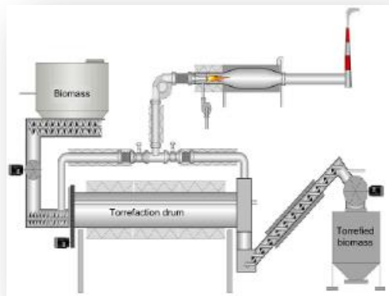
Torrefaction in SECTOR

Different technologies

Moving bed
(ECN)
pilot



© UmU

Rotary drum
(Umeå University)
pilot

Rotary drum
(CENER)
pilot

Toroidal bed
(Topell)
demo

Production with available pilot scale facilities
Typical test runs 50-100 hours
Typical production per test few tons
3-6 different feedstocks

Production with available demo plant
Continuous operation
Production of 100-200 tons
Specific feedstock

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Achievements - SECTOR milestones

Sampling analysis and test protocols validated through **round robin** testing

Value chains and deployment strategies and scenarios for further **sustainability assessment**

Optimised torrefaction & densification **recipes**

Feedstock selection for experiments based on availability, logistics & end-use boundary conditions

Results of **end-use testing** available to allow for optimisation of torrefaction & densification

2012 | 2013 | 2014 | 2015

Large scale batches of characterized torrefied products for tests in WP4, 6 and 7

Large scale batches of fully characterized densified torrefied feedstock for tests in WP6 and 7

Results of **initial logistics testing** to allow for optimisation of torrefaction & densification

Proposal for new product and quality assurance standards ready for forwarding to **CEN/TC and ISO**

Large scale milling and cofiring tests at Helen Limited

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Goals achieved

Support the market introduction of torrefaction-based bioenergy carriers as a commodity renewable solid fuel	All torrefaction-partners have **optimised their technologies** through extensive testing in SECTOR
	All torrefaction partners have developed **specific recipes** – more than 100t have been produced, quality demands are met
	New standard was proposed ISO 17225-8: "Solid biofuels - Fuel specifications and classes - Graded thermally treated densified biomass" and new analysis methods are being developed
	Assessment of torrefaction to activate more biomass potential and to enable international trade is ongoing
	Biomass to end use chains, storylines and scenarios were developed and calculated
	Project results were disseminated through more than 40 conferences, 2 workshops and through standardisation committees and platforms with membership of 13 SECTOR partners

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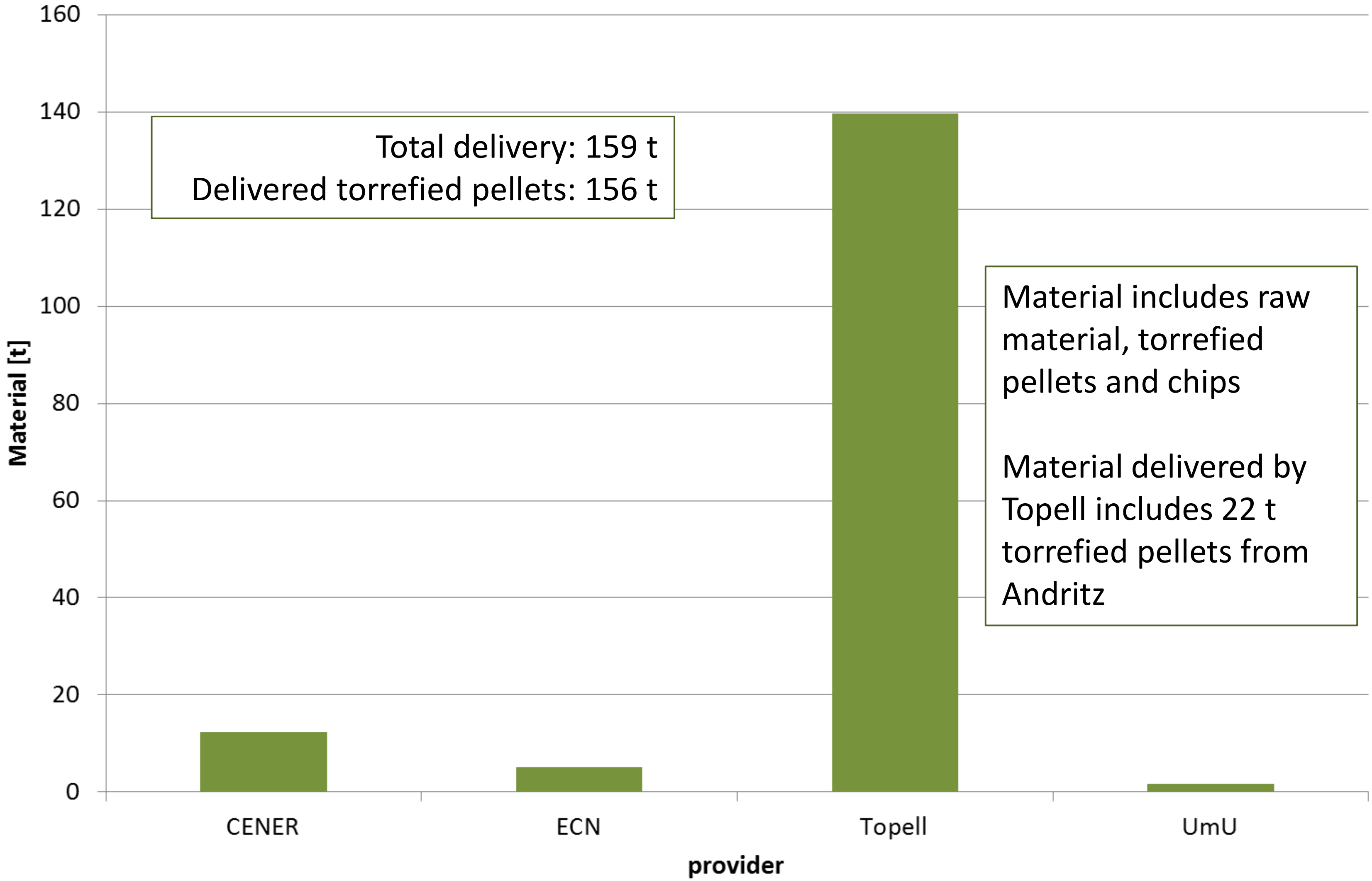
Torrefied and tested material in the project



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Conclusions

- All participants did excellent work despite many arising problems
- All project goals achieved or close to be achieved
- Now going into the details of the findings

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

thank you very much!

Daniela Thrän and the SECTOR Coordination Team

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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SESSION I – Torrefied Fuels
Part 1 - Torrefaction

Final Project Meeting, 06.05.2015 in Leipzig

Michiel Carbo
Energy Research Centre of the Netherlands - ECN






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Session I "Torrefied fuels" - Part 1: Torrefaction

- Execute series of lab/batch- and pilot tests in different torrefaction facilities in order to:
  - Further optimise torrefaction technologies (ECN, Umea Univ., CENER, Topell)
  - Broaden the feedstock range
  - Produce solid sustainable bioenergy carriers with properties that meet requirements set by subsequent densification, logistics and end-use

- Partners: CENER, ECN, OFI, Topell, UmU, VTT

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 282826

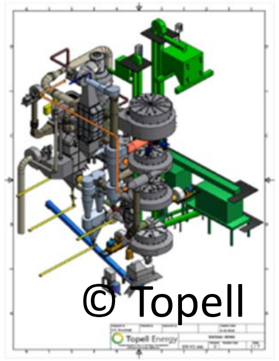
Torrefaction technologies

Different technologies

Moving bed*
(ECN)
pilot

Rotary drum / Auger
(Umeå University)
pilot

Rotary drum
(CENER)
pilot



Toroidal
(Topell Energy)
demo

Production with available **pilot scale facilities**
Typical test runs 50-100 hours
Typical production per test few tonnes
3-6 different feedstocks

Production with available **demo plant**
Continuous operation
Production of 100-200 tonnes
Specific feedstock

** And the resulting Andritz/ECN technology, successfully demonstrated in Denmark at a scale of 1 ton/h*

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 282826

Lab-scale torrefaction tests

- TGA measurements
  - On following feedstocks
    - ECN poplar, pine, spruce, bamboo
    - UmU pine, willow
    - CENER pine, straw
    - Bintuni mangrove
    - Viridis Energy PKS
    - Cradle Crops miscanthus
    - Anbenna sun flower husk
  - At following temperatures
    - 240, 260, 280, and 300°C

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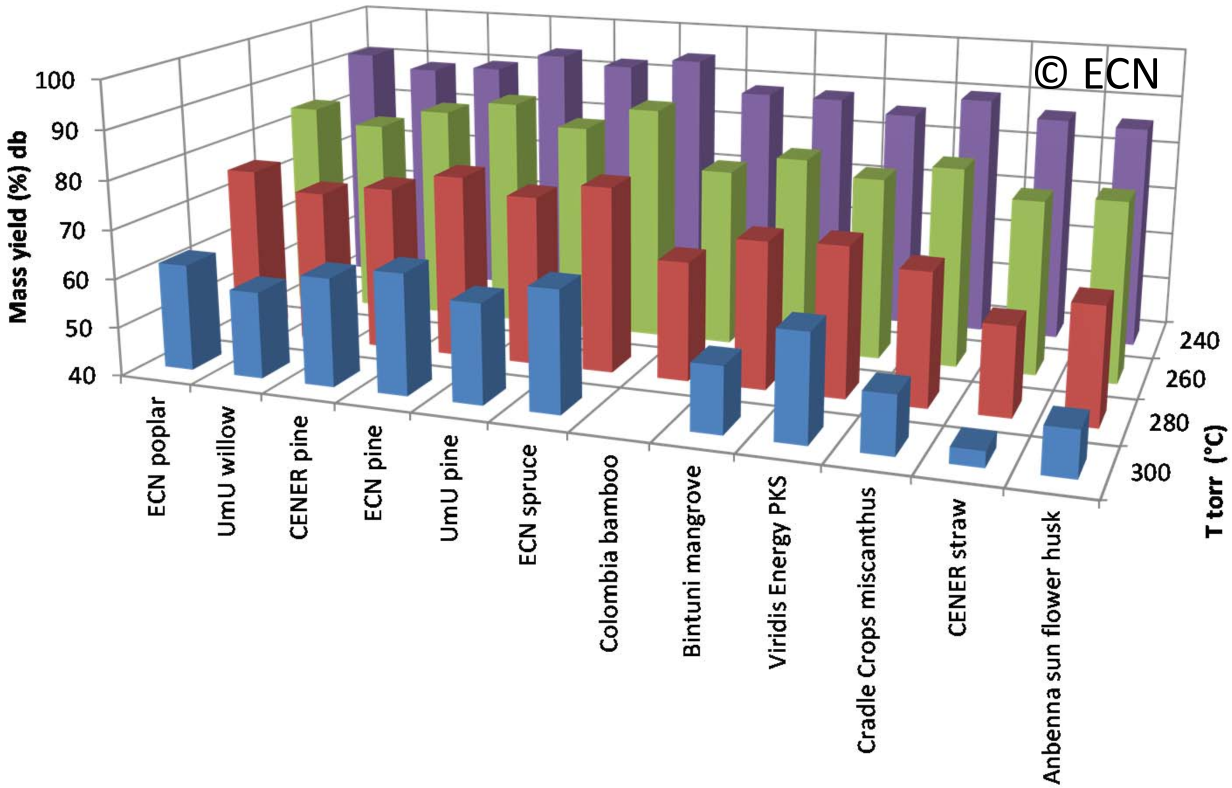
Lab-scale torrefaction tests

- TGA measurements
  - Mass yields at 45 min after reaching 200°C



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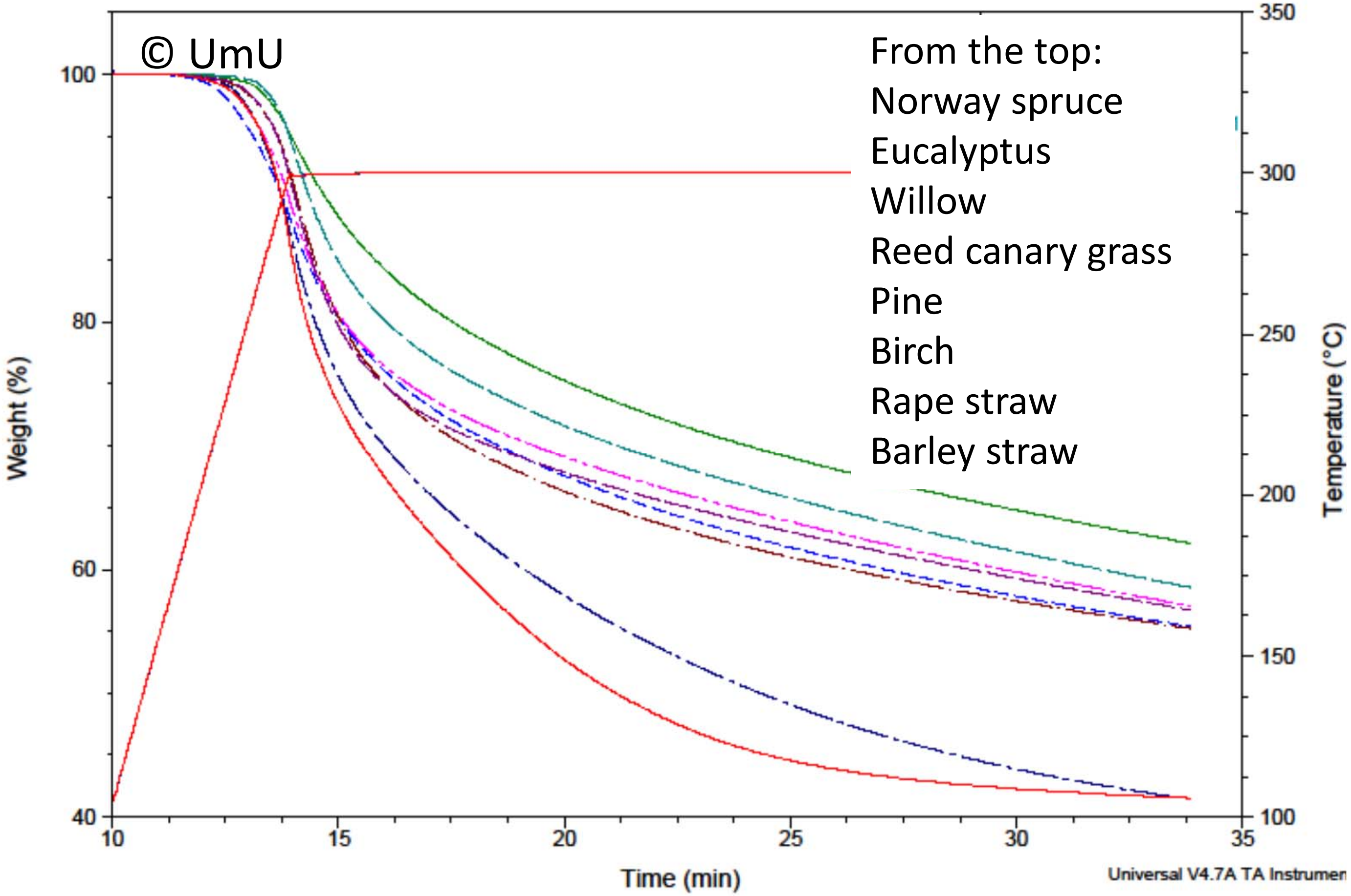
Lab-scale torrefaction tests

- Mass loss rate profiles (TGA experiments)



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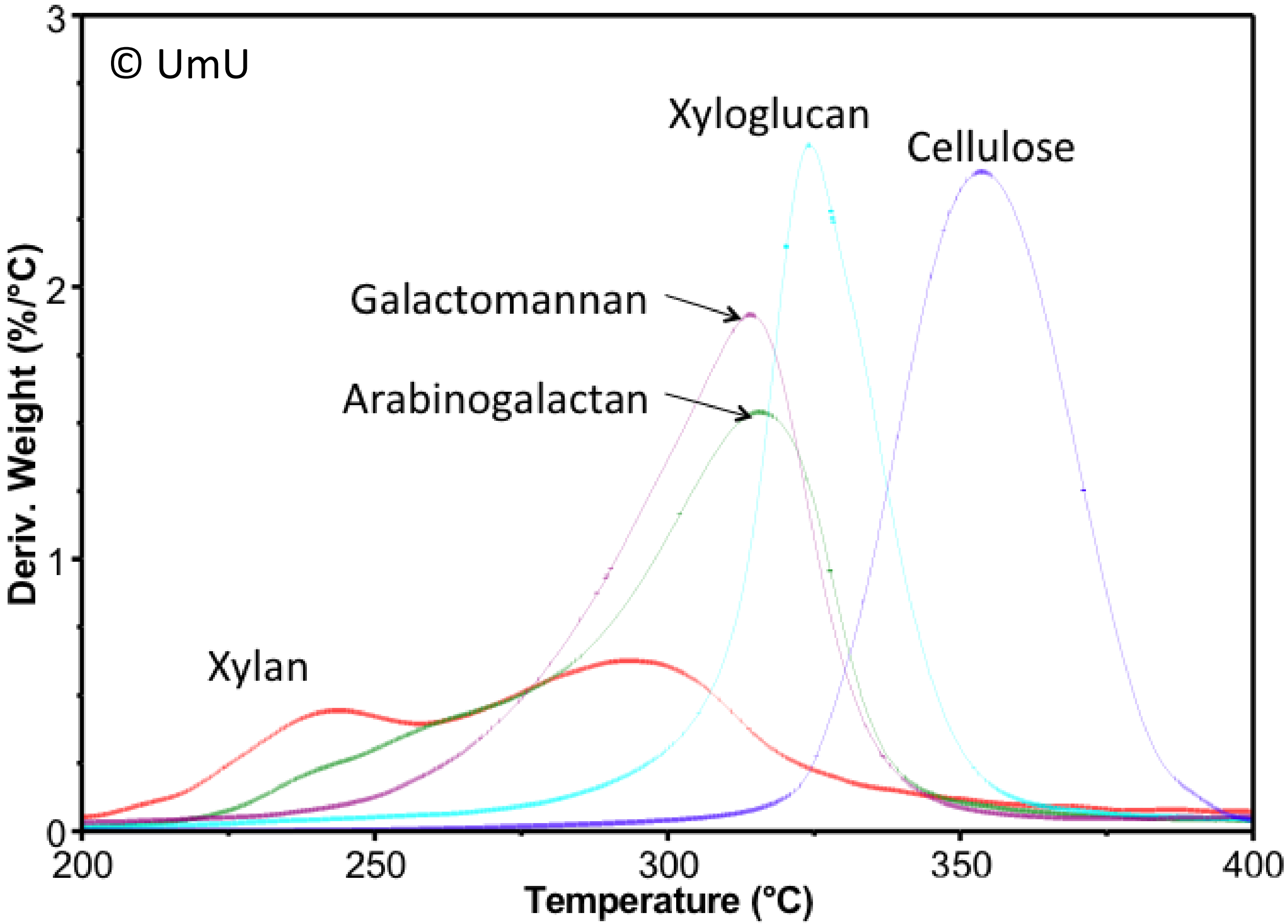
Lab-scale torrefaction tests

- Mass loss rate profiles (hemicelluloses)



This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 282826

WP 3: Results Task 3.1

- Batch reactor tests
  - On following feedstocks
    - ECN poplar, pine, spruce, bamboo
    - UmU pine, willow
    - CENER straw
    - Bintuni mangrove
    - Viridis Energy PKS
    - Cradle Crops miscanthus
    - Anbenna sun flower husk
  - At following temperatures
    - 240, 255, 260, 270, 280, or 300°C

    (not all temperatures for all materials)

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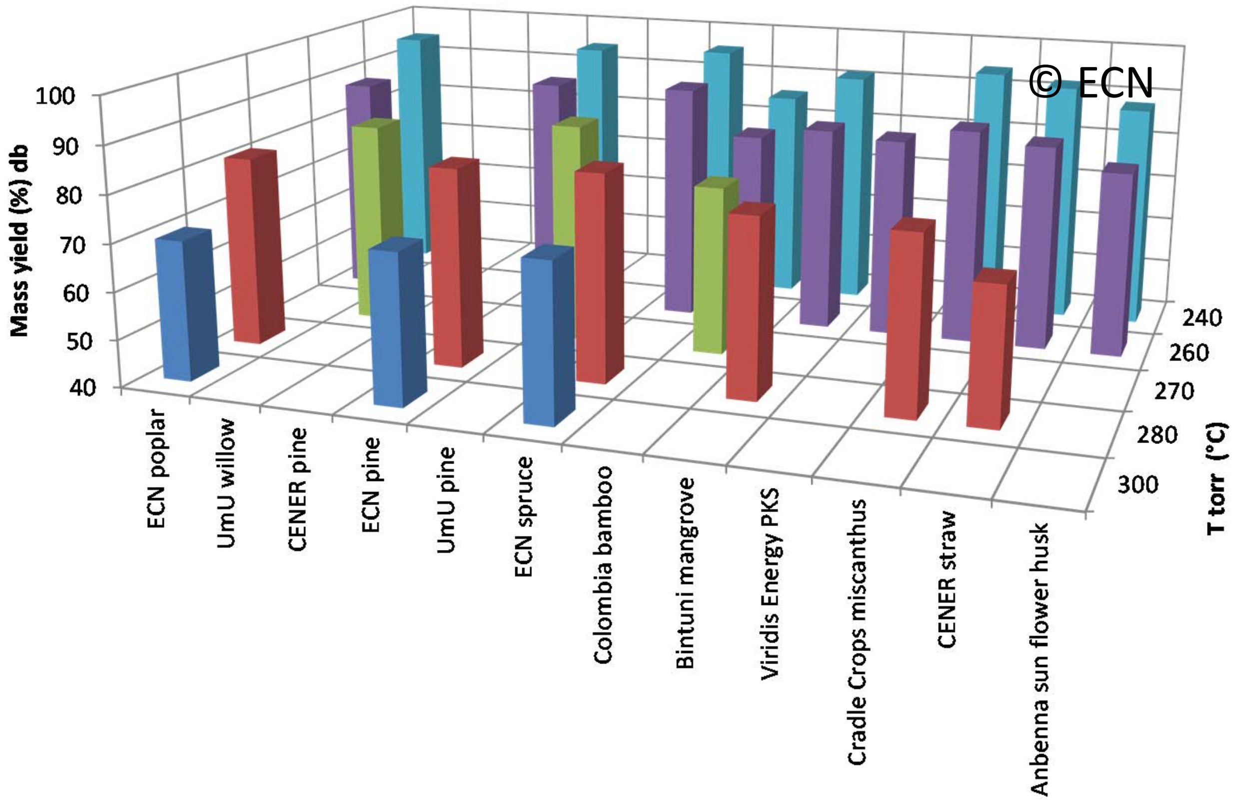
Lab-scale torrefaction tests

- Batch reactor tests
  - Mass yields at 45 min after reaching 200°C



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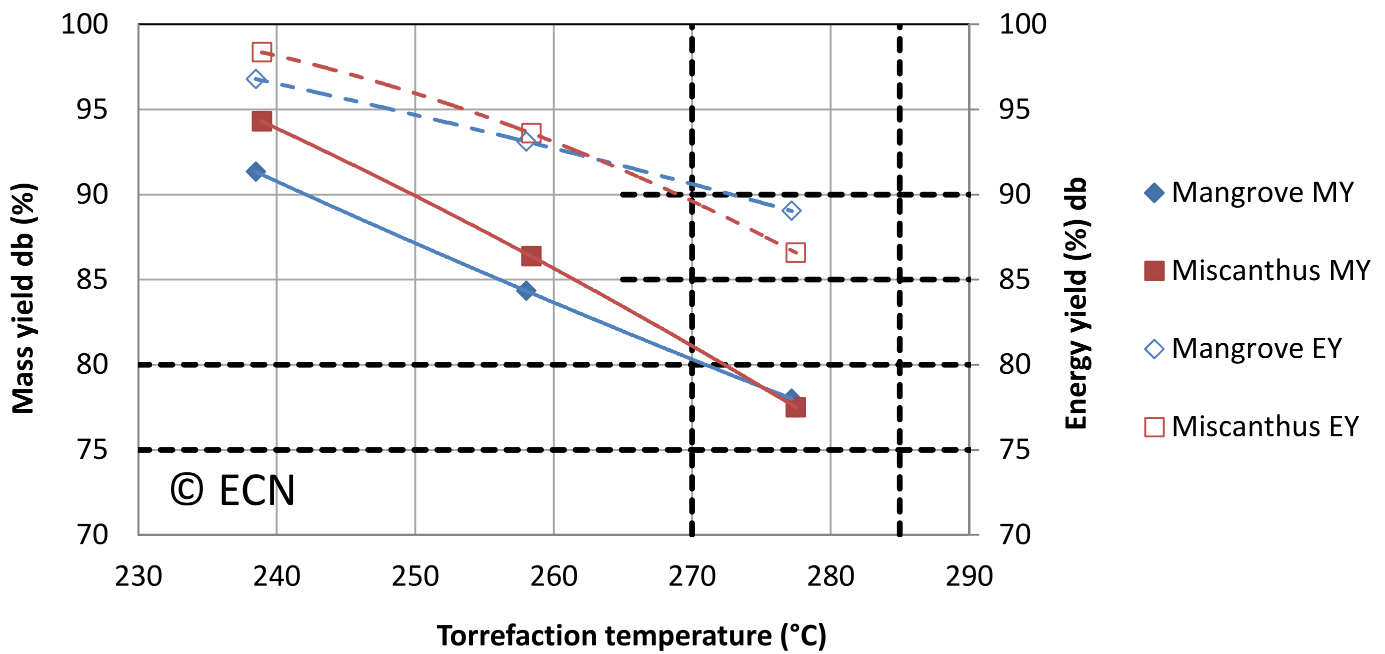
Lab-scale torrefaction tests

- Test results combined
  – Mass yields and energy yields for determining working window
  e.g. mangrove and miscanthus (from batch reactor tests)



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Pilot-scale torrefaction tests

No.	Selected feedstock	Partner responsible	Pilot test temperatures (ºC)	Pilot test production (kg)		
				CENER	ECN	UmU
1	Delimbed coniferous stem wood without bark, (Pine as reference raw material 1)	ECN, UmU, CENER	240, 270, 260, 280, 291, 300, 308, 315	15.341	3.738	3.400
2	Logging residue, coniferous	UmU	286, 308, 325	-	-	3.400
3	Delimbed broadleaves stem wood with bark, (Beech, reference raw material 2)	CENER	270	4.619	-	-
4	Poplar	CENER, ECN	270, 280, 290, 300	8.466	4.058	-
5	Straw (Oat and wheat, Southern conditions)	CENER	250, 260, 270	8.680	-	-
6	Prunings from olive trees –woody biomass	CENER	250, 260, 270	-	-	-
7	Eucalyptus	CENER	250, 260, 270	196	-	-
8	Paulownia	CENER	250, 260	6.052	-	-
9	Bamboo	ECN	245, 255, 265	-	1487	-
10	Bagasse	CENER	250, 260	Cancelled	-	-
11	Willow (Salix)	UmU	286, 308, 330	-	-	3.400
12	Spruce	ECN	240, 260, 280	-	16.973	-
			Subtotal	**43.354**	**26.255**	**10.200**
			TOTAL		**79.809**	

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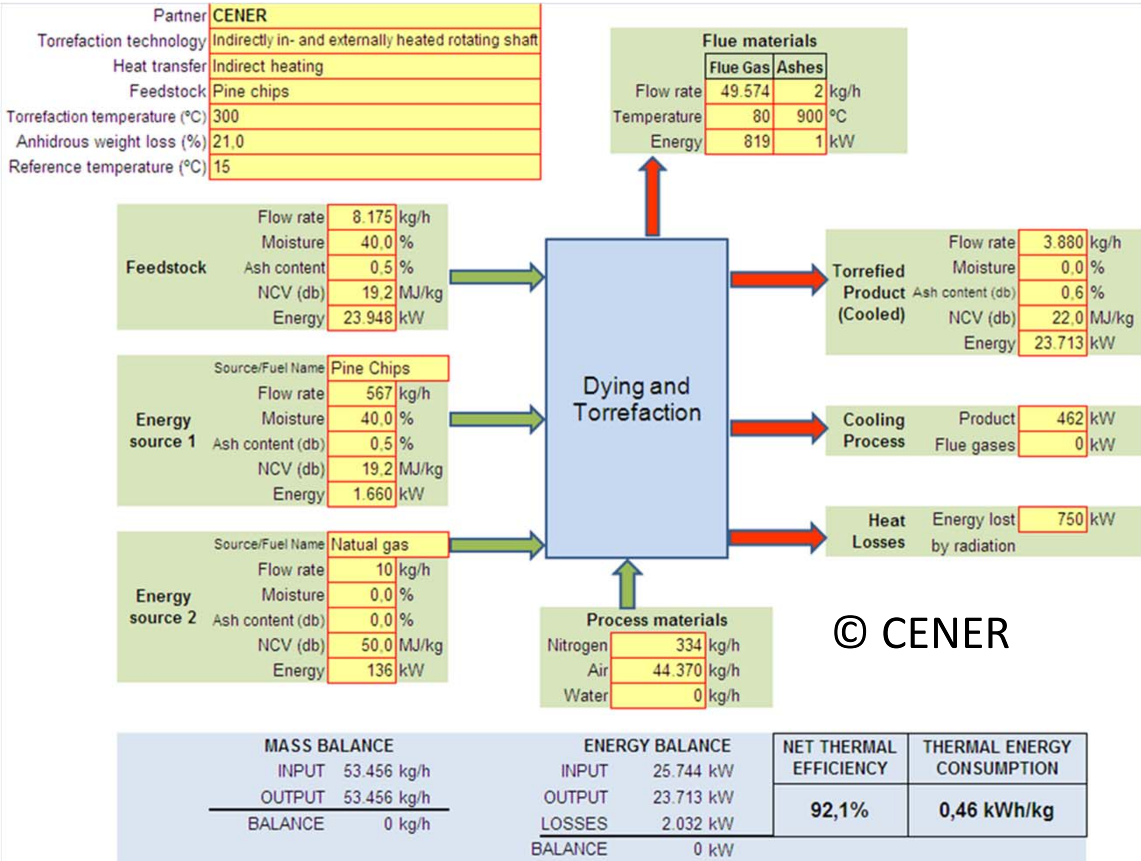
Pilot-scale torrefaction tests

- Mass and Energy balances prepared for pine by CENER, ECN & UmU



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Pilot-scale torrefaction tests

- Mass and Energy balances prepared for pine by CENER, ECN & UmU
- Net Thermal Efficiency (NTE) parameter is mainly influenced by biomass moisture content, mass yield of the torrefied product, energy integration and heat losses
- NTE values of cases including heat integration very similar

Partner	Torrefaction technology	Heat transfer type	Mass yield (% db)	Energy yield (% db)	Net thermal efficiency (%)	Thermal energy Consumption (kWh/kg[1])	Production capacity[2] (t/a)
CENER	Indirectly in- and externally heated rotating shaft	Indirect heating	79,0	90,5	92,1	0,46	31.041
UmU	Rotating drum	Indirect heating	75,7	87,9	83,6	0,30	114
ECN	Directly heated moving bed	Direct heating	81,3	87,6	92,4	0,34	112.682

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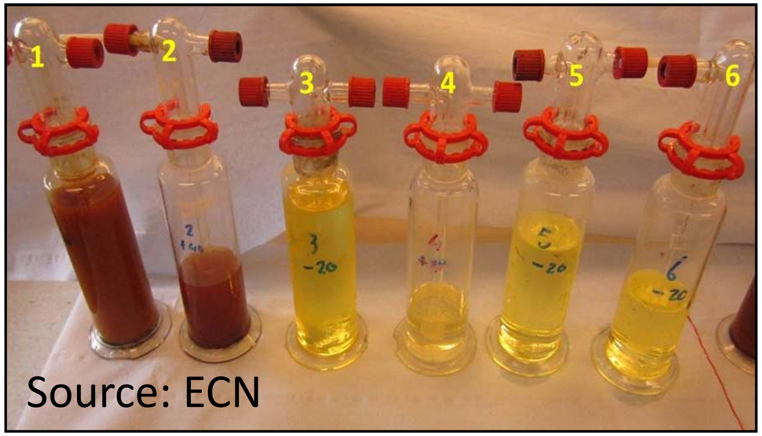
Feedstock and product analysis

- Gas composition during spruce torrefaction at 260 °C



Component	vol.% wet gas
CO	1.5
CO_2	2.2
N_2	45.6
H_2O	50.6

Component	Average gas concentration (g/Nm³)
Acetic acid	39,5
Hydroxyacetone	15,8
Methanol	10,2
Hydroxyacetaldehyde	8,5
Formic acid	8,0
2-Furanmethanol	7,6
2-Furaldehyde	4,9
Isoeugenol	3,4
1-Hydroxy-2-butanone	2,9
5-(Hydroxymethyl)-2-furaldehyde (HMF)	2,9
2(5H)-Furanone	1,5
2-Methoxyphenol	1,1
2-methoxy-4-vinyl-phenol	1,1
Pyrocatechol	1,1
Total detectable organics	108,3

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Feedstock and product analysis

- Torrefied product homogeneity during pilot production

	Homogeneity of the process: Sample analisys of each big-bag produced								
No.	Sample number	Big-bag code	production hours		Elemental analisys (% db)			Heat value (MJ/kg	
			Start	finish	C	H	N	HHV	LHV
1	230	12/007/TO03	10:45	11:45	54,0	6,0	0,18	21,68	20,43
2	231	12/007/TO04	11:45	12:36	53,8	6,0	0,13	21,65	20,40
3	232	12/007/TO05	12:36	13:22	53,7	6,1	0,16	21,63	20,38
4	233	12/007/TO06	13:22	14:09	53,4	6,1	0,16	21,39	20,14
5	234	12/007/TO07	14:09	14:55	53,4	6,1	0,11	21,55	20,30
6	235	12/007/TO08	14:55	15:41	53,4	6,1	0,13	21,44	20,19
7	236	12/007/TO09	15:41	16:20	53,4	6,0	0,13	21,51	20,27
8	237	12/007/TO10	16:20	17:11	53,3	6,1	0,11	21,44	20,19
9	238	12/007/TO11	17:11	17:55	53,5	6,1	0,14	21,53	20,27
10	239	12/007/TO12	17:55	18:37	53,5	6,1	0,13	21,51	20,26
11	240	12/007/TO13	18:37	19:23	53,3	6,2	0,14	21,37	20,08
12	241	12/007/TO14	19:23	20:08	53,1	6,1	0,12	21,41	20,15
Mean					53,5	6,1	0,14	21,51	20,25
Maximum					54,00	6,2	[illegible]	[illegible]	[illegible]
Minimum					53,10	[illegible]	[illegible]	[illegible]	[illegible]
Averaged desviation (%)					0,18	[illegible]	[illegible]	[illegible]	[illegible]
Maximun desviation (%)					0,52	[illegible]	[illegible]	[illegible]	[illegible]
Analysis acceptance repeatability criteria					0,39%	<0,2%	<0,03%	<0,12 MJ	

Differences are similar to analysis acceptance repeatability criteria

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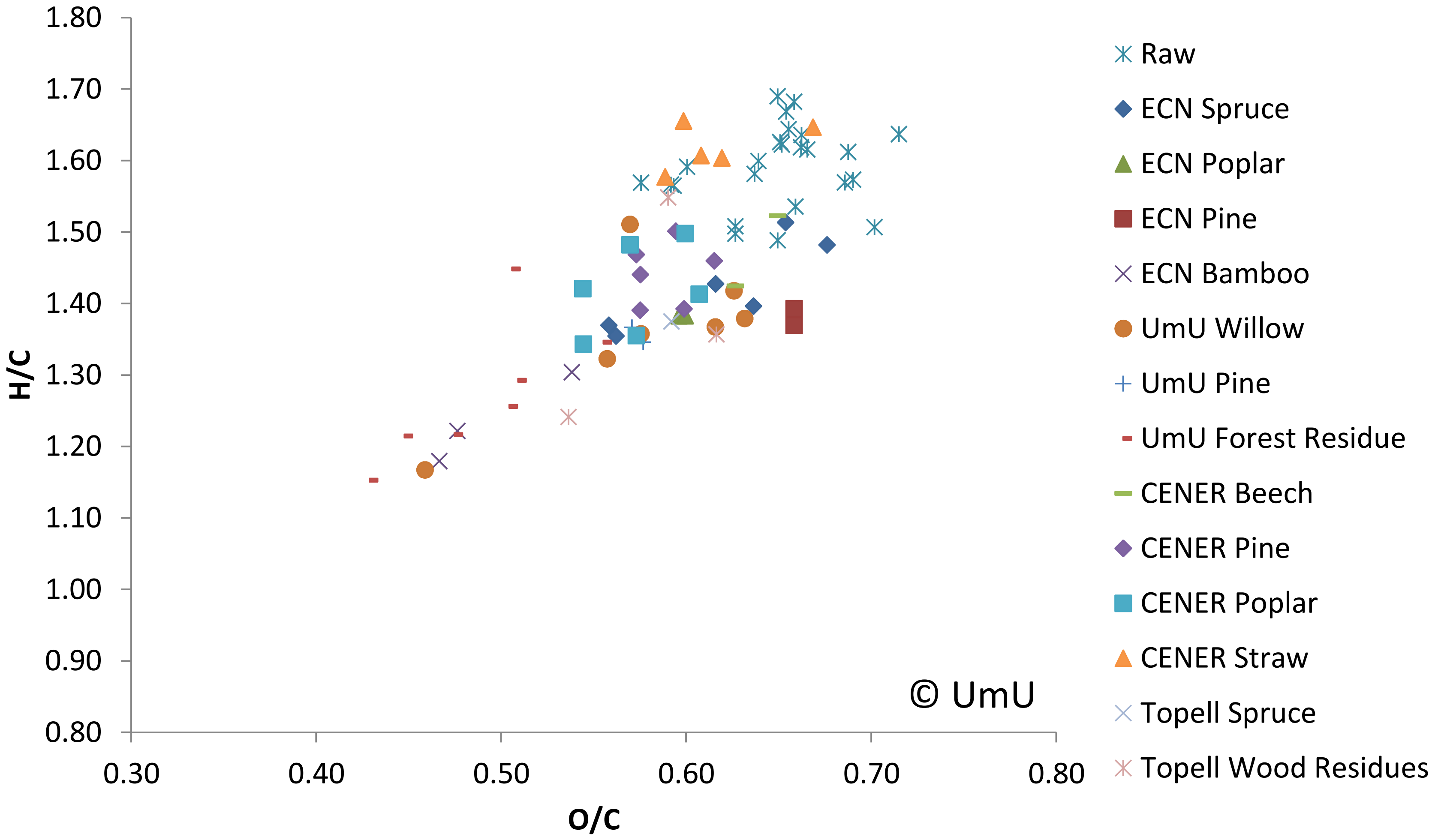
Feedstock and product analysis



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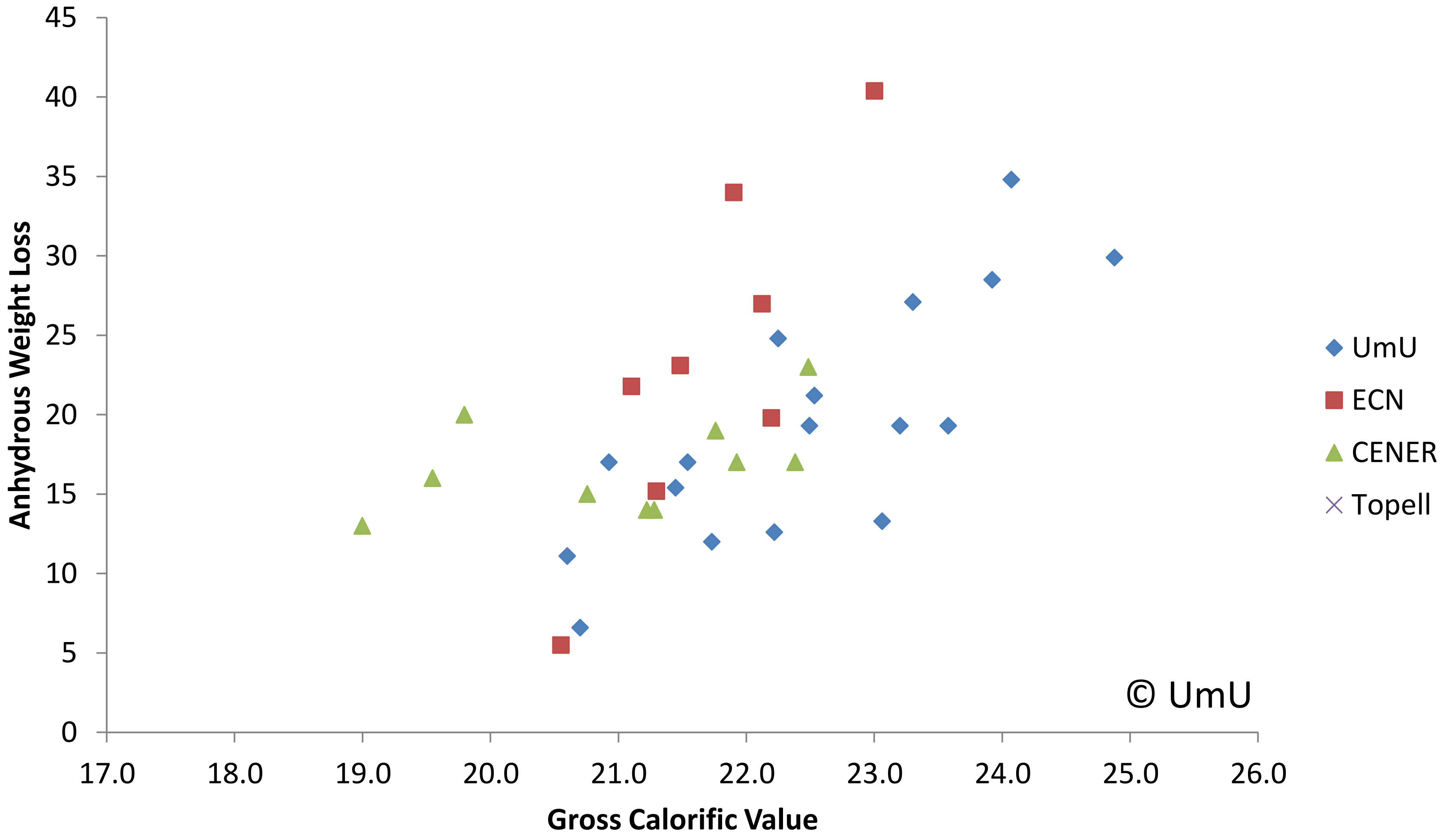
Feedstock and product analysis



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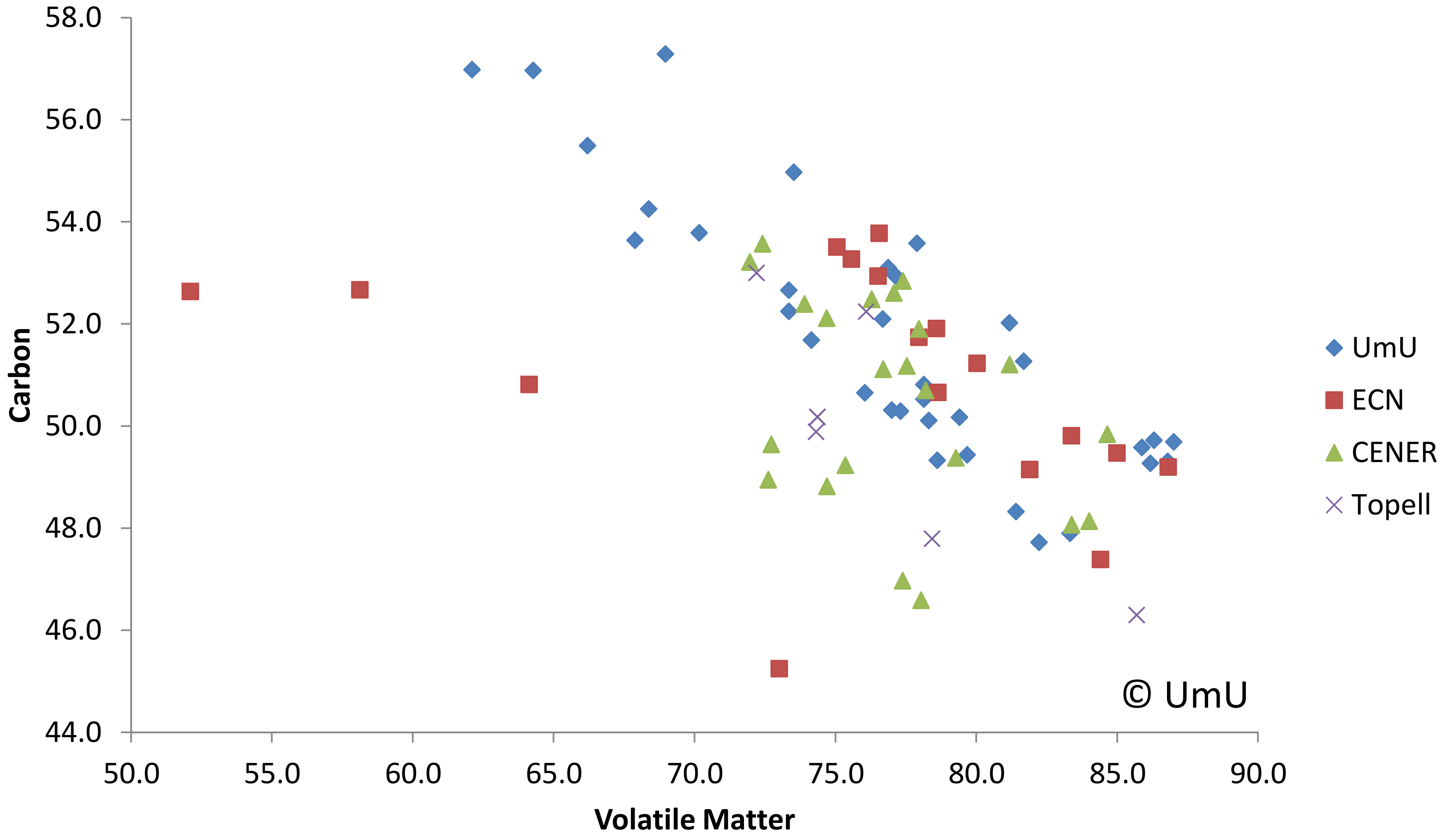
Feedstock and product analysis



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Annex I

Torrefaction process optimisation/integration

- Harmonised mass and energy balances (with belt dryer) presented in flow sheets of ECN, Topell and CENER processes
- Three main integration options: Saw mill, CHP, P&P mill
- Black box mass and energy balance data for calculations about integrated torrefaction
- Both feedstock and energy integration was explored
- The energy production of integrated torrefaction plants was based on biomass use (no energy use of natural gas or oil based product)
- The main advantages of integrations:
  - front end: wood acquisition, logistics, wood handling and pretreatment
  - more efficient energy use compared to stand-alone plants
  - favorable power and heat prices
  - lower the production price of TOP-pellets (bigger boiler in integrated concepts, scaleup and efficiency benefits)

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Torrefaction process optimisation/integration

- Base Case: Stand-alone plant (50 MW_{th} torrefied wood pellets)
- Alternative 1:
  New sawmill and torrefaction integrated (158 MW_{th})
- Alternative 2:
  Existing sawmill and new torrefaction plant (72 MW_{th})
- Alternative 3:
  Existing CHP-plant (5 000 h/a) and new torrefaction plant (50 MW_{th})
- Alternative 4:
  Existing CHP-plant (3 500 h/a) and new torrefaction plant (50 MW_{th})
- Alternative 5:
  Existing pulp mill and new torrefaction plant (279 MW_{th})
- Alternative 6:
  Existing pulp and paper mill and new torrefaction plant (70 MW_{th})
- Alternative 7:
  Existing pulp and paper mill and new torrefaction plant (140 MW_{th})
- Alternative 8 & 9: Stand-alone plant in Nordic region and SE USA (343 MW_{th})

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Torrefaction process optimisation/integration

	Base Case	Alternative 1	Alternative 2	Alternative 5	Alternative 8	Alternative 9
Plant capacity, t torrefied pellets/a	72 800	231 600	101 100	407 200	500 000	500 000
Production costs of pellets, M€/a	19.3	48.8	24.3	82.5	104.2	87.6
Production costs of pellets, €/t	265	211	240	203	208	175
Production costs of pellets, €/MWh	43	34	38	33	34	29
Market price of wood pellets, €/MWh (PIX Pellet Nordic Index, 2012)	30	30	30	30	30	30
Price compared to base case, %	100	79	91	76	79	66
Price compared to market price, %	145	115	126	111	114	96

Legend (colour key):

- Stand- alone plants (Base Case, Alternative 8, Alternative 9)
- Integrates (Alternative 1, Alternative 2, Alternative 5)

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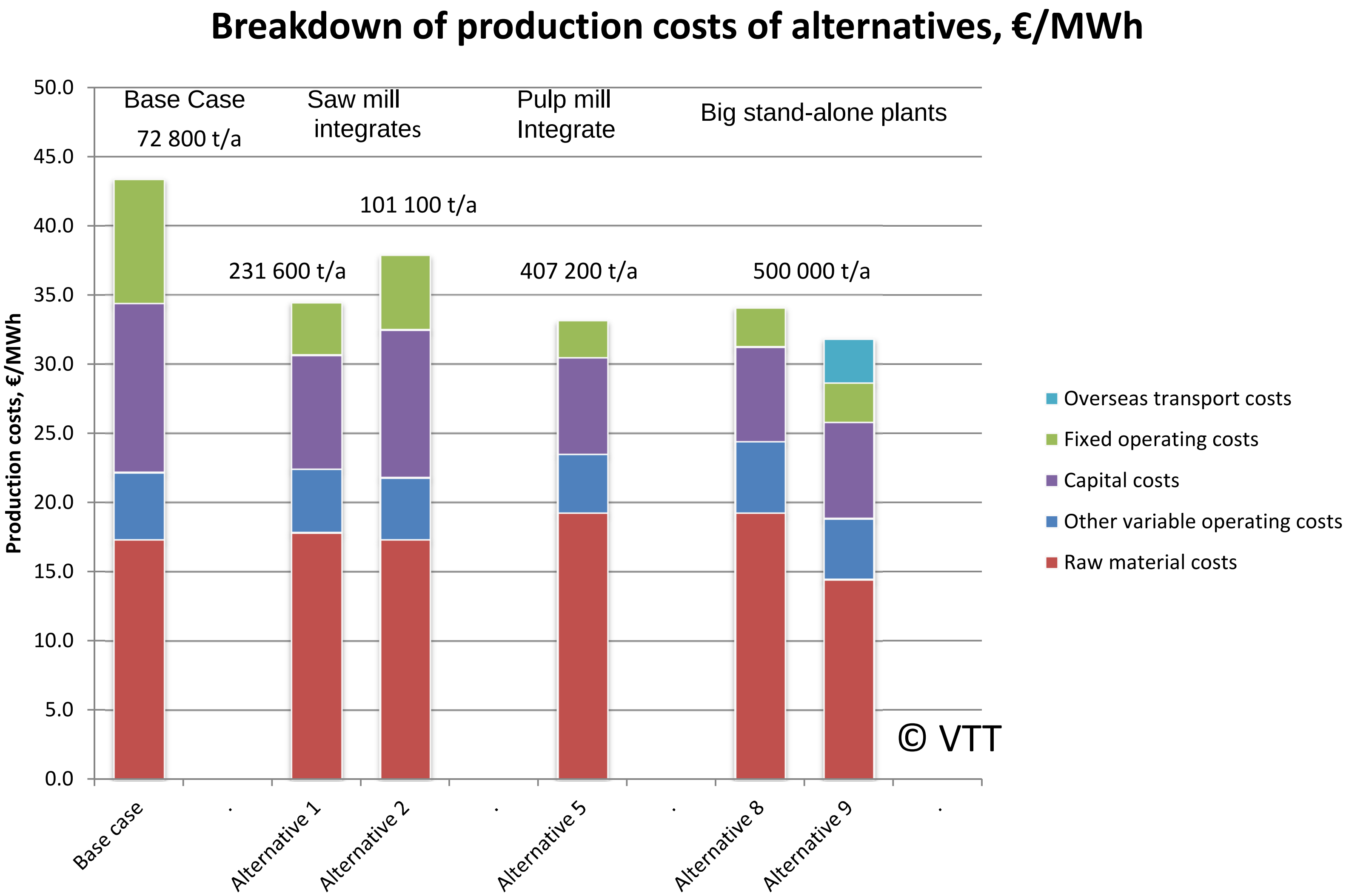
Torrefaction process optimisation/integration



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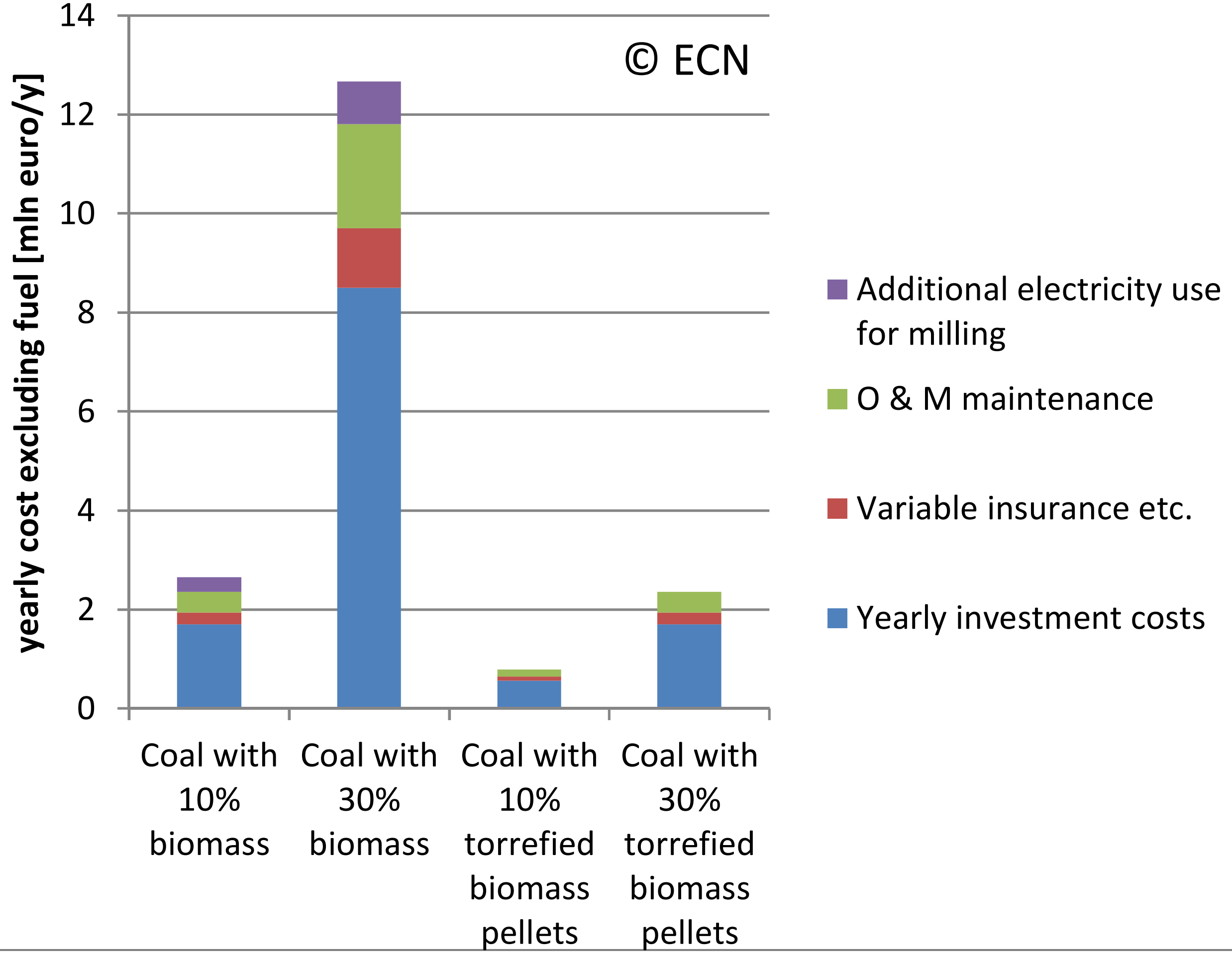
Torrefaction process optimisation/integration

- Purchasing power white wood vs. torrefied wood pellets



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Torrefaction process optimisation/integration

- Purchasing power white wood vs. torrefied wood pellets

		10% co-firing	30% co-firing
Cost difference between white wood and torrefied wood pellets	M€/y	1.86	10.31
Amount of biomass of pellets used	PJ	2.16	6.48
Price difference	**€/GJ**	**0.86**	**1.59**
Case 1: price difference at higher rate of return (12% → 15%)	€/GJ	1.08	2.02
Case 2: price difference at reduction of economic lifetime from 10 to 5 years	€/GJ	1.24	2.34

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Outlook

- A lot of experience gained within SECTOR
- Optimised recipes for integrated torrefaction and densification for mostly wood-based species
- Torrefied wood pellets can be a competitive alternative for white wood pellets
- Continue to broaden this experience for alternative feedstocks (agricultural residues, invasive species and other alternatives)
- Focus on upfront, in-situ or downstream removal of inorganic components

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thank you very much for your attention!

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SECTOR

Production of Solid Sustainable Energy Carriers
from Biomass by Means of TORrefaction

SESSION I - Torrefied Fuels
Part 2 - Densification

Final Project Meeting, 06.05.2015 in Leipzig

Wolfgang Stelte
Danish Technological Institute - DTI






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Session I "Torrefied fuels" - Part 2: Densification

Why densification?

- Torrefied biomass
  - Porous and brittle structure
  - Low density
  - Dust and dirt formation (health & explosion risk)
  - Poor handling properties

- Densification of torrefied biomass
  - Pelletization & Briquetting
  - Increase of density → lower storage and transportation cost
  - Reduced dust emissions → safety
  - Standardized size and shape → handling and trade
  - Technology adapted from wood pellet / briquetting industry

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Session I “Torrefied fuels” - Part 2: Densification

Challenges met when processing torrefied biomass

- Processing / Friction related
  - High energy uptake of pellet mill 150 kWh/t (50-60 kWh/t for wood)
  - Heat generation in pellet mill (risk of fire / dust explosion)
  - Lower capacity
  - More wear on the pellet mill parts

- Product quality
  - Durability
  - Density
  - Pellet surface
  - Moisture resistance

Issues are closely linked to:
- Biomass feedstock
- Torrefaction parameters
- Pelletization parameters
- Can be different case by case

→ **SECTOR Project to find solutions**

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Session I "Torrefied fuels" - Part 2: Densification

SECTOR tasks:

- How to ease processing of torrefied biomass
- Improve product quality
- Connect torrefaction & densification processes
- Pelletization vs. Briquetting
- Different Technology/different size
  - Lab scale screening
  - Pilot scale
  - Production
- Production of large scale batches of pellets/briquettes

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Session I “Torrefied fuels” - Part 2: Densification

Lab scale pelletizing and briquetting tests

Objective: Screening of densification properties / information for densification partners

- Test are made in a single pellet unit at DTI
- >50 torrefied materials tested so far
- Spruce, pine, poplar, bamboo, willow, straw, mixed residues
- From torrefaction units at ECN, CENER, UmU, SLU, Topell

Source: DTI

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Session I “Torrefied fuels” - Part 2: Densification

Bench and industrial-scale pelletizing

- Scale up and optimization of densification operations
- > 30.000 kg of torrefied pellets produced in pilot plants

Production at: ECN, CENER and SLU and Topell

Raw materials:

- Beech
- Pine
- Poplar
- Willow
- Straw
- Mixed residues

CENER NATIONAL RENEWABLE ENERGY CENTRE

Torrefaction / Pelletization plant at CENER

Source: CENER

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Session I "Torrefied fuels" - Part 2: Densification

Bench and industrial-scale briquetting

Briquetting tests at: C.F. Nielsen in cooperation with DTI and ECN

- Torrefied Spruce and Bamboo
- Mass and Energy Balances
- Optimization trials

DANISH TECHNOLOGICAL INSTITUTE
ECN
C.F. Nielsen

Source: DTI

Briquetting trials at C.F. Nielsen pilot plant

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Session I “Torrefied fuels” - Part 2: Densification

No.	Selected feedstock	Partner responsible	Torrefaction Temperatures (ºC)	Pilot test status			
				CENER	ECN	SLU	DTI / CF Nielsen
1	Delimbed coniferous stem wood without bark, (Pine as reference raw material 1)	ECN, UmU, CENER	240, 270, 260, 280, 291, 300, 308, 315	Pelletisation	Pelletisation	Pelletisation	-
2	Logging residue, coniferous	UmU	286, 308, 325	-	-	Pelletisation	-
3	Delimbed broadleaves stem wood with bark, (Beech, reference raw material 2)	CENER	270	Pelletisation	-	-	-
4	Poplar	CENER, ECN	270, 280, 290, 300	Pelletisation	Pelletisation	-	-
5	Straw (Oat and wheat, Southern conditions)	CENER	250, 260, 270	Pelletisation	-	-	-
6	Prunings from olive trees – woody biomass	CENER	250, 260	Pelletisation	-	-	-
7	Eucalyptus	CENER	270, 280, 290	Pelletisation	-	-	-
8	Paulownia	CENER	250, 260	Pelletisation	-	-	
9	Bamboo	ECN	245, 255, 265	-		-	Briquetting
10	Bagasse	CENER	250, 260	Cancelled	-	-	
11	Willow (Salix)	UmU	286, 308, 330	-	-	Pelletisation	-
12	Spruce	ECN	240, 260, 280	-	Pelletisation	-	Briquetting

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Session I “Torrefied fuels” - Part 2: Densification

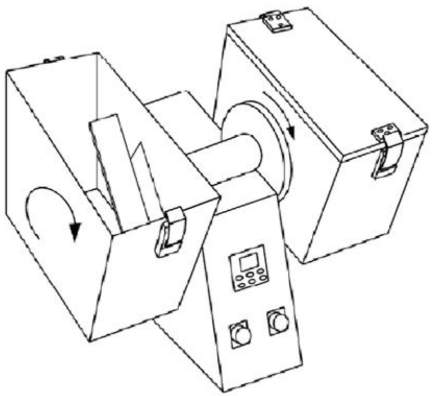
No.	Selected feedstock	Partner responsible	Torrefaction Temperatures (ºC)	Pilot test production			
				CENER	ECN	SLU	DTI / CF Nielsen
1	Delimbed coniferous stem wood without bark, (Pine as reference raw material 1)	ECN, UmU, CENER	240, 270, 260, 280, 291, 300, 308, 315	11.680	1.200	581	-
2	Logging residue, coniferous	UmU	286, 308, 325	-	-	581	-
3	Delimbed broadleaves stem wood with bark, (Beech, reference raw material 2)	CENER	270	4.236	-	-	-
4	Poplar	CENER, ECN	270, 280, 290, 300	7.685	3.800	-	-
5	Straw (Oat and wheat, Southern conditions)	CENER	250, 260, 270	7.258	-	-	-
6	Prunings from olive trees – woody biomass	CENER	250, 260, 270	1.836	-	-	-
7	Eucalyptus	CENER	250, 260, 270	146	-	-	-
8	Paulownia	CENER	250, 260	6.157	-	-	
9	Bamboo	ECN	245, 255, 265	-		-	600
10	Bagasse	CENER	250, 260	Cancelled	-	-	
11	Willow (Salix)	UmU	286, 308, 330	-	-	581	-
12	Spruce	ECN	240, 260, 280	-	4.666	-	600
			Subtotal	**38.998**	**9.666**	**1.743**	**1.200**
			Total	**51.607**			

Session I “Torrefied fuels” - Part 2: Densification

Quality analysis of pellets and briquettes

- Compilation and analysis of pellet quality analysis at partner sites and in cooperation with WP8
- Produced pellets were analysed for their quality according to methods listed under the European standard for wood pellets EN-14961

Parameter	Standard
1. Bulk density	EN 15103
2. Durability	EN 15210-1
3. Water content	EN 14774-1 or 2
4. Ash content	EN 14775
5. Calorific value	EN 14918
6. Chlorine and Sulfur content	EN 15289
7. Volatile matter content	EN 15148
8. Carbon, Hydrogen, Nitrogen content	EN 15104
9. Major elements content	EN 15290
10. Minor elements content	EN 15297
11. Ash melting behavior	CEN/TS 15370



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Session I "Torrefied fuels" - Part 2: Densification

Development of optimized torrefaction & densification recipes

PINE			STRAW		
Date	Pellet dur. (%)	Pellet photo	Date	Pellet dur. (%)	Pellet photo
Oct. 2012	88,8		Feb. 2013	84,2	
Jan. 2013	92,3		Sept. 2013	94,3	
Jun. 2013	94,7		Oct. 2013	96,6	
Nov. 2013	95,7		Nov. 2013	97,6	

Data from: CENER

Parameters optimized:

- Particle size of feedstock
- Moisture content of feedstock
- Torrefaction degree of feedstock
- Die: diameter/length
- Die rotation speed

Source: CENER

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Session I “Torrefied fuels” - Part 2: Densification

Pellets from torrefied wheat straw produced at CENER

Analysis type	Laboratory test	Units	Value
Ultimate analysis	C	% daf	51,5
	H	% daf	6,2
	N	% daf	0,58
Proximate analysis	Moisture content	% wb	8,5
	Ash content	% db	4,8
Net Calorific Value	NCV	MJ/kg daf	19,6
Physical analysis	Bulk density	kg/m^3 ar	710
	Energy density	GJ/m^3	13,9
	Fines content	%	0,02
	Pellet durability	%	97,6

Pellet photo

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Session I "Torrefied fuels" - Part 2: Densification

Key processing paramters and their optimization

- Raw material
- Degree of torrefaction
- Moisture
- Additives (Binder/Lubricant)
- Temperature
- Press channel dimensions
- Speed / holding time
- Combined effects torrefaction & densification
- Briquetting vs. Pelletization

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Session I "Torrefied fuels" - Part 2: Densification

- Raw Materials
  - Torrefied hardwoods, softwood and agricultural residues have been tested in SECTOR
  - **Species-related differences** result in different processing requirements and product quality
  - Torrefied **hardwoods** such as poplar, beech and willow were **relatively easy to pelletise** compared to other torrefied wood species. Especially torrefied poplar resulted in high product quality while observing a moderate increase of friction
  - Torrefied **softwoods** such as spruce and pine can be pelletised into high quality pellets by **optimisation of torrefaction and pelletisation parameters**
  - Torrefied **grasses and husks** can be regarded as **"challenging" raw materials** with respect to mechanical quality of the pellets (durability and strength). However, process adjustments can improve the quality significantly

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Session I "Torrefied fuels" - Part 2: Densification

- Degree of torrefaction
  - Generally, high torrefaction degrees (long torrefaction time and/or high temperatures) result in a more severe degradation of the biomass polymers hemicelluloses, celluloses and lignin
  - The greater the degree of torrefaction the more difficult it is to establish inter-particle bonds required to form a stable pellet
    - Removal of hydrogen bonding sites (less H-bonding)
    - Depolymerisation (less polymer bridges)
    - Destruction of fibre structure (less fibre entanglement

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Session I “Torrefied fuels” - Part 2: Densification

- Moisture addition
  - Water acts as a **plasticiser** lowering the softening temperature of lignin
  - **Reduction of friction**
  - **Improving of bonding** (better pellet durability and strength)

- Additives (Lubricants / Binders)
  - Additives can be used to **reduce friction** (lubricating effect) and to **improve the pellet strength** (inter-particle bonding)
  - **Oils, lignin and carbohydrates** have been tested in SECTOR
  - No additive could be identified that could both reduce friction and improve pellet strength at the same time

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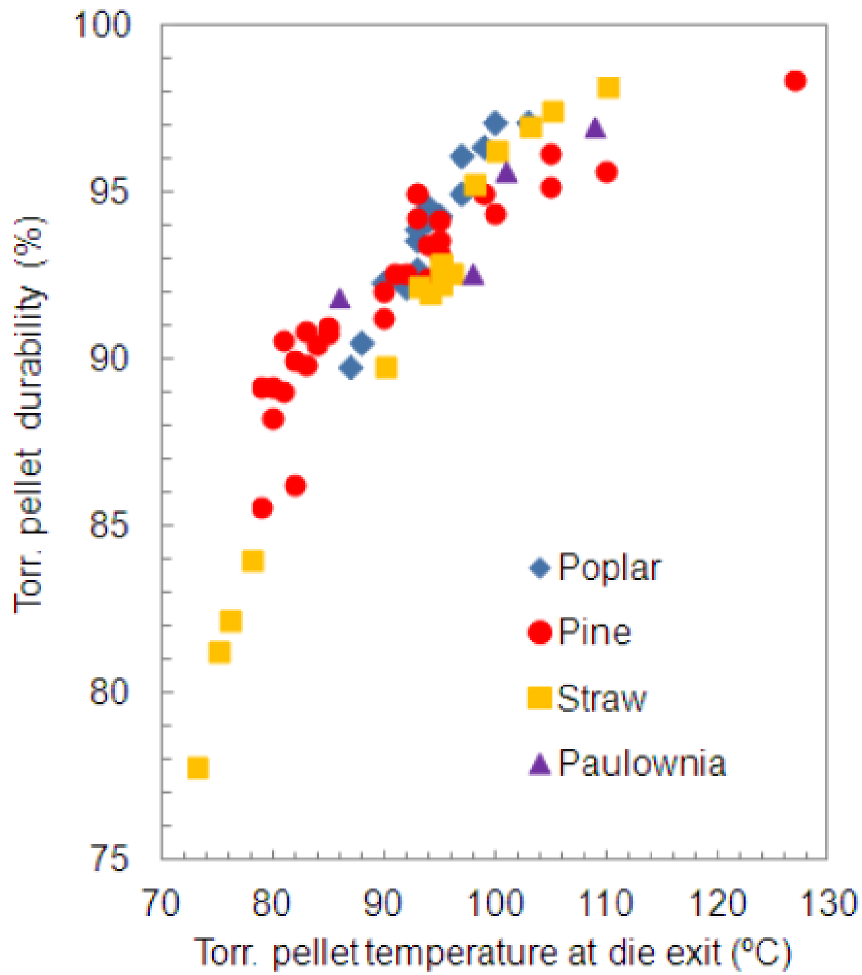
Session I “Torrefied fuels” - Part 2: Densification

- Temperature pelletization
  - Increasing the temperature during pelletization **reduced friction and improved pellet strength** (softening and flow of biomass polymers)



Data from: CENER

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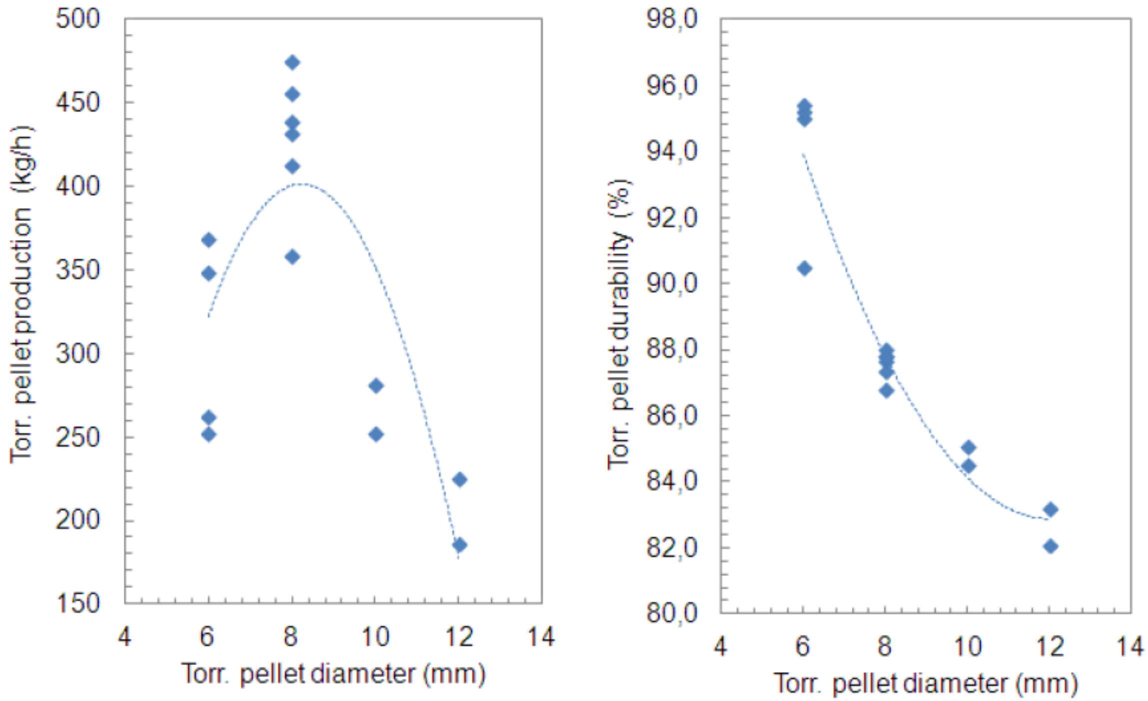
Session I “Torrefied fuels” - Part 2: Densification

Design of pelletizing die

- **6, 8, 10 and 12mm dies** (diameter) have been tested **with 6 mm resulting in the highest durability**
- **Capacity highest at 8 mm**



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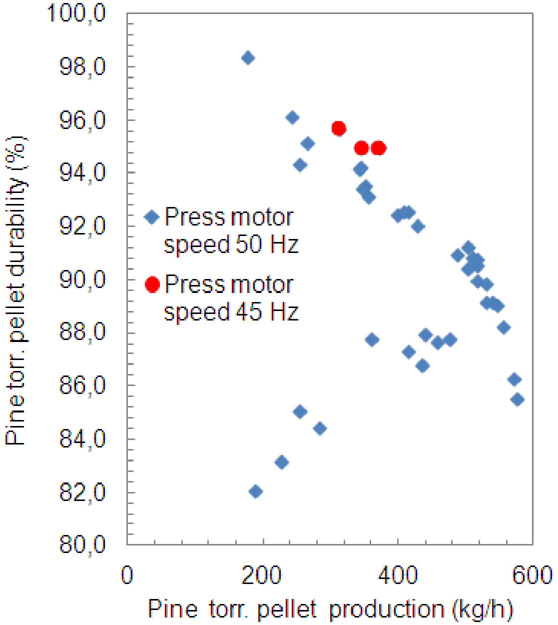
SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Session I "Torrefied fuels" - Part 2: Densification

- Rotation speed / Holding time in press channel
  - **Slower speed/lower capacity results in slightly higher durability** of the pellets (prolonged time in the press channel where pellet is exposed to heat and pressure)
  - Capacity is related to rotation speed of the die
  - More studies required to confirm this
  - Same for holding time in briquetting press → keeping the briquette under heat and pressure improve the stability

Data from: CENER



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Session I "Torrefied fuels" - Part 2: Densification

- Particle size
  - increased particle size resulted in a decrease of the pellet density,
  - small particles occupying all available empty spaces in the bulk and thus increasing the density.
  - pellets pressed from smaller particles are shorter with higher bulk density

Feedstock	Torr. Temp. (°C)	AWL[1] (%)	Average particle size (mm)	Torrefied Material photo	Torrefied pellets photo	Pellet bulk density (kg/m³)
Chopped straw (8 mm) 	250	13,1	1,11			620
	260	16,0	0,97			630
	270	22,1	0,87			710
Straw pellets 	260	13,7	0,73			720
	260	16,3	0,63			730
	260	20,4	0,55			730

[1] Anhydrous weight loss

Data from: CENER

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Session I "Torrefied fuels" - Part 2: Densification

- Combined effects
  - Parametric study varying degree of torrefaction, moisture content, particle size and densification temperature has been realised
  - **Mutual correlations between torrefaction and densification parameters haves been found.**
  - Results are published here→ Rudolfsson M, Stelte W, Lestander TA (2015) Process optimization of combined biomass torrefaction and pelletization for fuel pellet production–A parametric study. Applied Energy, 140:378-384.

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Session I "Torrefied fuels" - Part 2: Densification

- Briquetting vs. Pelletization
  - Briquetting can be a good, maybe better(?) alternative to pelletization
  - More flexible and less energy consuming
  - Next generation presses optimized for torrefied biomass

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Session I “Torrefied fuels” - Part 2: Densification

- Implementation of project results
  - Used by the SECTOR partners to improve their processes
  - Dissemination of SECTOR results in public workshop and conferences
  - Papers, journal articles, project website
  - Cooperation with IEA Task 40 and 32
  - Cooperation with IBTC and its members

- Knowledge has been picked up and exchanged with industry
  - Example: CF Nielsen has designed a new briquetting press optimized for large scale processing torrefied biomass

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Session I "Torrefied fuels" - Part 2: Densification

- Torrefaction/Denisfication knowledge dissemination

Date	Event
21.06.2012	Stelte W., Dahl J., Nielsen N.P.K.N., Hansen H.O., Densification concepts for torrefied biomass. Oral presentation at SECTOR workshop, Side event at 20th European Biomass Conference and Exhibition. Milano, Italy, 18-22 June, 2012
17.05.2013	Kiel, J.H.A., Torrefaction – product quality optimisation in view of logistics and end-use. Oral presentation at World Biomass Power Markets. Amsterdam, The Netherlands, 16-17 May 2013
06.06.2013	Stelte W., Nielsen N.P.K.N., Nielsen M.R.A., Knudsen M.S., Production scale briquetting of torrefied biomass. Oral presentation at: 21st European Biomass Conference and Exhibition. Copenhagen, Denmark, 3-7 June, 2013
20.06.2013	Gil, J., Cereal straw torrefaction and pelletisation: results on pilot plant tests. Oral presentation at 3rd Workshop on Cofiring Biomass with Coal, 20-21 June 2013, Groningen, Netherlands
18.11.2013	Stelte W., Pelletisation of torrefied Biomass. Torrefaction Pelletisation Workshop. Side event of the 2013 Conference & AGM. Wood Pellet Association of Canada. Vancouver, Canada, 18-20 November 2013
18.01.2014	Stelte W., Densification of torrefied materials – The SECTOR project. Central European Biomass Conference, Graz, Austria, 15-18 January 2014
04.06.2014	Carbo, M.C., Leiser, S., Kiel, J.H.A., Thrän, D., Witt, J., New results of the SECTOR-project: Production of Solid Sustainable Energy Carriers from Biomass by Means of Torrefaction. Oral presentation at Clearwater Clean Coal Conference, Clearwater, Florida, U.S.A., 1 -5 June 2014

And more to come…

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Outlook - Densification

- Torrefaction/Densification is technically possible
- Product quality and process development have improved a lot during the project
- Remaining tasks – Densification of torrefied biomass
  - Broaden the feedstock base
  - Further reduction of energy consumption and maintance intervals of machinery
  - Customer specific products (size, shape, quality)

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thank you very much for your attention!

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Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SESSION I - Torrefied Fuels
Part 3 - Demonstration

Final Project Meeting, 06.05.2015 in Leipzig

Alex Adell, Topell Energy






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Session I “Torrefied fuels” - Part 2: Demonstration

WP5: Motivation / Objectives of Work Package

- Production of small and large amounts of torrefied biomass:
  - Production and delivery of torrefied material for activities under other WP‘s
  - Demonstrate Topell‘s torrefaction technology at commercial scale
- Optimisation of torrefaction system and densification

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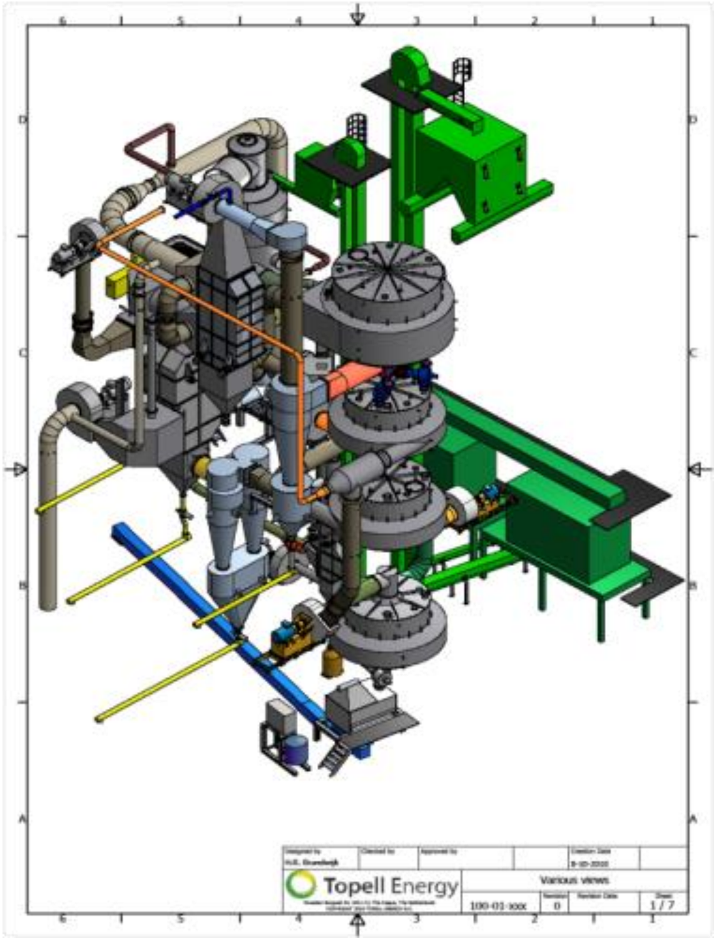
Topell Torrefaction Plant

- **Pre-conditioning (off-site)**
  - Size reduction to specification
  - No stones
  - No metals
- **Pre-drying (on site)**
  - Feedstock to 10-15wt% moisture
- **Torrefaction**
  - Column of toroidal reactors
  - Direct cooling of torrefied product
- **Densification**
  - Pre-conditioning for pelleting
  - Pelletisation of torrefied material
- **Heat integration**
  - Volatiles burned in combustor
  - Heat demand TTS provided by torrefaction gas
- **Feedstock**
  - Seasonal forest residues



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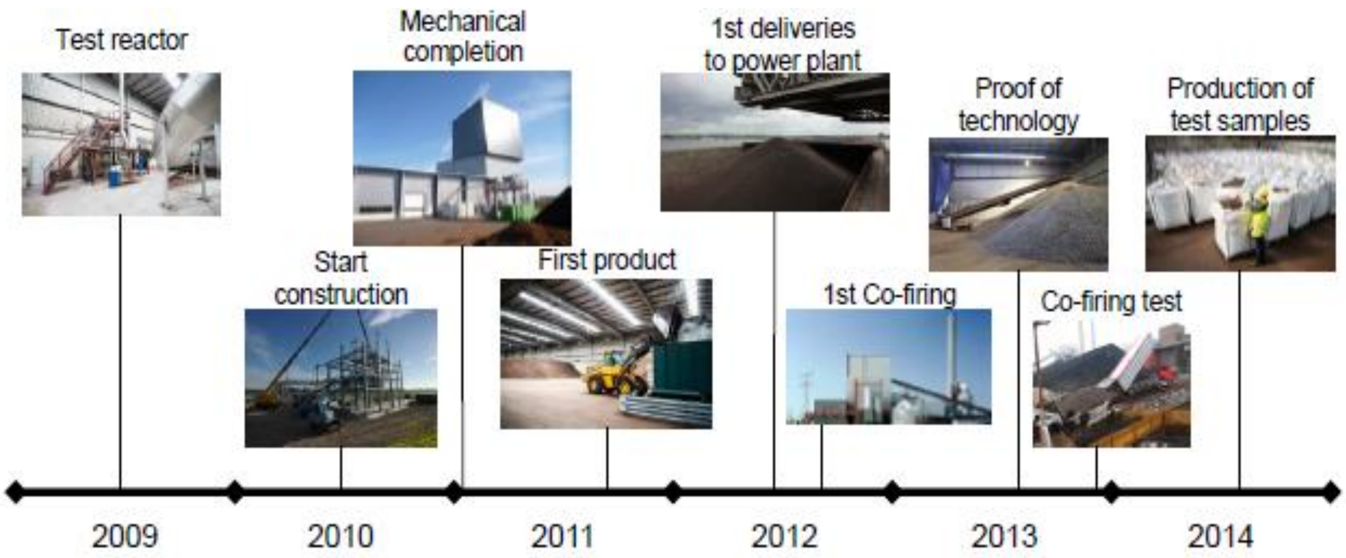
Progress of Topell's Energy technology

- Activities of Topell Energy including SECTOR



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WP5: Overview of activities

January 2012-November 2012

- Production of large amounts of pellets, out of specifications of receivers
  - high ash content
  - low durability
  - high content in dust and fines

November 2012-June 2013

- Major overhaul plant
  - Change combustor
  - Heat integration
  - Densification process
  - Optimisation of product quality

July 2013-December 2013

- Production of several thousand tons of pellets from torrefied forest residues
  - All pellets for deliveries under WP5 are produced
  - Increased product quality to specifications of utilities

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WP5: Overview of activities

- Improved plant-process

- Increased product quality

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WP5: Achieved results

- Total quantities produced and delivered

Material	Quantity (kg)
White chips	61.5
Torrefied chips	51.5
Torrefied pellets	139,887.5
TOTAL	140,000.5

- Use of materials supplied:
  - WP4: Densification characterisation and oxygen deplition
  - WP6: Outdoor storage (weathering, durability, transport, leaching)
  - WP7: Grinding, gasification, co-firing in small and large utilities
  - WP8: Characterisation (e.g. Prox/Ult analysis, ash composition)

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WP5: Achieved results

- Plant
  - All changes implemented commissioned and successfully tested
  - Optimisation of torrefaction unit and densification island tested
- Process
  - Successful production runs 4-6tons/h
  - Developed production recipies for different feedstocks
  - Several thousands tons of pellets already produced (all demand in the project included)
  - Pellets produced succesfully tested in power plant (press release end January 2014)
  - Optimisation of biomass pre-conditioning and product quality accomplished
- Leading position in the torrefaction sector
  - Due to the improvements on the process and product quality, Topell achieved a leading position in the torrefaction market.

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WP5: Progress beyond state of the art

- Proof of concept of Topell's torrefaction system in 2013 at commercial scale.
- Achieved continuous production of torrefied material and pellets from torrefied biomass at commercial scale with a smooth and easy operating system.
- Achieved and demonstrated continuous production of pellets from torrefied biomass at commercial scale with the product quality required by end consumer (co-firing biomass in power plants).
- Achieved and demonstrated full heat integration within the plant, including using the torgas produced during torrefaction process to supply most of the heat demand of the plant, including the drying and the torrefaction steps.
- Proofed the viability of co-milling and co-firing with coal up to 25wt% on one coal mill/burner.
- Proof that for torrefied pellets lower quality feedstock can be used compared to wood pellets.

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WP 5: Further research required (follow-up activities)

- Challenges
  - Market for product
  - Policies affecting the product/usage
  - End users demands (depending on utility and feedstock)
  - Production capacity vs life time of equipment
  - Hydrophobicity product

- Research topics:
  - Definition of torrefaction recipies for other feedstocks and mixtures per technology
  - Definition of densification recipies for other feedstocks and mixtures per technology
  - Hydrophobicity of product – outdoor storage
  - Further optimisation of the process and technology

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thank you very much for your attention!

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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SESSION II – Logistics

Final Project Meeting, 06.05.2015 in Leipzig

Michiel Carbo
Energy Research Centre of the Netherlands - ECN






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Session II "Logistics" - Handling and storage

- Characterise logistics performance:
  - First by small-scale tests, later followed by larger-scale outdoor storage and handling tests
  - Assess various logistic aspects and produce optimised torrefaction-based bioenergy carriers
  - Test optimised pellets under real case conditions, e.g. in existing coal-handling lines

- Partners: CENER, DTI, ECN, EON, OFI, Topell, UmU, Vattenfall, VTT

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Small-scale logistics tests

- Hygroscopic behaviour testing of raw and torrefied willow
- Samples were stored in a climate chamber at 11°C and a relative humidity of 81% until a constant weight was reached
- Similar results obtained for spruce and forest residues

	Temperature (°C)	Residence time (min)	Weight increase (%)
Chips	-	-	14.58
Chips	286	6	7.94
Chips	286	12	8.05
Chips	308	9	7.18
Chips	330	6	7.13
Chips	330	12	7.00
Pellets	308	9	9.48

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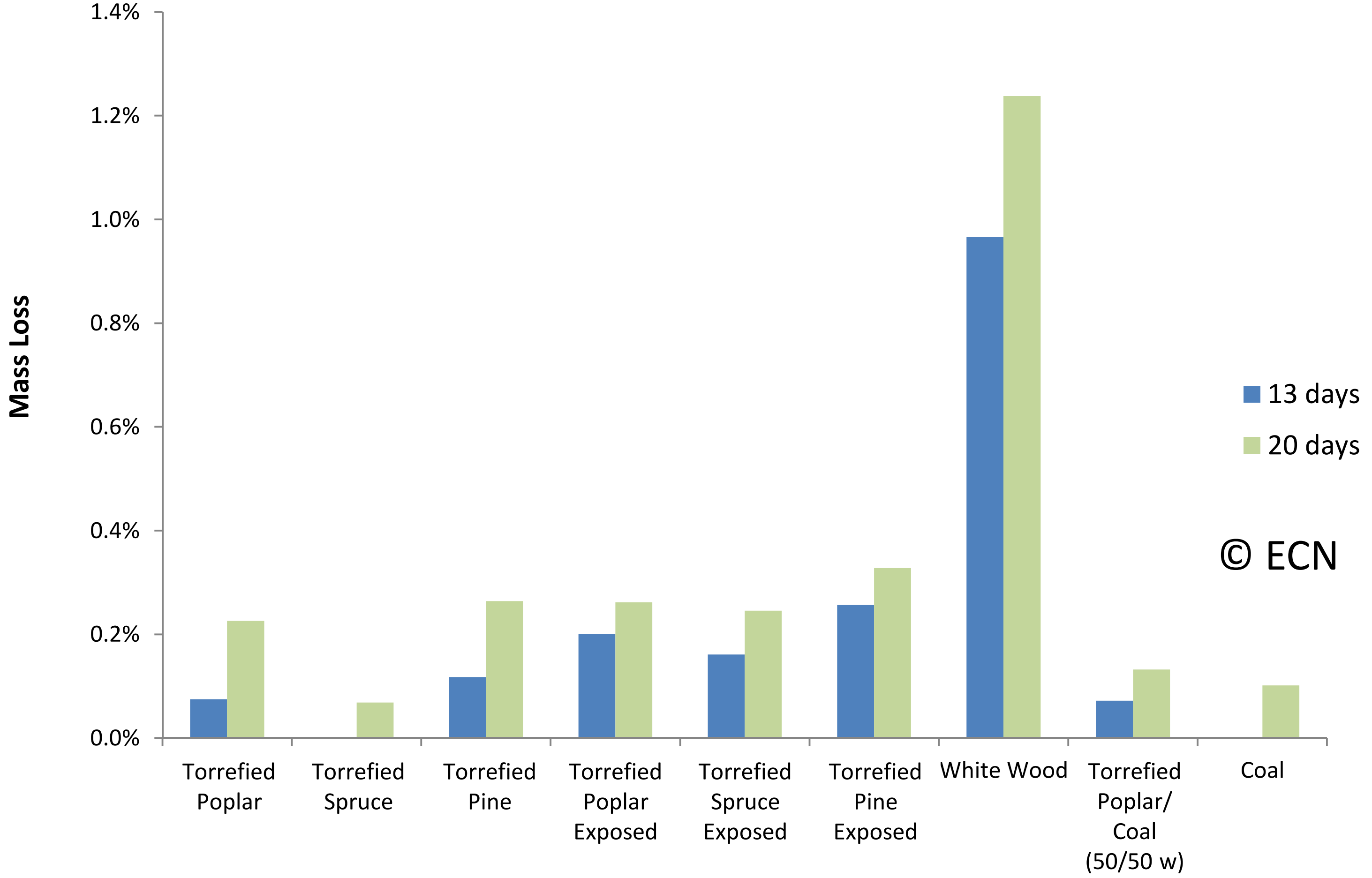
Small-scale logistics tests

- Biological degradation (exposure at 20ºC and RH 95%)



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Small-scale logistics tests

- Biological degradation (exposure at 20ºC and RH 95%)

White wood pellets

Coal/torrefied poplar pellets

Small-scale logistics tests

- Kilo-gram-scale uncovered open air storage tests

CENER

UmU

OFI

ECN

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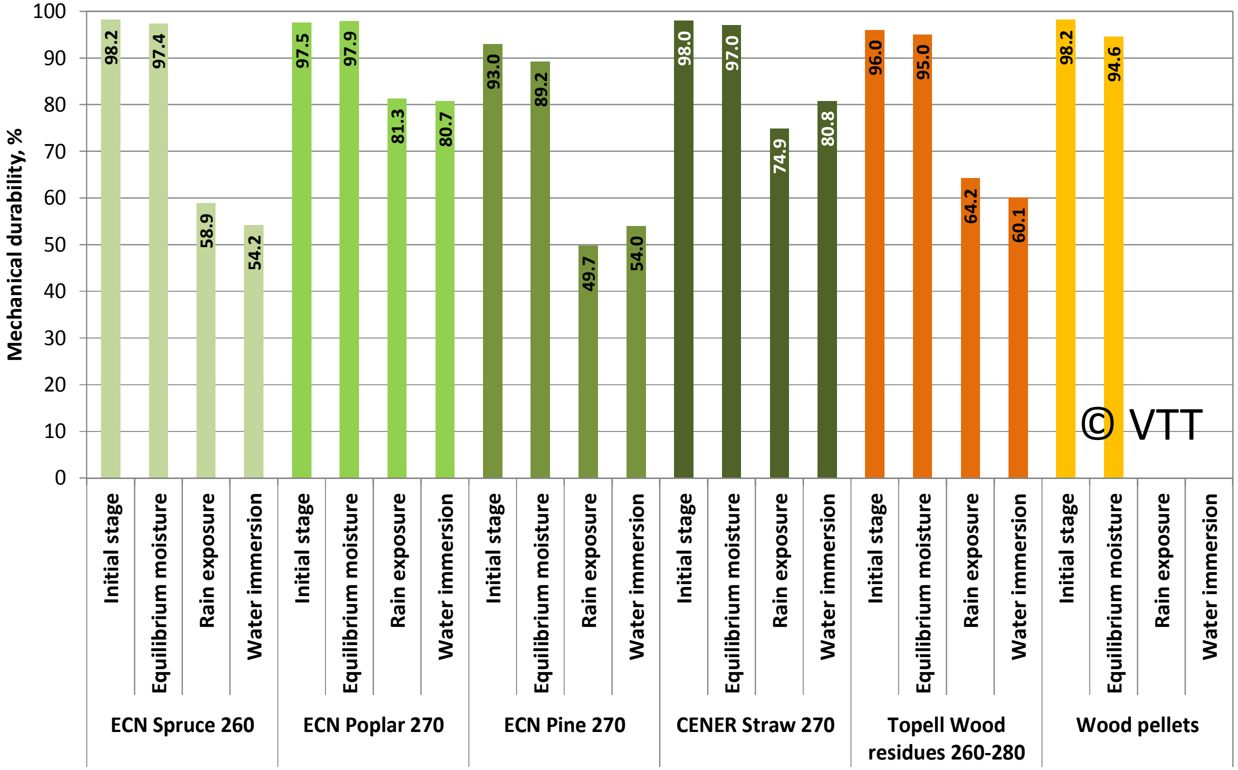
Small-scale logistics tests

- Durability of pellets has been determined after exposure testing by:
    - ECN, VTT, CENER, UmU, OFI



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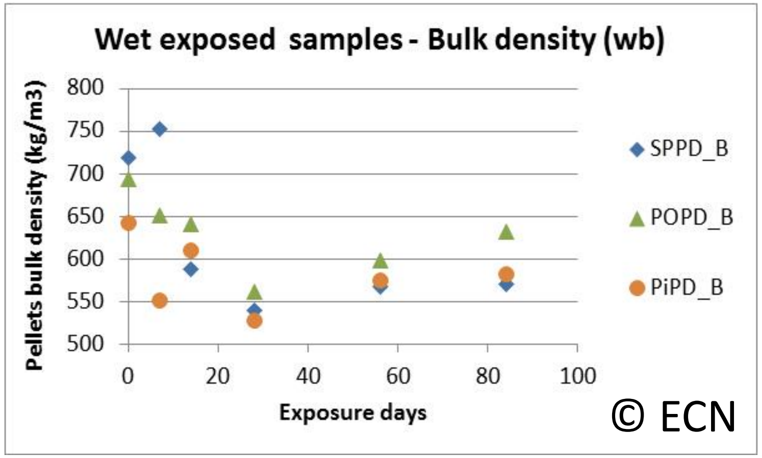
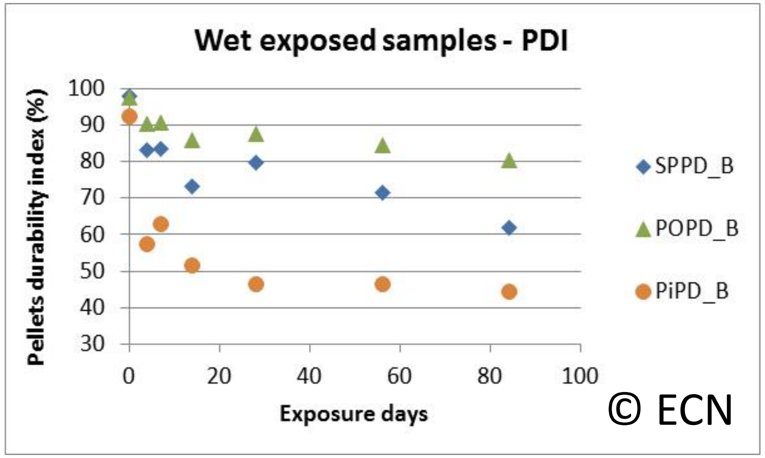
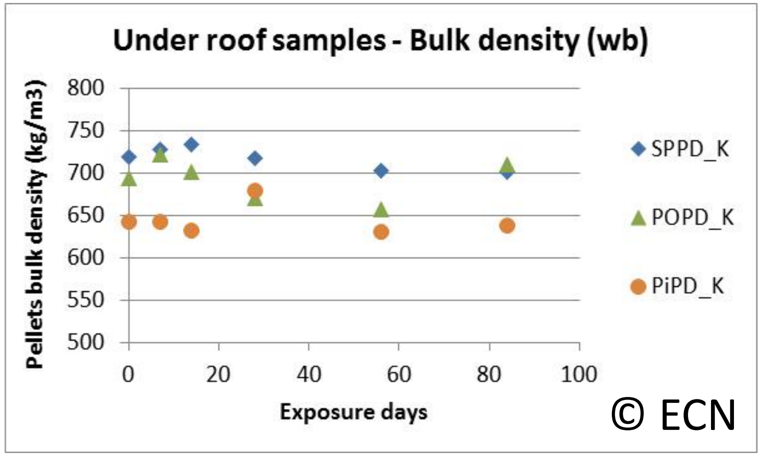
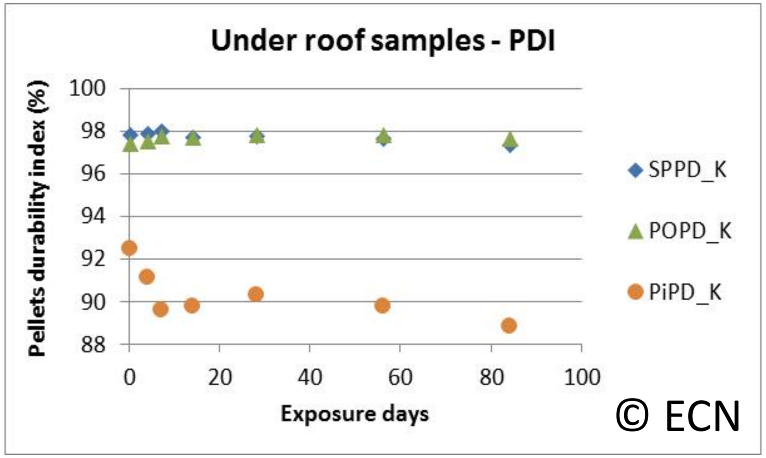
Small-scale logistics tests

- Uncovered (top) vs. covered (bottom) storage









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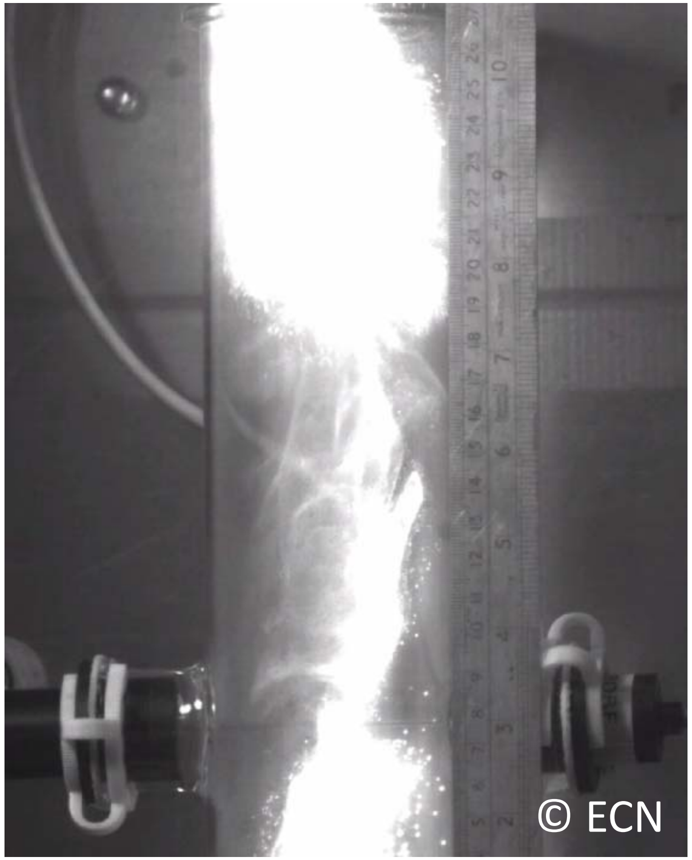
Small-scale logistics tests

- Explosivity measurements
  - Minimum Ignition Energy:
    - Dust obtained during tumbling of torrefied pellets
    - Pulverised torrefied pellets
    - also as function of particle size distribution



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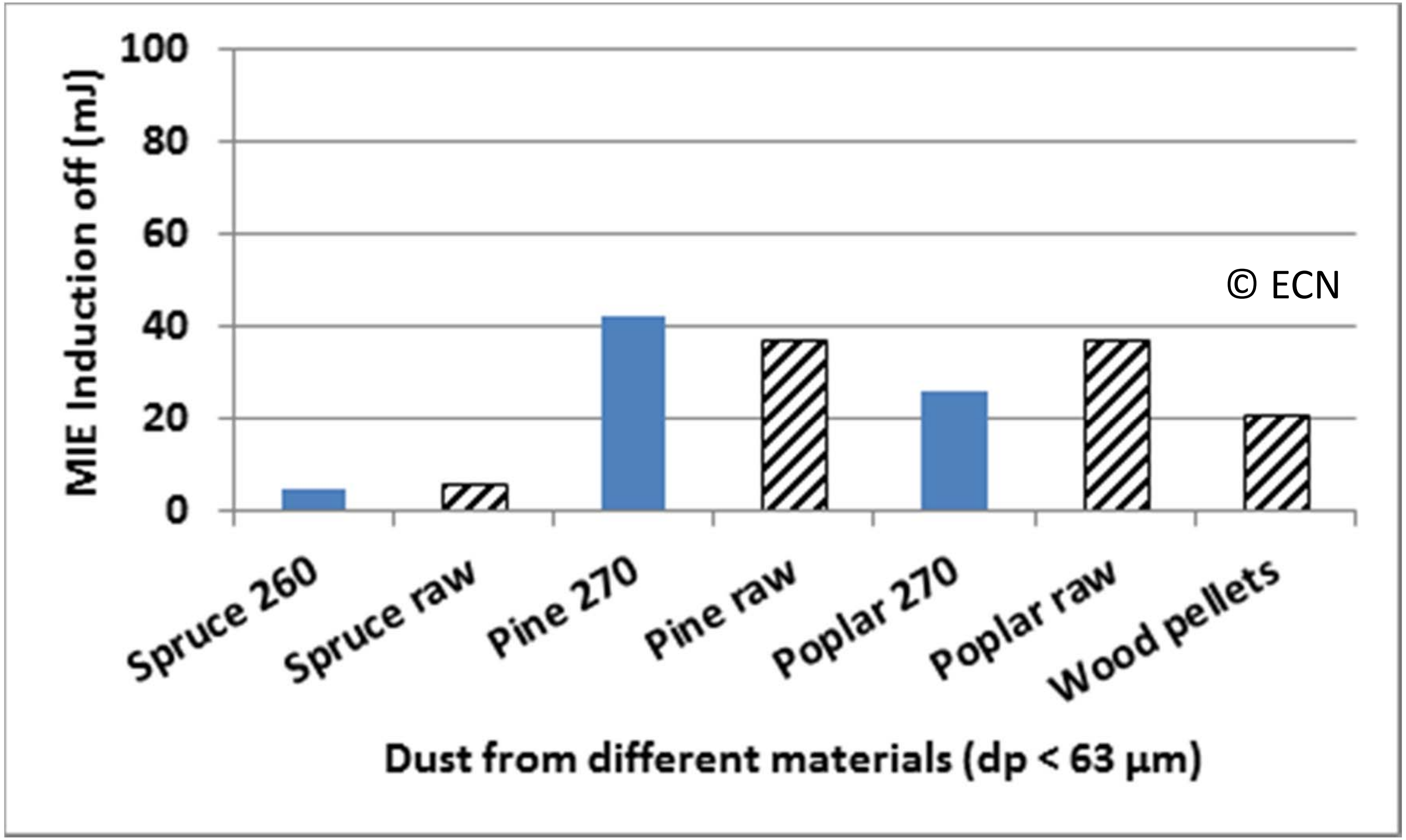
Small-scale logistics tests

- Explosivity measurements



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Outdoor storage and handling tests

Two outdoor storage piles were built in June 2013:

Peaked-topped pellets

- Model the formation of pellets after it has been delivered.
- 4 tonnes
- 2.34 x 2.36 x 1.5 m

Flat- topped pellets

- Model the formation of pellets after compaction (though no compaction has occurred)
- 3 tonnes
- 2.34 x 2.36 x 1.5 m

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Outdoor storage and handling tests

- Piles monitored from June 2013 to June 2014
- Cages removed from around piles, followed by material removal
- Free-flowing nature lost during one year of storage

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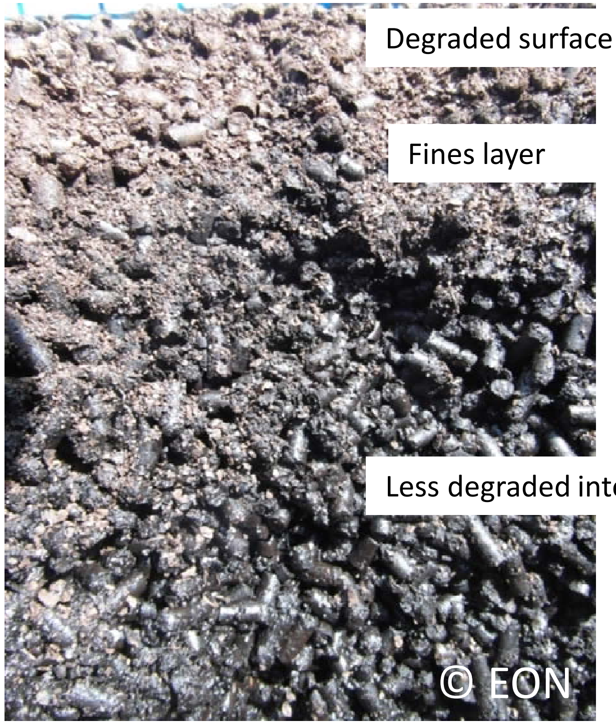
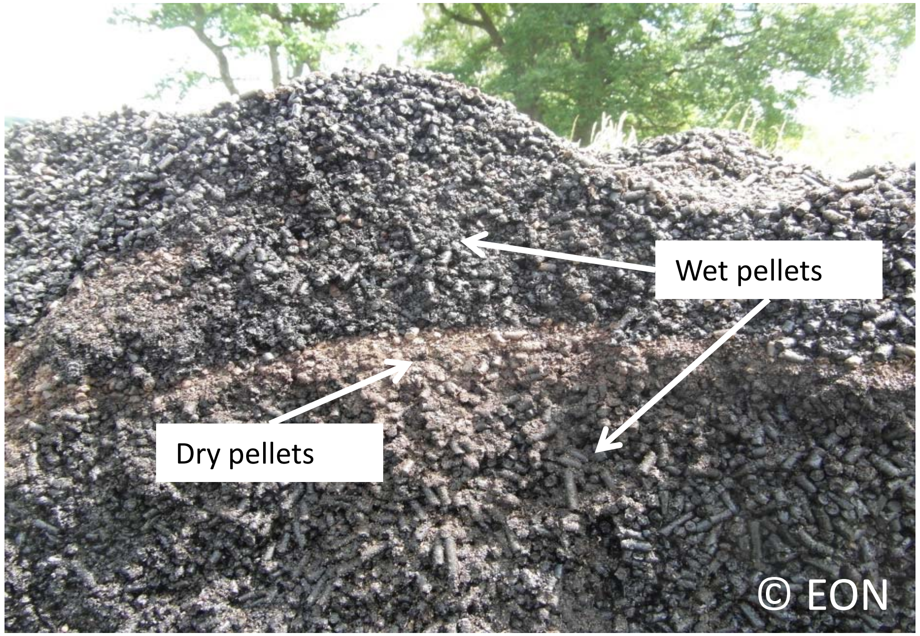
SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Outdoor storage and handling tests

- Pellets on pile surface heavily degraded
- Layer of wet fines beneath surface
- Further down, pellets more intact but areas with visibly different moisture contents





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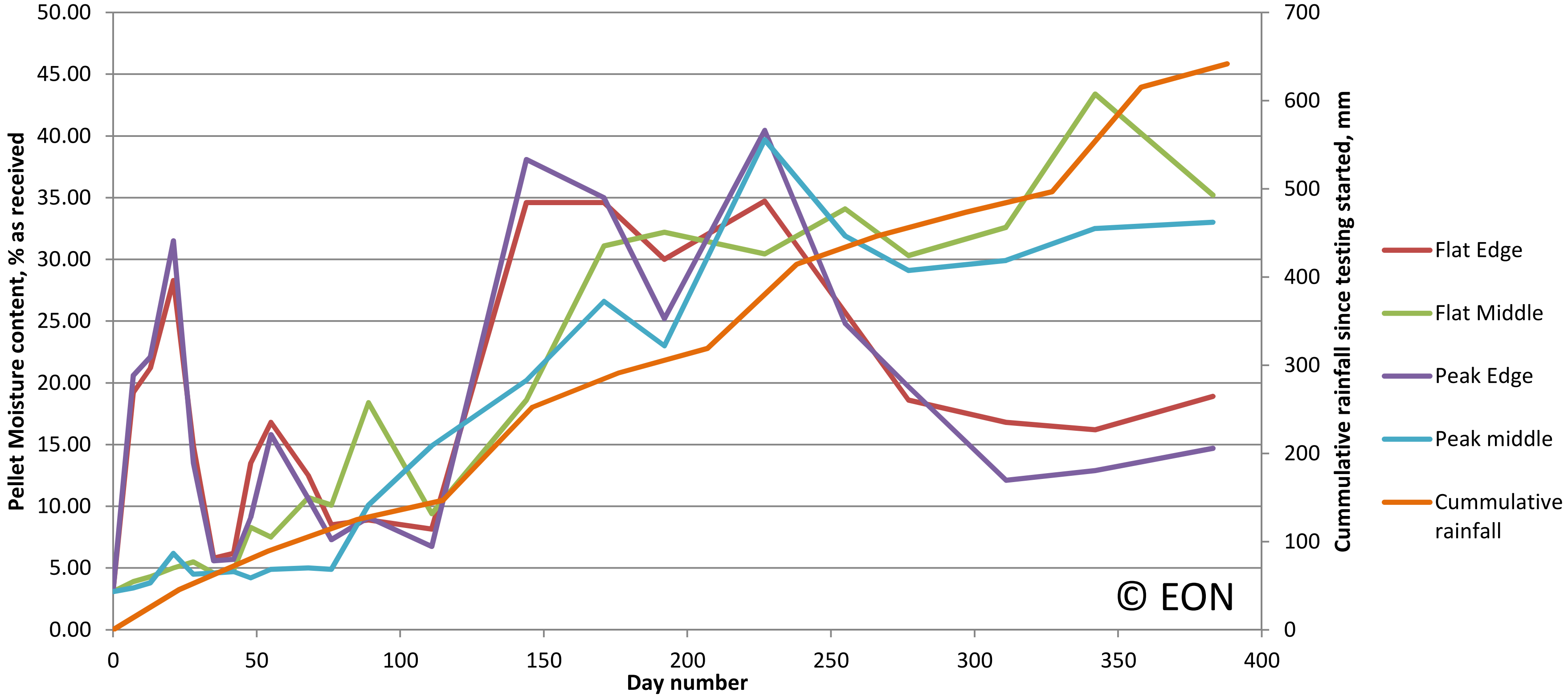
Outdoor storage and handling tests



- Moisture contents within the pile slowly increased with time
- Pellets on surface rapidly increased moisture content but then varied according to weather conditions

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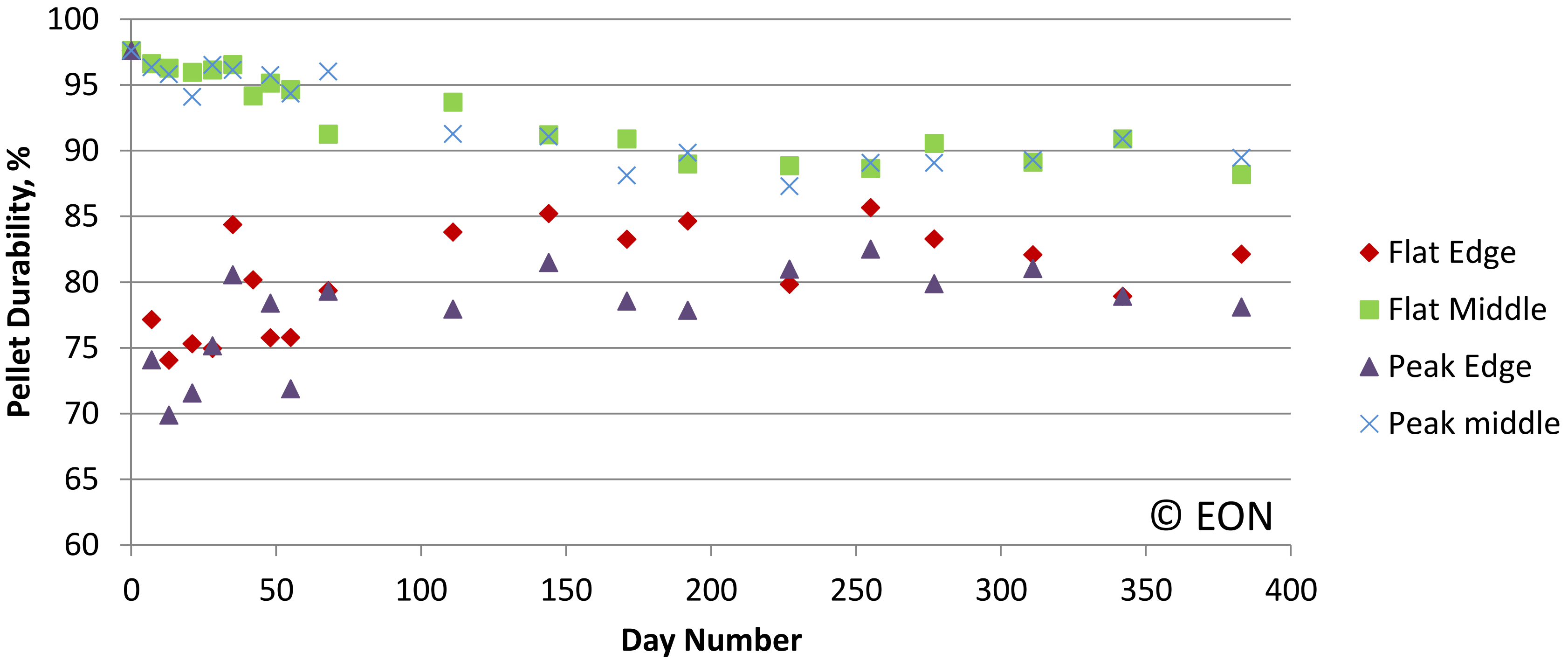
Outdoor storage and handling tests



- Immediate decrease in durability of pellets on surface of pile, stabilising at ~80-85%
- Durability within the pile decreased slowly with time

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Outdoor storage and handling tests

- Two different torrrefied materials tested
- “Piece of cake” design with a hatch to give access to middle of pile

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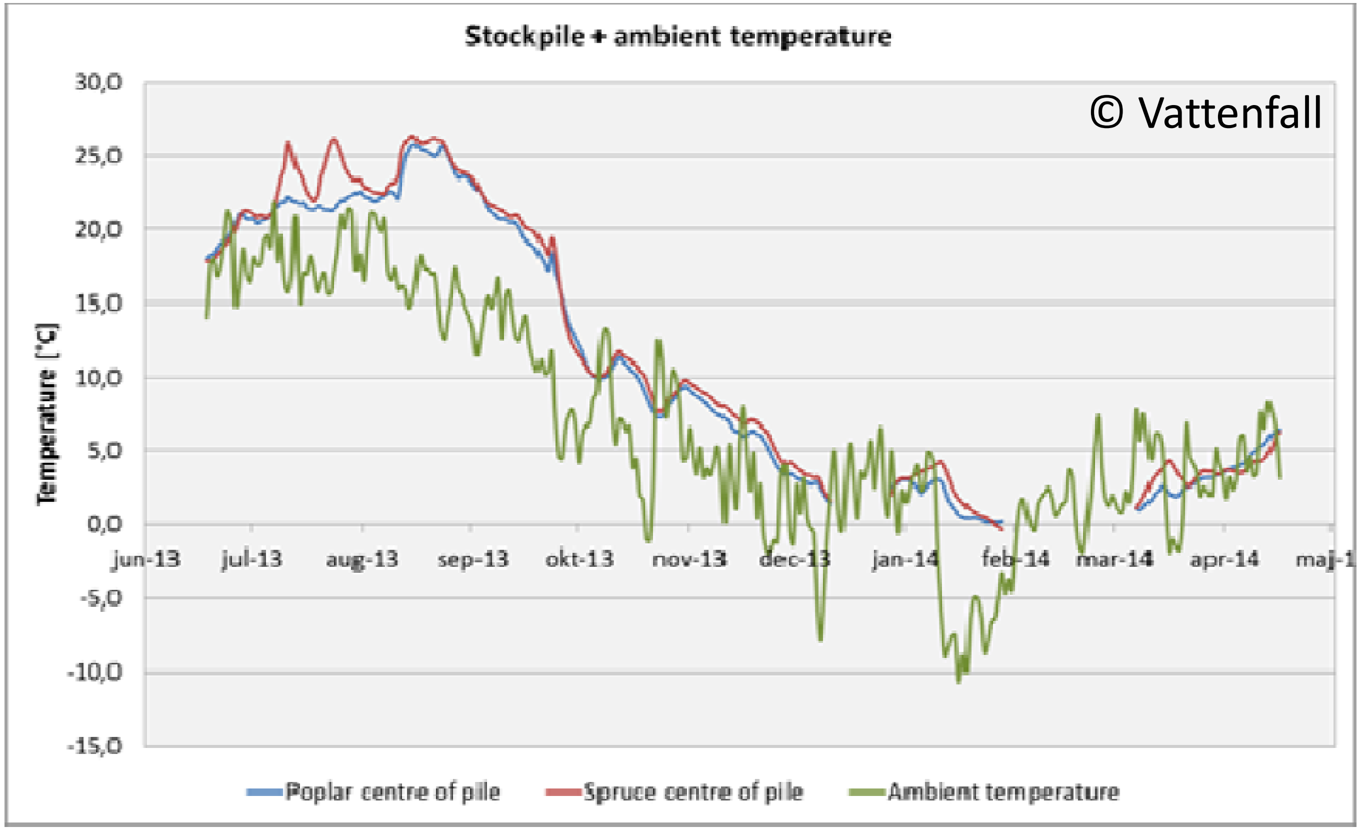
Outdoor storage and handling tests

- Temperature within both piles followed ambient conditions



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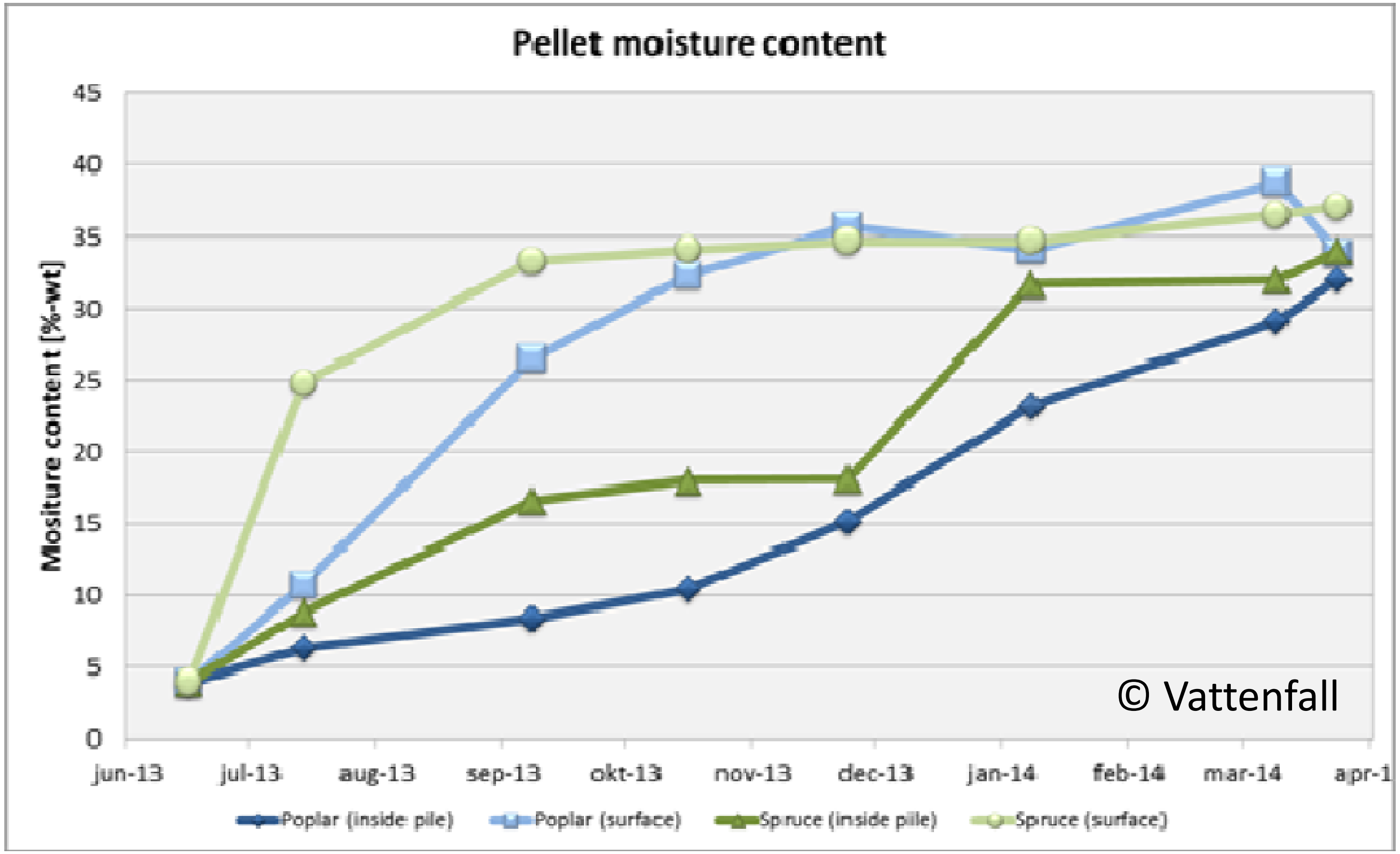
Outdoor storage and handling tests

- Moisture content of samples increased rapidly



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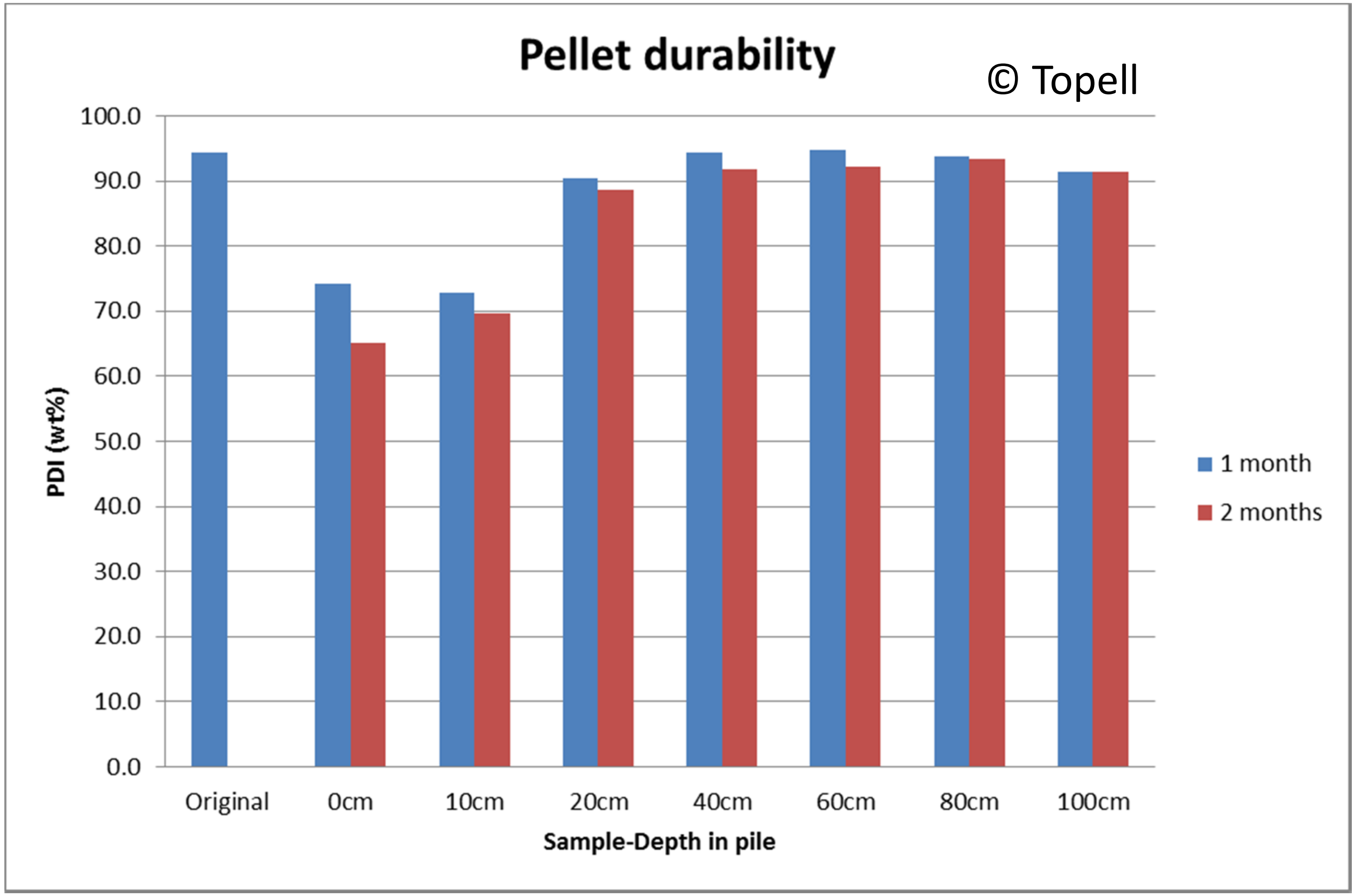
Outdoor storage and handling tests

- Alternative storage test where entire pile was sampled



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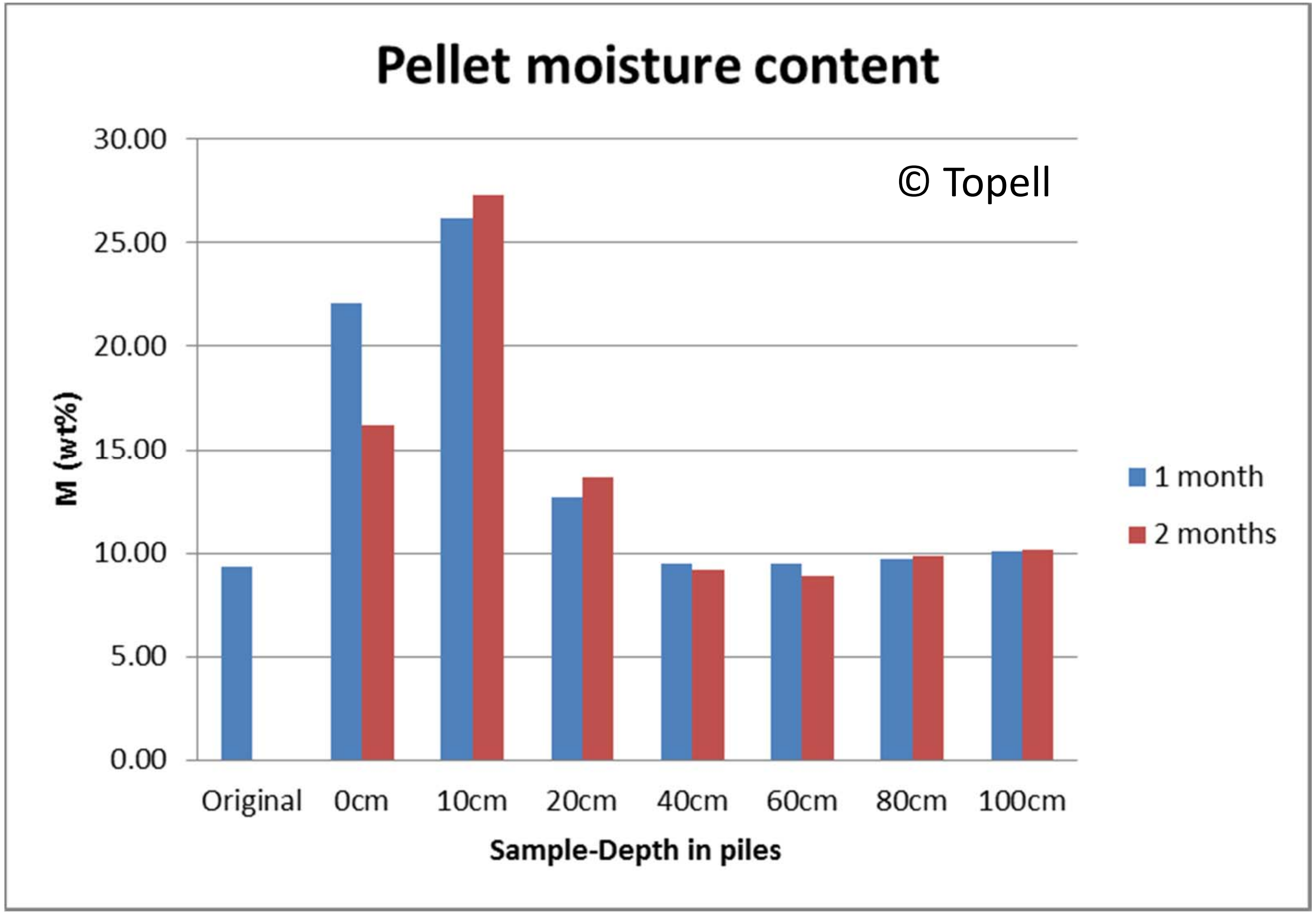
Outdoor storage and handling tests

- Alternative storage test where entire pile was sampled



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Outlook

- Torrefied wood pellets demonstrated much better weather resistance than white wood pellets
- This makes discharging and on-site logistics more straightforward, but also storage
- Outdoor storage is possible for a number of weeks, pile surface is affected but this is a minor share of a total pile; long-term storage should be covered (can be sheets)
- Pellet durability is a good indicator for weather resistance

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 282826

thank you very much for your attention!

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SECTOR

Production of **S**olid Sustainable **E**nergy **C**arriers from Biomass by Means of **TOR**refaction

SESSION III - End Use
Part 1 - Co-Milling

Final Project Meeting, 06.05.2015 in Leipzig

Collins Ndibe (University of Stuttgart)
Jörg Maier (University of Stuttgart)






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Task 7.1 Milling & feeding (USTUTT, ECN, UmU, DB)

Tasks:

- Impact of torrefied biomass on mill throughput, product fineness and the specific energy consumption of the various mills.
- Evaluate flowability, pulverized and slurry feeding behaviour
- Evaluate pressurization behaviour

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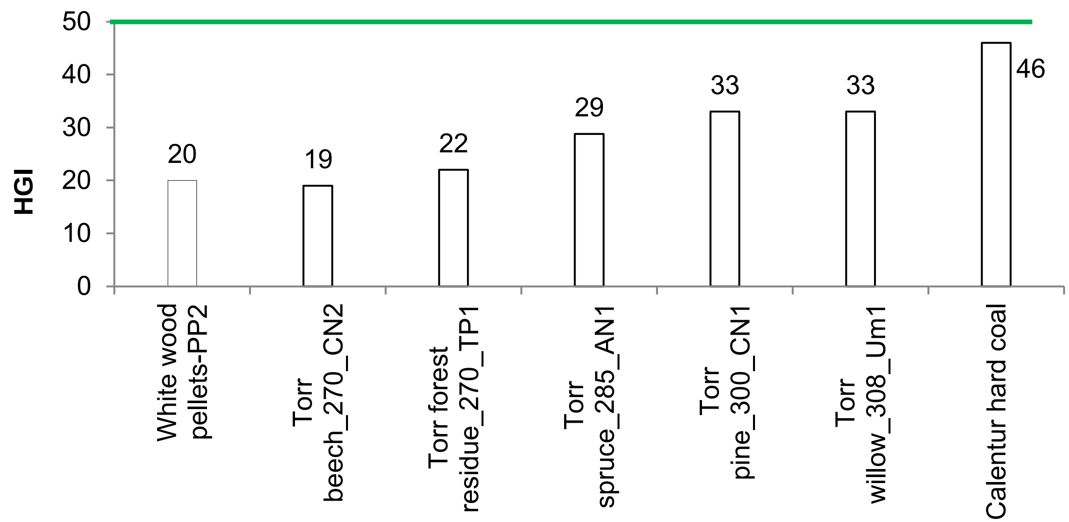
WP7.1: HGI tests with torrefied biomass at DB, USTUTT

50g
[0.63mm;
1.18mm]

60 revolutions
(284 N)

75 µm

mass < 75µm – HGI calibrated through 4 reference coals



Description	HGI values
UmU Willow 308	34
ECN Poplar270	26
ECN Pine 270	29
ECN Spruce 260	28
Topell	23
UmU Forest residue	53
UmU Pine 308	39

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WP7.1: Characterizing biomass grindability

No standard method for biomass, HGI not sufficient even for non standard coals

- Adaptation of the HGI

T.G. Bridgeman et al, ***An investigation of the grindability of two torrefied energy crops***, Fuel 89 (2010) 3911–3918
R.H.H. Ibrahim et al. ***Physicochemical characterisation of torrefied biomass*** / Journal of Analytical and Applied Pyrolysis 103 (2013) 21–30

1. Different densities → volume based HGI → constant running bed
2. Sieve requirement. 75µm too fine for biomass! Comparison with coal – different combustion requirements
   coal : D_{70} <75µm and $D_{99.5}$ < 300µm
   biomass: D_{90} <1mm

ACARP, ***HARDGROVE GRINDABILITY INDEX***, http://www.acarp.com.au/

S. Kastberg, C. Nilsson, ***Combustion Optimization Study of Biomass Powder***, SLU, 2002

J.J. Reuther, G.G. Karsner, S.T. Jack, ***Plane flame furnace combustion studies of pulverized wood***, Fundamentals of Thermochemical Biomass

3. Reference materials!!

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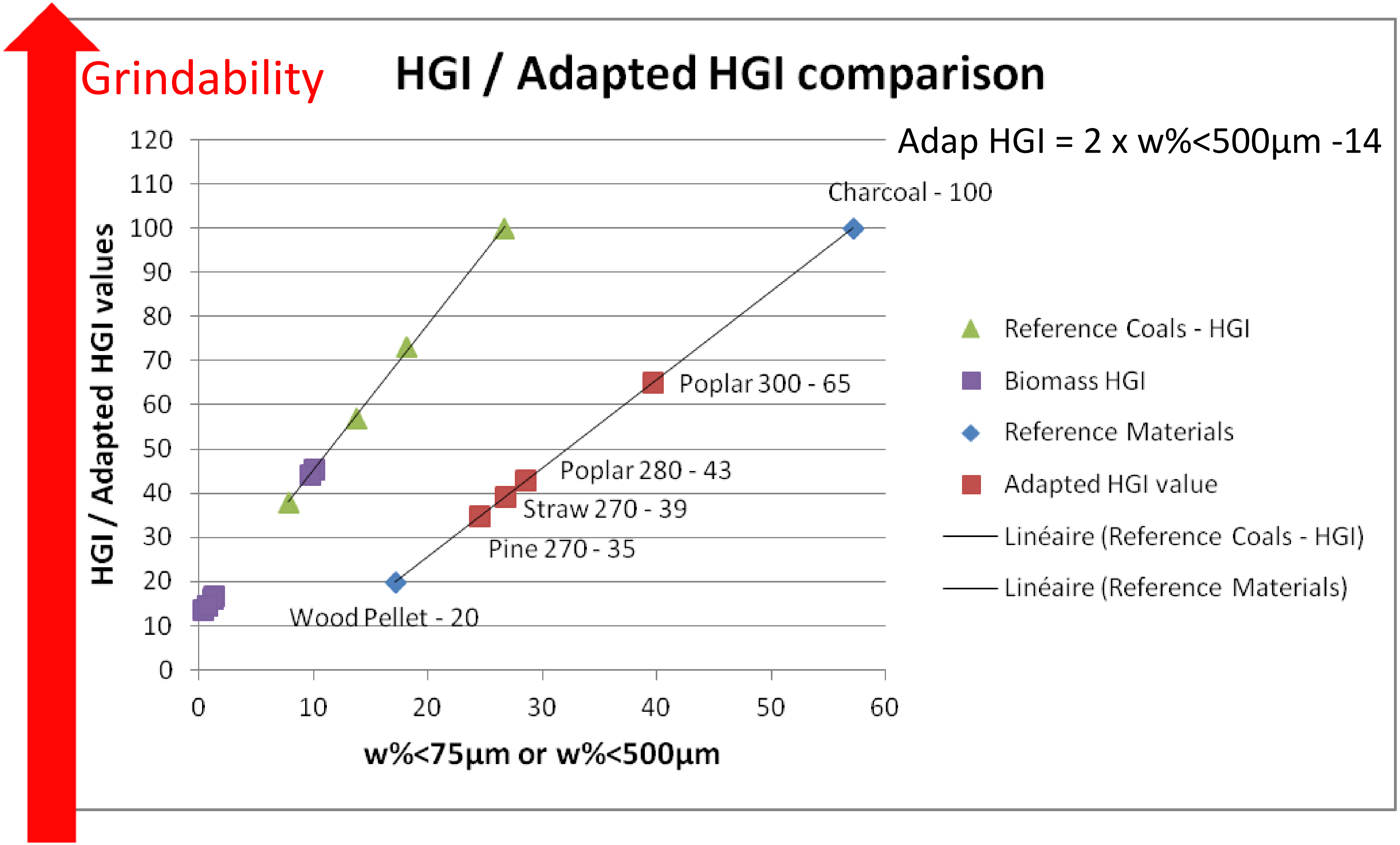
HGI adaptation (USTUTT)



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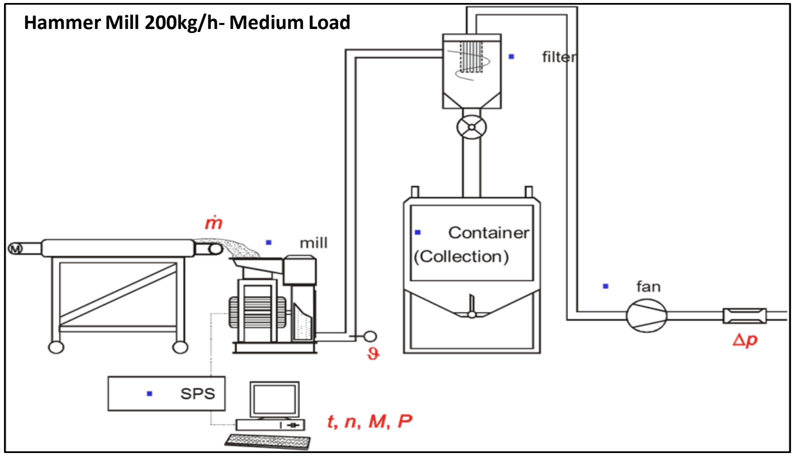
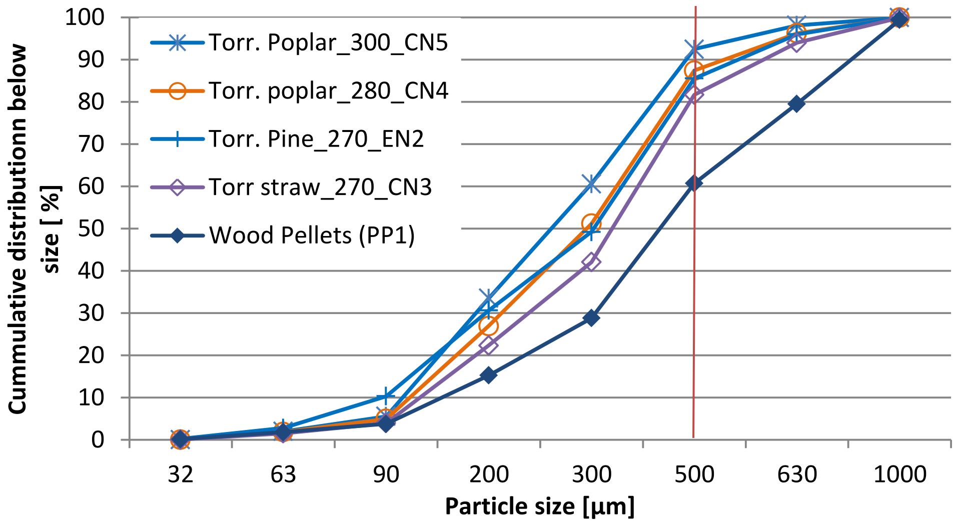
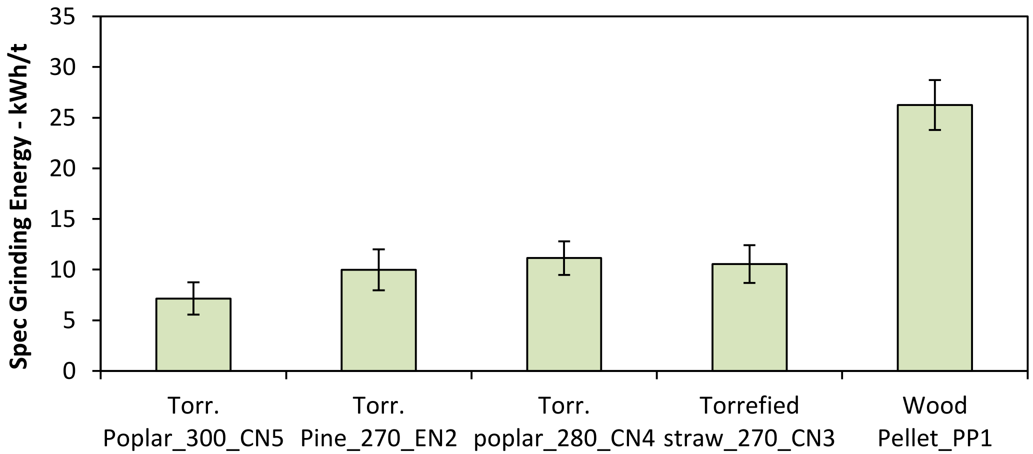
WP7.1: Torrefied pellet grinding in Hammer mill (200kg/h)-USTUTT





- ✓ Grinding energy savings - 58-73% for torrefied biomasses compared to white wood pellets ⇨
- ✓ Finer product distribution –improved combustion efficiency for PF boilers



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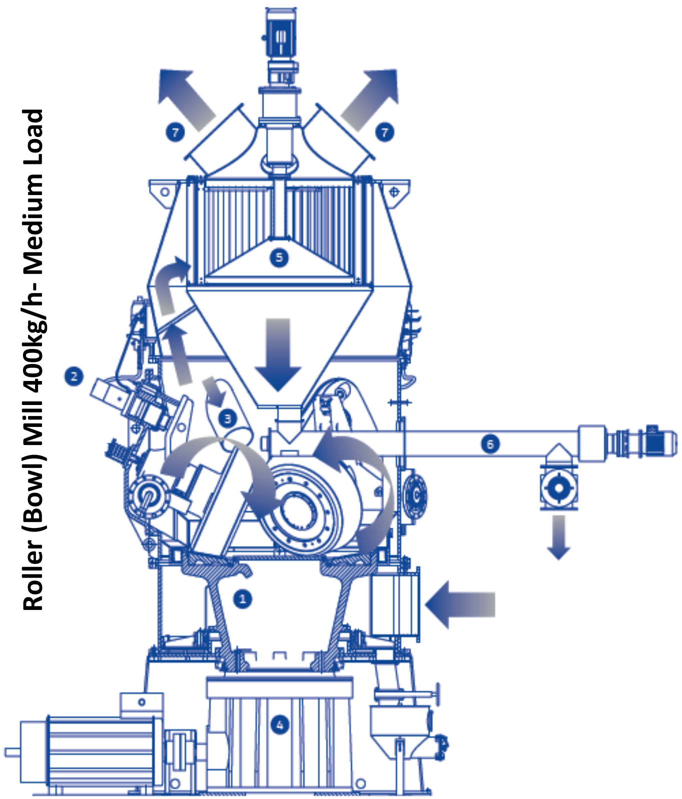
WP7.1: Torrefied pellet (co)grinding with coal(400kg/h)-USTUTT

Roller (Bowl) Mill 400kg/h- Medium Load



Setup	Bituminous Coal (Elcer)			Torrefied spruce Pellets (Ref1)		
	kg/h	wt-%	energy input-%	kg/h	wt-%	energy input-%
1	400	100	100	0	0	0
2	346	86,5	90	54	13,5	10
3	272	68	75	128	32	25
4	166	41,5	50	234	58,5	50
5	0	0	0	400	100	100

- Calibrate mill with bituminous coal in medium load (400 kg/h) to fineness analogous to power plant conditions
- Stepwise torrefied biomass addition (up to 60weight-%) at constant throughput
- Process parameters
  - power consumption
  - pressure loss of the mill
  - particle size distribution of the product

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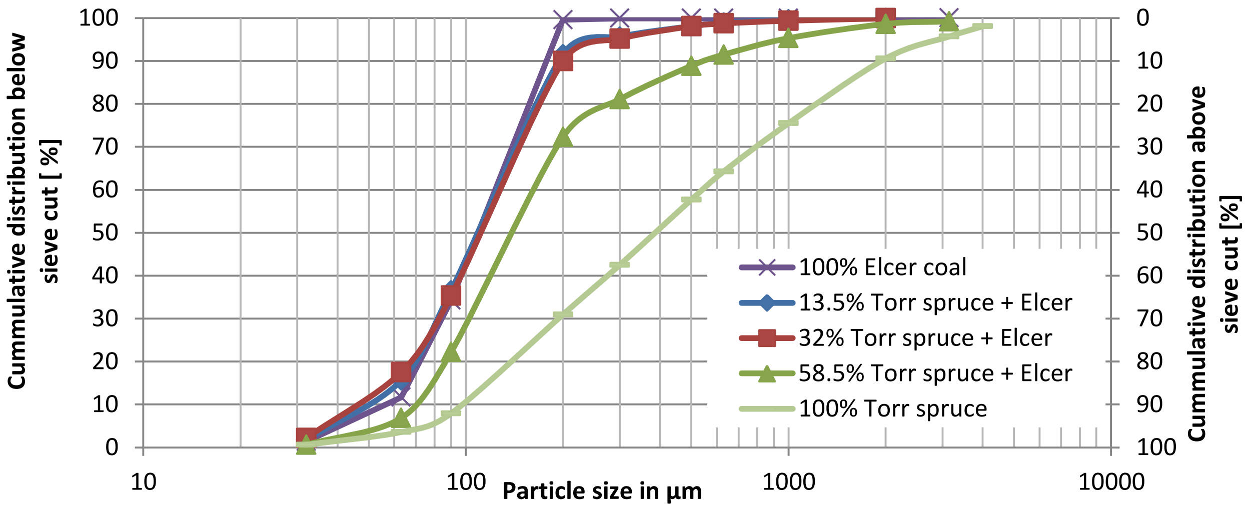
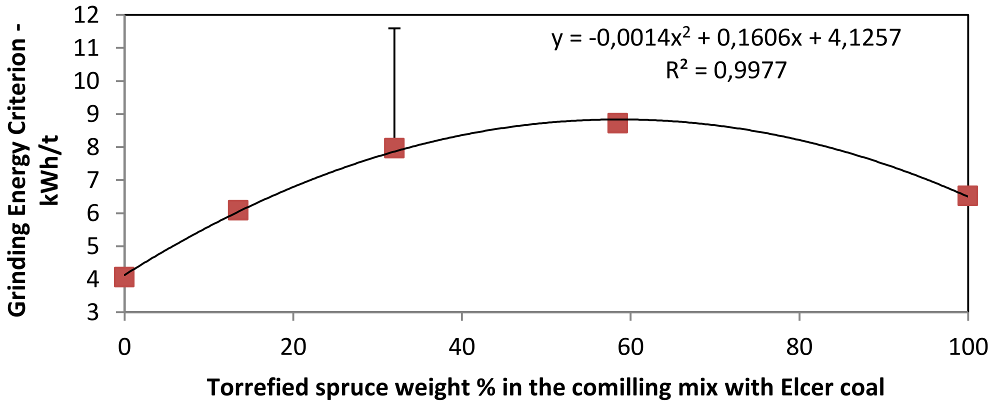
WP7.1: Torrefied pellet (co)grinding with coal(400kg/h)-USTUTT





- Co-grinding increases fineness compared to separate grinding
- Inevitable energy consumption increase: inhomogeneity

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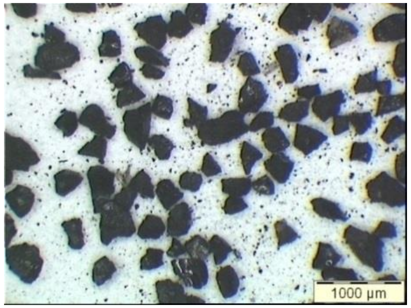
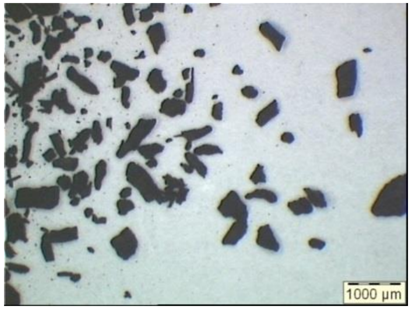
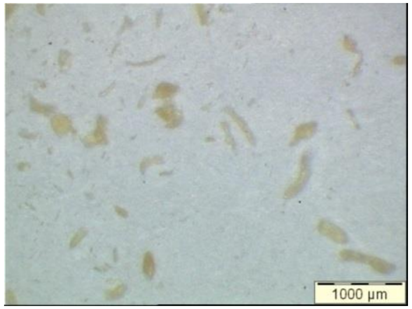
Particle Morphology







Coal

Torr wood

Non torrefied wood

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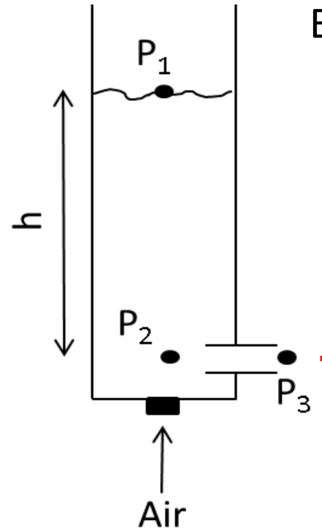
WP7.1: Flow behavior of torrefied biomass particles (ECN)

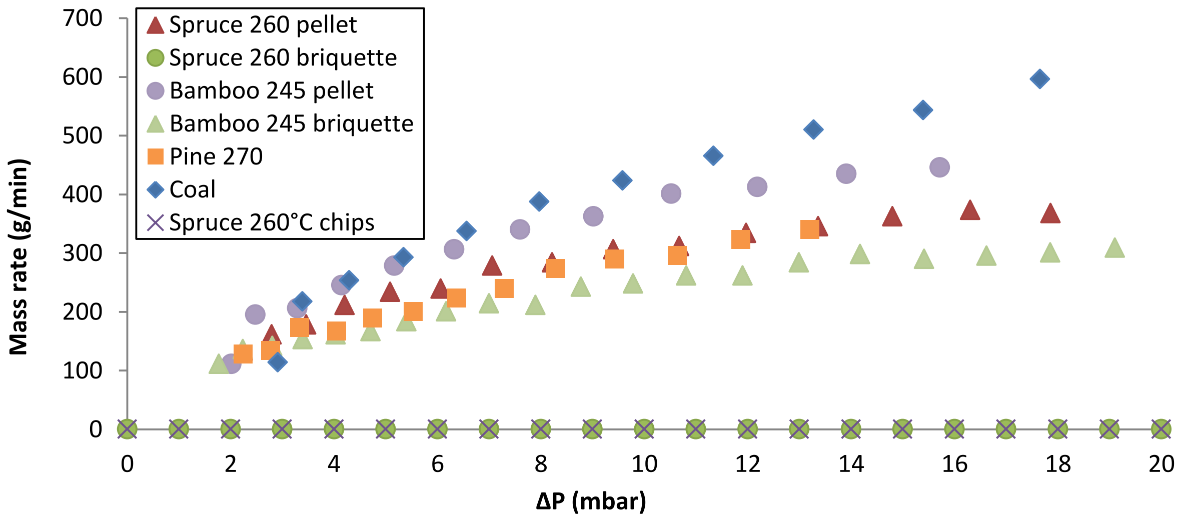


Biomass milled in a cutter mill-particle size range of 200-350 µm

$$\Delta P_{2,1} = P_2 - P_1$$
$$\Delta P_{2,1} = (P_1 + \rho g h) - P_1$$
$$\Delta P_{2,1} = \Delta P_{2,3}$$
$$\Delta P_{2,3} = \rho_{bulk} . g . h_{fixed\ bed}$$

flow rate of solids is measured at point 3

- Coal presents the highest flowability
- Spruce 260°C chips and briquettes -poor flowability
- Milled pellets have better flowability properties than milled briquettes



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SECTOR

Production of **S**olid Sustainable **E**nergy **C**arriers from Biomass by Means of **TOR**refaction

SESSION III - End use
Part 2 - Co-firing

Final Project Meeting, 06.05.2015 in Leipzig

Jaap Koppejan & Gert Jan vd Gulik, Procede
Collins Ndibe, USTUTT
Slawomir Kakietek, IEN
Will Quick, Hugh Burnham-Slipper, E.ON
Nader Padban, Vattenfall






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WP7.2: Summary of task description

Partner	Role	Reported in
IFK	- Pilot plant cofiring tests on cofiring with lignite and hard coal	D7.5
IEN	- Pilot plant cofiring tests on cofiring with hard coal	D7.5
Procede	- Task leader - CFD analysis of • IFK pilot plant with hard coal • EON UK plant with hard coal • Polish plant through IEN with hard coal	 D7.5 D7.8 D7.8
EON UK / Vattenfall	- Transfer and implementation study in hard coal boilers	D7.10

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Logistics

- Compared to wood pellets savings possible due to unloading and transport in open air
- Open air storage less attractive than coal due to water absorption in upper 20 cm layer
- Compared to coal, torrefied pellets appear unsuitable for long term storage, compaction and multiple handling events in coal yard
- Very limited biological degradation observed, only after long time storage and under extreme conditions
- Leachate not yet fully assessed
- Dust formation likely to require misting systems, though durability is already much better than in the start of the project

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Milling characteristics

- Milling characteristics better than wood pellets, but typically worse than difficult coals
- HGI values may be misleading for biomass and torrefied biomass
- Cogrinding is feasible

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COMBUSTION BEHAVIOUR

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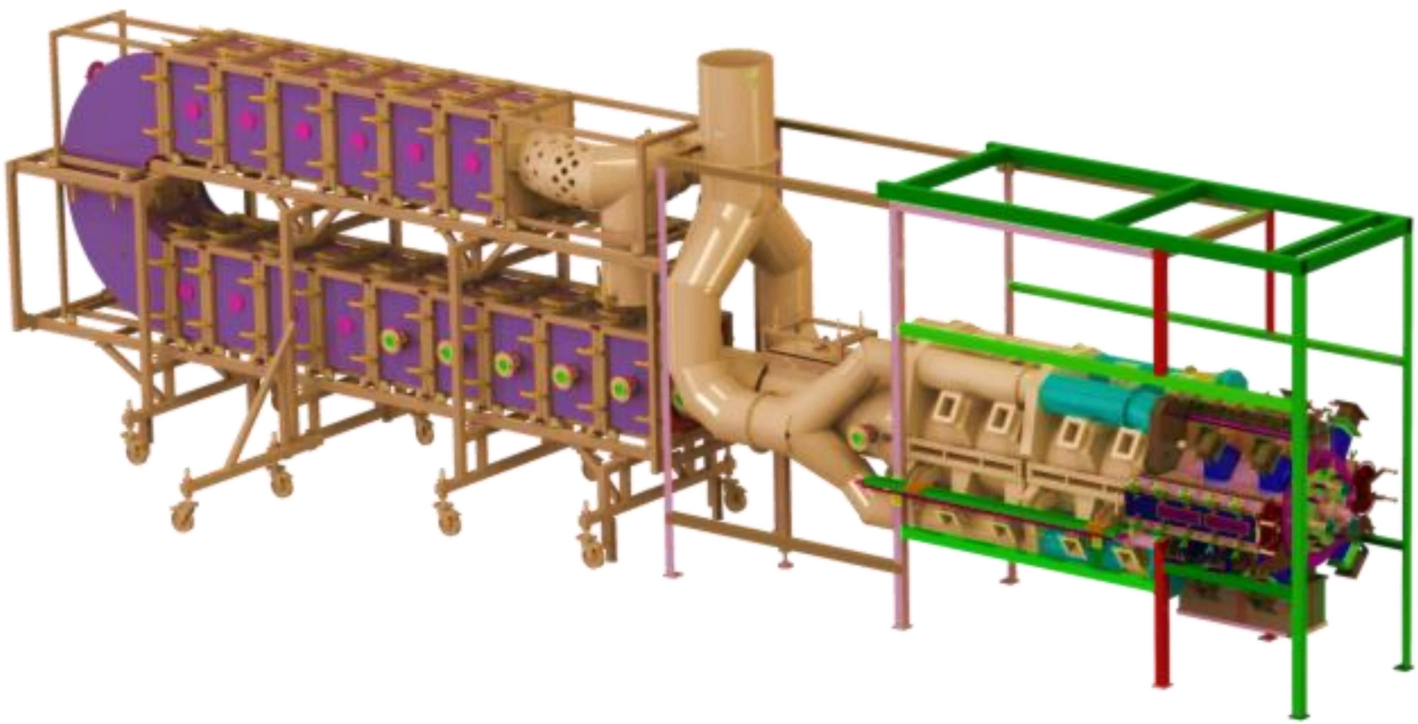
Parametric tests at 500 kW test rig at IEN



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Tests at IEN

- Many measurements of NO, CO, LOI

- both raw and torrefied biomass
- beech, pine, straw
- at 20% and 40% cofiring with hard coal
- At varying OFA flow rates

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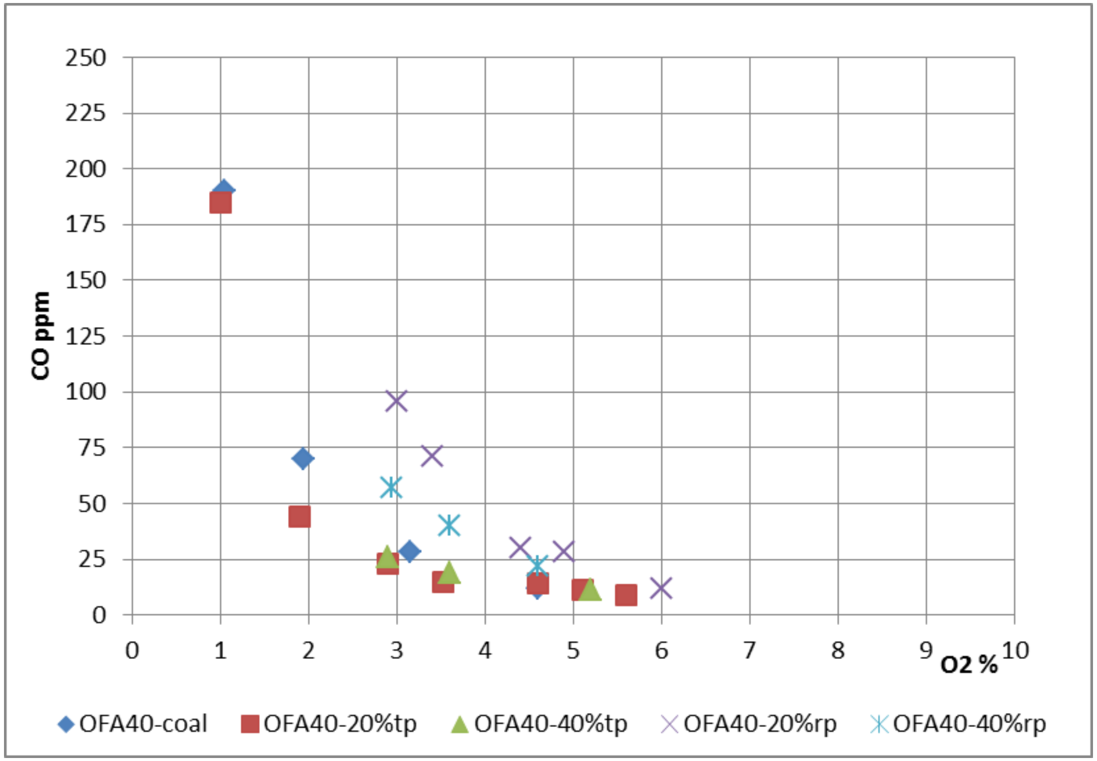
CO emissions

- Highest emissions for raw biomass, followed by torr. biomass
- Possibly due to larger particle size



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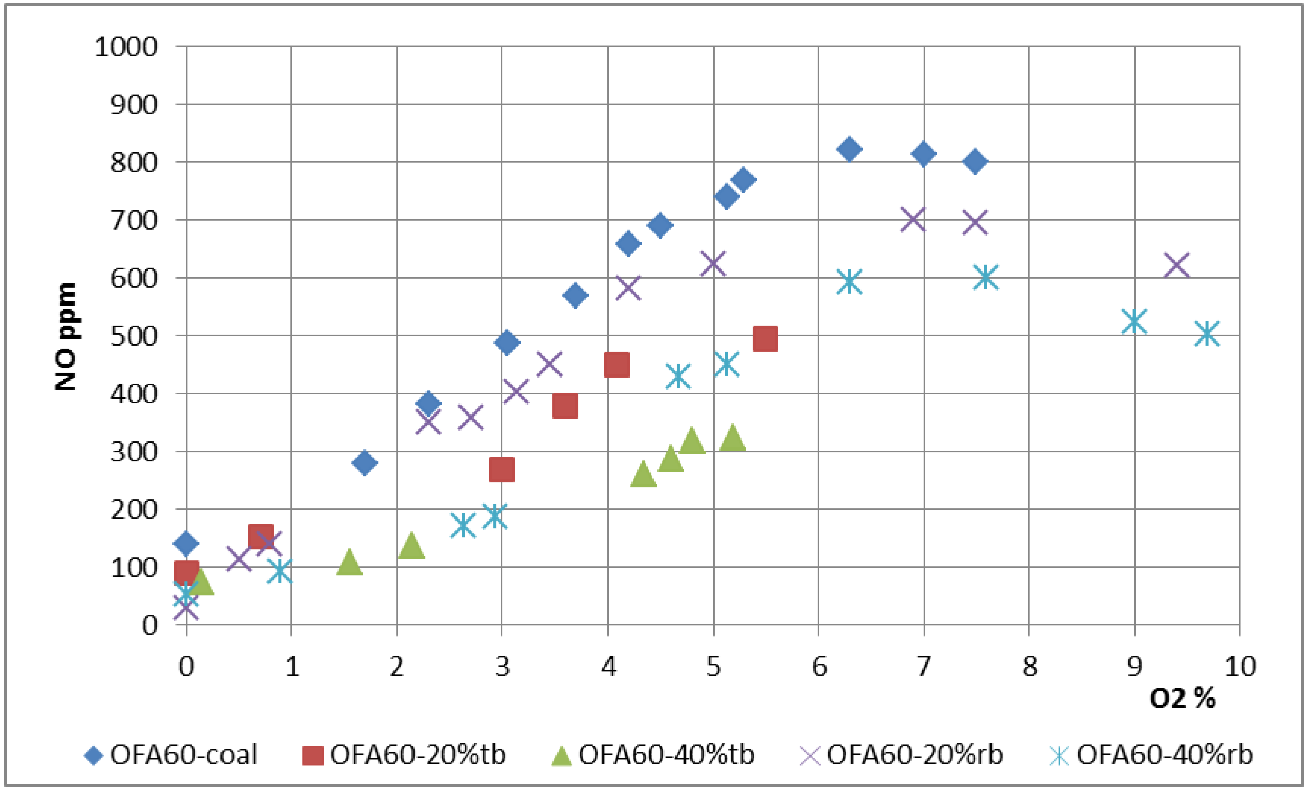
NO emissions

- Highest for coal
- Lower fuel N contents of biomass results in reduction
- Air staging reduces NOx emissions



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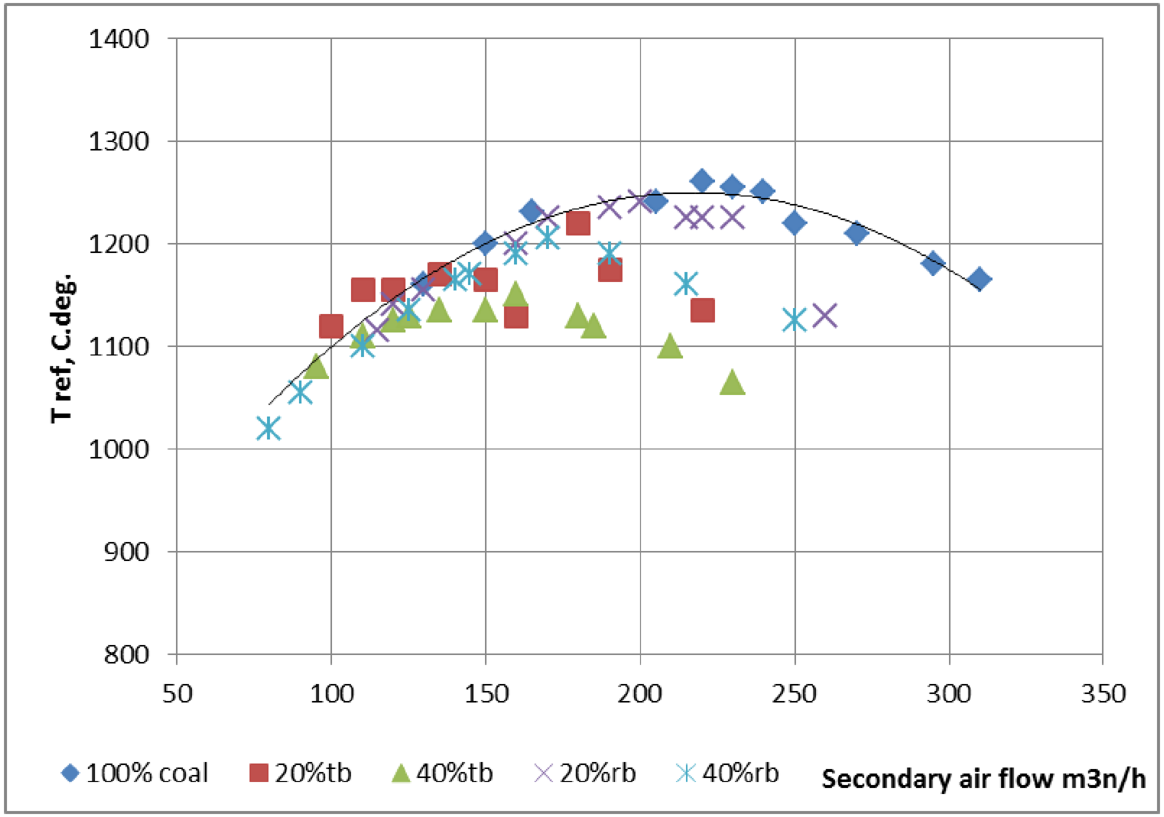
Temperature

- Highest temperatures observed for coal, lowest for biomass



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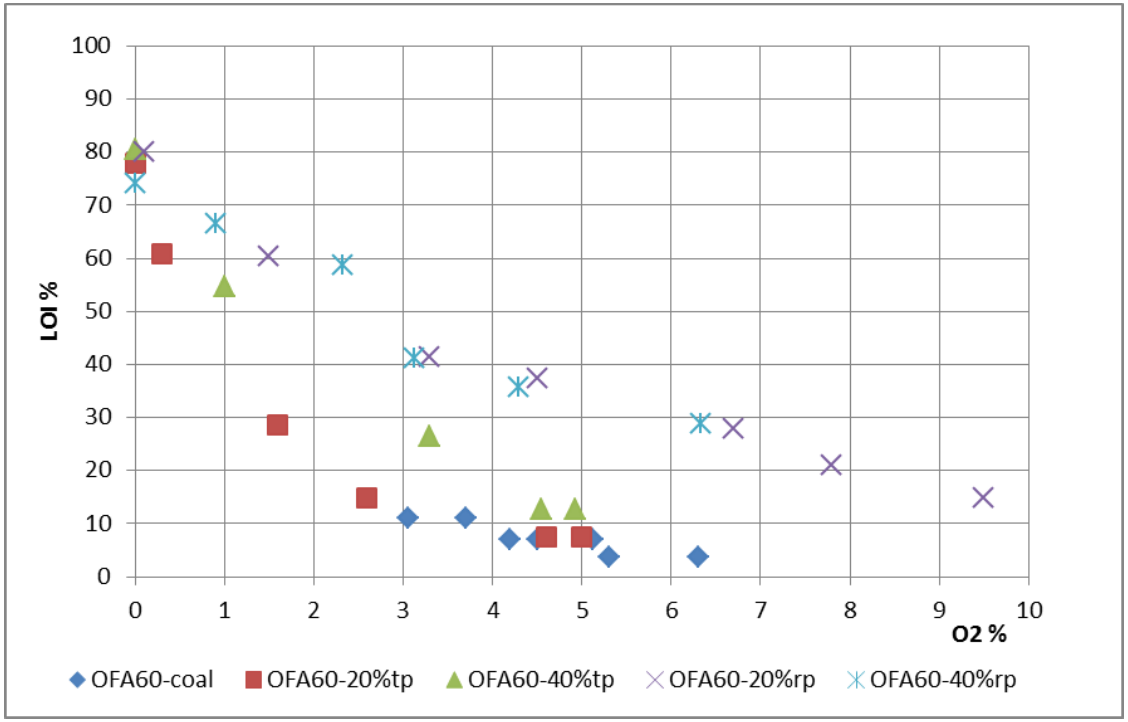
Loss on ignition

- Adding milled torrefied biomass does not have an effect
- Adding milled raw biomass leads to higher LOI, probably due to larger particle size



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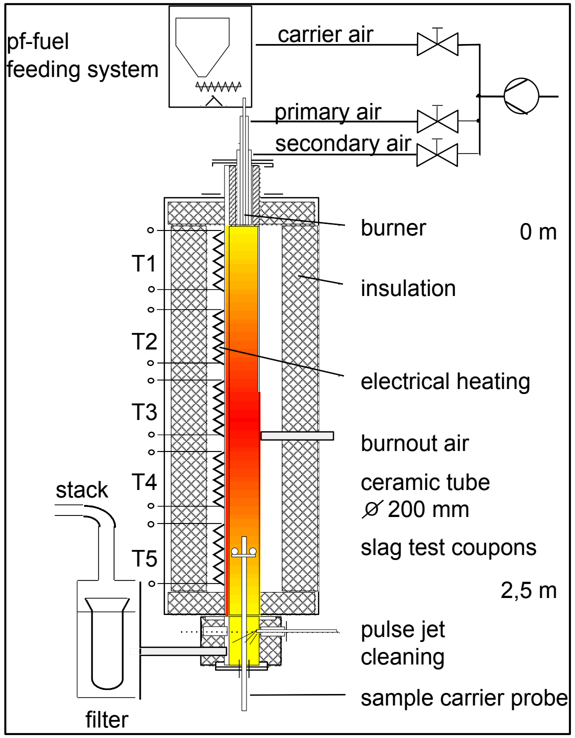
USTUTT BTS-VR (20kW atmospheric combustion test rig)

- Used for characterisation of combustion behaviour
- Gas measurements
- Deposit formation
- Ash quality, unburned matter



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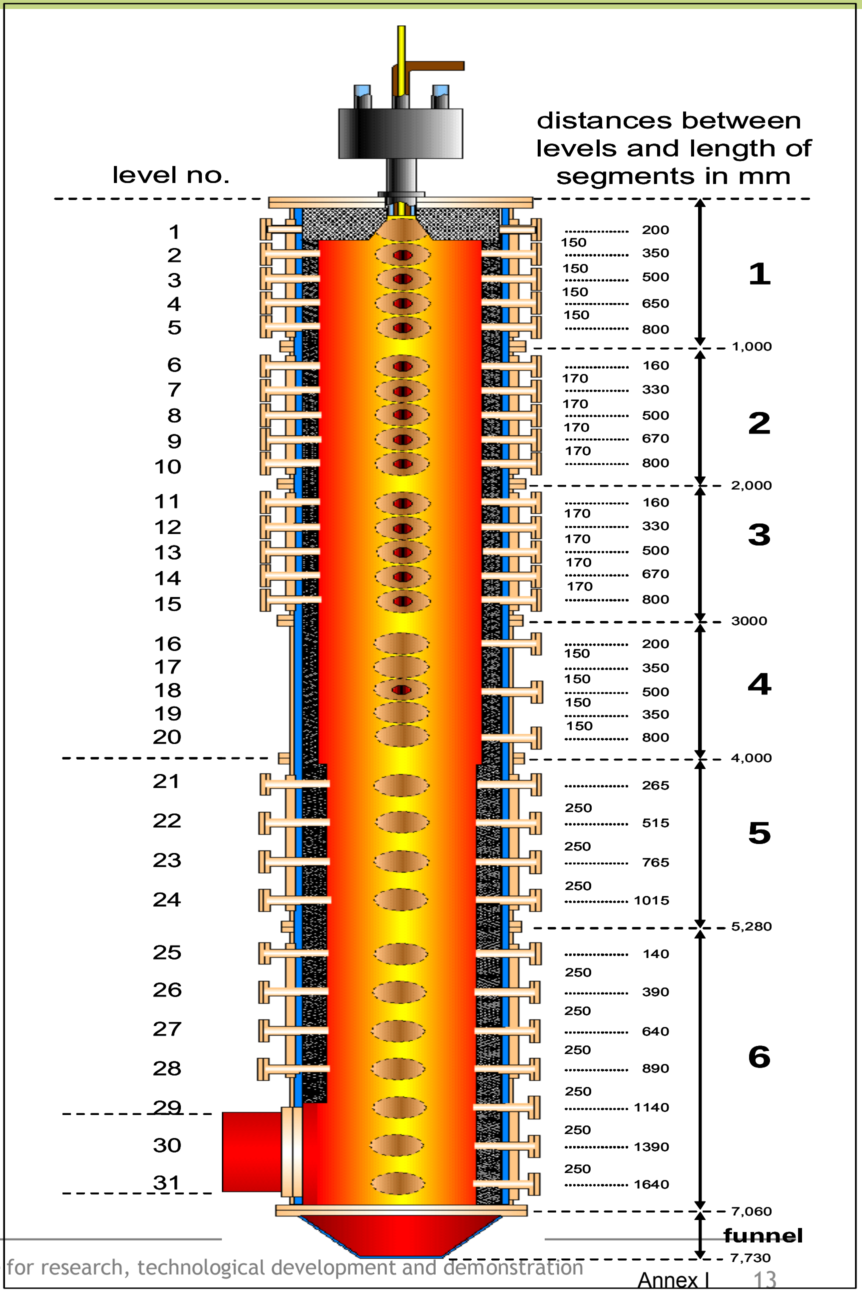
USTUTT KSVA reactor

- Cofiring tests in 500 kW_{th} KSVA reactor
- 2 different coals: El Cerrejon (bituminous) coal and LaTBK (lignite)
- Varying cofiring shares of torrefied spruce
- Gas measurements on many different locations
- Torr spruce significantly larger particle size than coal



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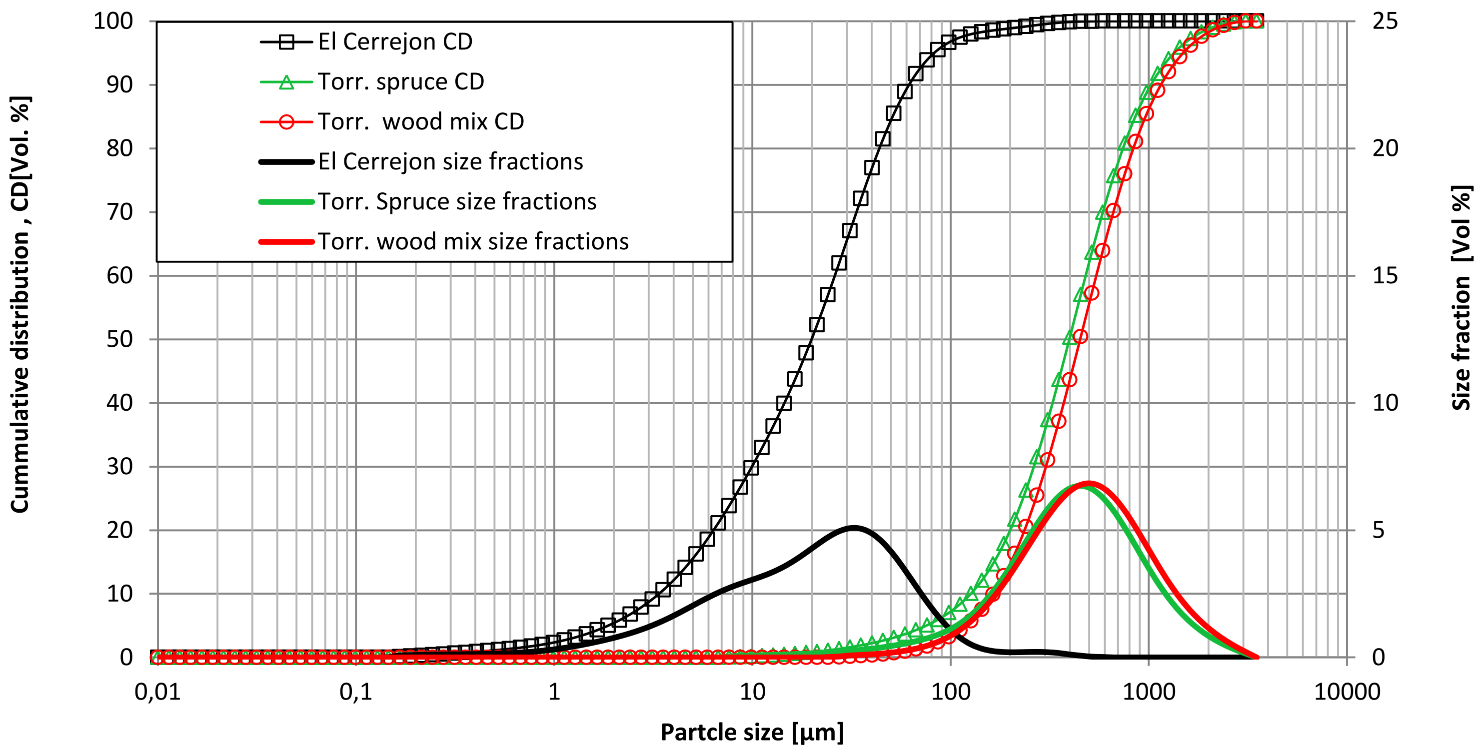
Fuel particle size

- Torrefied biomass particles (500 µm) much larger than coal fired particles (30 µm)



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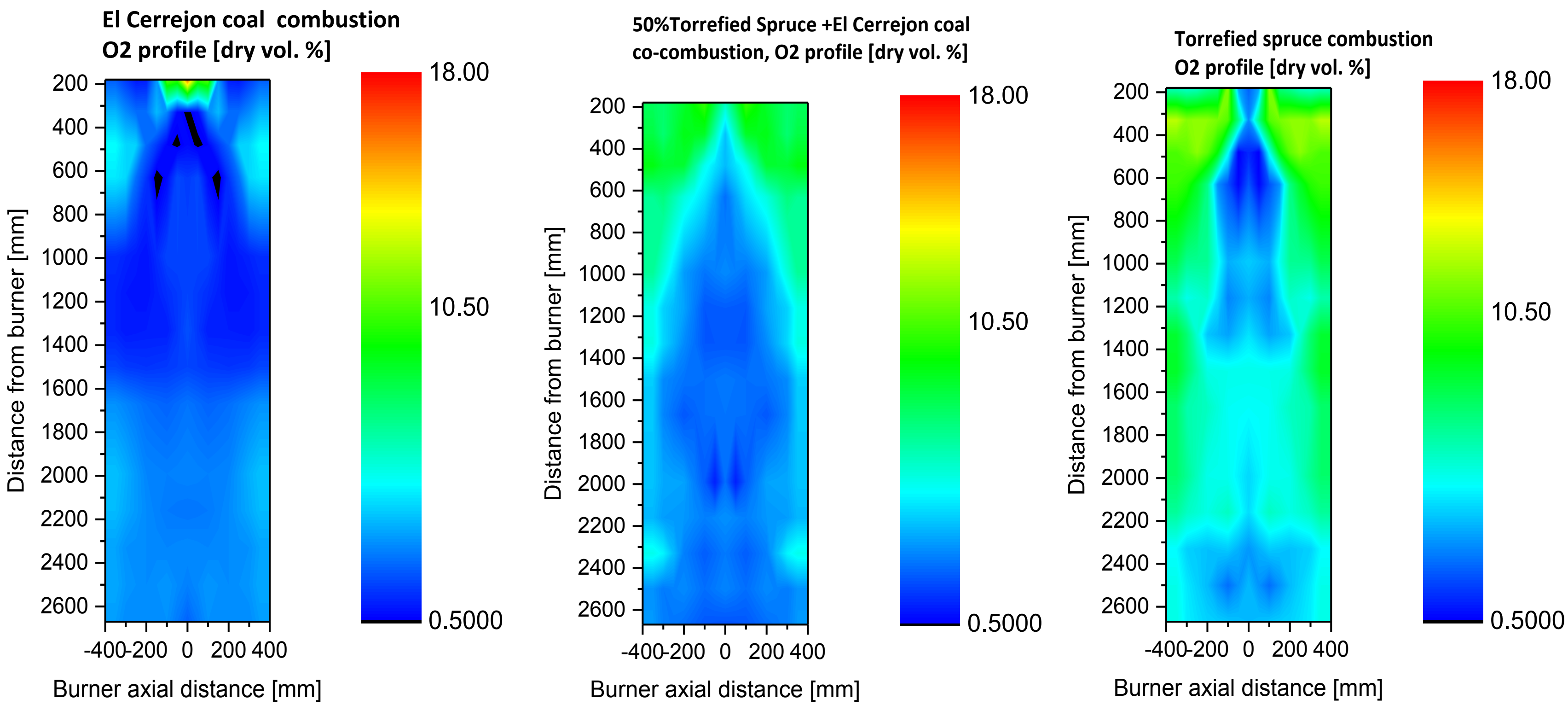
O_2 profiles

- Fastest combustion for coal, slowest for torrefied spruce



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CFD Modeling

Input

- Geometries of 3 systems (IFK pilot plant, IEN & EON full scale plants)
- From reference cases (coal) & cases with torrefied materials, that are comparable:
  - Mass flows
  - Material properties
  - Kinetics
  - Particle size distributions
  - Emmissions
  - Wall emmisivities (Input for radiation calculation)

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CFD Modeling

Output

- Position and shape of flame
- Flame instabilities
- Gas concentration profiles
- Temperature distributions (flame & wall)
- Emissions
- LOI in fly ash
- Wall heat flux

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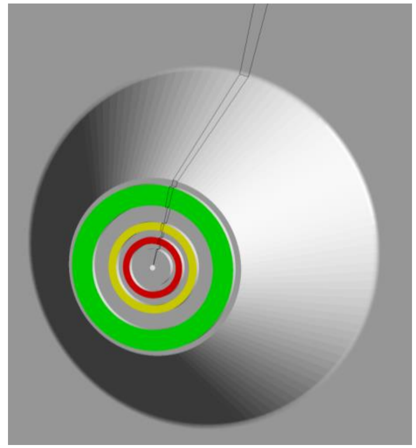
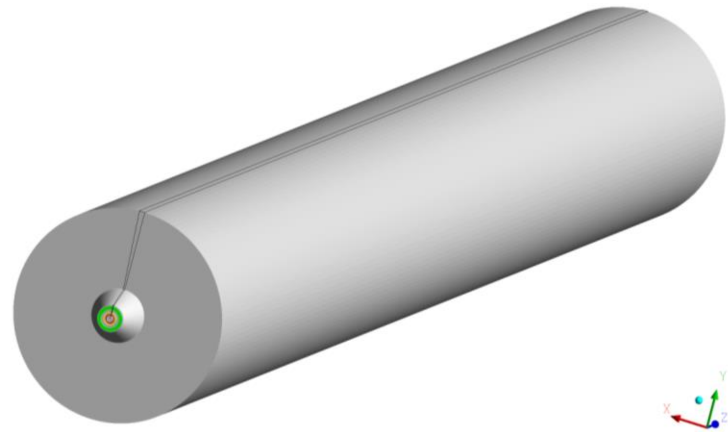
USTUTT burner configuration

coal

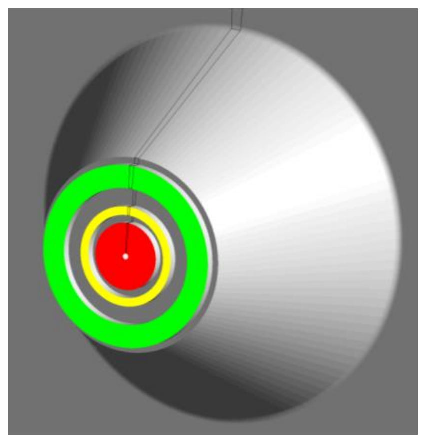
Inlet	Colour	Air [Nm^3/h]	Swirl	Coal [kg/h]
V3		243	45°	-
V2		30	30°	-
V1		35	0°	40

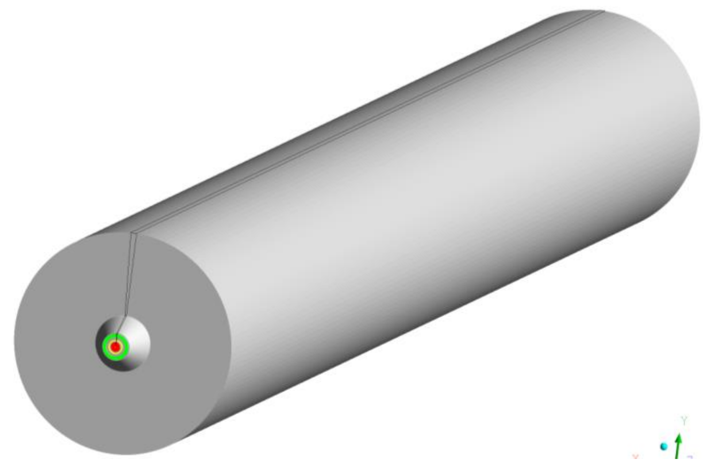




Biomass cofiring

Inlet	Colour	Air [Nm^3/h]	Swirl	Spruce [kg/h]
V3		237	45°	-
V2		60	30°	-
V1		49	0°	57





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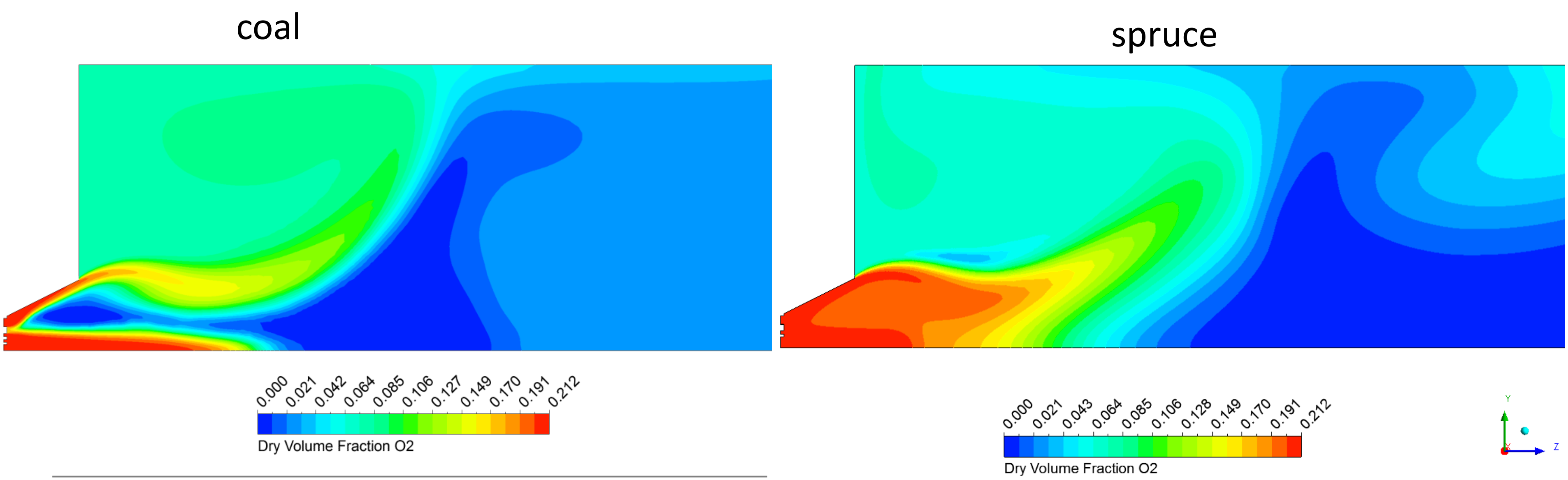
O_2 concentrations

- Combustion slower than for coal, close to the wall
- Diffusion limitations through larger particle size may be the cause



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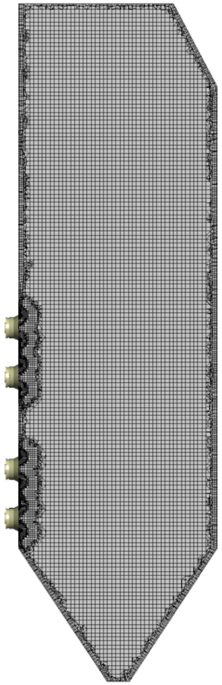
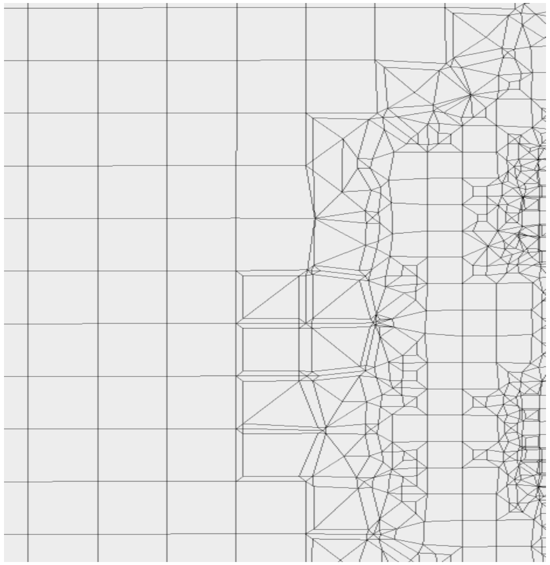
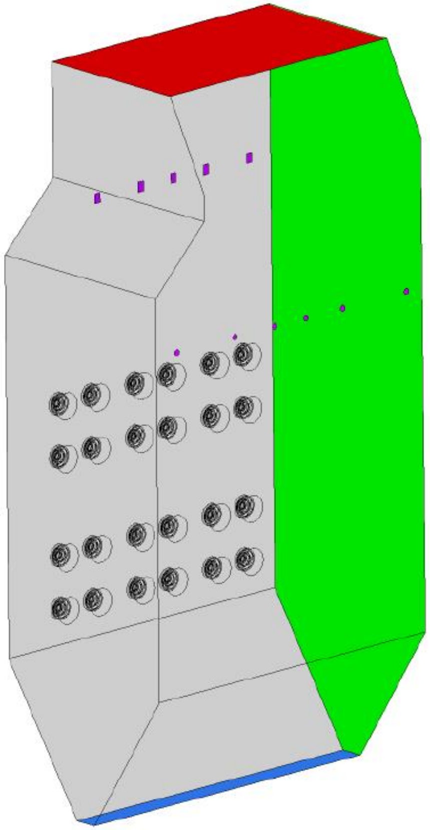
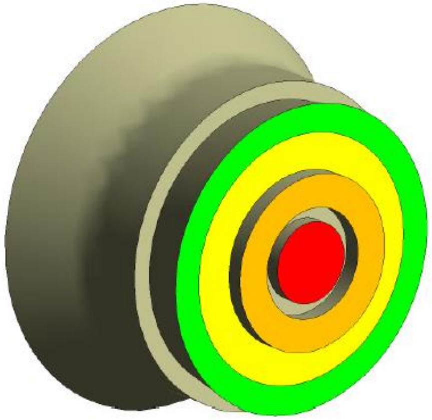
E-ON anonymous coal fired plant

- Front wall fired
- 48 burners with BOFA









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SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Inlet mass flows and temperatures

Burners	T[°C]	E7	E8	E9	G10	G11	G12
Swirl direction							
Air Secondary (45° swirl)	252	3.54			3.99		
Air Tertiary (30° swirl)	252	8.26			9.31		
Air Primary	80	8.67			9.17		
Coal	80	3.81			5.54		
Burners		C19	C20	C21	B22	B23	B24
Swirl direction							
Air Secondary (45° swirl)	252	2.43			2.67		
Air Tertiary (30° swirl)	252	5.67			6.23		
Air Primary	80	0			0		
Coal	80	0			0		
Burners		F31	F32	F33	A34	A35	A36
Swirl direction							
Air Secondary (45° swirl)	252	5.76			4.89		
Air Tertiary (30° swirl)	252	13.44			11.41		
Air Primary	80	10.51			9.76		
Coal	80	4.31			4.8		
Burners		D43	D44	D45	H46	H47	H48
Swirl direction							
Air Secondary (45° swirl)	252	6.00			5.55		
Air Tertiary (30° swirl)	252	14.00			12.95		
Air Primary	80	10.3			10.4		
Coal	80	4.42			4.35		

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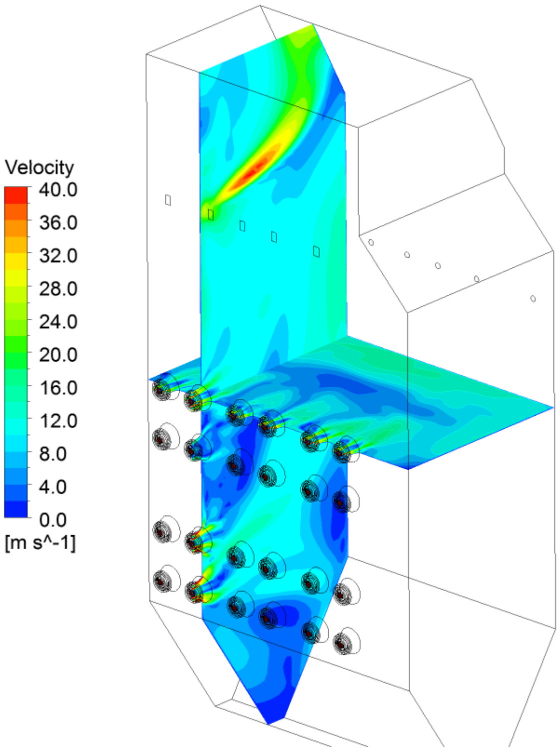
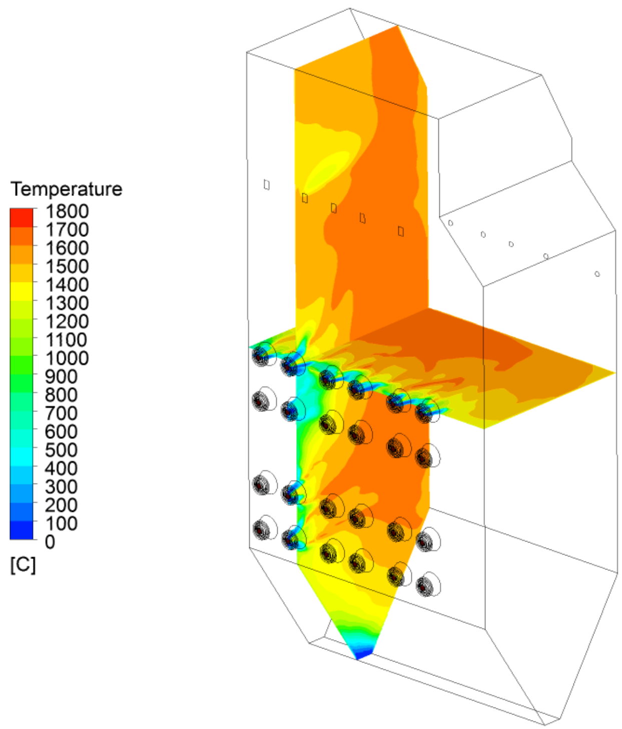
Velocity and temperature





max 1750 °C

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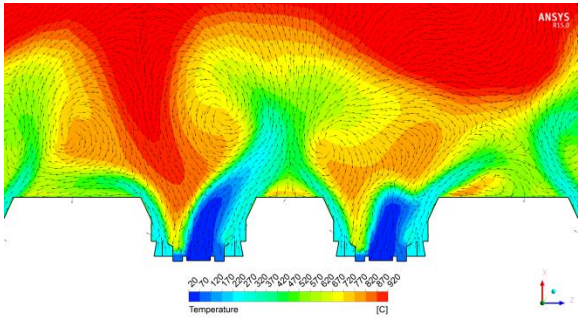
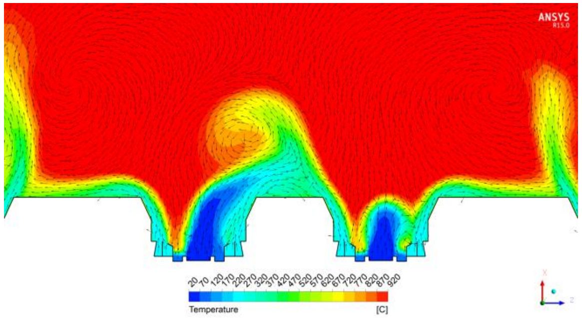
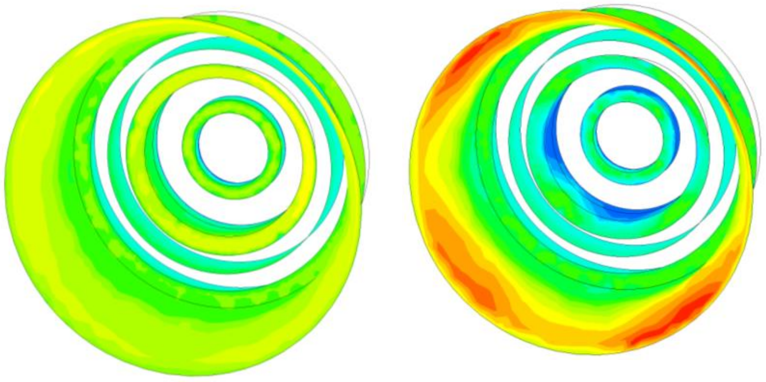
Higher temperature around the burners

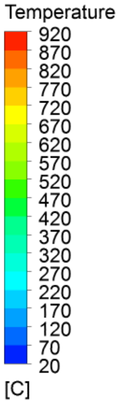
100% coal

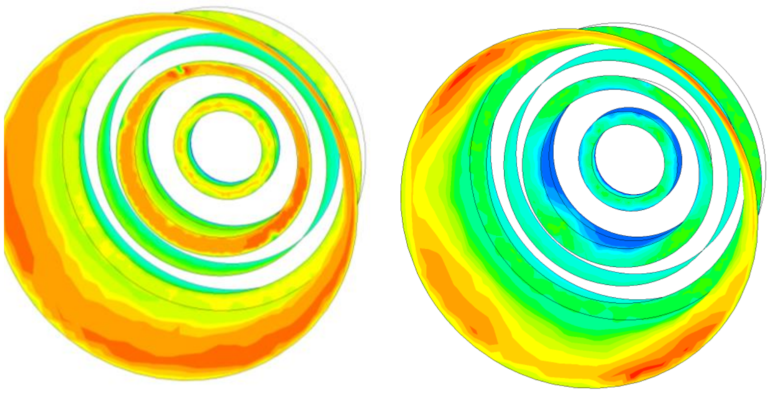
100% torrefied biomass











Row 3, burner 3 Row 2, burner 2 Row 3, burner 3 Row 2, burner 2

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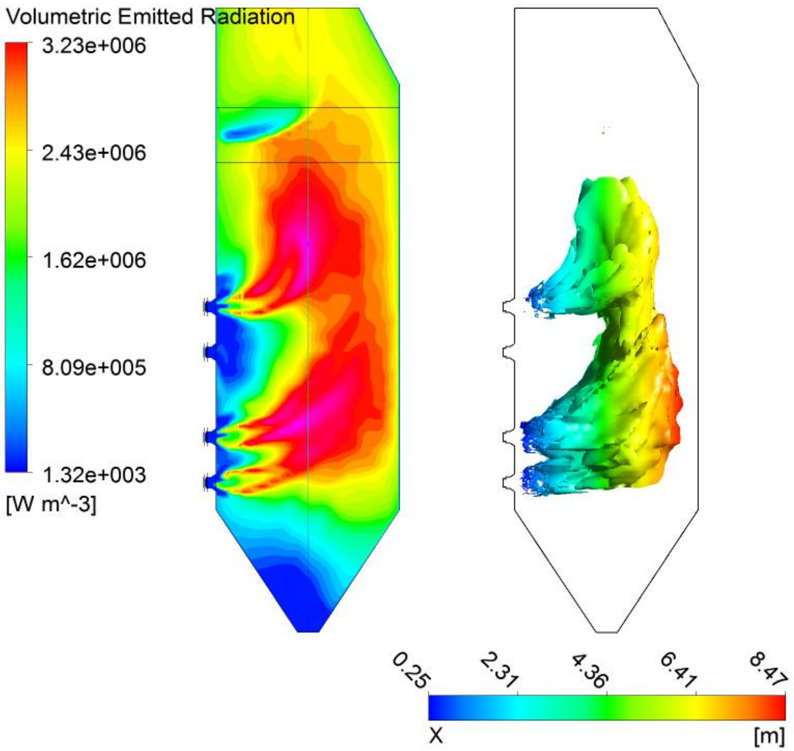
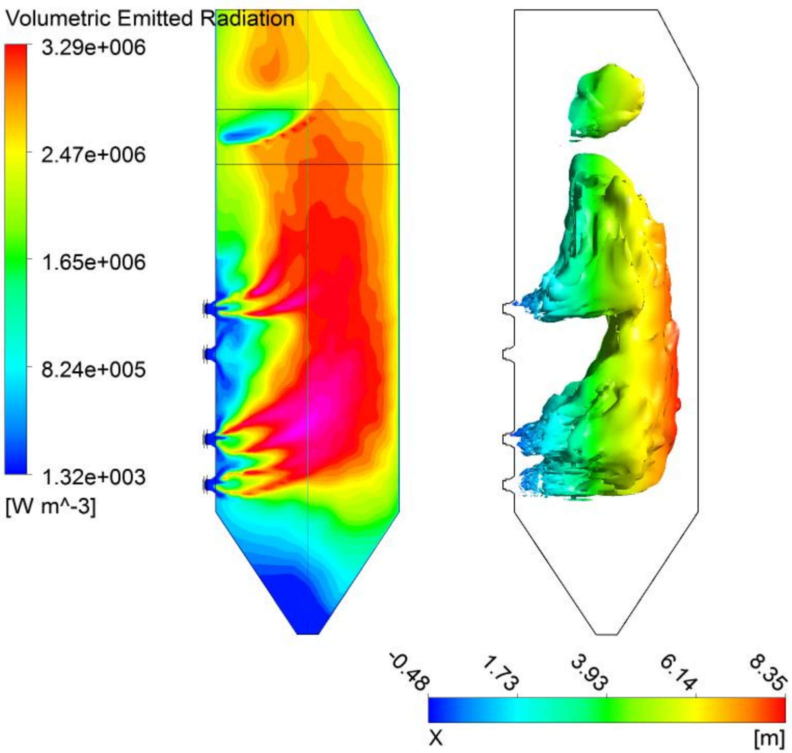
Volumetric emission radiation (MW/m³)

100% coal



100% torrefied biomass



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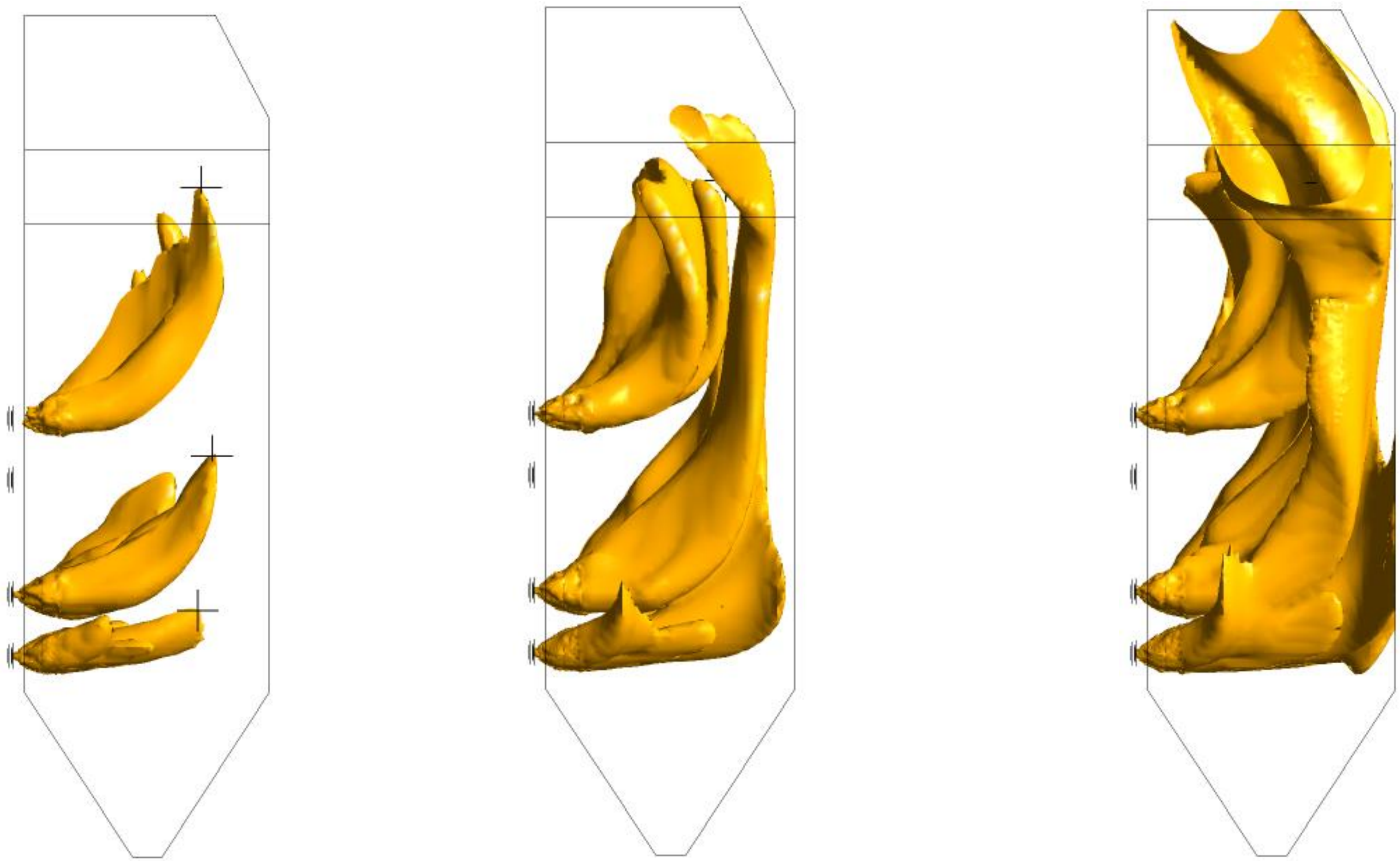
Combustion reaction extends further into the furnace

Isovolume of 2.5w% combustible gas



100% coal | 50% coal/50% torrefied biomass | 100% torrefied biomass

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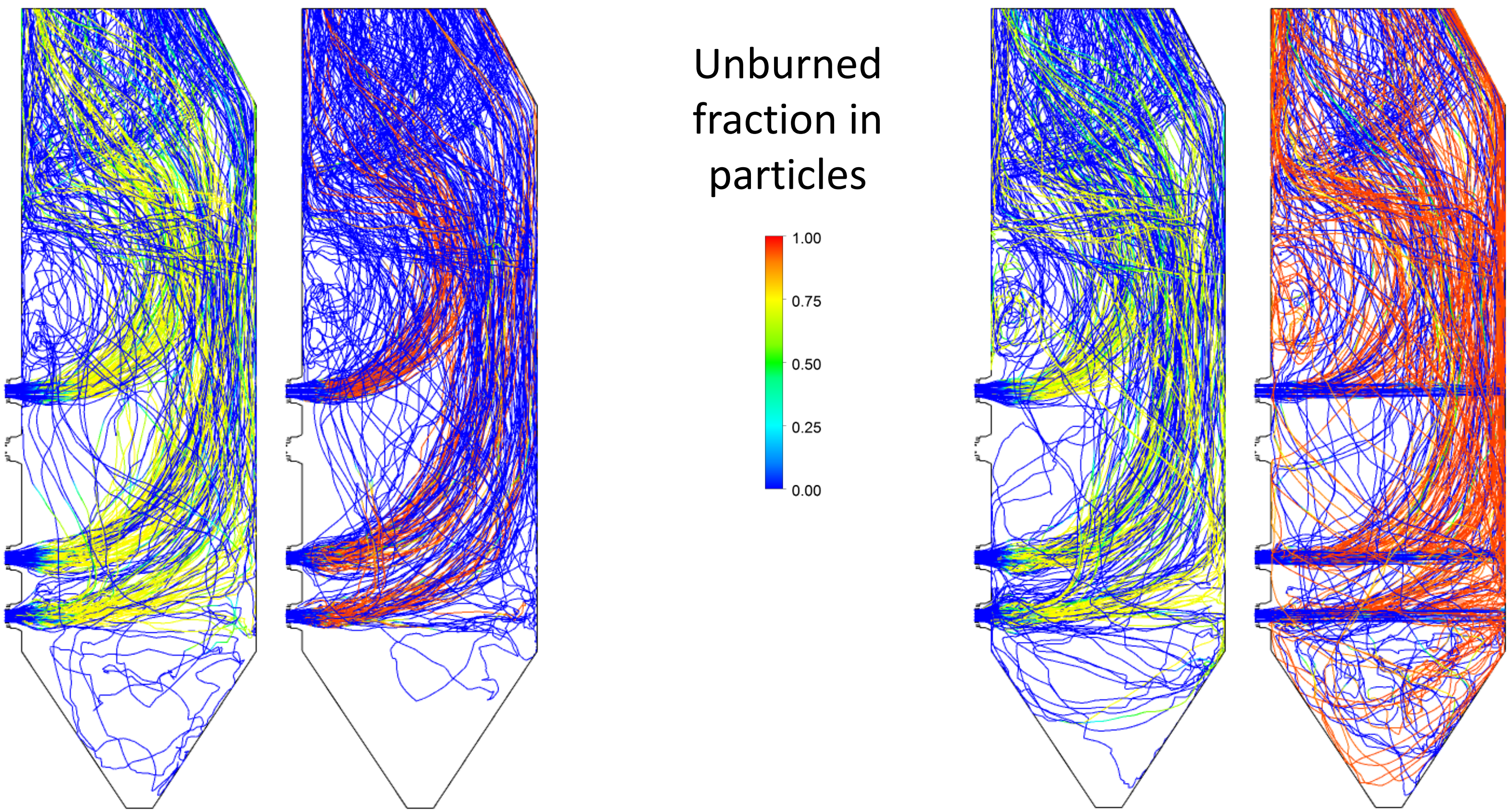
Influence of particle size on LOI

Same particle size distribution | Larger torr biomass particle size distribution



50% coal | 50% torr biomass | 50% coal | 50% torr biomass

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Ash fractions

Not all particles are burned yet at exit of domain

#	Description	Char (kg/s)			Ash (kg/s)			LOI (%)
		From coal	From torrefied material	Total	From coal	From torrefied material	Total	
1	100% HC	0,405		0,405	3,120		3,120	11%
2	50% HC, 50% TM	0,358	0,020	0,378	1,560	0,055	1,615	19%
3	100% TM		0,048	0,048		0,110	0,110	30%
4	50% HC, 50% TM (larger particles)	0,214	0,343	0,557	1,550	0,055	1,605	26%

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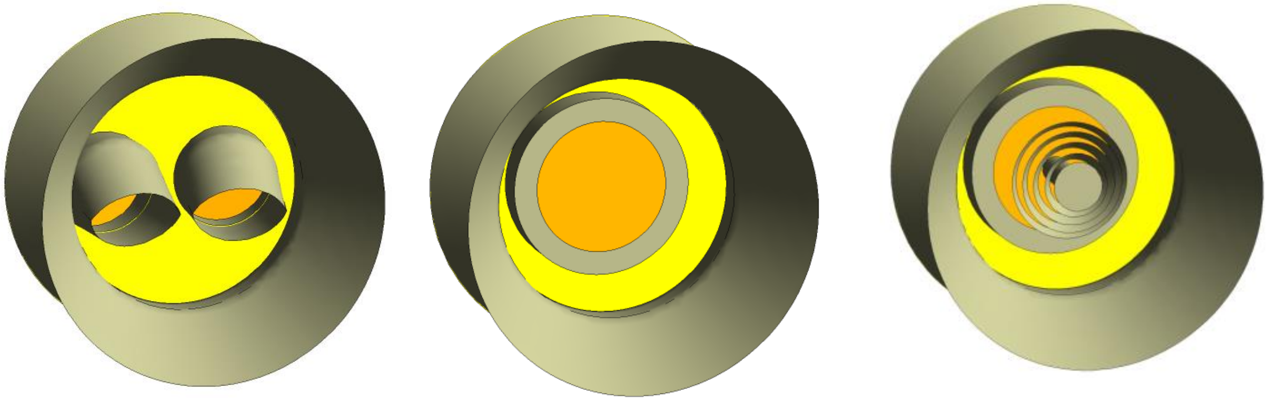
Anonymous Polish power plant

- Front wall fired, 40 burners
- Very similar results, not shown here



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ASH DEPOSITION

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Ash analysis

Ash Analysis, [mass%] ash	Torr. wood mix	Torr. Spruce	PP1(white wood pellets)	La TBK (Brown coal)	El Cerrejon (Hard coal)
SiO_2	20.99	21.16	44.40	21.47	**52.80**
Al_2O_3	1.73	4.59	3.70	4.59	**28.70**
Fe_2O_3	2.52	12.09	2.06	24.70	5.17
MgO	5.46	6.74	6.53	9.80	1.03
CaO	**39.10**	**25.64**	**25.35**	**26.60**	4.80
Na_2O	**1.47**	**1.06**	**1.92**	0.10	0.287
K_2O	**17.44**	**21.95**	9.26	0.45	1.22
TiO_2	0.09	0.08	1.34	0.28	1.45
P_2O_5	**7.10**	**6.70**	**2.86**	0.28	1.76
SO_3	3.70	0.00	2.59	11.20	2.30

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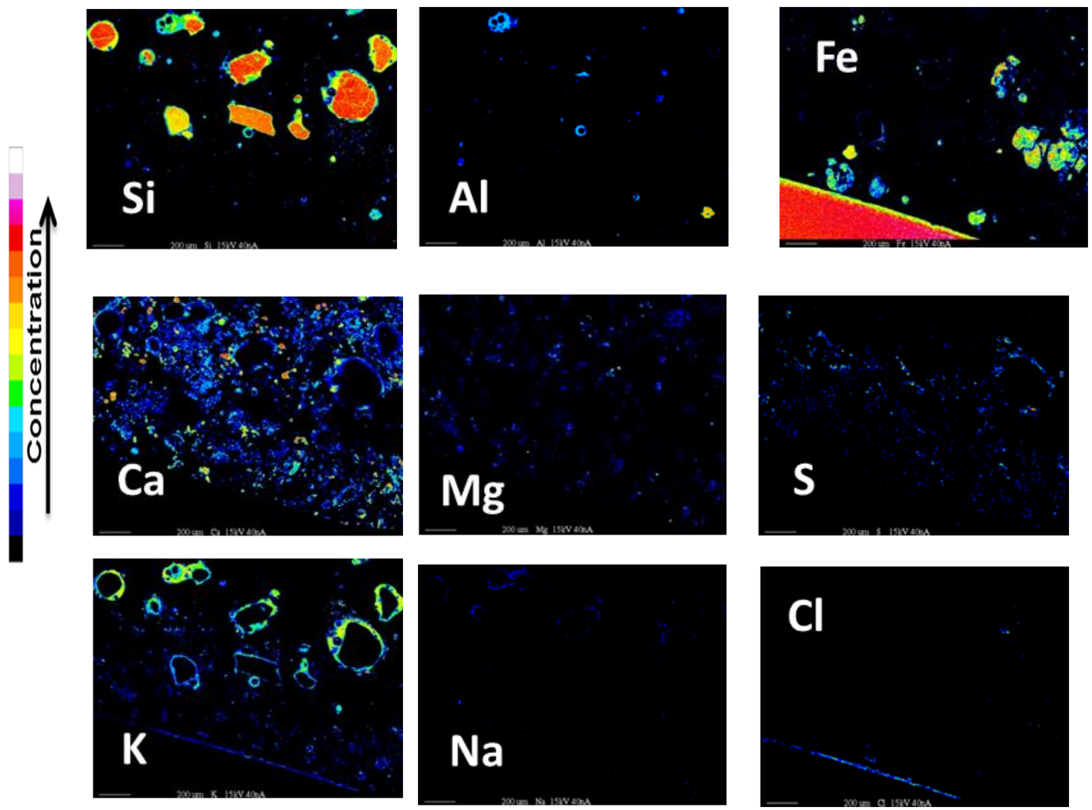
Deposits Torrefied wood mix (mono-firing)

- Potassium silicate particles formed
- Condensed KCl on probe surface forms a corrosion risk



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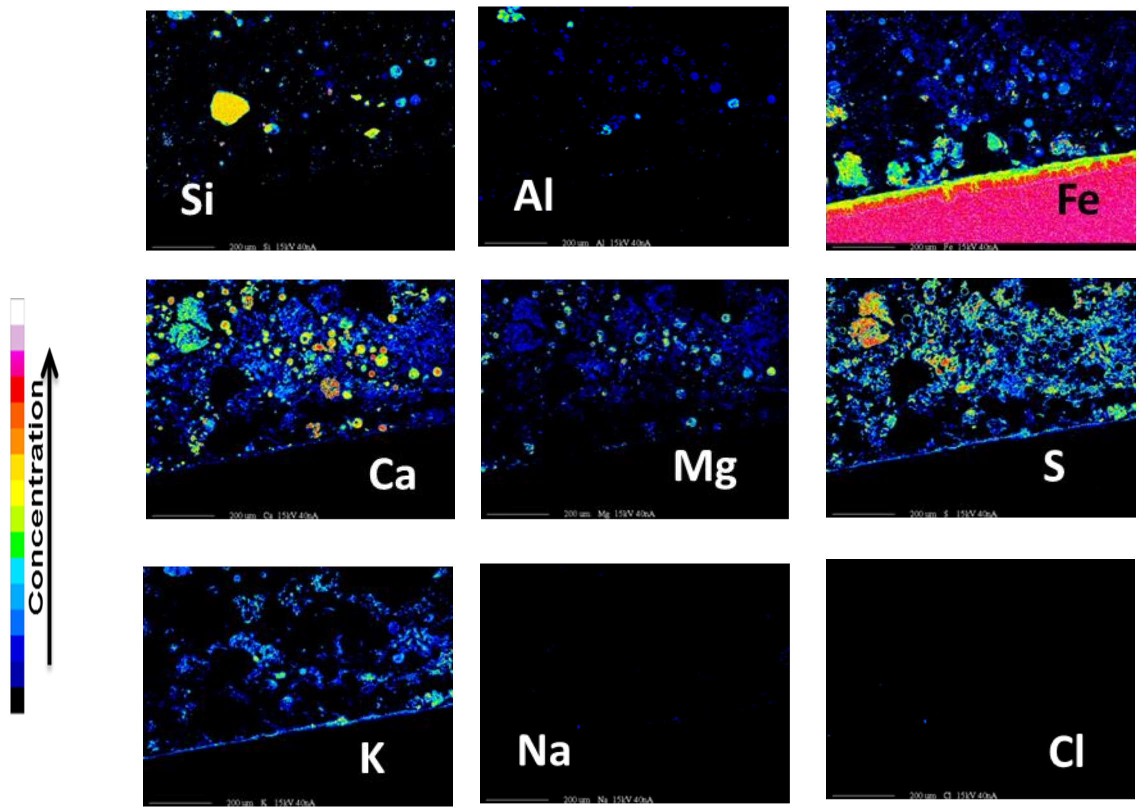
Deposits 25% torrefied wood mix + LaTBK brown coal (co-firing)

- K_2SO_4 particles formed
- Less potassium silicates formed
- No chloride salts condensation on metal surface



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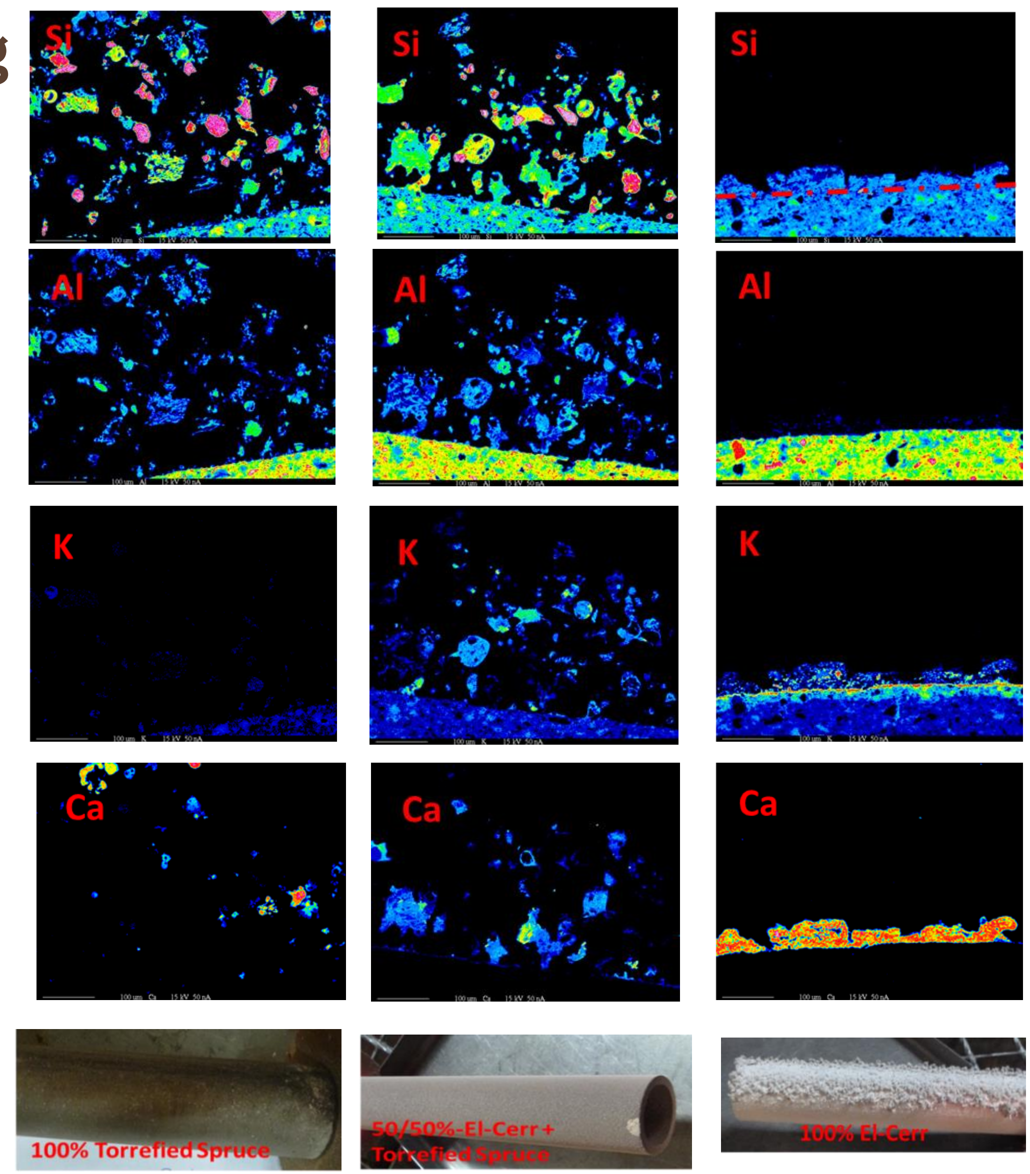
Deposits from KSVA test rig

- When cofiring, Ca and K reacts with Alumina silicates to form solid K alumino silicates (easy to remove), prohibiting KCl
- Mono combustion results in Ca and K silicates (low melting hard deposits) and corrosive KCl



Torr spruce | 50/50 cofiring | El Cerrejon

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EMISSIONS

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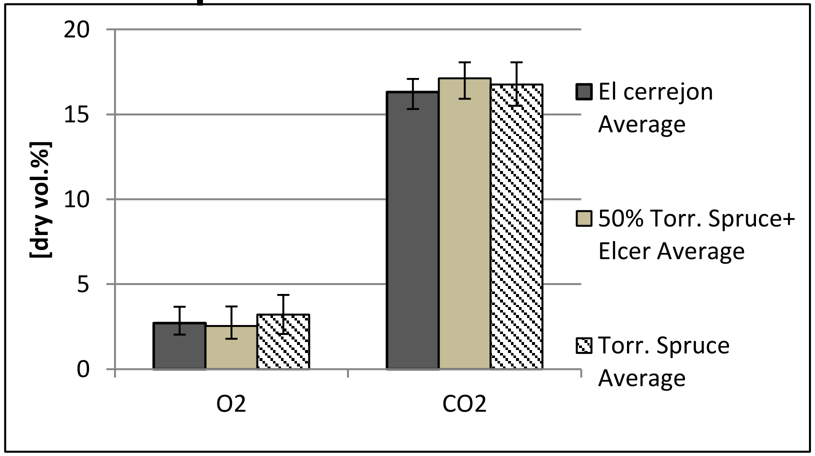
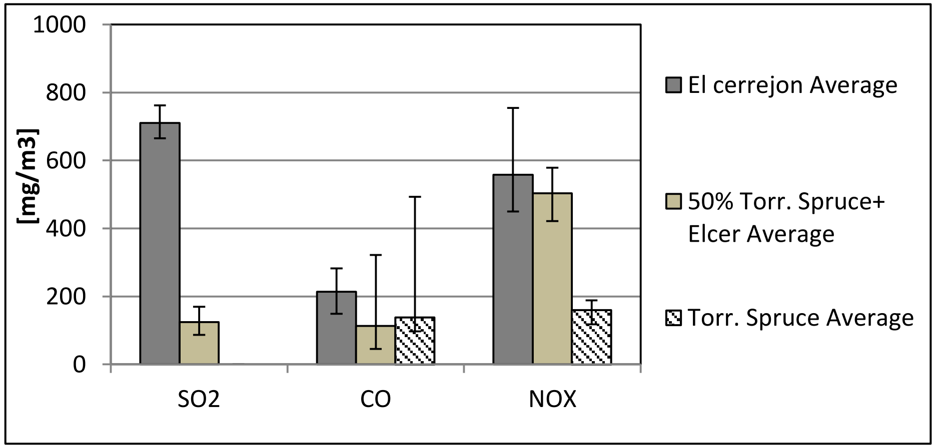
Gas composition at furnace exit

- Highest CO for coal, lowest when adding biomass
- SO_2 and NO_x decrease when adding torrefied spruce





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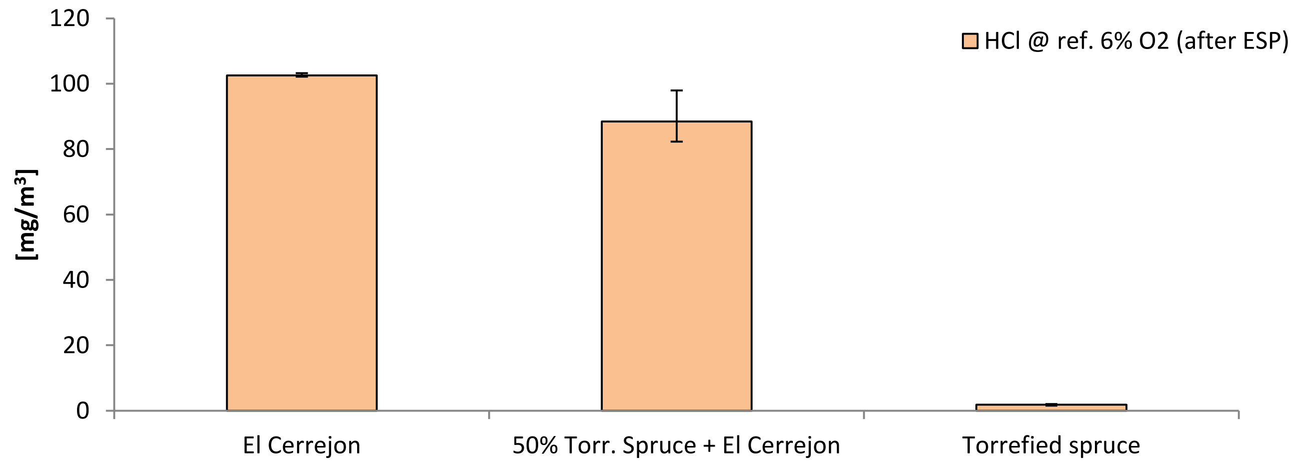
HCl emissions

- Negligible for torrefied spruce case, where K reacts with Cl instead to form KCl instead of K_2SO_4 with S from coal



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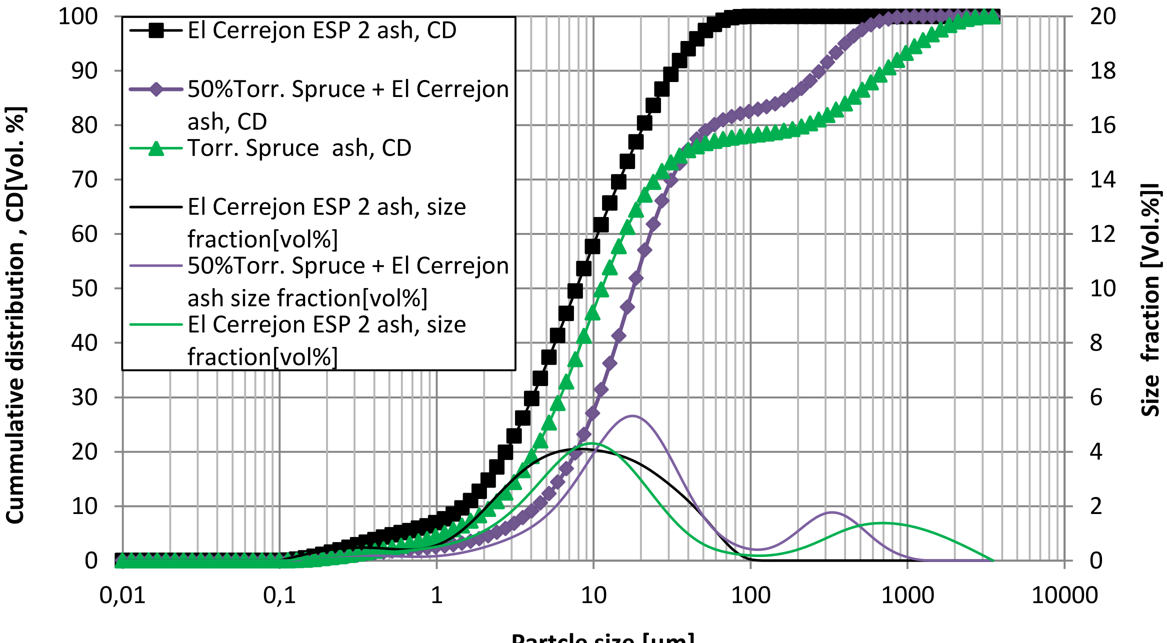
Particle size distribution of fly ash

- Torr spuce fly ash has much larger particles, but concentrations are lower and LOI is better
- ESP Capture efficiency drops from 99,5 to 95% when cofiring torrefied spruce, possibly since finer coal ash particles can pass through



This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Task 7.2: Progress beyond state of the art

- Combustion trials done at pilot scale in two setups, providing fundamental insight in combustion behavior, LoI, emissions, deposition aspects, etc.
- Validated CFD model used to extrapolate effects on full scale PC boilers

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Task 7.2: Impact on technology, end use resp. framework in respect of market implementation

- Detailed insight made available into required modifications to enable torrefied biomass in two PC boilers
- Results showed that all impacts can be dealt with, after minor plant modifications
- Impact on other boilers can be quickly evaluated

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Task 7.2: Tangible products developed

- Validated CFD model to evaluate impacts of torrefied biomass on PC boilers
- Reports with results

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Task 7.2: Further work

- Discussions with power plants and governments on application of torrefied biomass (e.g. through IEA Bioenergy)
- Research on mitigation of Cl based corrosion at higher cofiring ratios from enhanced Cl removal through torrefaction, coal fly ash injection and other measures
- Development of optimized low NOx burners for torrefied biomass
- Standardisation of torrefied biomass

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Task 7.2: Market conditions

- Difficult to obtain long term offtake contracts, required for financing a substantial torrefaction facility
- Prices of coal and CO2 too low for commercial market introduction, additional incentives required
- Expected cost of delivery almost equal to wood pellets. Cost savings at power plant predominantly at higher cofiring ratios and for PC plants without cofiring history

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thank you very much for your attention

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SECTOR

Production of **S**olid Sustainable **E**nergy **C**arriers from Biomass by Means of **TOR**refaction

SESSION III - End use
Part 3 - Co-Gasification

Final Project Meeting, 06.05.2015 in Leipzig

Compiled by Anders Nordin
Presented by Linda Pommer
Full author list: (see last slide)






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Session III "End use" - Part: (Co-)gasification

Task description

- Objectives of Task 7.3
  – **(Co-)Gasification in entrained flow gasifiers**:

  Evaluate the end-use application of torrefied biomass in medium-large-scale gasification and co-gasification in entrained flow gasifiers

  - assessment of torrefied biomass during handling, milling, plant availability, quality of syngas, operating problems

- Partners involved:
  - UmU
  - Vattenfall
  - ECN

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Work performed

- **Modeling work**
  - Detailed chemical equilibrium evaluation study of the influence of torrefaction pretreatment on the theoretical syngas composition (UmU)
  - Chemical equilibrium modeling of slag formation in EFG (ECN)
- **Lab/Bench-scale studies**
  - Feeding tests to evaluate liquid or slurry feeding by mixing torrefied materials with pyrolysis oil (UmU)
  - Conversion and ash behavior in the Lab-scale Combustion and gasification Simulator (ECN)

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Work performed (continued)

- **Pilot scale EFG studies**
  - Initial feasibility campaign in the 0.5 MW MEVA cyclone entrained flow pilot-scale gasifier (UmU)
  - Initial feasibility campaign in a 1 MW pressurized entrained flow biomass gasifier (UmU)
  - Second campaign focus on evaluation of products of incomplete gasification in the 1 MW PEBG EFG (UmU)
- **Industrial scale EFG studies**
  - Feasibility campaign in the MEVA CHP cyclone entrained flow gasifier (3.6 MW) for electricity production via a gas engine in Hortlax, Sweden (UmU)
  - Feasibility study of black pellets in the 240 MW_{el} Shell EFG in Buggenum, the Netherlands (Vattenfall)

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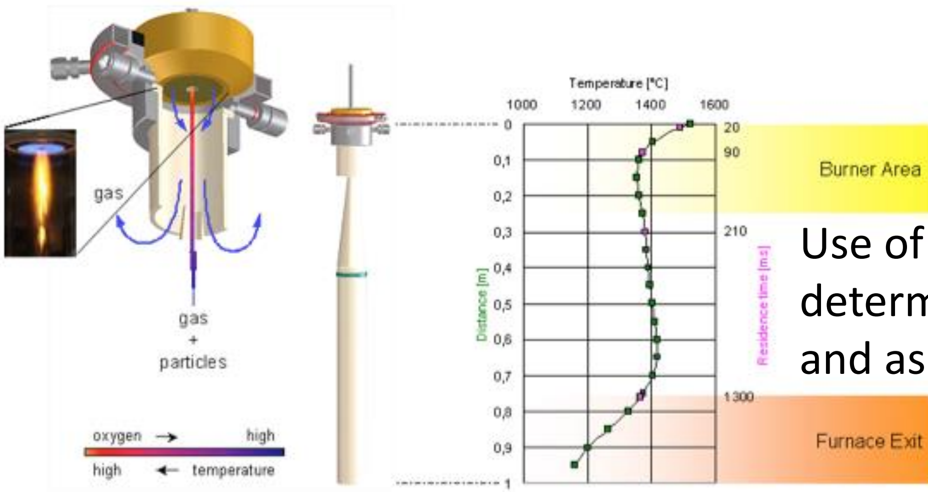
Lab-/bench-scale studies (ECN-examples)



Use of the ECN lab scale gasification simulator to determine: fuel conversion, slagging behavior and ash release upon gasification

Slag behavior – SEM of deposit probes

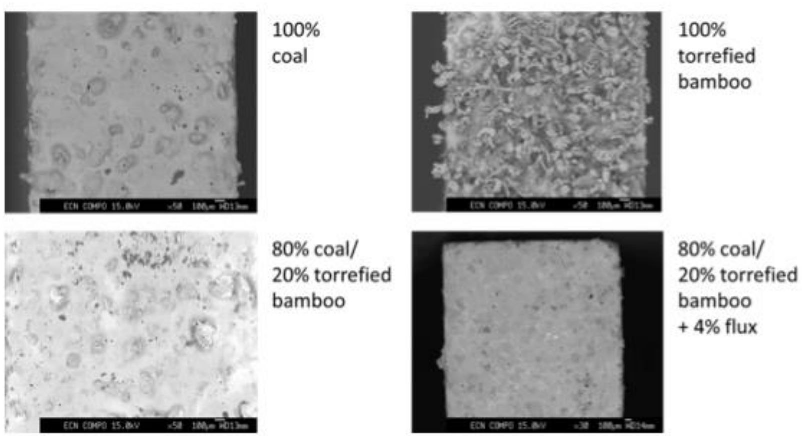
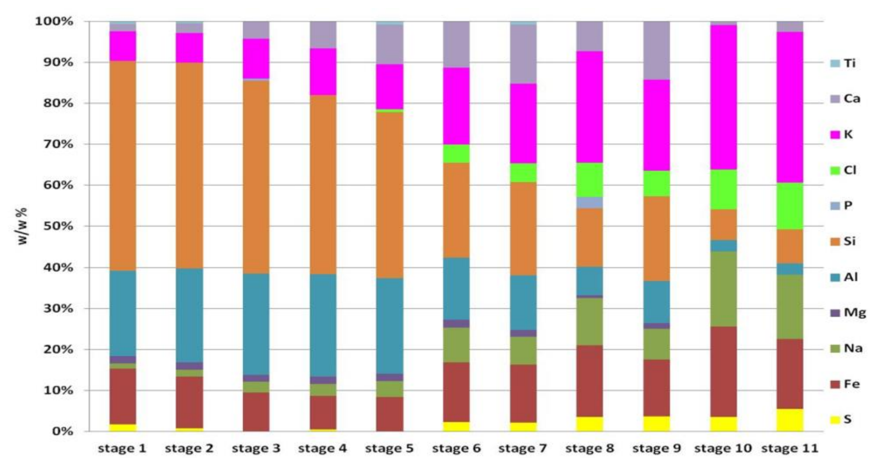


Figure 7 **SEM-EDX imaging (composition mode) of different slag samples**

Significant aerosols gettering by mineral additives



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Summary of EFG campaigns

Table 1 Summary of experimental campaign conditions

Facility	0.5 MW Cyclone EFG	3.6 MW Cyclone EFG	1 MW PEFG	1 MW PEFG	240 MW$_e$ PEFG
Load	100%	100%	~27%	60-80%	52%
Pressure	Atm.	Atm.	2 bar	7 bar	27 bar
Objective	Feasibility, comparing fuels	Feasilbility, comparing fuels	Feasibility, comparing fuels	Feasibility, PIC generation	Co-gasification 70% (e/e) torrefied mtrl
Feedstocks	Ref. wood, bark, peat, rice husk, torrefied wood	Ref. wood, torrefied wood residues	3 torrefied fuels, ref wood	Spruce wood, torrefied spruce wood	Coal torrefied wood residues
Compaction	Briquettes	Pellets	Wood chips and pellets	Pellets	Pellets
Variables	Fuel types	ROC, process temperature	Temp, constant λ	Varying load and ROC	Feasibility, load fraction
Temperature	~800°C	900-950°C	1190-1270°C	1100-1250°C	1425°C
λ or ROC	λ=0.2	ROC=0.3/0.4	λ=0.44	ROC=0.3/0.4	λ=0.3

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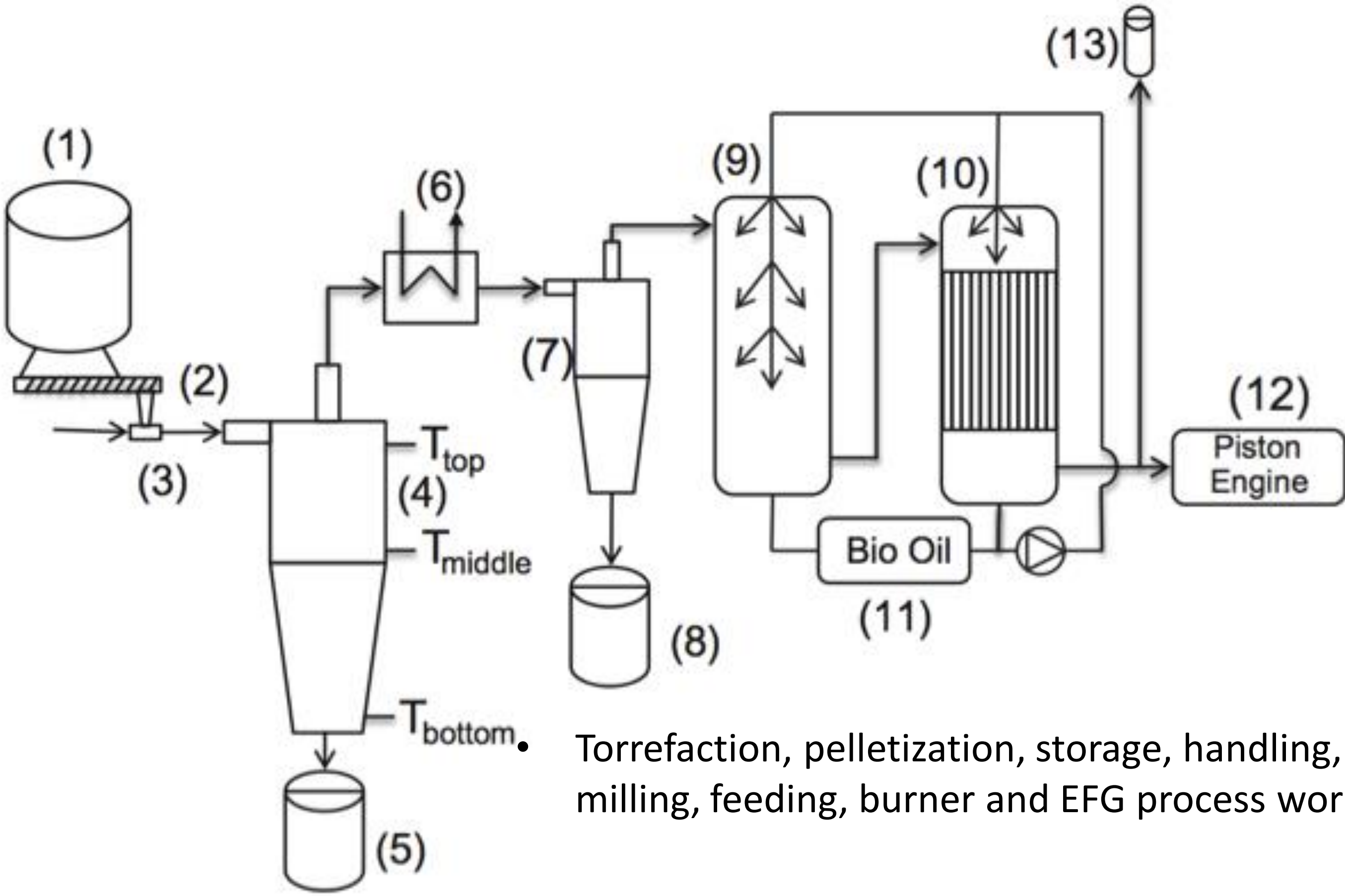
Pilot-scale studies (UmU/MEVA-example)



- Torrefaction, pelletization, storage, handling, transport, milling, feeding, burner and EFG process worked well

Figure 1 Schematic illustration of the 0.5 MW Cyclone EFG pilot plant. 1. Powder hopper; 2. Screw feeder; 3, Ejectors; 4. Cyclone gasifier; 5. Char bin; 6. Heat exchanger; 7. Multi-cyclone; 8. Multi-cyclone bin; 9. Bio-scrubber; 10. WESP; 11. Bio-oil; 12. Gas engine; 13. Flare. Illustration from Risberg et al 2014.

Risberg et al. Influence from fuel type on the performance of an air-blown cyclone gasifier. Fuel, 116, 15, 2014, 751–759

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Fuel powder size distributions BP=> smaller than biomass powder

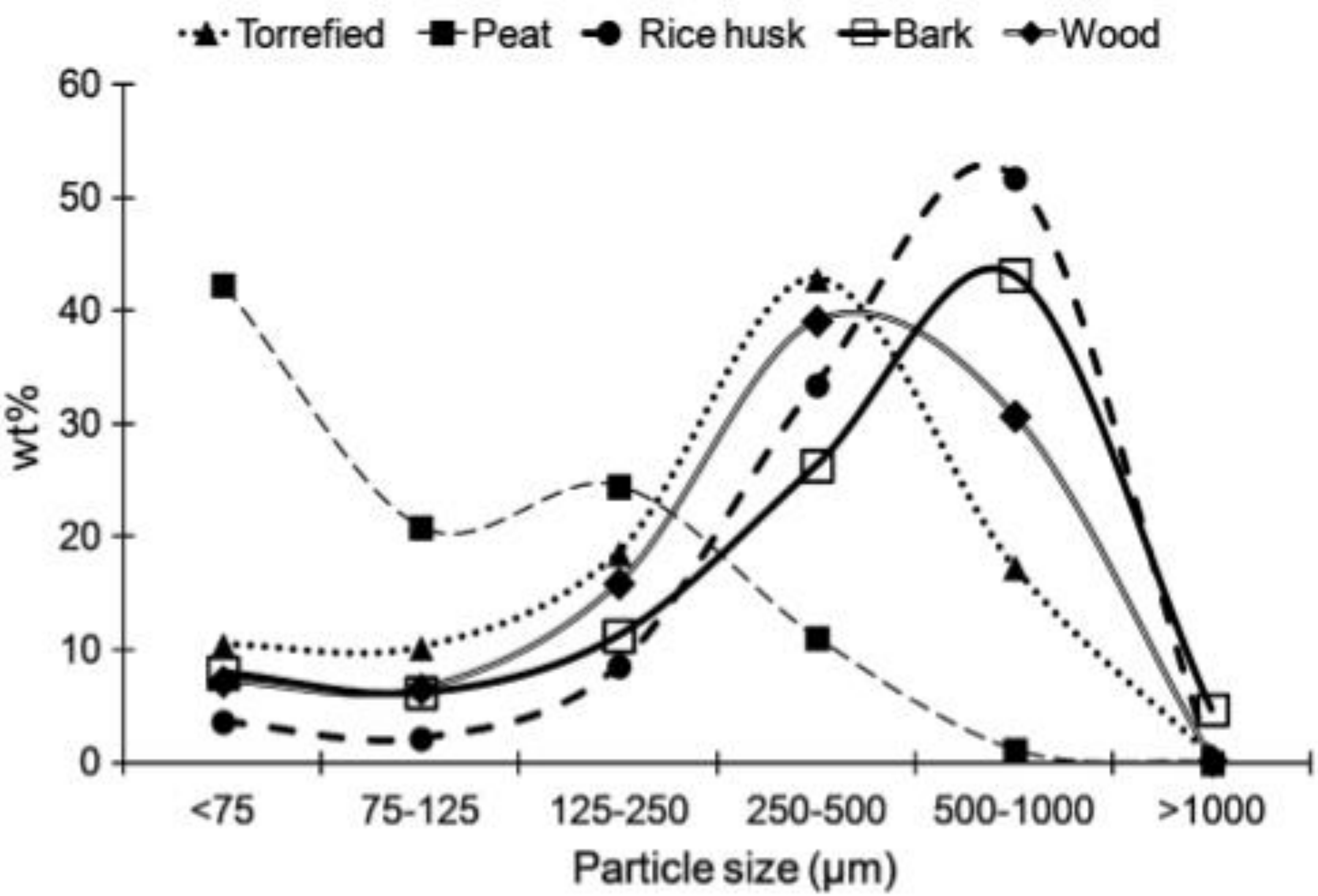


Fig. 3. Particle size distributions of the fuels tested.

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Pilot-scale studies (UmU/ETC-I example)

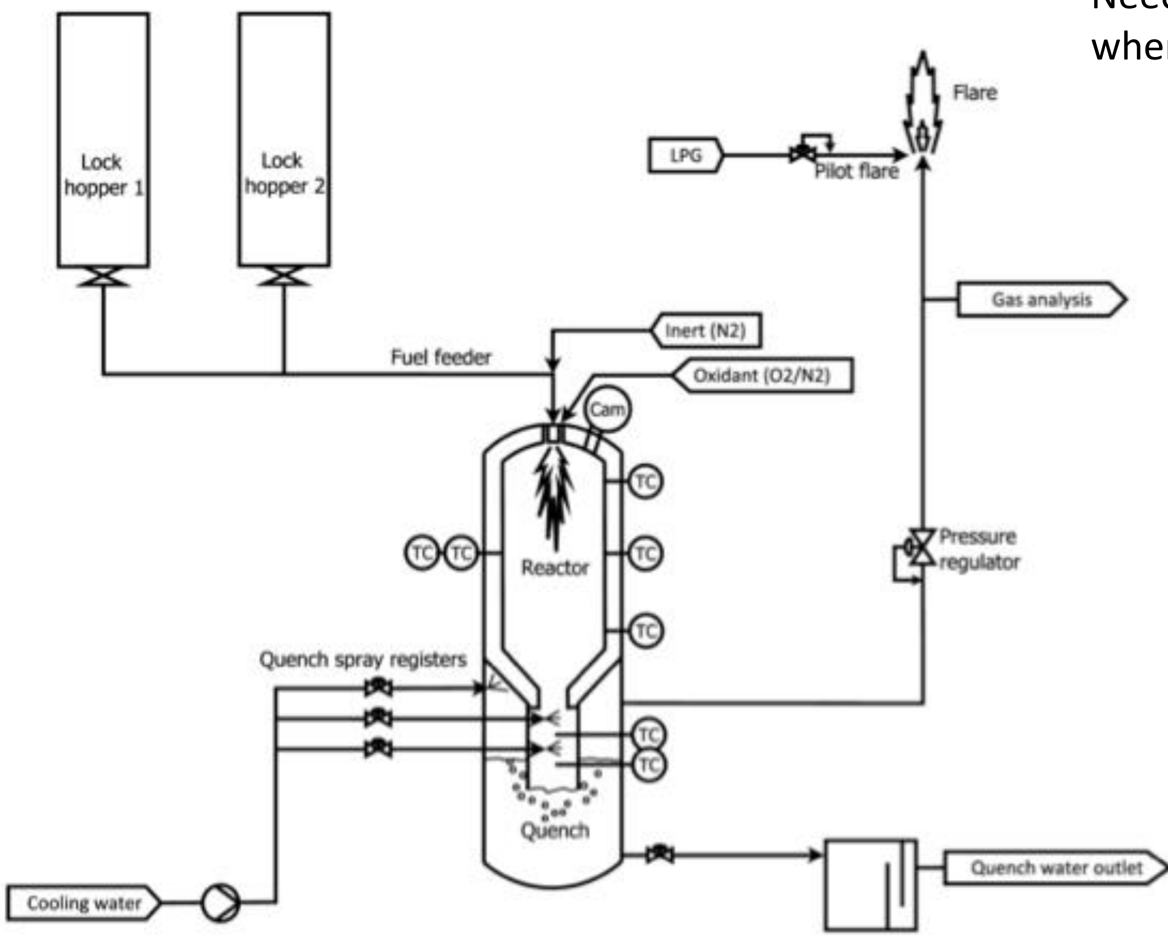

Figure 3 Schematic illustration of the 1 MW PEBG plant (From Weiland et al 2013)

- Need to use ROC instead of lambda when comparing fuels

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Pilot-scale studies (UmU/ETC-I example)

- Torrefaction, pelletization, storage, handling, transport, milling, feeding, burner and EFG process worked well
- Less losses by methane formation from EFG of BP:

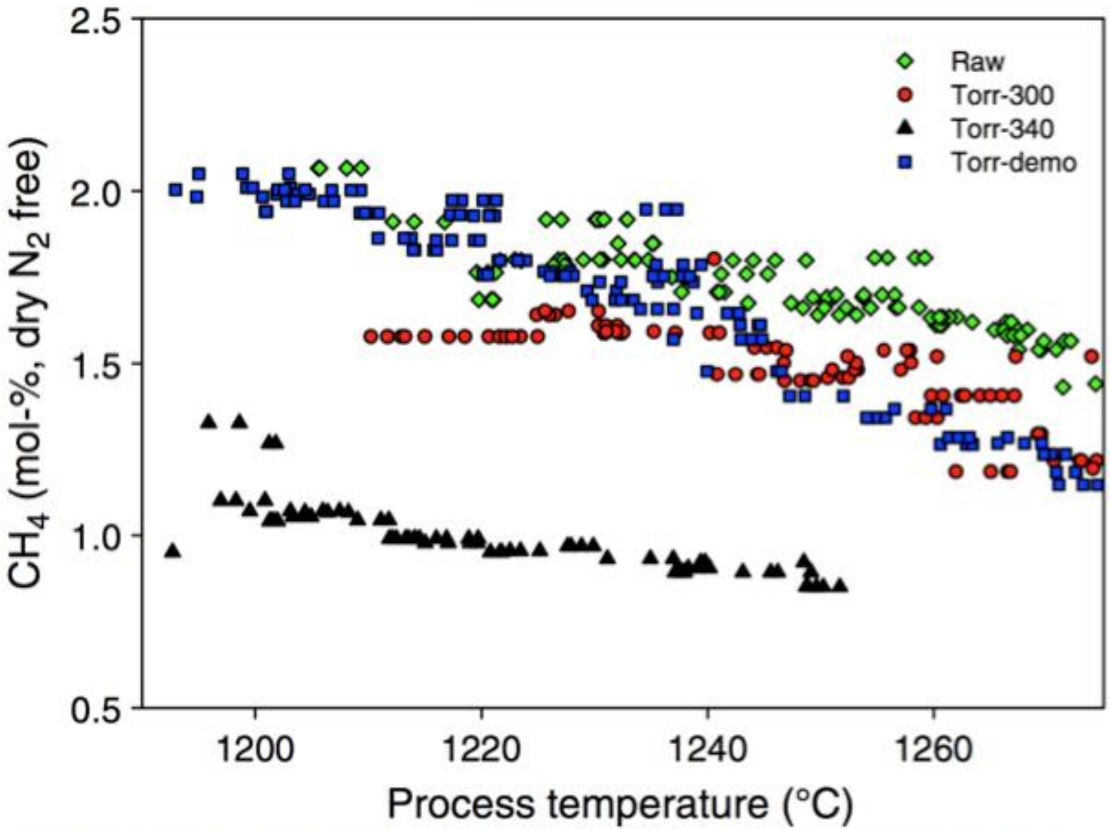
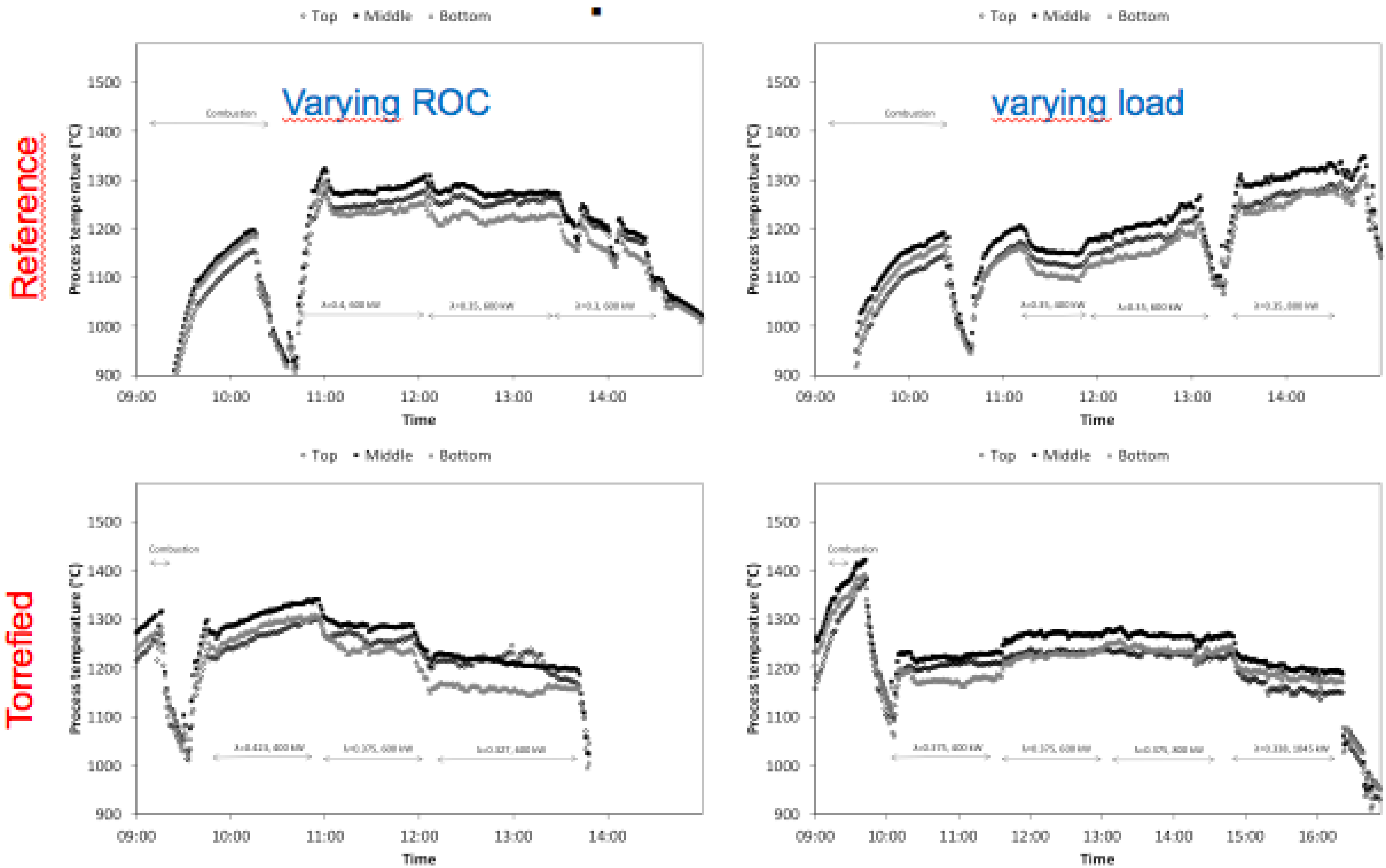


Figure Syngas methane concentrations (dry and N2 free) versus process temperatures for the different fuels (From Weiland 2014).

Weiland et al. Entrained flow gasification of torrefied wood residues. Fuel Processing Technology 125 (2014) 51–58

Pilot-scale studies (UmU/ETC-II example)



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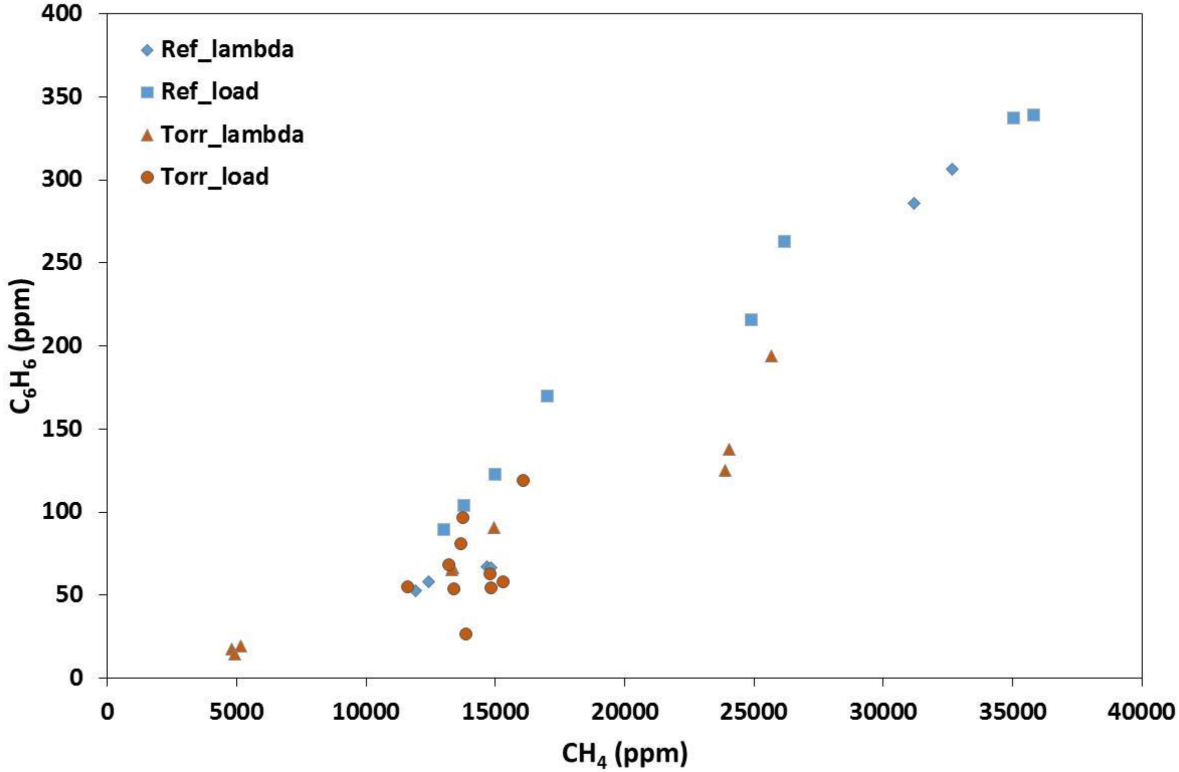
Pilot-scale studies (UmU/ETC-II example)

- Torrefaction, pelletization, storage, handling, transport, milling, feeding, burner and EFG process worked well
- Dedicated focus on most products of incomplete gasification, PIG (analysis results still pending)
- Preliminary results indicate similar or somewhat lower losses to PIG for BP

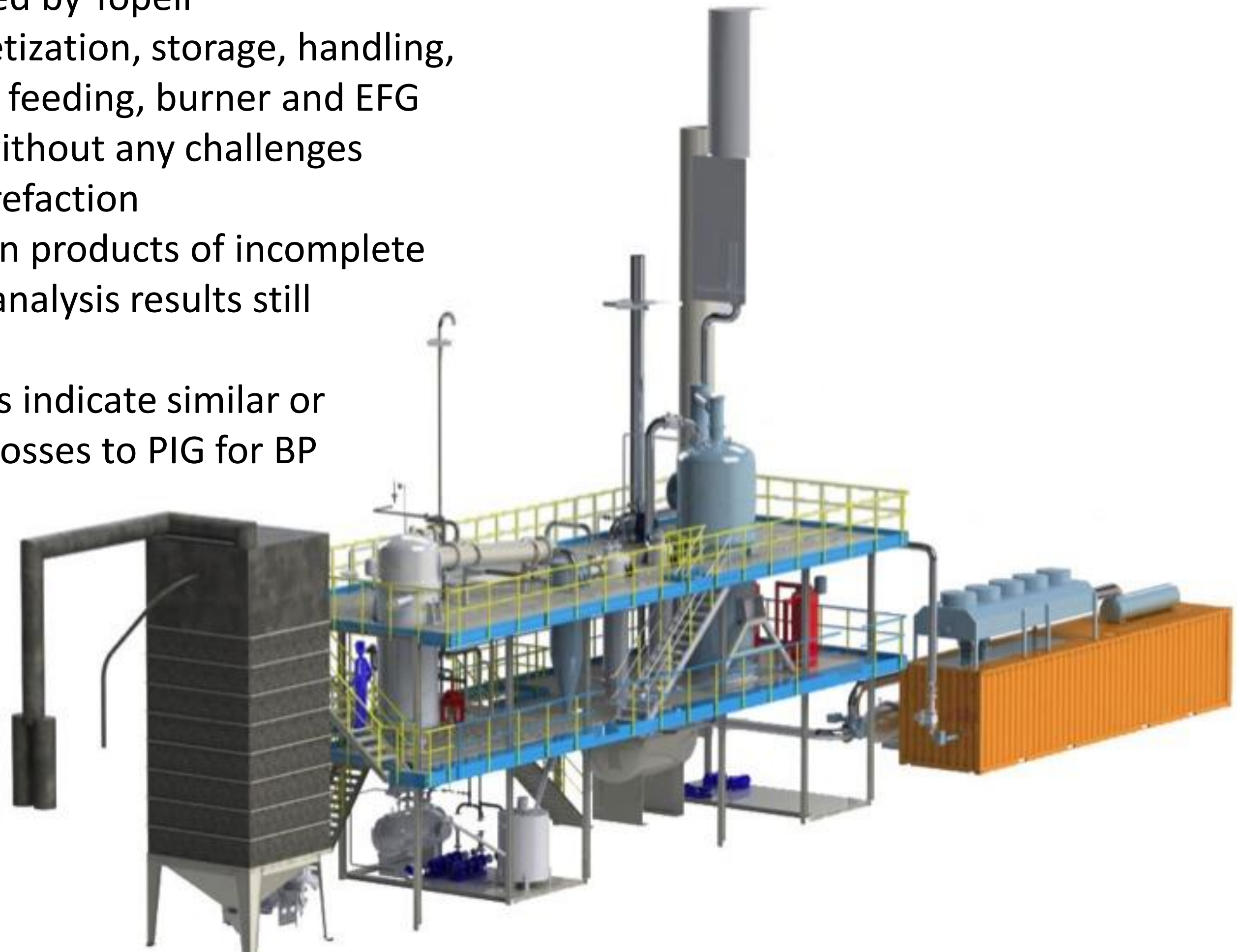


Weiland et al. Effects of torrefaction on entrained flow gasification efficiency of wood – gas characteristics and products of incomplete gasification. Manuscript.

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Industry-scale studies (UmU/MEVA-examples)

- 30 ton BP produced by Topell
- Torrefaction, pelletization, storage, handling, transport, milling, feeding, burner and EFG process worked without any challenges related to the torrefaction
- Dedicated focus on products of incomplete gasification, PIG (analysis results still pending)
- Preliminary results indicate similar or somewhat lower losses to PIG for BP



Khwaia et al. Effects of torrified and raw biomass on tar generation and other products of incomplete gasification in a commercial cyclone gasifier. Manuscript

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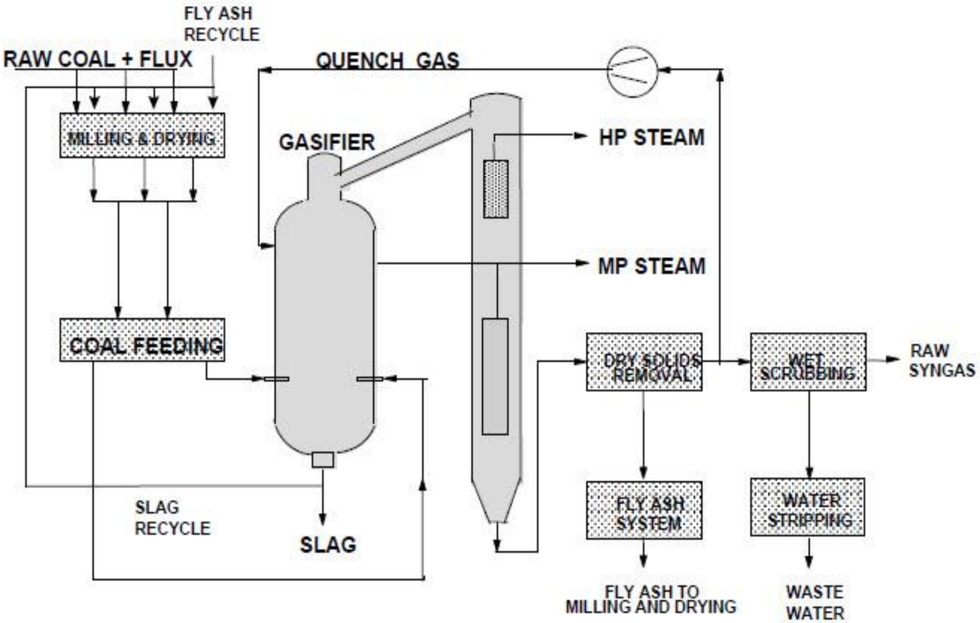
Industry-scale studies (Vattenfall-examples)



Padban and Khodayari. Experiences from large-scale tests with torrefied biomass fuel at the IGCC plant Willem Alexander Centrale. Internal complementary deliverable report to SECTOR-project. GA No. 282826, 2014

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Dusting issues during unloading and internal transport

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But generally it worked well - conclusions

- ✓ Unloading, storage, reclaiming, blending with coal and conveying of the torrefied pellets with the existing mechanical installation was basically possible.
- ✓ Necessary to install new dust suppression equipments
- ✓ The milling was not an important issue - sufficiently high grindability of the tested torrefied pellets.
- ✓ The sluicing and feeding system worked stable, no problems were reported.
- ✓ With a torrefied material with higher heating value (estimated on 22 MJ/kg) and good quality it will be possible to reach the power output of ~230 MWe (96% of full load at only coal) at the 70 % (e/e) co-gasification with small hardware modifications, adjustments and fine-tuning.
- ✓ The impact on the syngas was in the line with what one could expect
- ✓ Fouling was not an issue
- ✓ The fly ash system worked stable
- ✓ Several smaller issues but no game-stoppers

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Summary and conclusions of 7.3 (1)

Quite wide ranges of torrefied materials, EFG technologies and plant scales were included in the evaluation program, thus ensuring beneficial use of the present conclusions.

- Transport, handling, unloading, milling and feeding of “black pellets” generally worked well and have not resulted in any majour issues to and in any of the facilities within the program. To reduce risk of powder explosions, a dedicated (water spray) dust suppression system was installed in the large-scale plant.
- Torrefaction and increased torrefaction degrees resulted in finer powder particles, also with less fibrous structure
- Gasification performance and efficiencies attained for torrefied materials were generally reported to be improved or approximately in the same range as for the reference fuels. Gasification plant efficiency, was also improved by torrefaction because of the reduced milling energies.

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Summary and conclusions (2)

- Burners and gasification processes generally behaved nice and smooth with approximately the same characteristics for both torrefied biomass and reference fuels. Introducing new powder fuels could however benefit from some fine-tuning of final feeding and burners.
- Syngas composition and quality remained approximately the same as for the reference fuel
- Comparison with reference fuels need to be carried out for the same relative total oxygen content and not as typically done with the same equivilance ratio (λ).
- Products of incomplete gasification (PIG) were found to remain in typically the same or somewhat lower levels as for the reference fuels
- Tar (PAH) fingerprints in the syngas were documented to be in low concentrations and approximately the same for gasification white and black pellets

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Summary and conclusions (3)

- From one of the studies, the results indicate somewhat enhanced soot/char formation from the torrefied fuel compared to the reference fuel
- An overall assessment is that the small differences observed in gasification efficiencies and gas qualities could probably be overcome with minor optimization work, and the reactivity of the black material seem to be fully sufficient for efficient gasification and thus further progressing the route decentralized pretreatment of biomass via torrrefaction followed by centraliced large scale entrained flow gasification.
- Also the smaller scale EFG of torrefied biomass materials seem interesting to be further evaluated and progressed, especially the heat and fuel integration aspects of small scale CHP and torrefaction.

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Outlook

Five extensive experimental feasibility campaigns of entrained flow gasification (ranging from 0.5 to 240 MW) of torrefied biomass materials were carried out for the first time.

It was clearly demonstrated that torrefied biomass materials may well be used without (or with minor) modifications of the fuel handling and gasification systems.

Torrefaction, densification, storage, transport, handling, unloading, milling, feeding, burners, gasification, conversion, ash and syngas behavior all seemed to work well with the new fuel. Marginal and expected changes influenced the processes positively. Somewhat (minor changes): more fines, higher reactivity, shifted gas composition, less products of incomplete gasification

Main conclusion beyond state of the art: EFG of torrefied materials are now demonstrated to work!

As soon as production of torrefied materials is sufficient, EFG of these materials is ready for demonstration scale and market implementation.

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Outlook (cont.)

The SECTOR sub-project have demonstrated the feasibility of torrefied biomass in EFG-plants without any major re-designs. Extensive know-how has been gained, as well as different methods for fuel and process characterization. Intelligent fuel mixing at the pre-treatment site was suggested as critical to control the ash behavior in the gasification process.

The next step will be to produce large 10-1000 ton batches for large scale demonstration and long term optimization and evaluation of ash and process behavior. Fine tuning of the new fuel/process combinations will also be part of the next phase.

Further work on ash behavior and development of dedicated actual low cost intelligent fuel mixtures

The presently low oil prize is right now a challenge for the next phase, but with time (it will increase) and further economic CO_2-incentives the market conditions for green liquid fuels and petrochemicals will improve. Fortunately, all the benefits demonstrated for torrefied materials and the progress in torrefaction technologies will pave the way for brown pellets in general and when sufficient production capacity have been attained, there is probably also market conditions for EFG and synthesis of petro-products.

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Thanks for your attention

NUON 240 MW_e

Reports and publications:

- Padban and Khodayari. Experiences from large-scale tests with torrefied biomass fuel at the IGCC plant Willem Alexander Centrale. Internal complementary deliverable report to SECTOR-project. GA No. 282826, 2014
- Risberg et al. Influence from fuel type on the performance of an air-blown cyclone gasifier. Fuel, 116, 15, 2014, 751–759
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- Weiland et al. Entrained flow gasification of torrefied wood residues. Fuel Processing Technology 125 (2014) 51–58
- Weiland et al. Effects of torrefaction on entrained flow gasification efficiency of wood – gas characteristics and products of incomplete gasification. Manuscript.
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MEVA 0.5 + 3.6 MW

SP-ETC PEBG 1 MW_e

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This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

SECTOR

Production of **S**olid **S**ustainable **E**nergy **C**arriers from Biomass by Means of **TOR**refaction

Session III: End-use
Part 4: Small-to-Medium Scale Combustion

Final Project Meeting, 06.05.2015 in Leipzig

Friedrich Biedermann (BIOS),

Thomas Brunner (BIOS),Ingwald Obernberger (BIOS), Martina Blank (BIOS), Sabine Feldmeier (BE2020), Manuel Schwabl (BE2020), Hans Hartmann (TFZ), Peter Turowski (TFZ), Elisabeth Rist (TFZ), Claudia Schön (TFZ)






This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Summary of task description

- Objectives of Task7.4 – **Small to medium-scale pellet boilers**:

  Evaluate the end-use application of torrefied biomass in commercial small-scale pellet boilers with a main focus on combustion behaviour, emissions as well as the gaining of insights into operational problems

- Partners involved:
  - BIOS BIOENERGIESYSTEME GMBH, Austria (BIOS, Task leader)
  - TECHNOLOGIE- UND FORDERZENTRUM IM KOMPETENZZENTRUM FÜR NACHWACHSENDE ROHSTOFFE TFZ, Germany (TFZ)
  - BIOENERGY 2020+ GMBH, Austria (BE2020)

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Work performed

- **Fundamental investigations**
  - Lab-scale reactor and TGA tests with torrefied pellets (BIOS)
  - Particle layer model adaptation and CFD simulations of selected combustion trials (BIOS)
- **Combustion technology screening and fuel assessment trials**
  - Test runs with a 21 kW overfed pellet boiler (BIOS)
  - Test runs in different state-of-the-art small-scale heating systems with different torrefied fuels, testing under continuous and variable power output conditions (TFZ)
  - Performance of long term test trials over several days (TFZ)
  - Tests in 4 different small-scale combustion technologies with capacities of up to 50 kW (BE2020)
  - Test runs with 5 different fuels (BE2020)
  - Flue gas condensation tests with an in-house method to determine the corrosion load on chimneys (BE2020)

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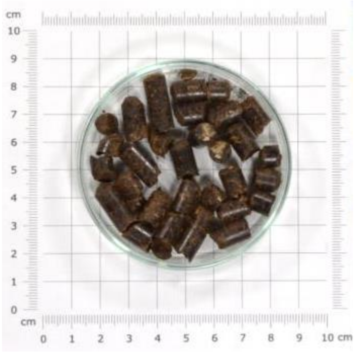
Fuel properties and analysis (1)

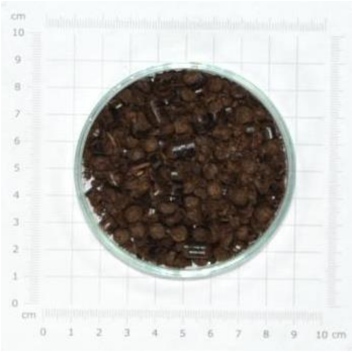
Spruce raw

CENER_beech



TOPELL_spruce

CENER_pine



- The bulk density of the torrefied fuels is higher (680 – 700 kg/m^3 w.b.) than for softwood pellets (650 kg/m^3 w.b.)
- The gross calorific value of torrefied fuels is 1.5 to 9.5% higher than for softwood pellets and the energy density is 9.2 to 17.1% higher
- As expected the C contents of the torrefied fuels (54 to 55.3 wt% d.b.) are higher than for softwood pellets (50.2 wt% d.b.)

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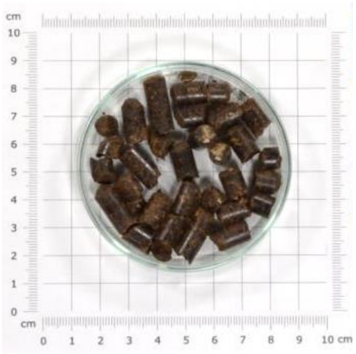
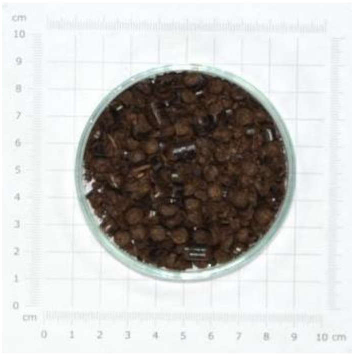
Fuel properties and analysis (2)

Spruce raw **CENER_beech** **TOPELL_spruce** **CENER_pine**



- The N content in the torrefied fuels mainly depends on the N content in the raw material. However, approx. 10 – 20 wt% N is released during torrefaction
- In general the ash content and concentrations of ash forming elements should be slightly higher in torrefied material compared to the untreated original biomass fuel due to the loss of volatiles during torrefaction
- Ash forming elements are typically not released during torrefaction except Cl and S. Approx. 70 – 80 wt% of Cl and 20 – 30 wt% of S are released during torrefaction → this leads to an improved fuel quality

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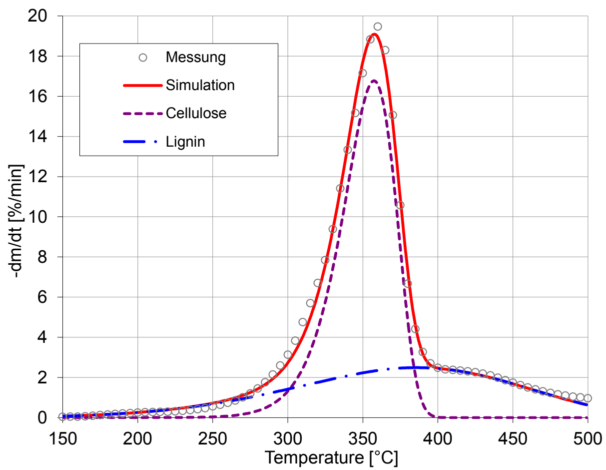
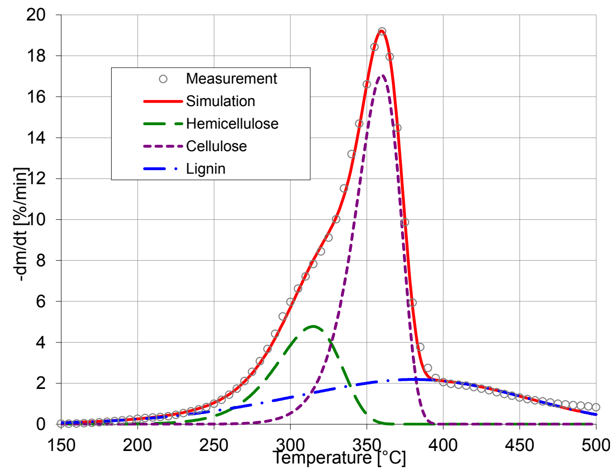
SECTOR
Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

TGA tests (1)

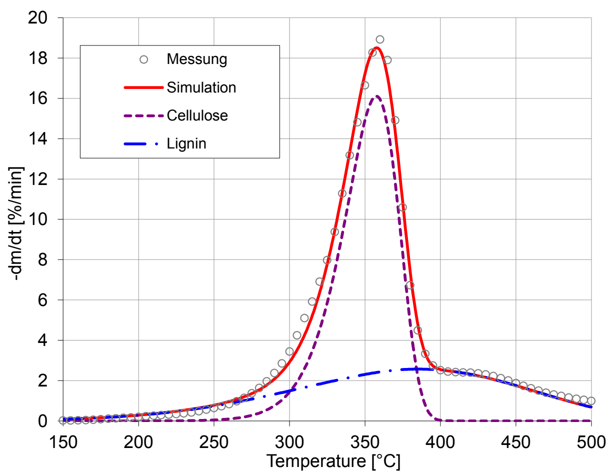
TOPELL_spruce



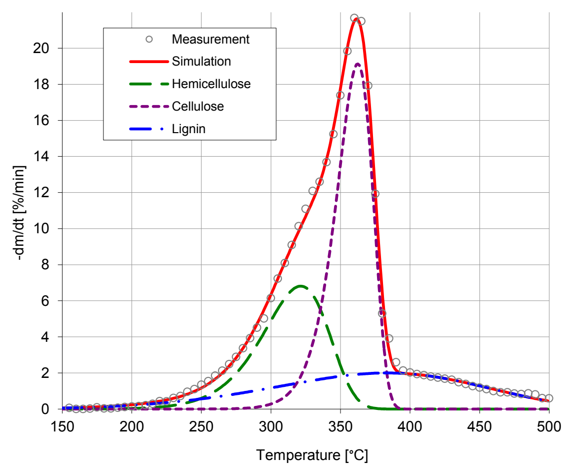
CENER_beech-270



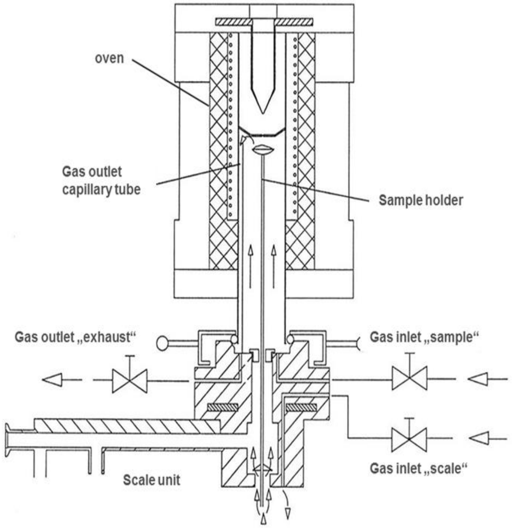
CENER_pine-300



Softwood pellets (reference)



- 3 torrefied materials and softwood pellets have been investigated by means of TGA (Thermo-Gravimetric Analysis)



Measuring principle of TGA tests performed

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TGA tests (2)

- The volatiles content of the torrefied materials is lower than for softwood pellets (62 – 65.8 wt% d.b. compared to 73 wt% d.b.)
- The fixed carbon content is with 32.6 to 37.6 wt% d.b. higher than for softwood pellets (26.7 wt% d.b.)
- The volatile content of CENER_beech-270 is the highest for all torrefied materials tested and the carbon content is the lowest
- Since hemicellulose is released during the torrefaction process usually only a small amount of hemicellulose is detected in torrefied materials
- However, for CENER_beech-270 a considerable amount of hemicellulose is detected (14 wt% d.b.). This indicates that the torrefaction rate was considerably lower for the CENER_beech-270 sample compared to the other torrefied materials

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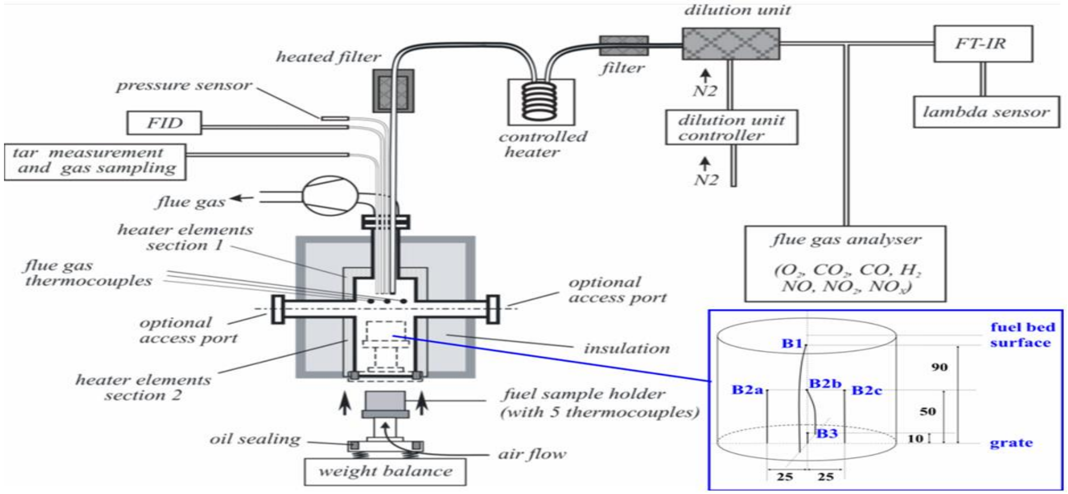
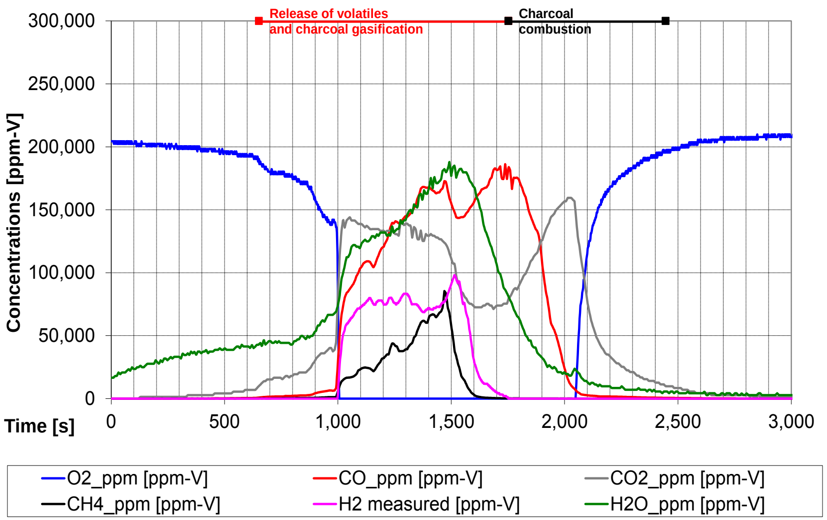
Lab-scale reactor tests (1)

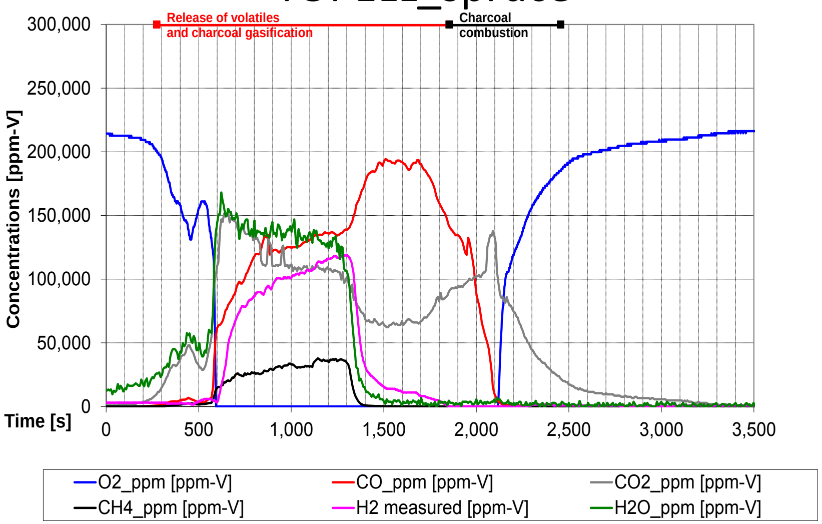


Left: scheme of the lab-scale reactor used including measurement set-up

softwood pellets



TOPELL_spruce



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Lab-scale reactor tests (2)

- Lab-scale reactor tests have been performed with TOPELL_spruce and softwood pellets
- The drying phase took longer for softwood pellets which is mainly due to the higher moisture content (7.1 wt% w.b. compared to 3.2 wt% w.b.)
- The main decomposition phase (release of volatiles and charcoal gasification) took longer for TOPELL_spruce compared to softwood pellets and the respective degradation rate was smaller
- The charcoal degradation rate ($dm_{Charcoal}/dt$) is slightly higher for TOPELL_spruce compared to softwood pellets (approx. 11%)
- The overall combustion process for TOPELL_spruce is slower than for softwood pellets
- For both fuels almost the whole N in the fuel is converted to TFN (Total Fixed Nitrogen – spezies: NO, NH_3, HCN, NO_2, N_2O)
- Almost all Cl is released to the gas phase for both fuels (93 – 97%) as well as the major amount of S

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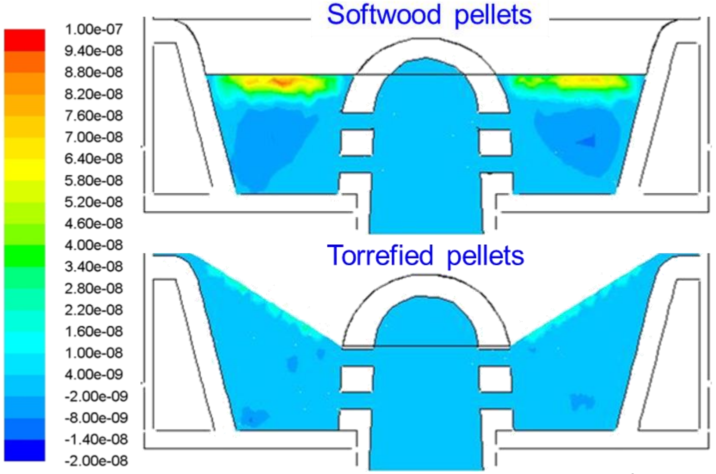
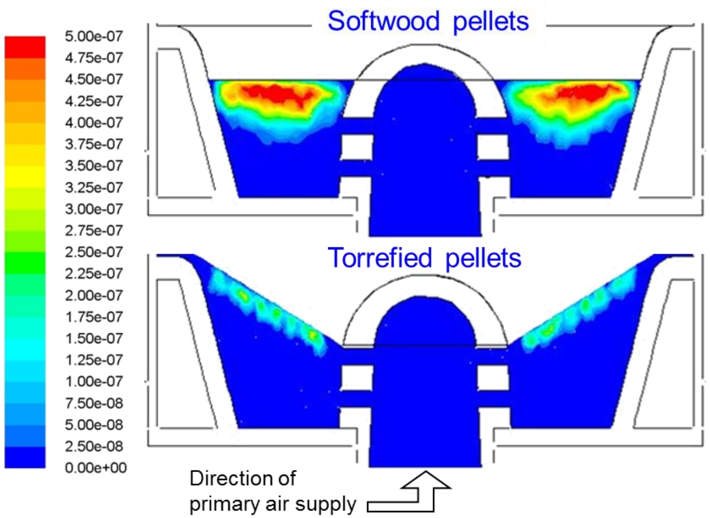
Particle layer model adaptation and CFD simulations

- The particle layer model has been adapted for torrefied biomass fuels
- CFD simulations of selected test runs for a modern overfeed pellet boiler operated with softwood and torrefied pellets under consideration of the fuel bed and the gas phase conversion have been performed
- Release of water vapour and volatiles is reduced for torrefied pellets compared to softwood pellets
- Higher bed temperatures are expected for torrefied pellets with a maximum of about 1,500 °C
- The burnout time is for torrefied pellets approx. 29% higher than for softwood pellets
- The simulated values are in good agreement with the measurements performed



Fuel bed - release of water vapour [kg/s]



Fuel bed - release of volatiles [kg/s]

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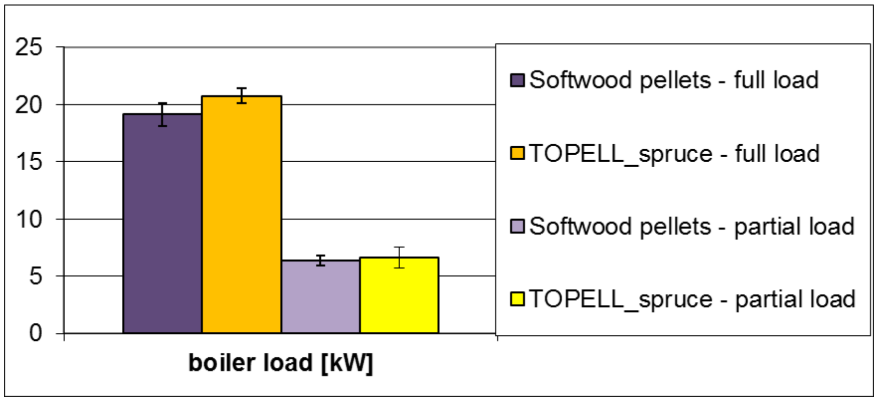
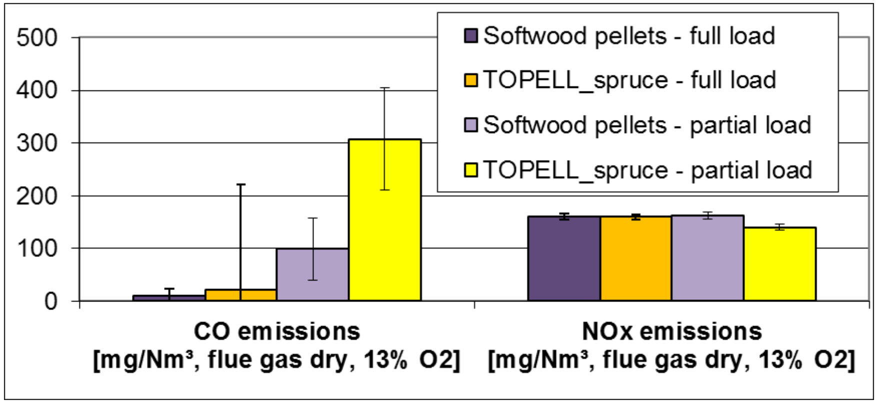
Test runs with a modern overfeed pellet boiler (1)

- Combustion tests with a modern pellet boiler have been performed with torrefied pellets (TOPELL_spruce) and softwood pellets





- Full load and partial load (at approx. 30% of the nominal boiler capacity) test runs have been performed. For all test runs stable load conditions have been achieved.
- CO emissions are only slightly higher at full load for TOPELL_spruce pellets (22 mg/Nm^3) compared to softwood pellets (10 mg/Nm^3)
- At partial load the CO emissions are generally higher. For TOPELL_spruce pellets the CO emissions are approx. 3 times higher (further optimizations of the control settings required)
- NO_x emissions are similar for softwood pellets and TOPELL_spruce

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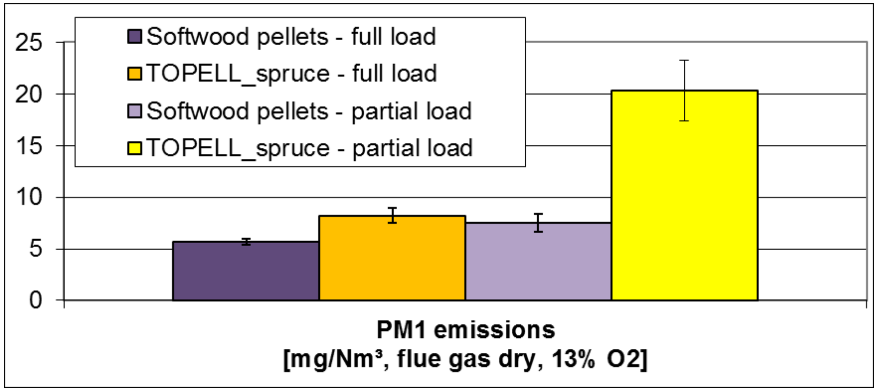
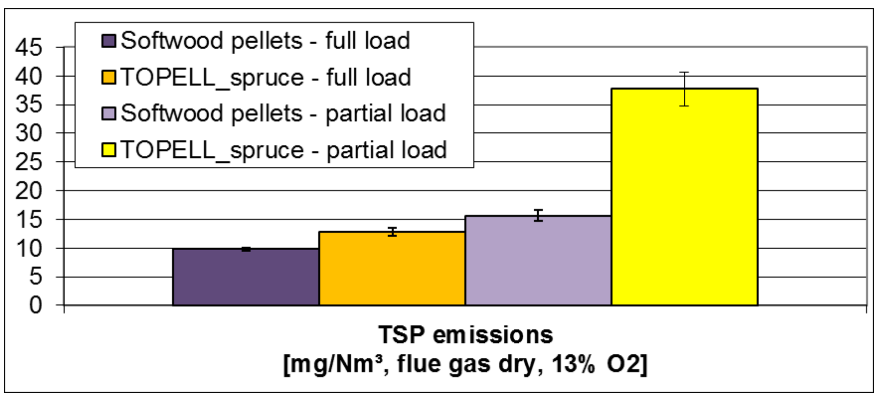
Test runs with a modern overfeed pellet boiler (2)





Explanations:
PM_1 … Paticulate Matter < 1 µm
TSP … Total Suspended Particles

- The PM_1 and TSP emissions at full load were for softwood pellets on a low level and for TOPELL_spruce pellets only somewhat higher
- PM_1 and TSP emissions increased considerably for TOPELL_spruce pellets at partial load. It is most likely that the air ratio in the primary combustion chamber was not favorable at partial load for TOPELL_spruce and that the bed temperatures were higher which leads to a higher K release from the fuel bed

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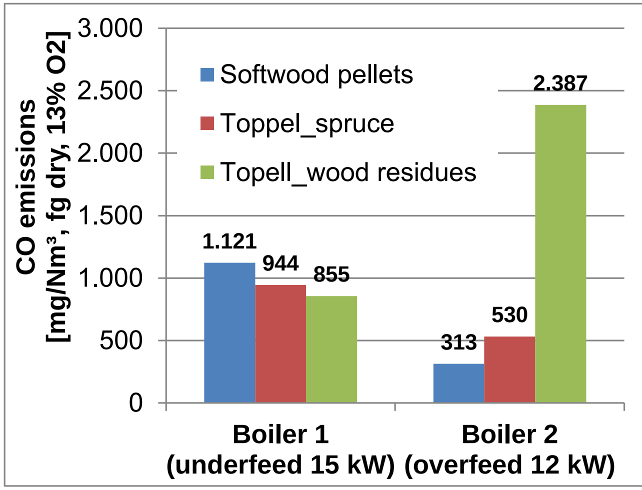
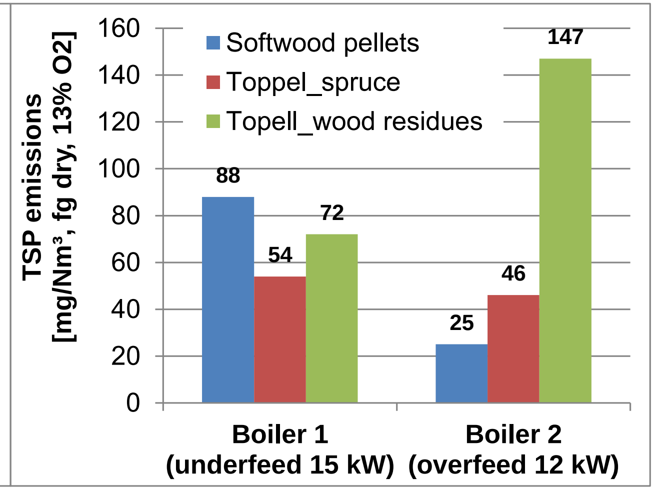
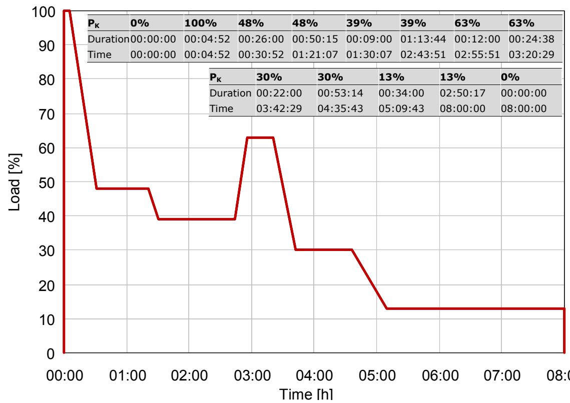
Boiler technology and fuel assessment (TFZ)

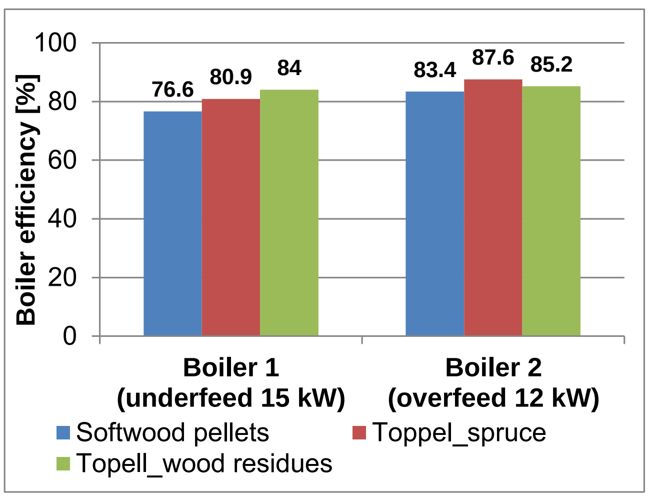
Results of load cycle tests (average values over the entire load cycle)





Standard load cycle (8-h-test)





- At constant or variable load similar emissions are achieved as with softwood pellets, given that torrefied pellets have the same fuel origin
- Efficiency at full & partial load: same range as for softwood pellets is achievable
- Efficiency at variable load: advantages for torrefied pellets are possible

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Combustion technology screening (BE2020, 1)

- Tests have been performed with 4 different boiler types
- Increased emissions during start up over a 1 h period occur
- Increased fuel mass on the grate observed → impact on emissions possible, burnout quality might decrease, deashing intervals may need adaption
- Increase of temperature on the grate
- Depending on control strategy:
  - Increased power output during nominal load possible
  - Variation in excess air ratio possible

  → Control settings must be adapted individually for torrefied pellets for each boiler type
- Corrosiveness of the flue gas seems to be more dependent on composition of raw material than influenced by torrefaction

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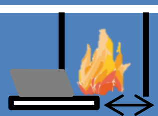
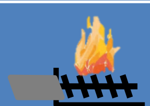
Combustion technology screening (BE2020, 2)

Boiler technology	CO during start	Mass on grate	Temperature on grate	Power output	Air excess ratio
	**+ 590 %**	+ 40 %	+ 79°C	**+ 9 %**	+ 2 %
	+ 30 %	**+ 100 %**	**+ 94°C**	+ 6 %	- 3 %
	+ 20 %	n.d.	+ 47°C	+ 4 %	**- 6 %**
	**+ 220 %**	**+ 130 %**	**+ 158°C**	+ 3 %	- 4 %

Explanations: percentage shown are related to torrefied pellets in comparison to conventional softwood pellets (=100%)

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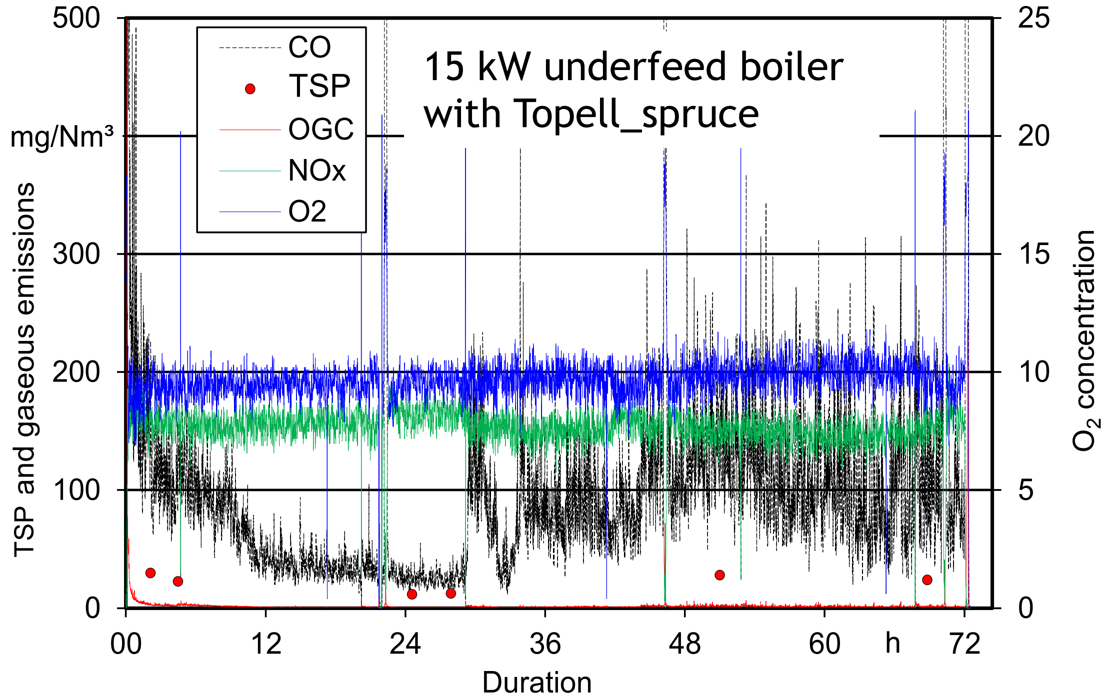
Long-term performance tests (TFZ)



- Tests over 72 h have been performed with an underfeed and an overfeed boiler
- Underfeed boiler: operation becomes instable after 30 h of operation
- Granulometric assessment shows generally higher risk of slag formation than with wood pellets (applies to both boilers)
- Clogging of air inlet nozzles requires more frequent maintenance with torrefied pellets


Slag deposits (underfeed boiler)


Ash agglomerates (underfeed boiler)


Air nozzles clogged, (overfeed boiler)

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Summary and conclusions (1)

- In principle torrefied pellets can be applied in commercial small-scale wood pellet boilers. However it has to be considered that
  - Higher char contents in torrefied fuels lead to increased need for burnout time (adaptations of the grate and the burnout zone are therefore possibly required)
  - The air ratio and air staging as well as the control settings need some adaptations. This depends on the specific boiler technology applied
  - The level of pollutant emissions is largely similar to that of wood pellets, given that similar wood resources are used. This was observed for CO, OGC, NO_x and PM emissions. However, due to the higher expected fuel bed temperatures of torrefied fuels fine particle emissions may increase
  - The use of torrefied pellets may be associated with a higher share of slag formed during combustion due to the higher fuel bed temperatures expected. Measures to inhibit slagging are therefore of major relevance

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Summary and conclusions (2)

→ Following, modifications especially regarding process control are needed

- Torrefied wood pellets have the potential to provide at least the same or even a higher combustion efficiency as achievable with wood pellets
- In principle, it is not permitted to operate the heating systems with fuels which are not certified by the boiler manufacturers
- Manufacturers should perform field tests over a full heating period with torrefied pellets before approval of these fuels

→ Close cooperation with the boiler manufacturers is required to make torrefied fuels suitable for small-scale pellet boilers

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Thank you very much for your attention

Relevant publications available:

Deliverable report No. D7.3 and D7.4:
Executive summary and 3 partner reports

Available at www.sector-project.eu

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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Session IV: Value chains, sustainability, standardisation
Part 1: GHG Emissions and Value chains

Final Project Meeting, 06.05.2015 in Leipzig

Stefan Majer, DBFZ
Fabian Schipfer, TU Wien






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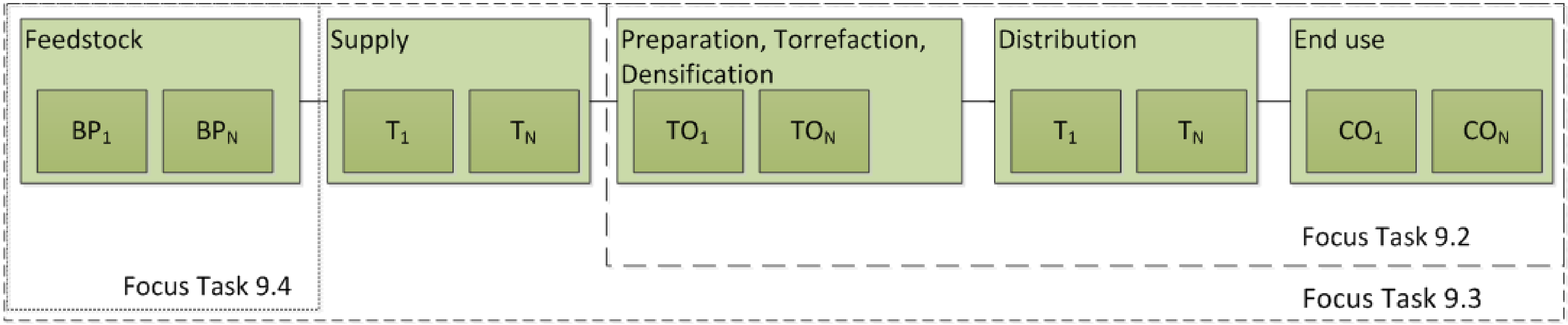
WP9: Motivation / Objectives of Work Package

Structure:

- three assessment tasks = three different system boundaries for the assessment

- Task 9.1 & 9.2 = scenarios and value chains
- Task 9.3 = GHG-emissions
- Task 9.4 = environmental impact assessment



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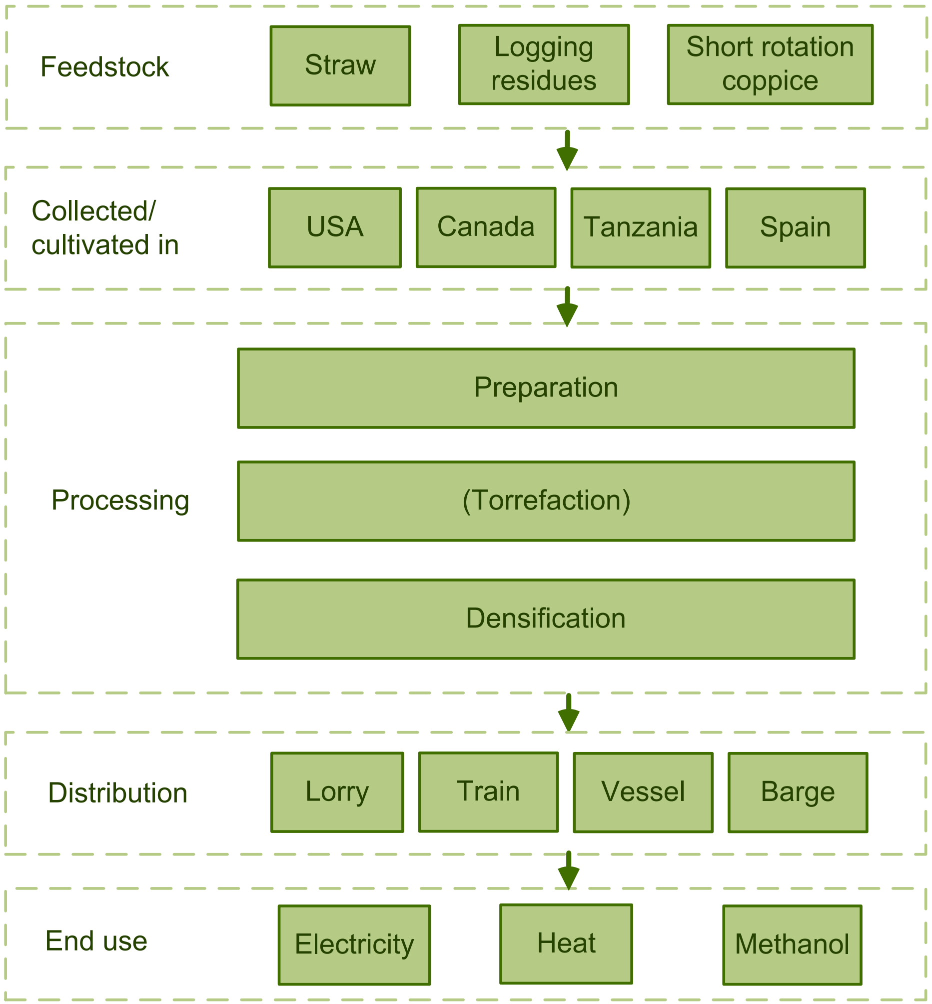
WP 9 - GHG-emissions - pathways and system boundaries

- 3 feedstocks and 4 different locations
- torrefied pellets and white pellets
- in each case transport to Europe (Rotterdam)
- different end uses



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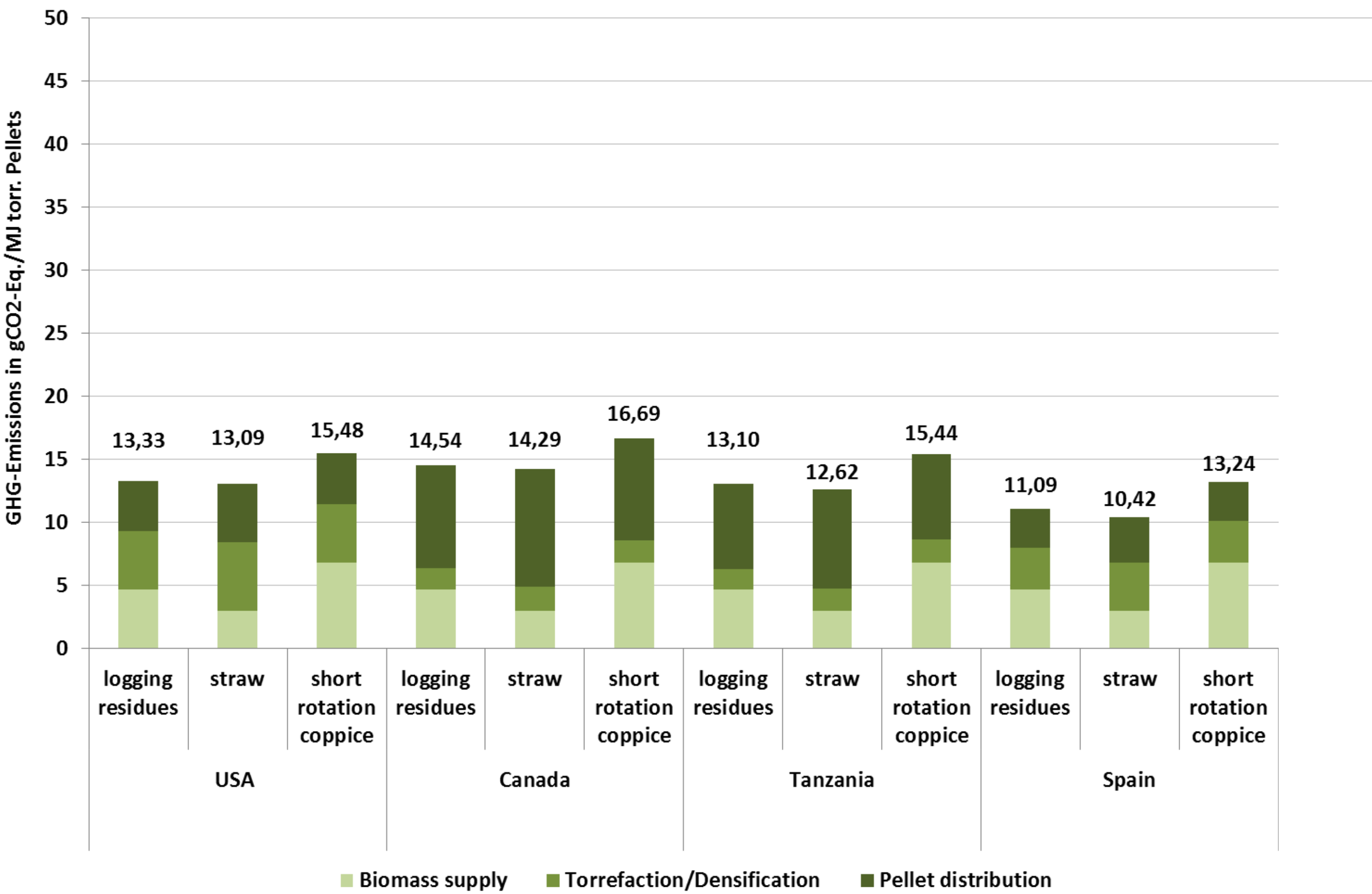
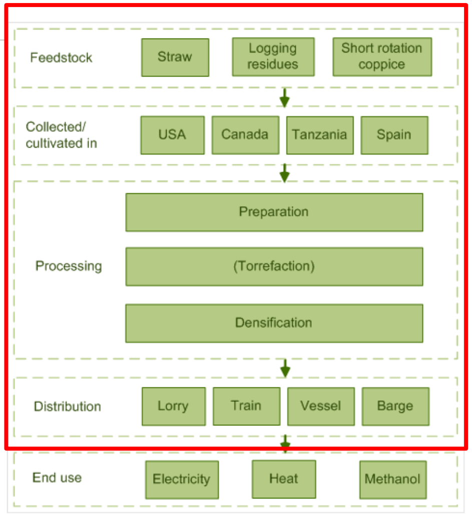
WP 9 - GHG-emissions - torrefied pellet production and distr.





source: own Sector calculations & BioGrace II

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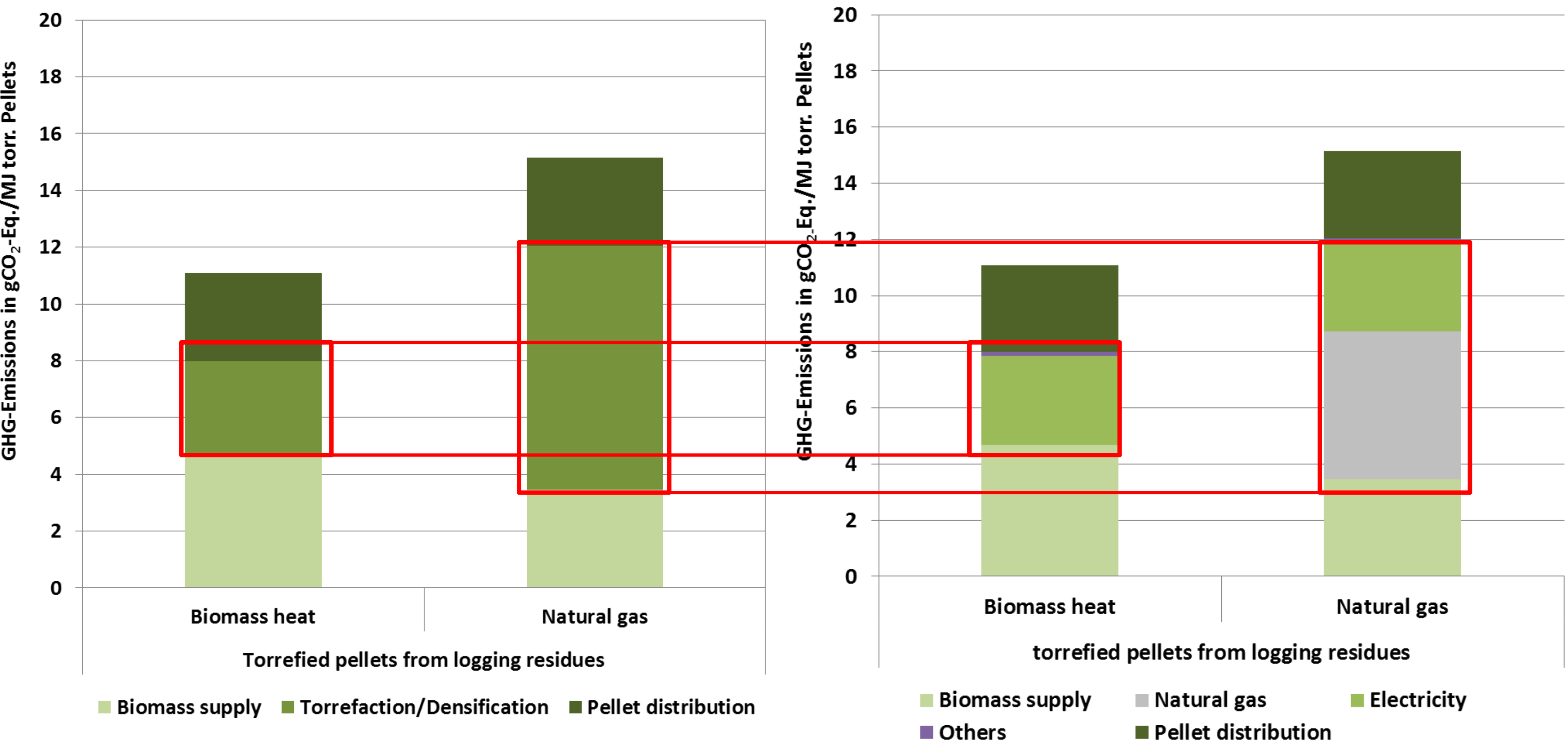
WP 9 - GHG-emissions - torrefied pellet production and distr.

significant impact of heat supply for torrefaction & densification



Source: own Sector calculations & BioGrace II

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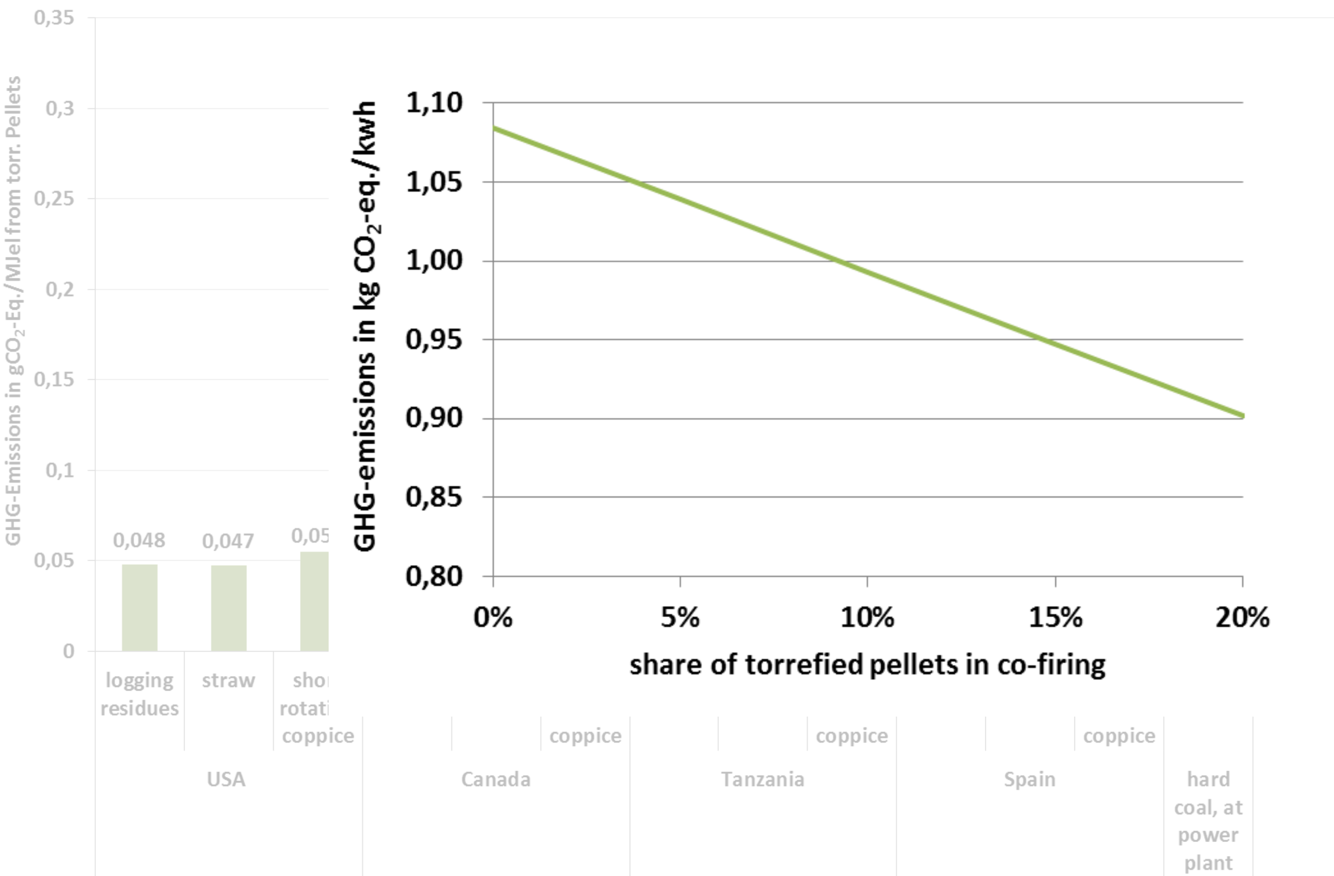
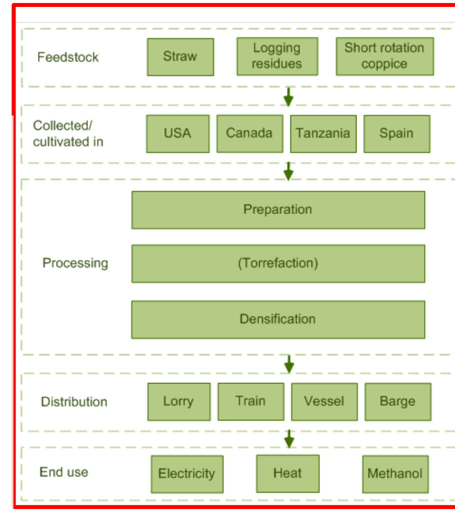
WP 9 - GHG emissions - results end use I

GHG-emissions from electricity production





GHG-mitigation potential of 72% - 86%

Source: own Sector calculations & Ecoinvent

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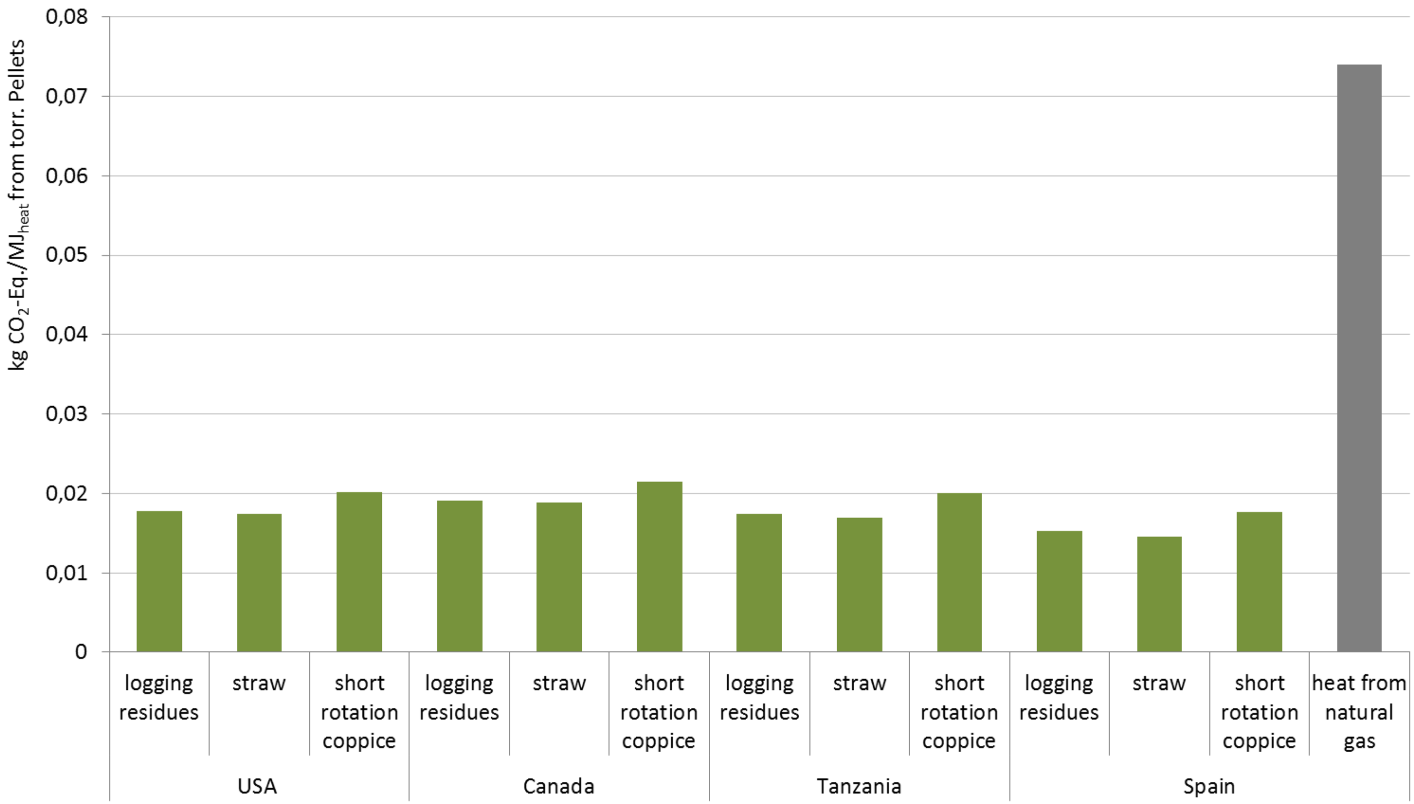
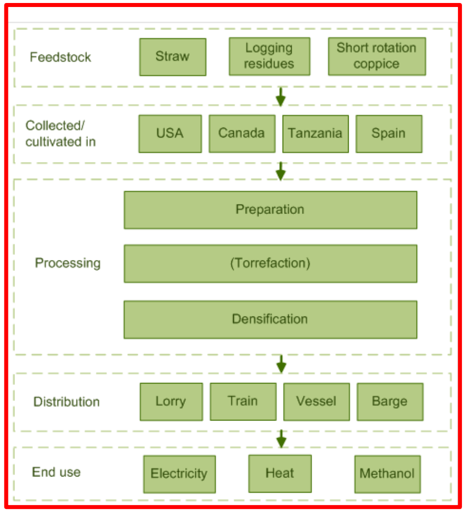
WP 9 - GHG emissions - results end use II

GHG-emissions from heat production





GHG-mitigation potential of 71% - 80%

Source: own Sector calculations & Ecoinvent

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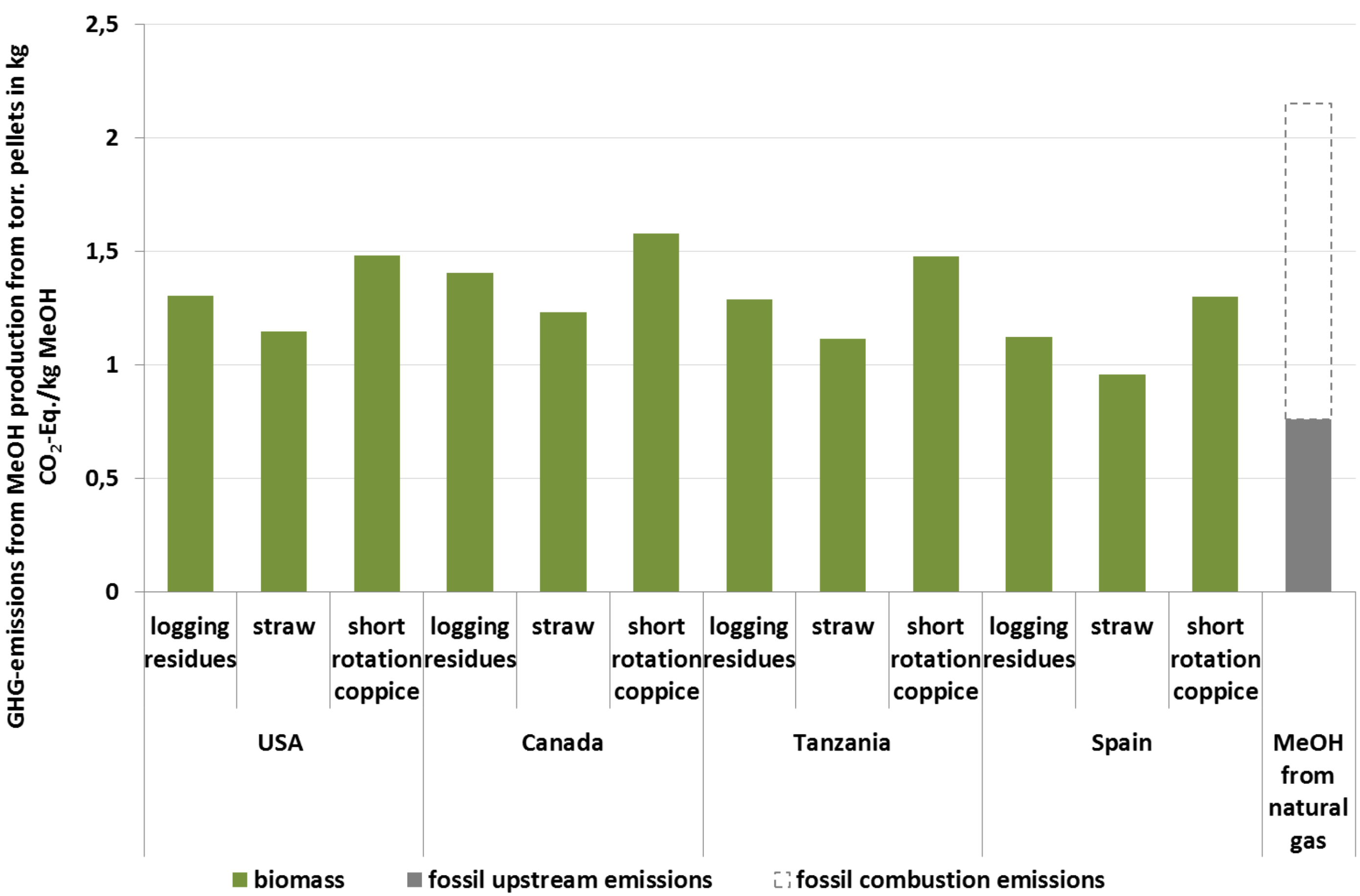
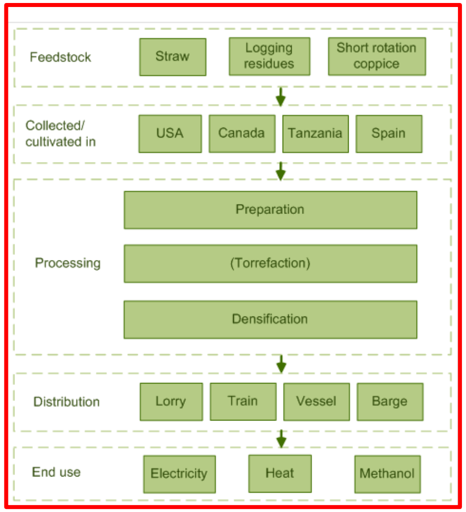
WP 9 - GHG emissions - results end use III

GHG-emissions from MeOH production





Source: own Sector calculations & Ecoinvent

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

VALUE CHAINS

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

WP 9 - value chains - generic chain assessment

- What could illustrative, possibly relevant biomass-to-end-use chains based on torrefaction look like?

  - systems perspective including regional to overseas supplies
  - all elements of biomass-to-end-use chains (feedstocks, logistics, end use ..)
  - calculation of costs enabling comparability to reference supply chains (white pellets)
  - inclusion of the supply side based on WP2 results (number of feedstocks including supply potentials)
  - sensitivity analysis for most important impact parameters

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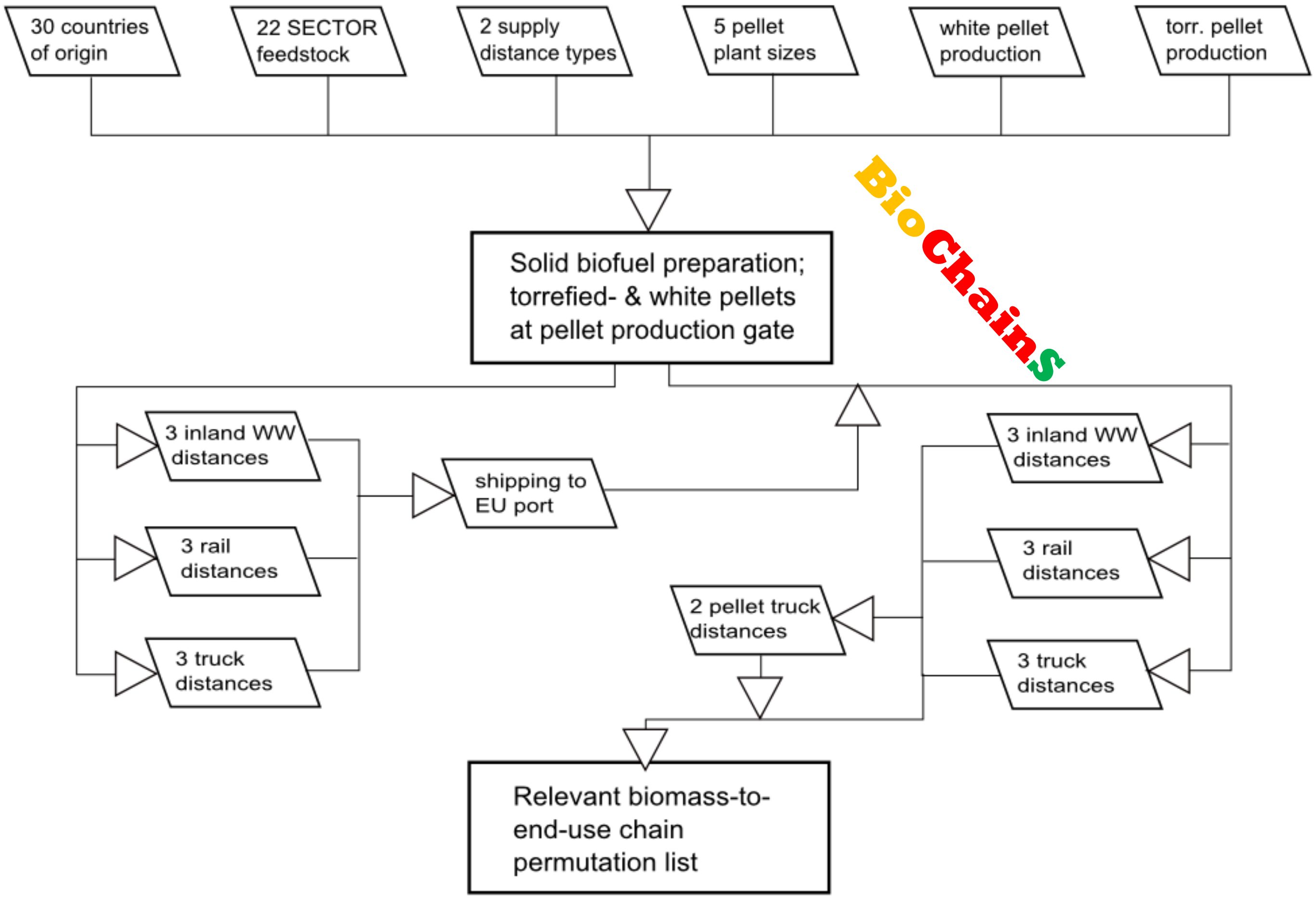
WP 9 - value chains - the BioChainS tool

Tool **BioChainS** was adapted to research questions, feedstocks and pretreatment technologies to generate large set of probable relevant biomass-to-end-use chains.



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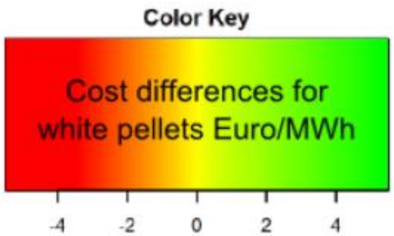
WP 9 – selected results – generic chain assessment



Average costs (number in the boxes, Euro2013/MWh) for torrefied pellets based on saw dust for selected biomass-to-end-use chain constellations

	100km EU-transport, large end use	400km EU-transport, large end use	800km EU-transport, large end use	100km EU-transport, small end use	400km EU-transport, small end use	800km EU-transport, small end use
US/CA,low supply dist., Pellet plant size <101kt	39.7	43.8	49.2	42.5	46.5	52
EU,low supply dist., Pellet plant size <101kt	35.8	39.8	45.3	38.5	42.6	48
US/CA,high supply dist., Pellet plant size <101kt	41.8	45.9	51.3	51.2	55.3	60.7
EU,high supply dist., Pellet plant size <101kt	38	42	47.5	47.4	51.4	56.9
US/CA,low supply dist., Pellet plant size >199kt	39.2	43.3	48.7	42	46	51.5
EU,low supply dist., Pellet plant size >199kt	35.4	39.5	44.9	38.1	42.2	47.7
US/CA,high supply dist., Pellet plant size >199kt	44	48	53.5	53.4	57.4	62.9
EU,high supply dist., Pellet plant size >199kt	40.3	44.4	49.8	49.7	53.8	59.2

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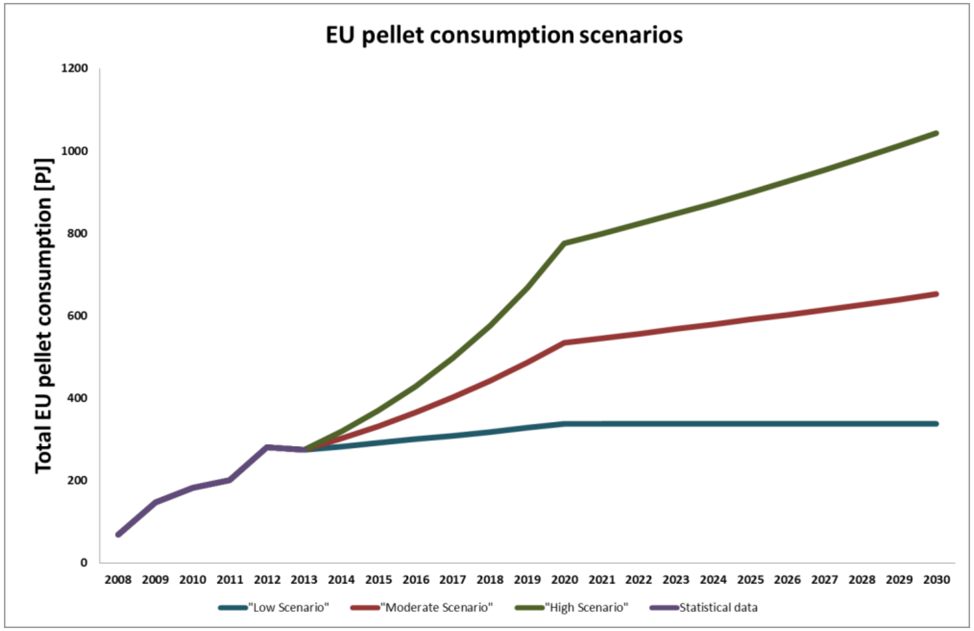
WP 9 - value chains - deployment scenarios

- How could torrefaction deployment develop up to 2030 with regard to economic, social and environmental criteria?
- three scenarios based on different publications for the potential size of future markets (e.g. Mantau 2010, Kokko 2012, Mergner 2014):

- „low scenario“: no import of wood pellets for small scale consumption, only domestic production (saw dust) for household consumption
- „moderate scenario“: demand exceeds the potential supply based on domestic saw dust → additional feedstocks and imports
- „high scenario“: high demand for small scale pellet consumption as well as for large scale (mainly co-fired coal plants) → additional feedstocks and imports



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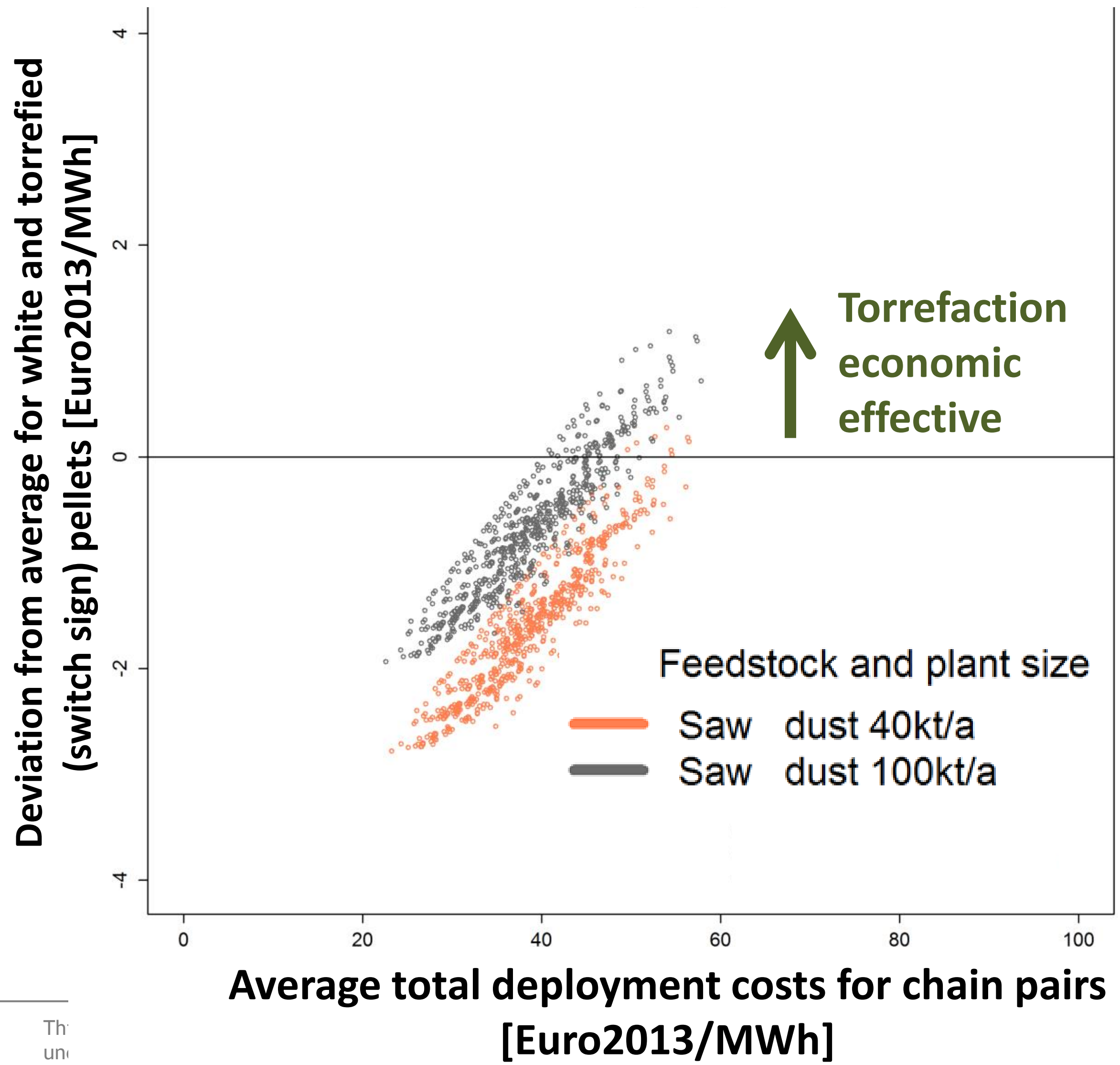
Differences between white and torrefied pellets for similar chains related to their avarage deployment costs

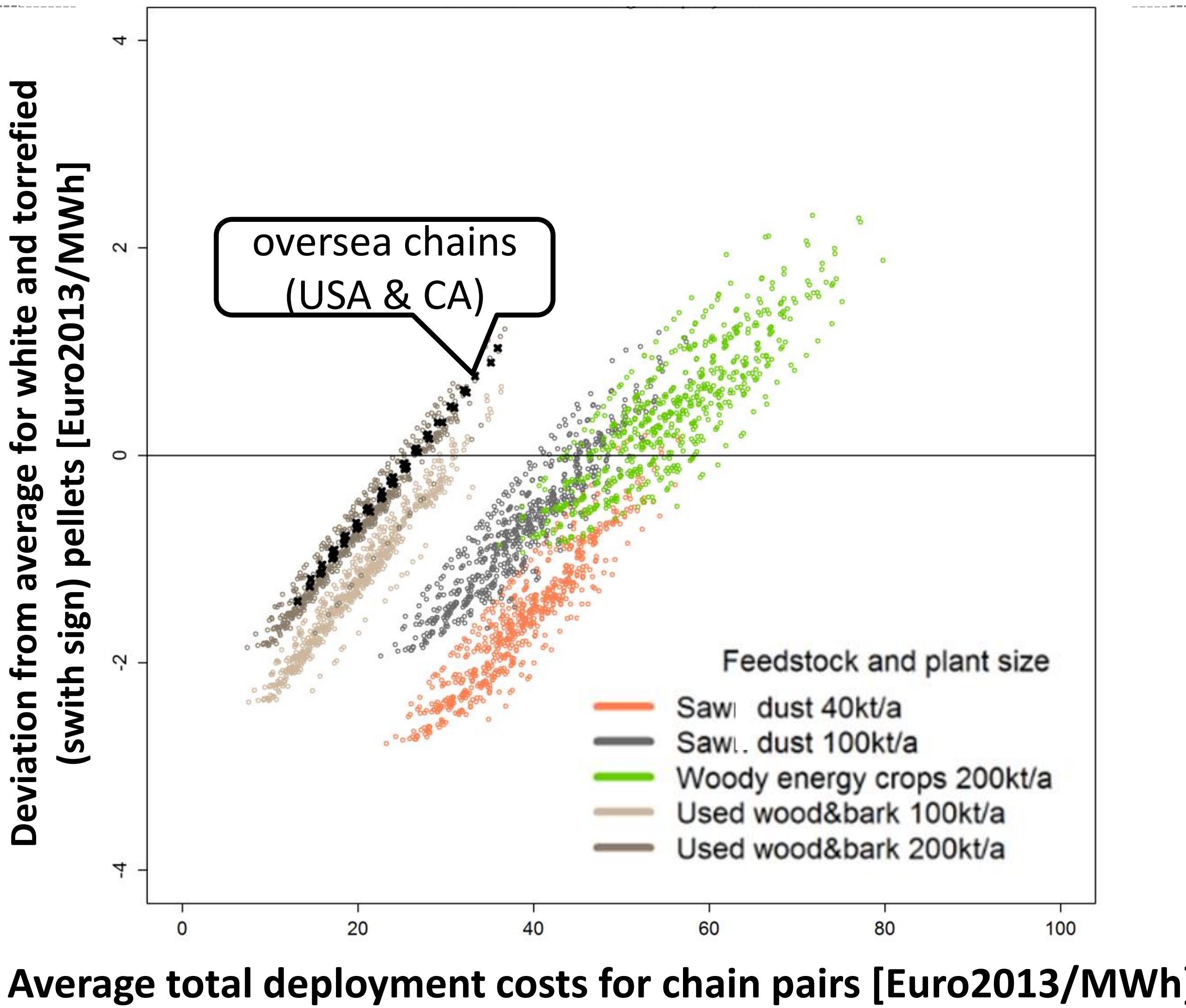


„low scenario“

- using domestic saw dust potential

SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Differences between white and torrefied pellets for similar chains related to their avarage deployment costs



„moderate scenario“

- pellet import
- additional feedstock for small scale (stem wood)
- additional feedstock for large scale (used wood)

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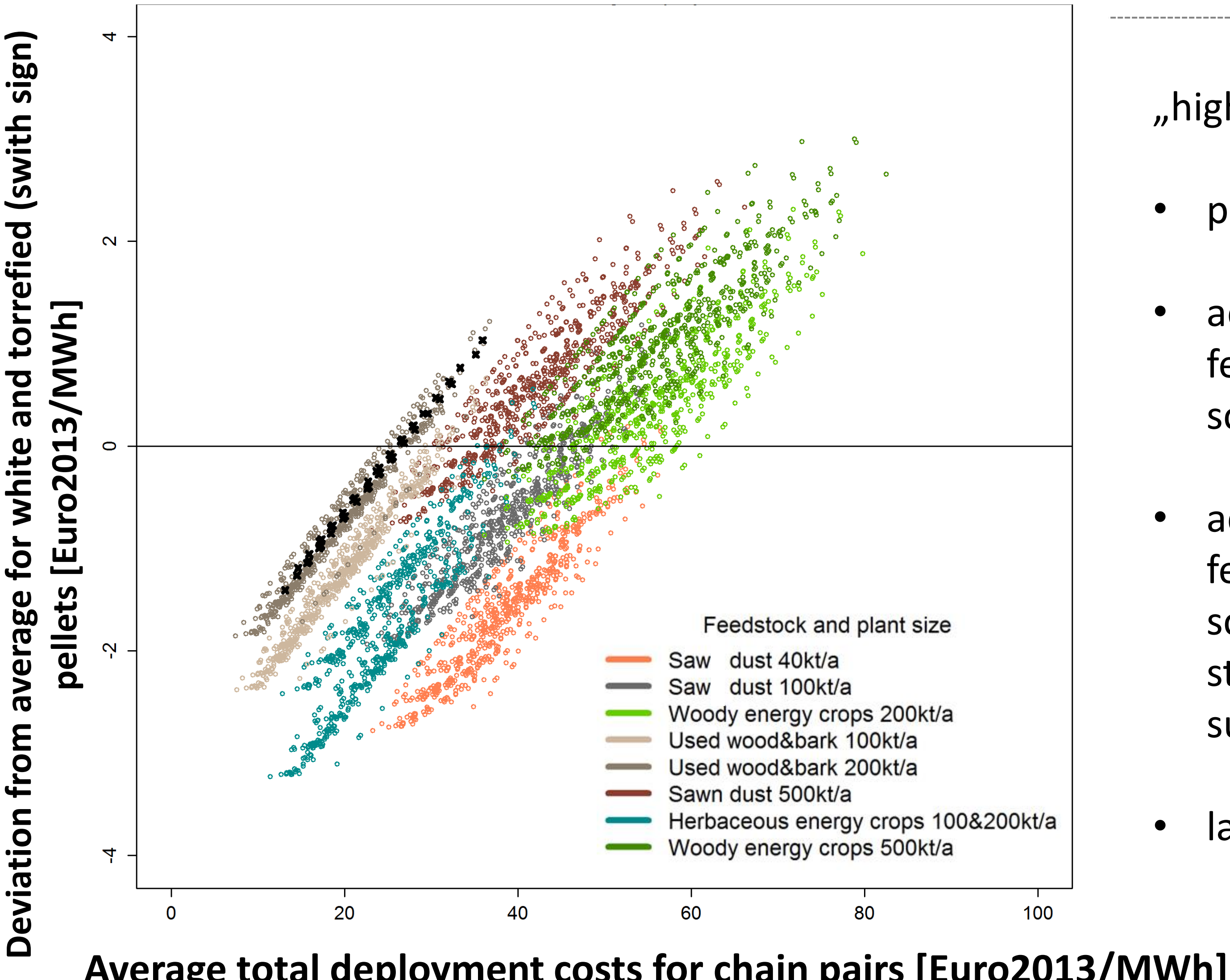
Differences between white and torrefied pellets for similar chains related to their avarage deployment costs



„high scenario“

- pellet imports
- additional feedstock for small scale (stem wood)
- additional feedstock for large scale (used wood, straw and sunflower husks)
- larger pellet plants

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WP 9 value chains - conclusions

- Considerable cost savings in scenarios with higher pellet deployment
- CO_2 emissions lower – emission reduction costs only in general lower for higher fossil fuel prices
- No conclusions about employment effects possible (yet)
- Diversifying white pellets market with torrefied pellets market reduces risks of price volatility, especially for higher qualities (small scale/household)

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

thank you very much for your attention

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SECTOR

Production of Solid Sustainable Energy Carriers
from Biomass by Means of TORrefaction

Session IV: Value chains, sustainability, standardisation
Part 2: Environmental Assessment

Final Project Meeting, 06.05.2015 in Leipzig

Markus Meyer, UFZ
Tanzilla Chand, UFZ
Jörg Priess, UFZ






This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Local/regional environmental impacts

GHG & air pollution

Water

Photos: SECTOR, Henle, Künzelmann und Rönicke/UFZ, Wikipedia

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Research questions

- Analysis of certification schemes:

1. *Do certification schemes allow for a reliable and feasible assessment of local/regional environmental impacts?*

- *Improvement option A: regional environmental assessment*

2. *How do impacts on ESS differ for different solid bioenergy feedstock, i.e., forestry and agriculture? Do landscape scale factors affect ESS and biodiversity?*

- *Improvement option B: approaches to make global biomass production regions comparable*

3. *What are the advantages and disadvantages of different techniques to compare environmental and ESS impacts under environmental heterogeneity?*

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Research question

- Analysis of certification schemes:

1. *Do certification schemes allow for a reliable and feasible assessment of local/regional environmental impacts?*

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Existing certification schemes

(Solid) biofuel production e.g. ISCC, IWPB	Agricultural e.g. GlobalGAP	Forestry e.g. FSC
Global indicator sets	Global indicator sets	Global indicator sets

Photos: Blogspot, SECTOR, Künzelmann/UFZ, Noy/UN

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Indicator rating scales

Reliability

Indicator type (cause vs. effect-related)		
1	Driver	management practices
2	Driver	management practices related to state or impact
3	Pressure	emissions
4	State	concentration of pollutant in environmental compartment
5	Impact	environmental changes attributable to emissions

Feasibility

Required resources (assessment interval)	
1	daily assessment/measurements required
2	seasonal assessment/measurements required
3	annual assessment/measurements required
4	less than annual measurements
5	no measurement, only completing of survey

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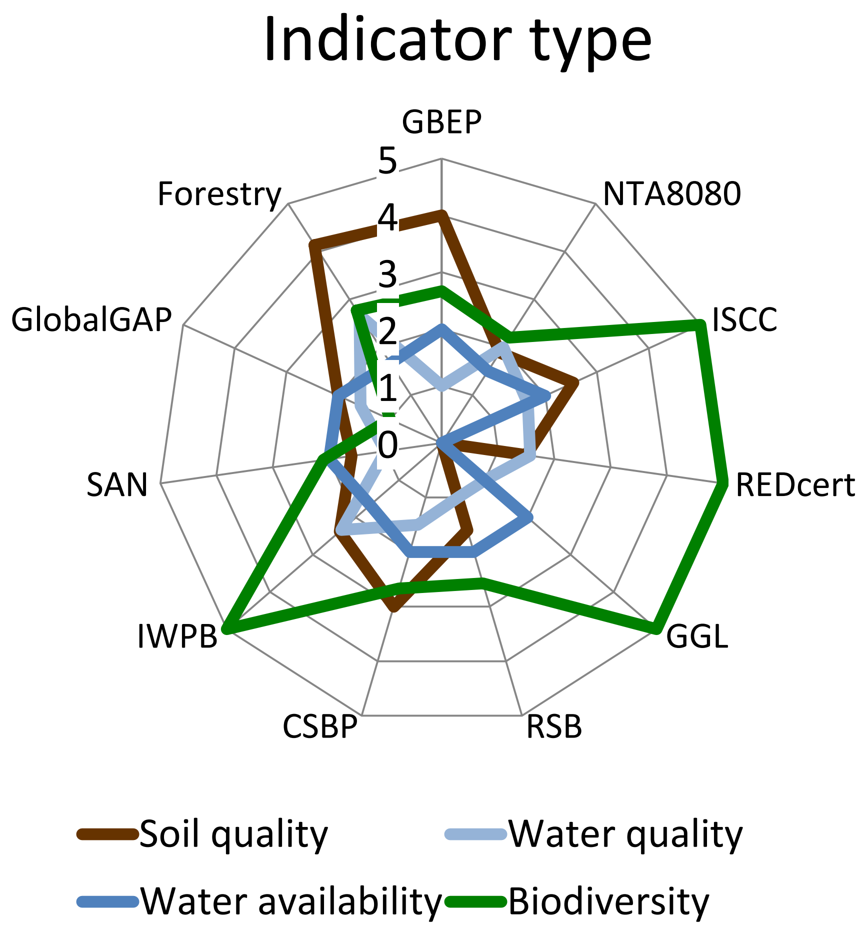
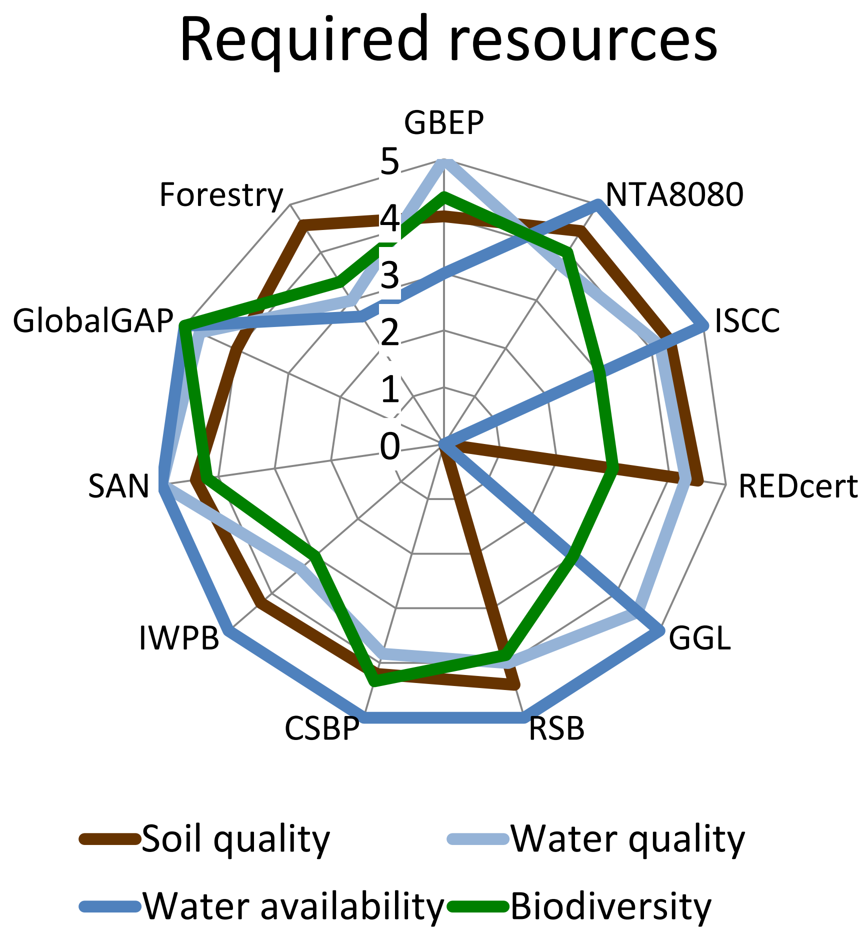
Highly feasible, less reliable indicators

Reliability



Feasibility



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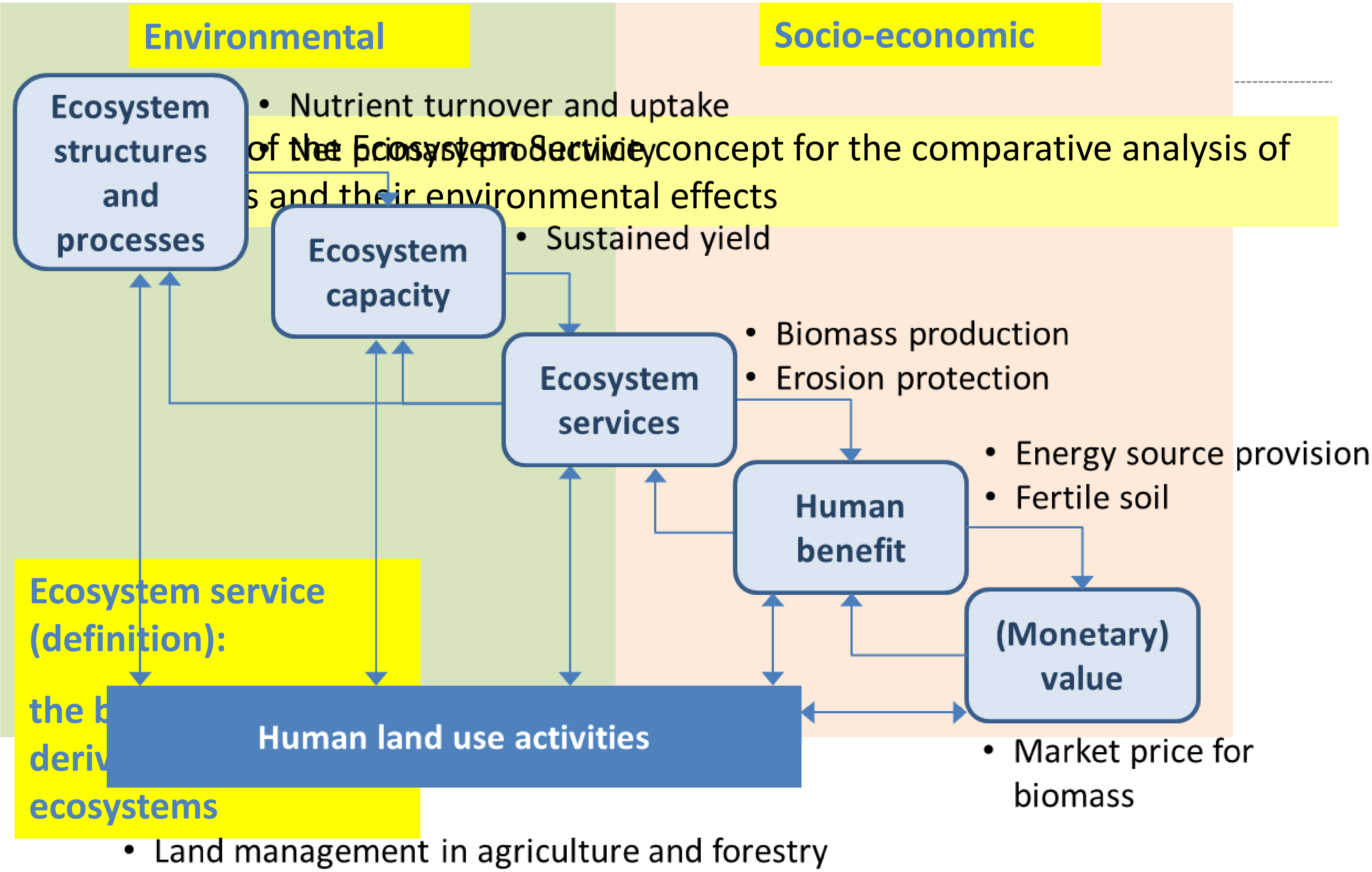

Environmental
Socio-economic
of the Ecosystem Service concept for the comparative analysis of
s and their environmental effects
Ecosystem structures and processes
• Nutrient turnover and uptake
• Net primary productivity
Ecosystem capacity
• Sustained yield
Ecosystem services
• Biomass production
• Erosion protection
Human benefit
• Energy source provision
• Fertile soil
(Monetary) value
• Market price for biomass
Ecosystem service (definition):
the b
deriv
ecosystems
Human land use activities
• Land management in agriculture and forestry

Environmental

Ecosystem structures and processes

Available water holding capacity [cm,33>1500 kPa]
Saturated hydraulic conductivity [cm³/s]
Nutrient turnover and uptake [mg/l]

Water quality
Nutrient sedimentation [mg/l]
Pesticide immobilization rate [mg active ingredient/l]

Water availability
Δ groundwater level [mm]
Evapostranspiration [mm]
Precipitation [mm]
Runoff [mm]

Biodiversity
Structural complexity [various]
Habitats of special concern [ha]
Ecological corridors and buffer zones [presence]
Species richness and evenness [Simpson or Shannon-Wiener index]
Taxa of special concern [presence]
Indicator species [n/ha]
Net primary productivity [t C/(ha*a)]

Land cover and landscape
Land cover type and spatial distribution [ha]

Ecosystem capacity

Sustained yield [t/(ha*a) or MJ/(ha*a)]

Regulation and maintenance
Min. SOC content [g/kg]
Max. soil bulk density [g/cm³]
Max. nutrient removal potential [kg/(ha*a)]
Recycling/immobilization potential of chemicals [kg active ingredient/(ha*a)]
Peak storm flow [l/s]
Minimum base flow [l/s]
Max. sustainable water use [m³/(ha*a)]
Minimal population [n] and habitat size [ha]
Ecosystem integrity [max./min. n (indicator species)/ha]

Land use activities

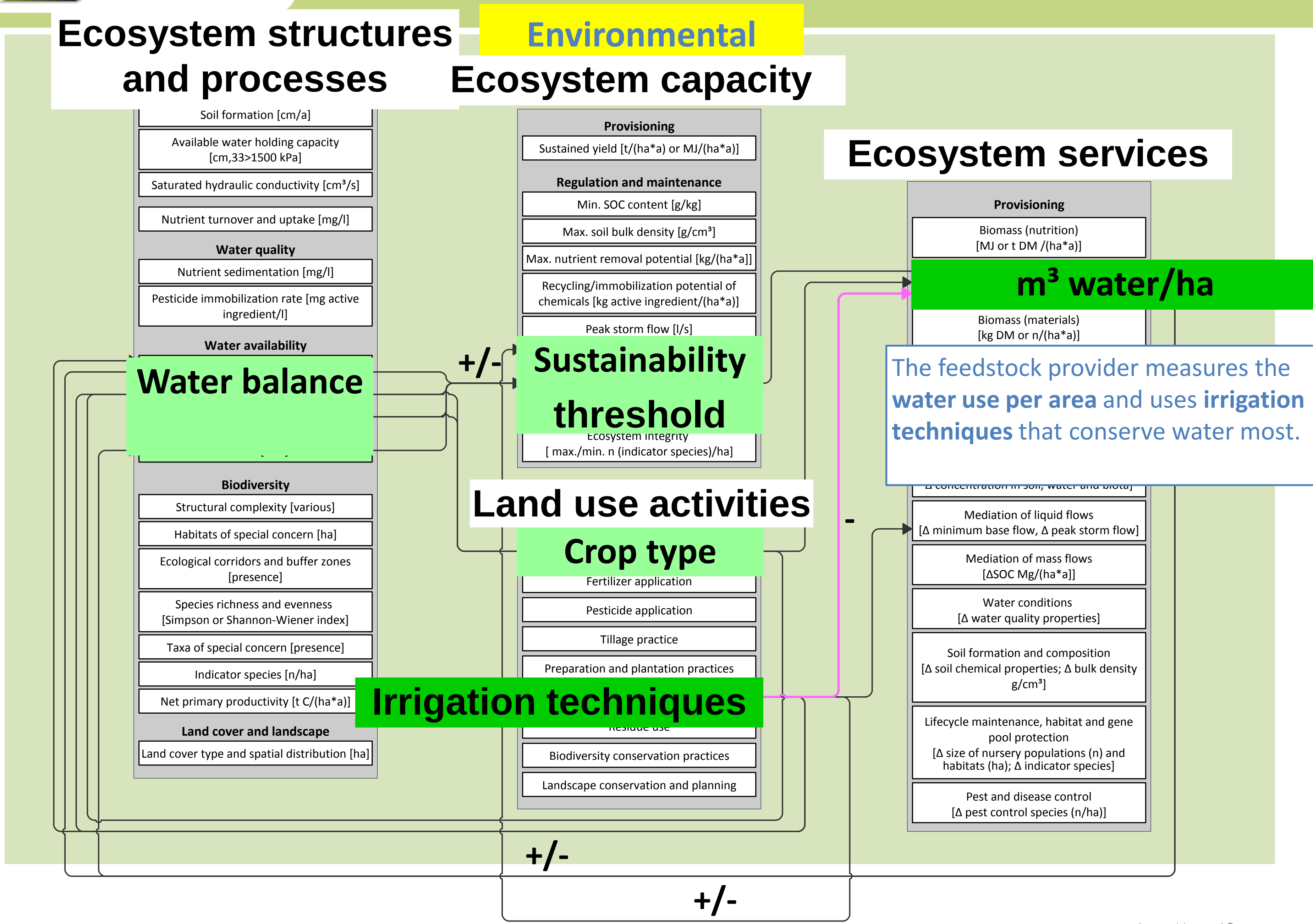
Crop type
Fertilizer application
Pesticide application
Tillage practice
Preparation and plantation practices
Irrigation techniques
Residue use
Biodiversity conservation practices
Landscape conservation and planning

Ecosystem services

Provisioning
Biomass (nutrition) [MJ or t DM /(ha*a)]
m³ water/ha

The feedstock provider measures the **water use per area** and uses **irrigation techniques** that conserve water most.

Mediation by biota and ecosystems [Δ excess nutrient balance/(Δ soil and water chemical properties); pesticide application - Δ concentration in soil, water and biota]
Mediation of liquid flows [Δ minimum base flow, Δ peak storm flow]
Mediation of mass flows [ΔSOC Mg/(ha*a)]
Water conditions [Δ water quality properties]
Soil formation and composition [Δ soil chemical properties; Δ bulk density g/cm³]
Lifecycle maintenance, habitat and gene pool protection [Δ size of nursery populations (n) and habitats (ha); Δ indicator species]
Pest and disease control [Δ pest control species (n/ha)]


Ecosystem structures and processes
Environmental
Ecosystem capacity
Ecosystem services
Soil formation [cm/a]
Available water holding capacity [cm,33>1500 kPa]
Saturated hydraulic conductivity [cm³/s]
Nutrient turnover and uptake [mg/l]
Water quality
Nutrient sedimentation [mg/l]
Pesticide immobilization rate [mg active ingredient/l]
Water availability
Water balance
Biodiversity
Structural complexity [various]
Habitats of special concern [ha]
Ecological corridors and buffer zones [presence]
Species richness and evenness [Simpson or Shannon-Wiener index]
Taxa of special concern [presence]
Indicator species [n/ha]
Net primary productivity [t C/(ha*a)]
Land cover and landscape
Land cover type and spatial distribution [ha]
Provisioning
Sustained yield [t/(ha*a) or MJ/(ha*a)]
Regulation and maintenance
Min. SOC content [g/kg]
Max. soil bulk density [g/cm³]
Max. nutrient removal potential [kg/(ha*a)]
Recycling/immobilization potential of chemicals [kg active ingredient/(ha*a)]
Peak storm flow [l/s]
Sustainability threshold
Ecosystem integrity
[max./min. n (indicator species)/ha]
+/-
Land use activities
Crop type
Fertilizer application
Pesticide application
Tillage practice
Preparation and plantation practices
Irrigation techniques
Residue use
Biodiversity conservation practices
Landscape conservation and planning
Provisioning
Biomass (nutrition) [MJ or t DM /(ha*a)]
m³ water/ha
Biomass (materials) [kg DM or n/(ha*a)]
The feedstock provider measures the water use per area and uses irrigation techniques that conserve water most.
Δ concentration in soil, water and biota]
Mediation of liquid flows [Δ minimum base flow, Δ peak storm flow]
Mediation of mass flows [ΔSOC Mg/(ha*a)]
Water conditions [Δ water quality properties]
Soil formation and composition [Δ soil chemical properties; Δ bulk density g/cm³]
Lifecycle maintenance, habitat and gene pool protection [Δ size of nursery populations (n) and habitats (ha); Δ indicator species]
Pest and disease control [Δ pest control species (n/ha)]
-
+/-
+/-

Discussion and conclusion

- Emphasis on feasible indicators of land management practices

→ Trade-off between reliability and feasibilty

- Assessment focus at plot/farm scale (esp. human land use activities)

→ Impacts on regional scales (e.g. water availability at watershed) hardly covered

To which extent is it necessary and realistic to modify certification schemes for a reliable environmental assessment?

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Research question

- *Improvement option A: regional environmental assessment*

2. *How do impacts on ESS differ for different solid bioenergy feedstock, i.e., forestry and agriculture?*

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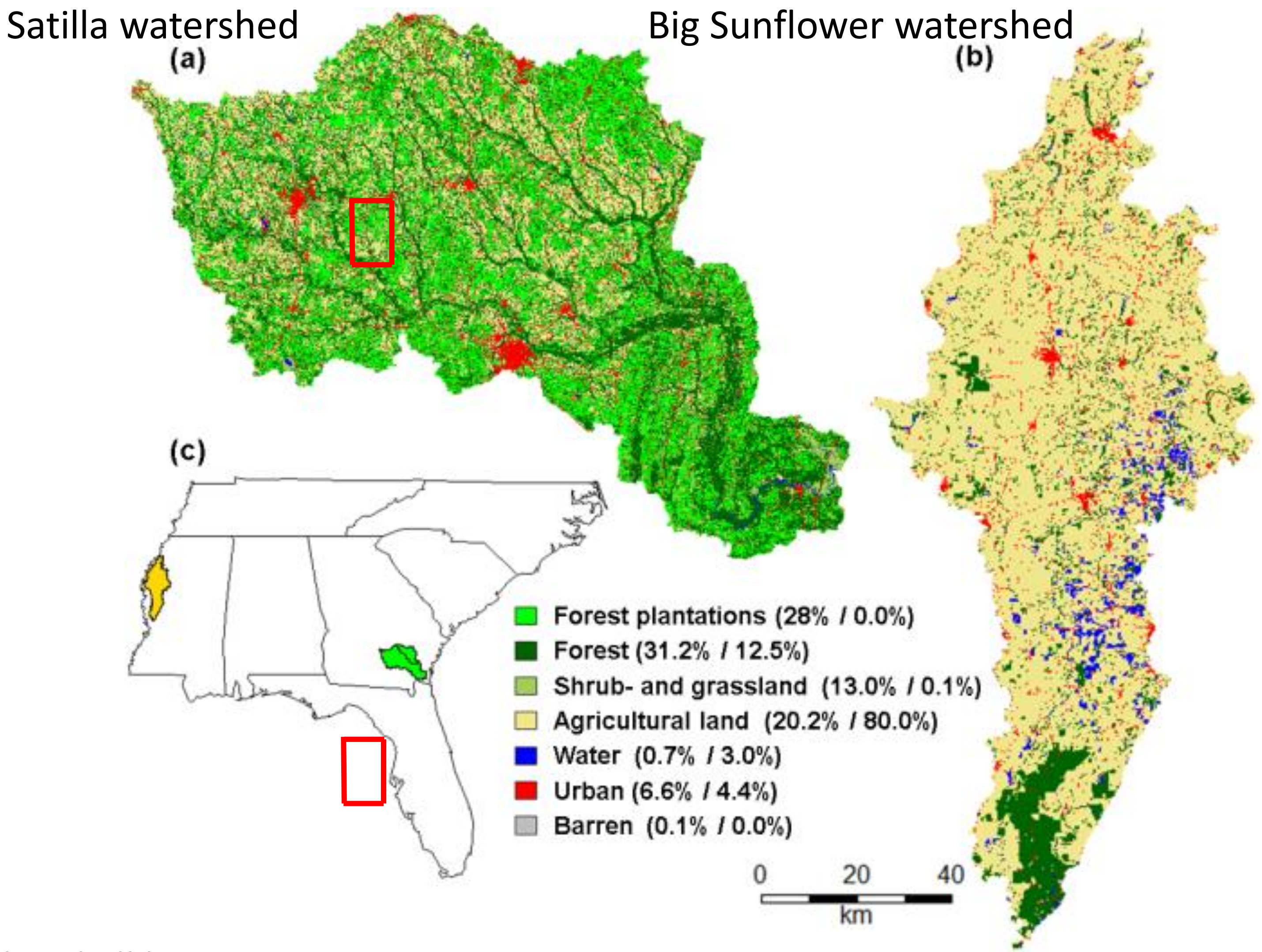
Environmental assessment: case studies



Source: USDA, 2012

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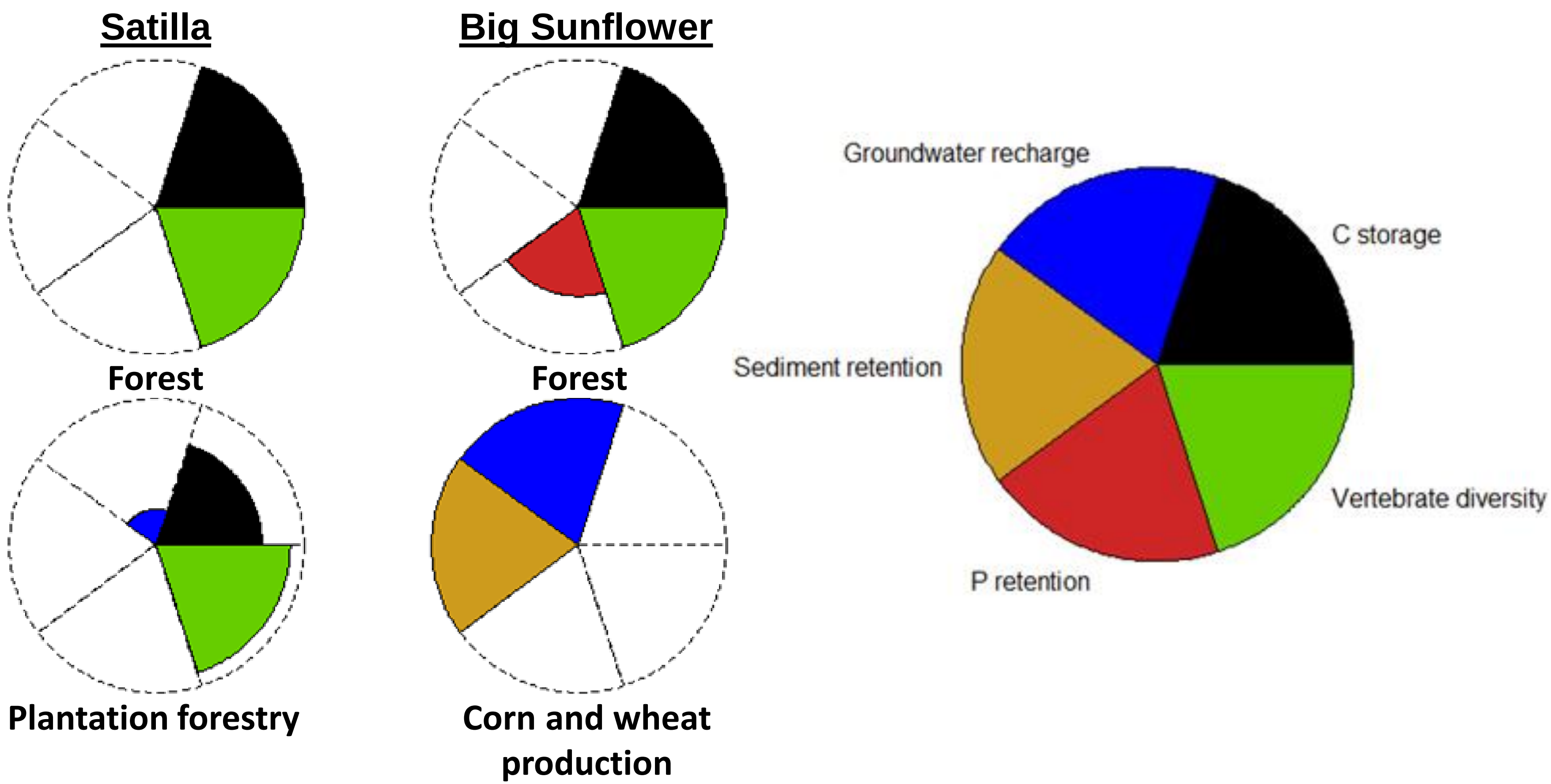
ESS provision and trade-offs



- less tradeoffs of plantation forestry compared to forests (= reference system) than corn and wheat production

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Research question

- *Improvement option B: approaches to make global biomass production regions comparable*

3. *What are the advantages and disadvantages of different techniques to compare environmental impacts under environmental heterogeneity?*

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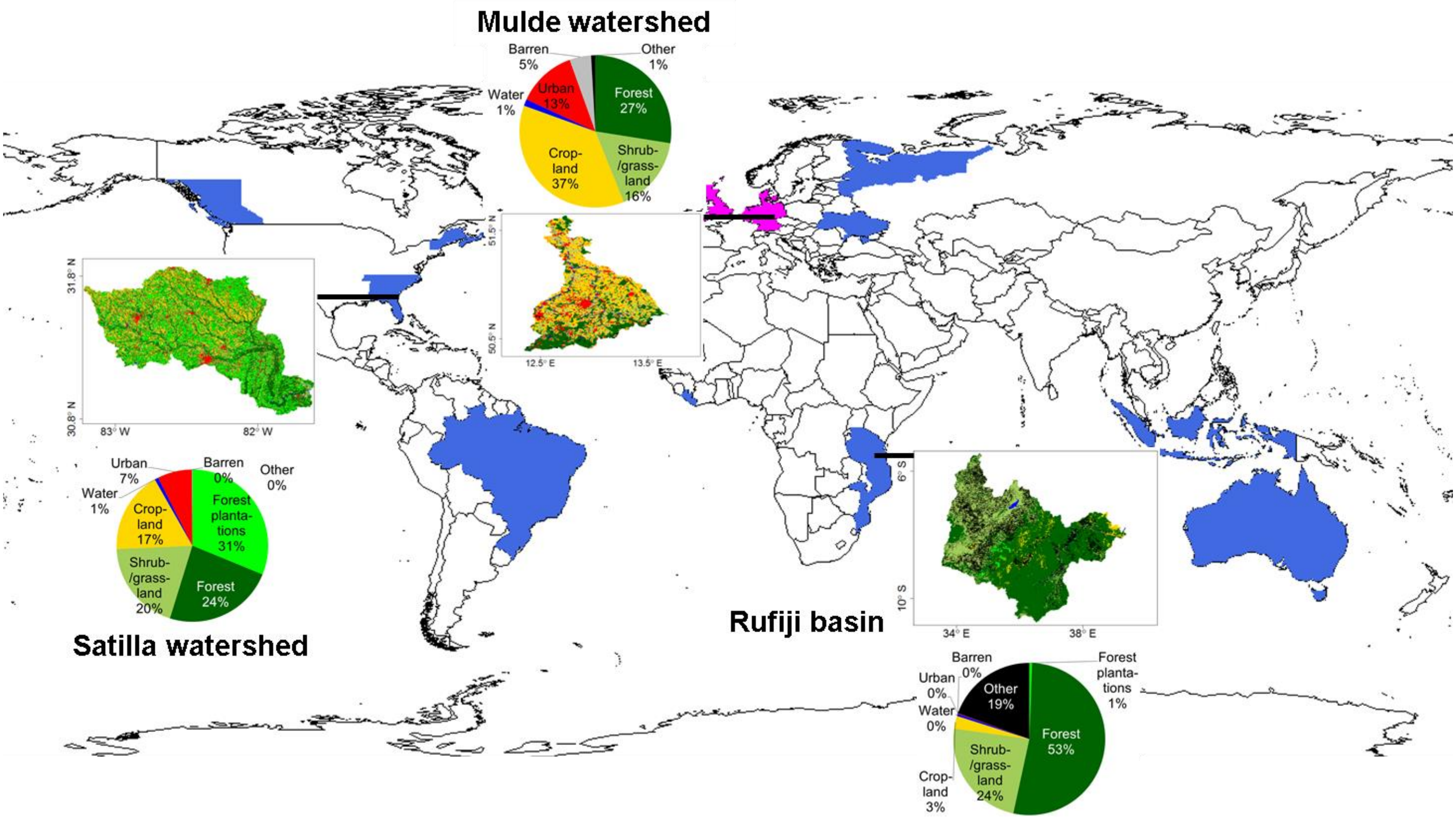
Current and future solid biomass supply regions



Source: Partly based on Lamers et al., 2014

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Results and discussion

- Ranking of LU/LC within case studies following the order of naturalness (forestry, plantation, cropland)
- Ranking of ESS between case varies between approaches
- Natural conditions as reference case more reliable, stratification more feasible and environmental thresholds more relevant
- Future studies on the congruence of the approaches for broader empirical basis
- Application especially due to increasing global trade of agricultural and forestry products that need to be compared for sustainable production

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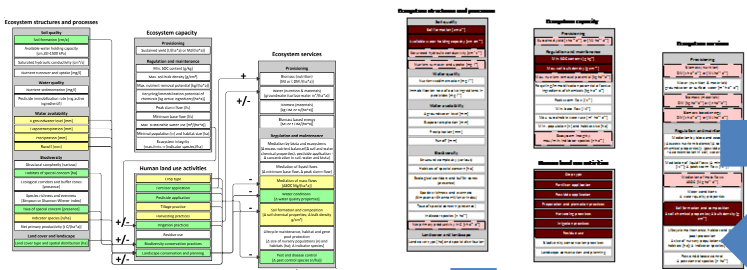
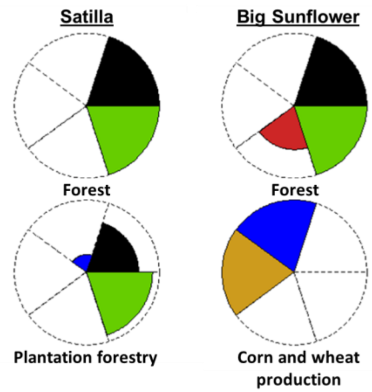
Synthesis of results

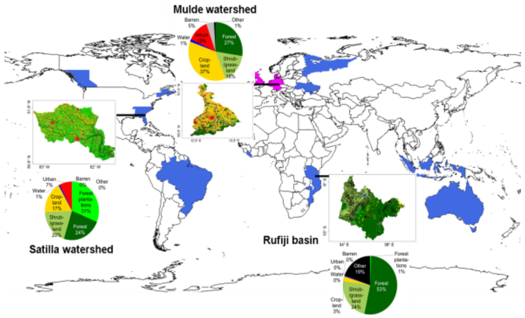
Deficiencies of certification schemes



Regional environmental assessment



Comparing regional ESS under environmental heterogeneity



Further application:

- Environmental assessment for other biomass or agricultural production systems
- Ecosystem service assessments

Is the current EU approach of certification schemes to demonstrate compliance and partly precise legislation suitable?

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References

Meyer, M.A., Priess, J.A., (2014): Indicators of bioenergy-related certification schemes - An analysis of the quality and comprehensiveness for assessing local/regional environmental impacts. Biomass & Bioenergy 65 , 169 – 151

Meyer, M.A., Chand, T., Priess, J.A., (2015): Comparing bioenergy production sites in the southeastern US regarding ecosystem service supply and demand
PLOS One 10 (3), e0116336

Meyer, M.A., Seppelt, R., Witing, F., Priess, J.A., (2015): How can we compare environmental and ecosystem service assessments for biomass production systems in different parts of the world? *Global Environmental Change* submitted

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement n° 282826

Thank you very much for your attention

contacts for Task 9.4 (environmental assessment)

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Jörg Priess, UFZ, joerg.priess@ufz.de

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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Session IV: Value chains, sustainability, standardisation
Part 3: Standardisation

Final Project Meeting, 06.05.2015 in Leipzig

Eija Alakangas, VTT
Hans Hartmann, TFZ
Christoph Göbl, ofi
Ute Wolfesberger-Schwabl, ofi






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Content

- Product standard for thermally treated biomass fuels - EN ISO 17225-8
  Eija Alakangas, VTT

- Round robin test results
  Christoph Göbl and Ute Wolfesberger-Schwabl, OFI

- Particle size analysis by image analysis and flowability
  Hans Hartmann, TFZ

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Fuel specification and classes - EN ISO 17225-1 to 8

Part	Standard title	Stage of development
EN ISO 17225-1	**General requirements** *Thermally treated biomass fuels in also taken into account*	Published, has superseded EN 14961-1
EN ISO 17225-2	Graded wood pellets	Published, has superseded EN 14961-2
EN ISO 17225-3	Graded wood briquettes	Published, has superseded EN 14961-3
EN ISO 17225-4	Graded wood chips	Published, has superseded EN 14961-4
EN ISO 17225-5	Graded firewood	Published, has superseded EN 14961-5
EN ISO 17225-6	Graded non-woody pellets	Published, has superseded EN 14961-6
EN ISO 17225-7	Graded non-woody briquettes	published
EN ISO 17225-8	Graded thermally treated densified biomass fuels	Under preparation, CD version available

SECTOR project (task 8.3) is supporting drafting EN ISO 17225-8.

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EN ISO 17225-1:2014 - Thermally treated biomass included

- Tables for pellets and briquettes include ”extra” property classes for thermally treated biomass
  - Moisture content for pellets, M05 and M08 added
  - Bulk density property for pellets up to 800 kg/m^3
  - Fixed carbon and volatile matter requested
- Table for charcoals added
- Table for undensified thermally treated biomass added
  - Moisture content, M (M03 to M10)
  - Ash, same as for pellets
  - Bulk density, BD200, BD250, BD300
  - Net calorific value, Q (MJ/kg)
  - Fixed carbon, C20, C25, C30, C35, C40
  - Volatile matter, VM, value to be stated

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EN ISO 17225-1:2014 - Thermally treated biomass

- Example of product declaration based on EN 15234-1

Thermally treated pellets – EN ISO 17225-1:2014			
Normative	Property	Unit	Value
	Origin and source		1.2.1 Chemically untreated by-products and residues from wood processing industry
	Traded form		Pellets, torrefied
	Dimensions (D)	mm	D06
	Moisture, M	w-%	8
	Ash content, A	w-% dry	1
	Mechanical durability, DU	w-%	96.5
	Amount of fines, F	w-%	2
	Additives	w-%	none
	Bulk density, BD	kg/m^3	700
	Net calorific value, Q	MJ/kg as received	20
	Fixed carbon, C	w-% dry	C20
	Volatile matter, VM	w-% dry basis	75.0

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Fuel specification and classes, Part 8 - EN ISO 17225-8

- Thermal treatment includes processes such as
  - torrefaction
  - steam treatment (explosion pulping)
  - hydrothermal carbonization and charing
- SECTOR project is supporting drafting standard and developing testing methods
- Drafting standard is carried out under WG2 of ISO/TC238
- About 100 data collected of 3 technologies
- Problems: some of the properties are based on raw material and some on technology.

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Fuel specification and classes, Part 8 - EN ISO 17225-8

- Standard developed for non-industrial and industrial use
  - TW 1* classes for pellets and briquettes recommended for non-industrial use (feedstock woody biomass)
  - TA** classes mainly for industrial use (non-woody biomass)
- Classes for woody biomass: TW1, TW2, TW3 (for pellets and briquettes)
- Classes for non-woody biomass: TA1, TA2 and TA3 (for pellets and briquettes)
- Note to be added into the scope about importance of safety, health and environmental issues to be added like in EN 15234 standards, but not list of standards.

* TW= thermally treated woody biomass

** TA = thermally treated non-woody biomass (e.g. agrobiomass)

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Fuel specification and classes, Part 8 - EN ISO 17225-8

- Agreed to add also the following properties (if methods available)
  - **Hygroscobicity** (water uptake and wet mechanical durability)
  - **Grindability** (grinder energy consumption to be measured)
  - SECTOR has develop testing methods for this, WG2 members of ISO/TC 238 also participated in round-robin tests.
- For briquette also particle density in TW1
- For TW 1 maximum 10% additives accepted, others no limitations
- Ash melting behaviour as an informative:
  - Need for ISO method, WG 5 is proposed work item of this.
  - Can coal method ISO 540:2008 used?

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EN ISO 17225-8 - proposal from WG2 secretariat
(technology based properties to be selected separately)

Property	Classification			
Net calorific value as received, Q (MJ/kg) ISO 18125				
Q18 ≥ 18 MJ/kg	Q19 ≥ 19 MJ/kg	Q20 ≥ 20 MJ/kg	Q21 ≥ 21 MJ/kg	Q22 ≥ 22 MJ/kg
Mechanical durability, DU (w-%), ISO 17831-1				
DU 96,0 ≥ 96,0%	DU 96,5 ≥ 96,5%	DU 97,0 ≥ 97,0%	DU 97,5 ≥ 97,5%	DU 98,0 ≥ 98,0%
Bulk density, BD (kg/m^3 as received) ISO 17828				
BD 650 ≥ 650 kg/m^3	BD 700 ≥ 700 kg/m^3	BD 750 ≥ 750 kg/m^3	BD 800 ≥ 800 kg/m^3	
Volatile matter, VM (w-% dry) ISO 18123				
VM 60 ≥ 60 w-%	VM 65 ≥ 65 w-%	VM 70 ≥ 70 w-%	VM 75 ≥ 75 w-%	

- To be discussed in WG2 meeting in June 2015

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Next steps for EN ISO 17225-8

- Discussion of secretariat proposal and other comments to CD version in June 2015
- USA and Canada is proposing to publish TS (technical specification)
- Next version will be DIS (Draft international standard)
  ☞ last change to send technical comments.
- DIS version will be sent for voting before end of December 2015.
- DIS version to be sent for FDIS voting in February 2016.
- Publishing in 2016
  - ISO 17225-8 in outside Europe, national decission
  - EN ISO 17225-8 in Europe, all EU-countries will adopt

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Session IV - Round robin tests - standard methods

- Round Robin I (RRI)– Validation of “standard“ test methods
  - 43 Participants (19-41 participants per parameter)
  - 17 Countries
  - 11 Parameters

Parameter	Method/ Standard
Bulk density	acc. EN 15103
Mechanical durability	acc. EN 15210-1
Moisture content	acc. EN 14774-1 or 2
Ash content	acc. EN 14775
Calorific value	acc. EN 14918
Content of chlorine and sulphur	acc. EN 15289
Content of volatile matter	acc. EN 15148
Content of carbon, hydrogen, nitrogen	acc. EN 15104
Content of major elements	acc. EN 15290
Content of minor elements	acc. EN 15297
Ash melting behaviour	acc. CEN/TS 15370

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Results of Round Robin I

- Comparison of results with solid biofuels performance from BIONORM II Round Robin test
(project no. 038644 founded by European Commission)
  - **Ash**, **moisture content**, **chlorine** and **sulfur content**, **CHN** analysis – comparable
  - **Net calorific value** – reproducibility limit is higher than for solid biofuels
  - **Ash melting behavior** – reproducibility of deformation temperature is high; subjective method
  - **Minor elements** – low concentration/close to detection limits (as for solid biofuels)
  - **Mechanical durability** and **bulk density** no comparable validation available

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Round Robin II - new test methods

- Round Robin II – Validation of new test methods
  - 31 Participants (12-29 participants per parameter)
  - 15 Countries
  - 6 Parameters

Test Series		Number of participants registered	Number of participants evaluated
Grinding energy	New method description	12	11
Water absorption	New method description	25	23/21
Carbon content	EN 15104	25	24
Gross calorific value	EN 14918	29	27
Ash melting behavior	CEN/TS 15370	15	10
Diameter and length	ISO/DIS 17829 or EN 16127	26	20/24

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Results of Round Robin II

- **Water absorption** – promising; detailed information in method description required
- **Grindability** – promising; different feeding systems used
- **Gross calorific value** – Reproducibility and Repeatability does not meet EN 14918 requirements
- **Ash melting behavior** – subjective method; repeatability good
- **Carbon content** – Reproducibility high
- **Diameter and length** – no comparable data available

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Comparison results of RR I & RR II

- Carbon Content

Carbon content		torrefied Pellets (SECTOR) RR I	torrefied Pellets (SECTOR) RR II	Olive stones (BIONORM II)1	Woodchips (BIONORM II)1	
General mean = assigned value	m	53.0	51.5	48.1	50.3	w-%
Repeatability limit	r	0.43	0.55	0.78	0.40	w-%
		0.81	1.07	1.63	0.80	%
Reproducibility limit	R	1.93	4.56	1.55	1.54	w-%
		3.64	8.86	3.23	3.07	%
Number of participants	n	32	24	30	30	
Overall number of individual results	l	125	102	145	143	

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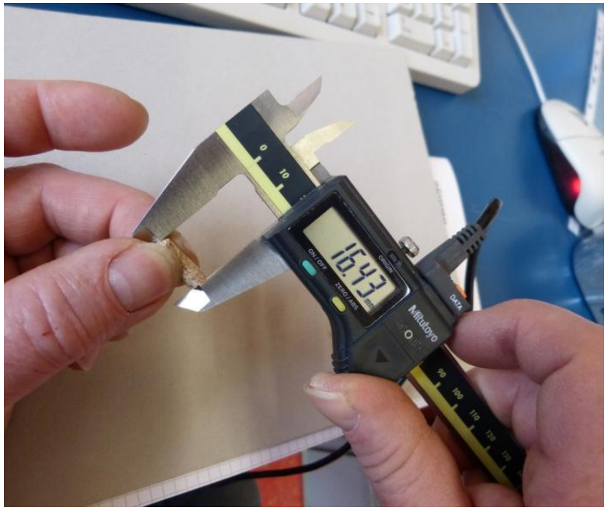
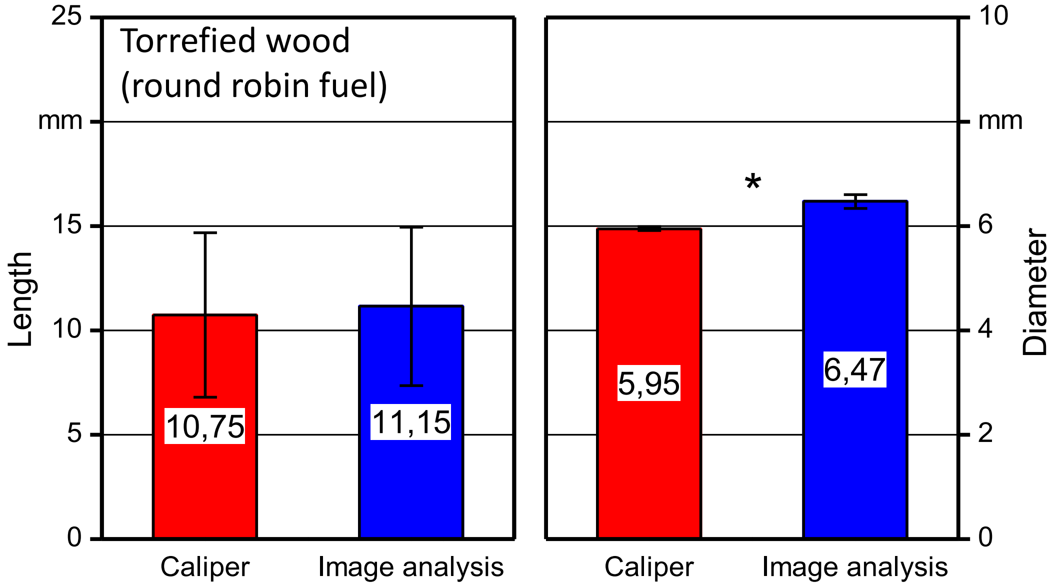
Particle size distribution - main results

Image analysis



Caliper



- Image analysis is a quick and suitable method for determining the share of oversized pellets.
- New evaluation routines are required for determination of mean particle length by image analysis.
- A draft standard was provided to ISO TC238 WG4: "Size classification by image analysis – Calibration of the instrument!

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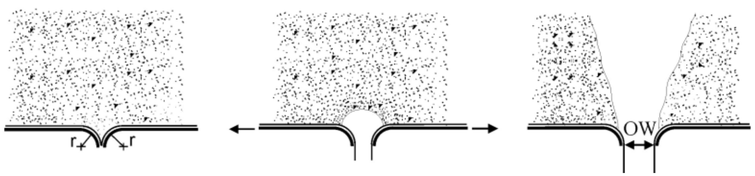
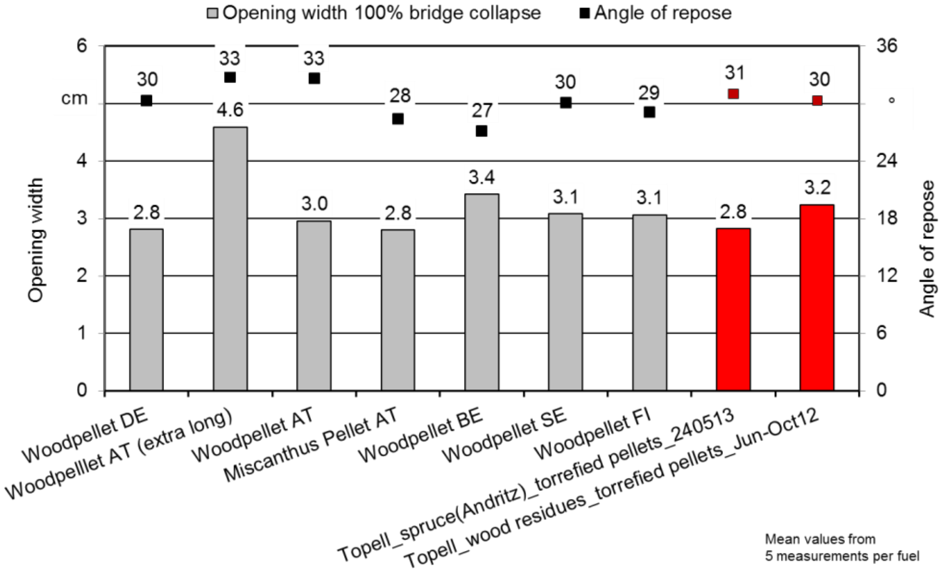
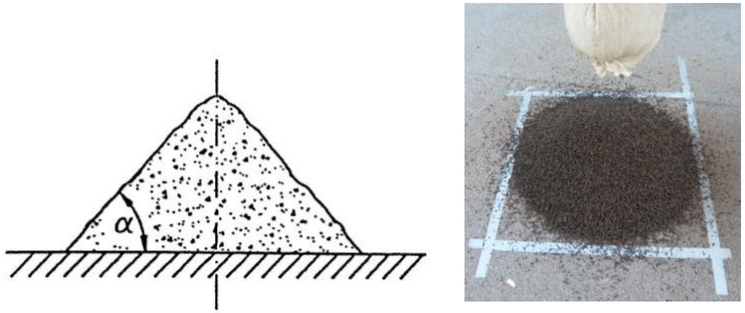
Flowability - main results of bridging tests



Bridging properties: Movable floor with expandable opening (direct measurement)



- Flowability can be described by bridging tests
- Bridging properties of torrefied pellets are comparable to wood pellets
- The angle of repose should be measured by determining the dimensions of a cone on a flat surface.
- 2 draft standards were provided or modified:
  - Method for determining the angle of repose
  - Method for determining bridging properties



Angle of repose

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thank you very much for your attention

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SECTOR

Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

SESSION V – Strategy and perspectives for market implementation

Final Project Meeting, 06.05.2015 in Leipzig

Janet Witt (DBFZ)
Kay Schaubach (DBFZ)
Jaap Koppejan (Procede)






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Drivers for a new Market Strategy

- Torrefaction is an important conversion technology especially for the sustainable substitution of fossil coal
- R&D activities are needed to stimulate future market development
- SECTOR is the leading R&D project globally – thus interest in results from market actors is high
- BUT: Timing has changed in the global biomass business, industrial market implementation might come later than expected and after SECTOR finalization

→New strategy might be needed for market implementation

Source: statement advisory board, Hubert Röder, Brussels, 18.03.2014

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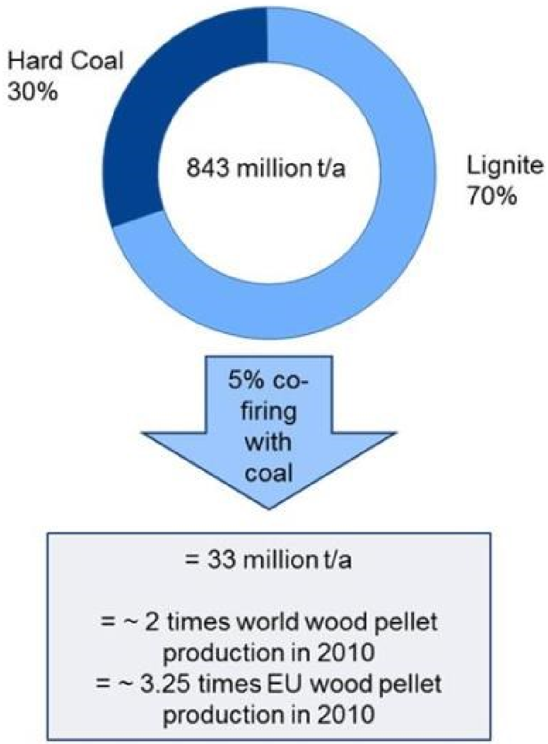
SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Torrefaction is an important conversion technology especially for the sustainable substitution of fossil coal

Wood pellet cofiring potential
(5% with coal) in more than 100 existing pulverised coal-fired plants in Europe



source: Pöyry, pelletforum

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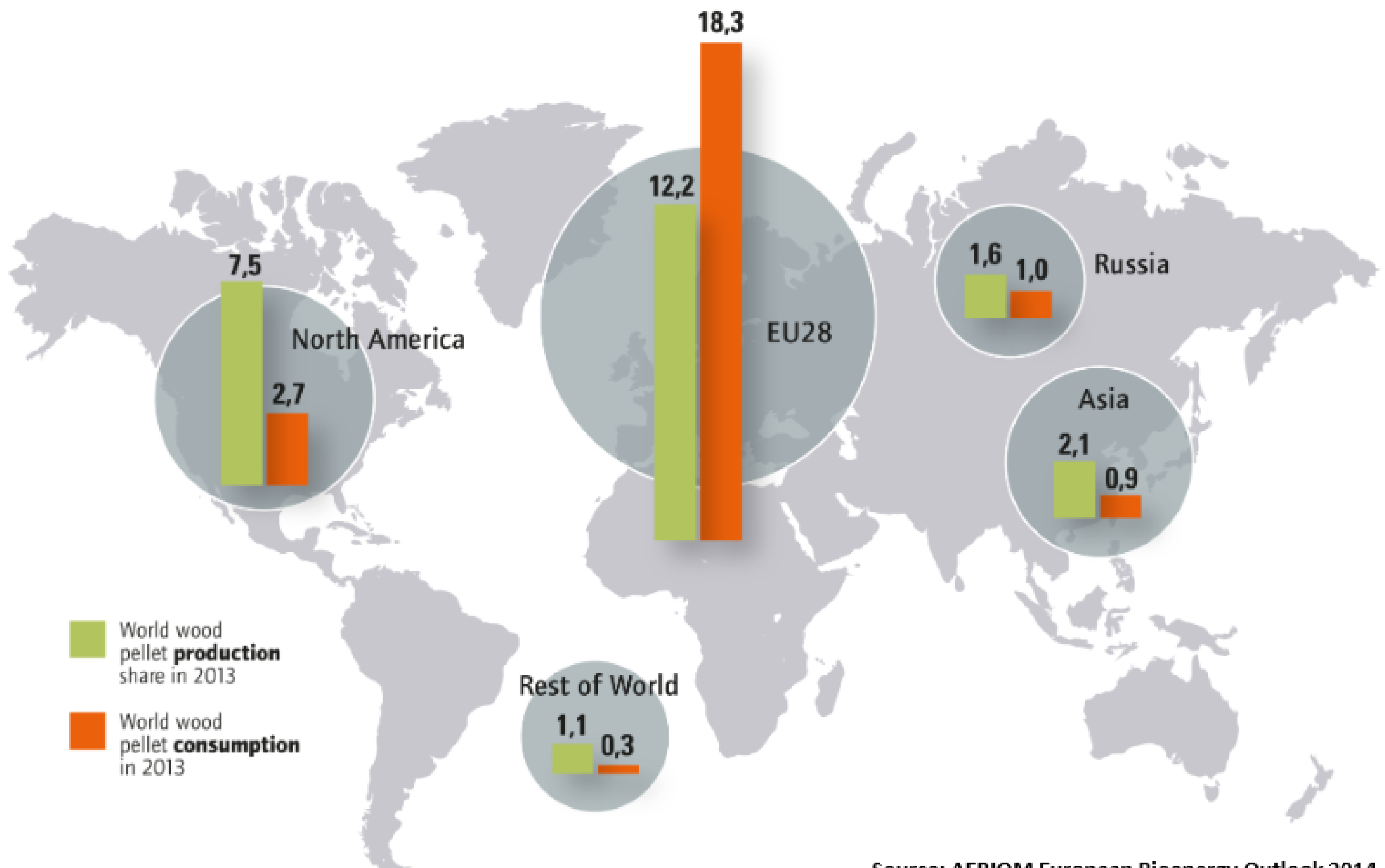
Torrefaction is an important conversion technology especially for the sustainable substitution of fossil coal

World pellet production/consumption in 2013 [in million of tonnes]



Source: AEBIOM European Bioenergy Outlook 2014

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Torrefaction is an important conversion technology especially for the sustainable substitution of fossil coal

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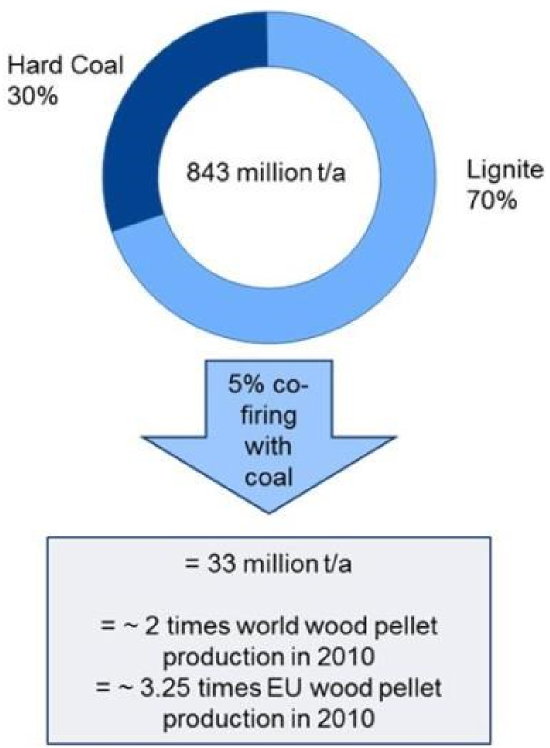

source: Pöyry, pelletforum

- Total coal use was 772 million tons in Europe in 2012.
- Biggest coal users in Europe are Germany, Poland, Ukraine, United Kingdom and Czech Republic.
- By torrefied pellets replacement could be as high as 50%* from the technical point
- Today we know maybe 30% will be most cost efficient

➲ **However, this makes European market hugely significant.**

2013: worldwide wood pellet production about 25 Mio. t
2014: EU production approximately 20 Mio. t wood pellets

*source: *Wilén, C., Jukola, P., Järvinen, T., Sipilä, K. Verhoeff, F. & Kiel, J. 2013.* Wood torrefaction – pilot tests and utilisation prospects, VTT Technology 122, 73 p.

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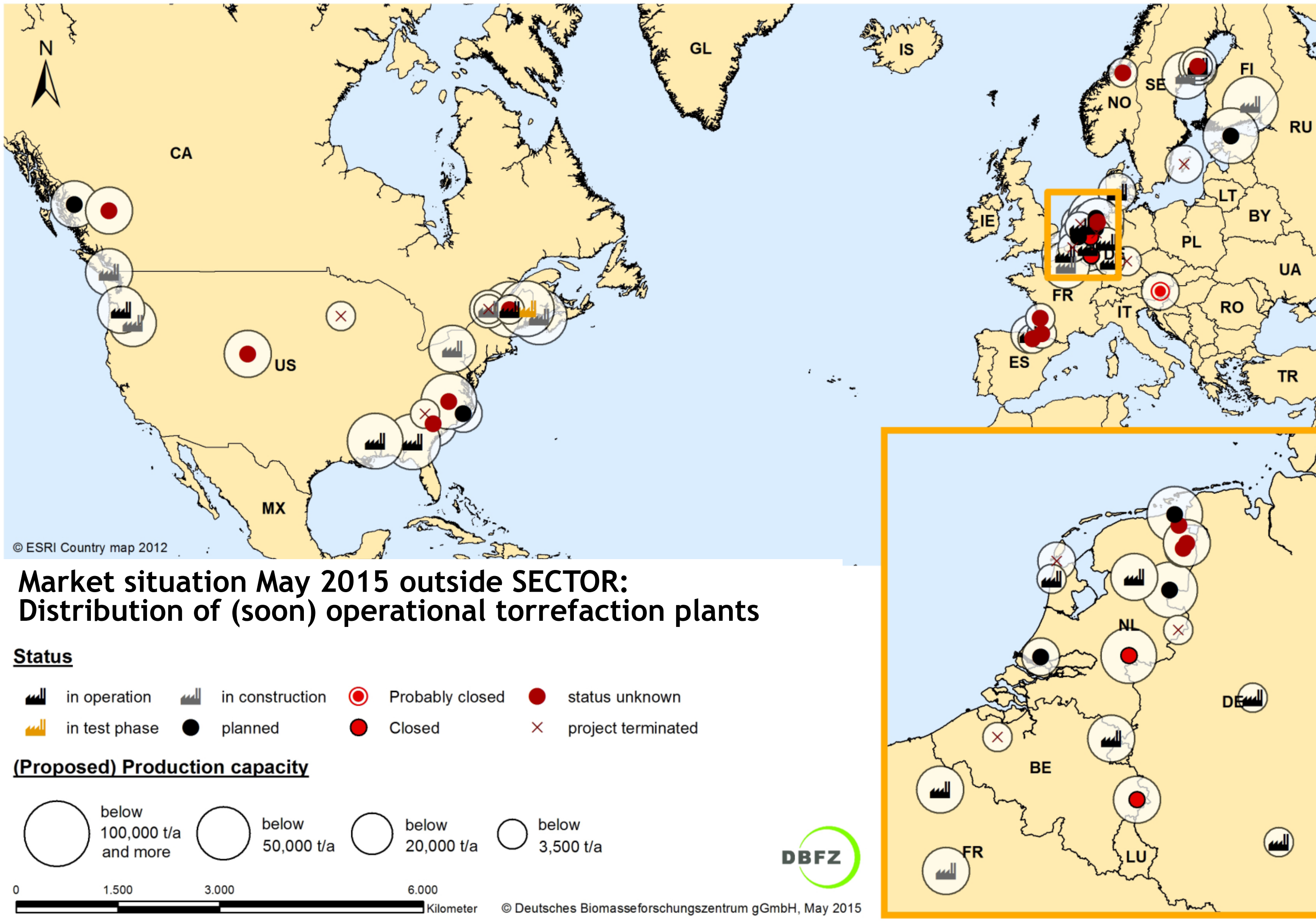
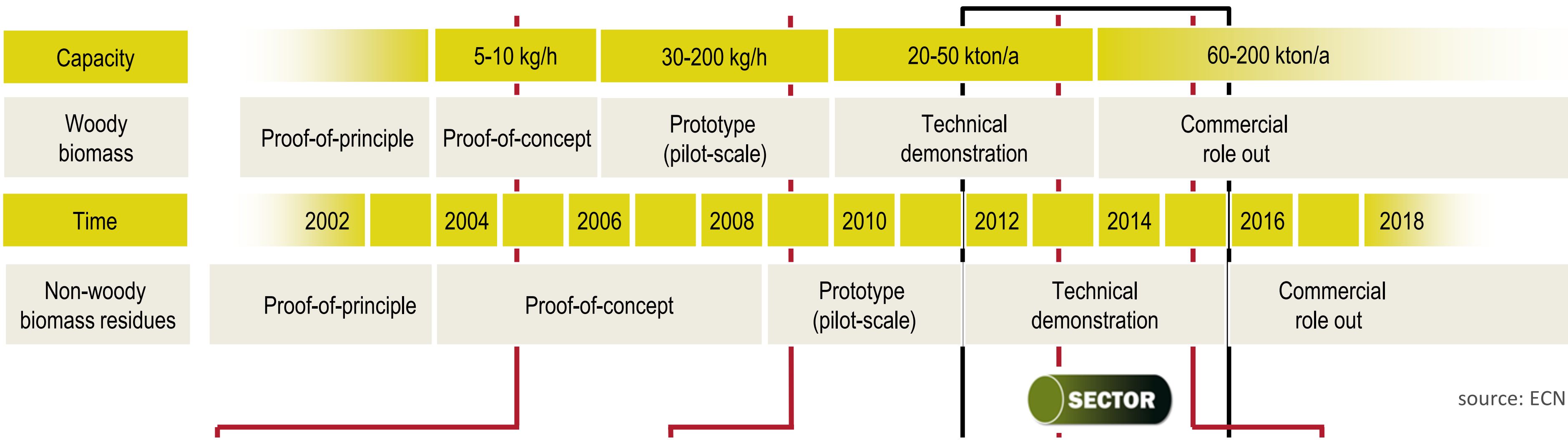
SECTOR is the leading R&D project globally - thus interest in results from market actors is high



R&D activities are needed to stimulate future market development



source: ECN

BUT: Timing has changed in the global biomass business, industrial market implementation might come later than expected and after SECTOR finalization
→ original project focus on large scale applications (power market)
→ NOW: orientation towards alternative markets (e.g. small and medium heating and CHP application, additionally intermediate product for transport fuel market and / or bioeconomy sector

STILL REQUIRED: Investors are needed to build up commercial plants

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Key Questions for the market implementation strategy

- **Political Framework** conditions - Is a revival of incentive schemes or carbon credits to be expected to improve cost competitiveness of sustainable biofuels in the short term?
- Which **new markets** are attractive for torrefied biomass?
- What are concrete **trigger points** for implementation?
- How to ensure **relevance of results** for medium to long term future investments?

Source: statement advisory board, Hubert Röder, Brussels, 18.03.2014

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Political Framework: R&D focus areas - EC goals

- 20-20-20 goals defined for 2020
  - CO_2 emission reduction of 20% compared to 1990
  - Energy efficiency increase of 20%
  - Renewable energy share of 20% in the overall energy consumption
- Targets for 2030 of the EC
  - CO_2 emission reduction of 40% compared to 1990
  - Renewable energy share of 27% in the overall energy consumption
  - 30% improvement in energy efficiency (compared to projections)

https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

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SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

The way ahead: EC policies to achieve the targets

- **A reformed EU emissions trading scheme (ETS)**
- **New indicators for the competitiveness and security of the energy system**, such as price differences with major trading partners, diversification of supply, and interconnection capacity between EU countries
- First ideas on a new governance system based on national plans for competitive, secure, and sustainable energy. These plans will follow a common EU approach. They will ensure **stronger investor certainty, greater transparency, enhanced policy coherence and improved coordination across the EU.**

https://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy

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New market strategy - possible products

- business areas
  - torrefaction technology
    - sublicensing torrefaction technology
    - selling torrefaction technology
  - torrfuel production
    - in biomass surplus regions within/ outside EU with destination EU
    - in regions with difficult biomass to mobilize it
    - production and sale of torrfuels outside EU, e.g. Asia
  - production of chemicals or biomaterials
    - development of bioeconomy products of the torrgas condensate (e.g. biodegradable pesticides, wood protection substances)

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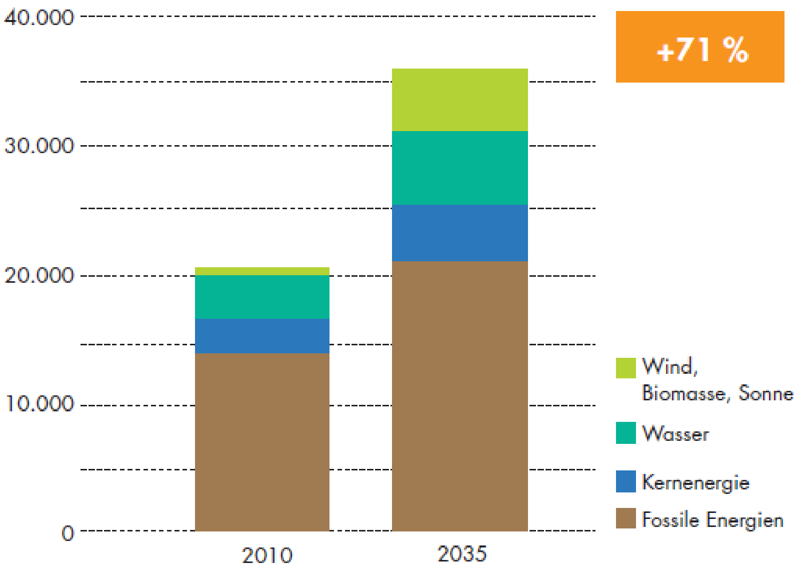
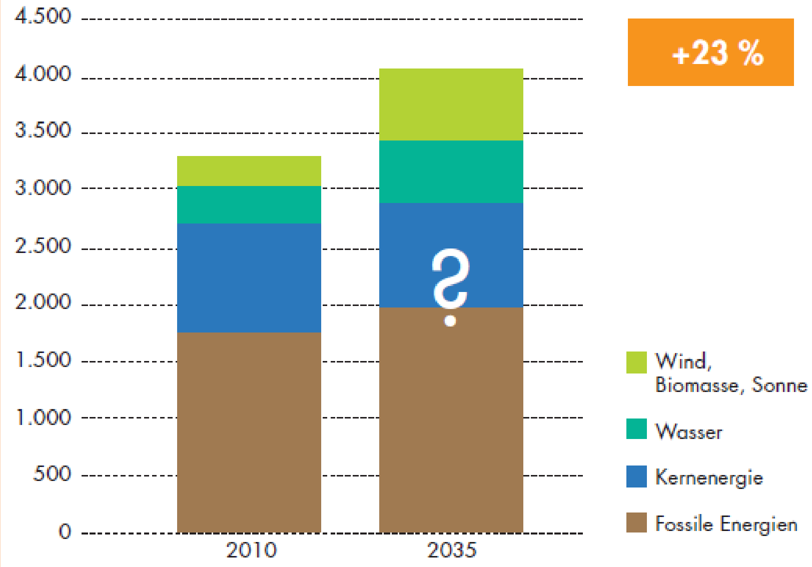
Market Conditions: Renewable Energy Outlook

Perspective of Electricity Production in Mrd. (10^9) kWh

Expected growth of electricity production <u>worldwide</u>



Expected growth of electricity production <u>in the EU</u>



Background:

- World population growth appr. 83 Mio. annually (doubling since 1960). Currently about ¼ of the world population (in total 7,2 Mrd. people) have still no access to electricity.
- The EU produce appr. 16% of the world electricity (3 346 Mrd. kWh); till 2035 a growth of 0,8% annually is estimated.

Source: VGB PowerTech, 2013/14

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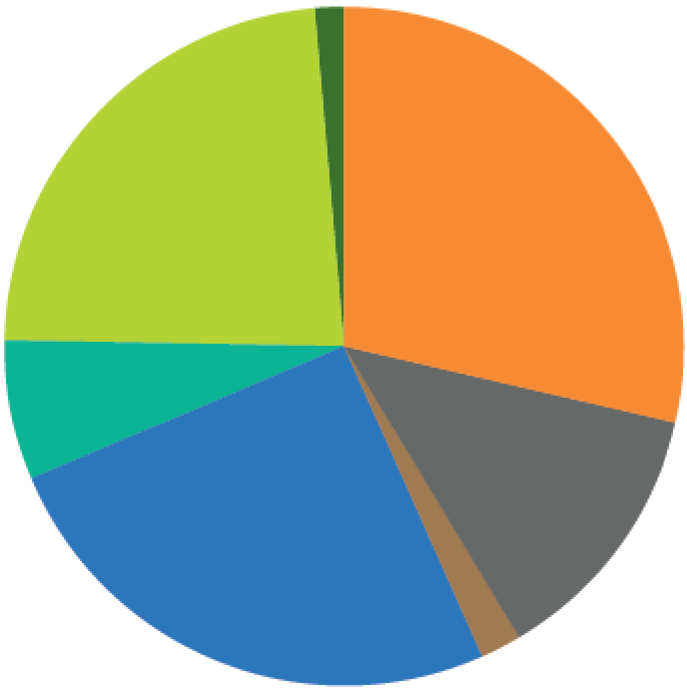
Planned & announced new power plant projects in Europe

Shares of Energy Carriers
(2007 – 2020)



Total: 239 701 MW

- Gas (72 406 MW; 30,21 %)*
- Oil (0 MW; 0 %)*
- Hard Coal (28 685 MW; 11,97 %)*
- Lignite and Peat (4 695 MW; 1,97 %)
- Nuclear (57 200 MW; 23,86 %)
- Hydro (16 559 MW; 6,91 %)
- Wind (57 014 MW; 23,79 %)
- Biomass (955 MW; 0,4 %)
- Residues and Waste (203 MW; 0,08 %)
- Other Renewables (1 983 MW; 0,83 %)

Source: Zahlen und Fakten, VGB PowerTech, 2013/14

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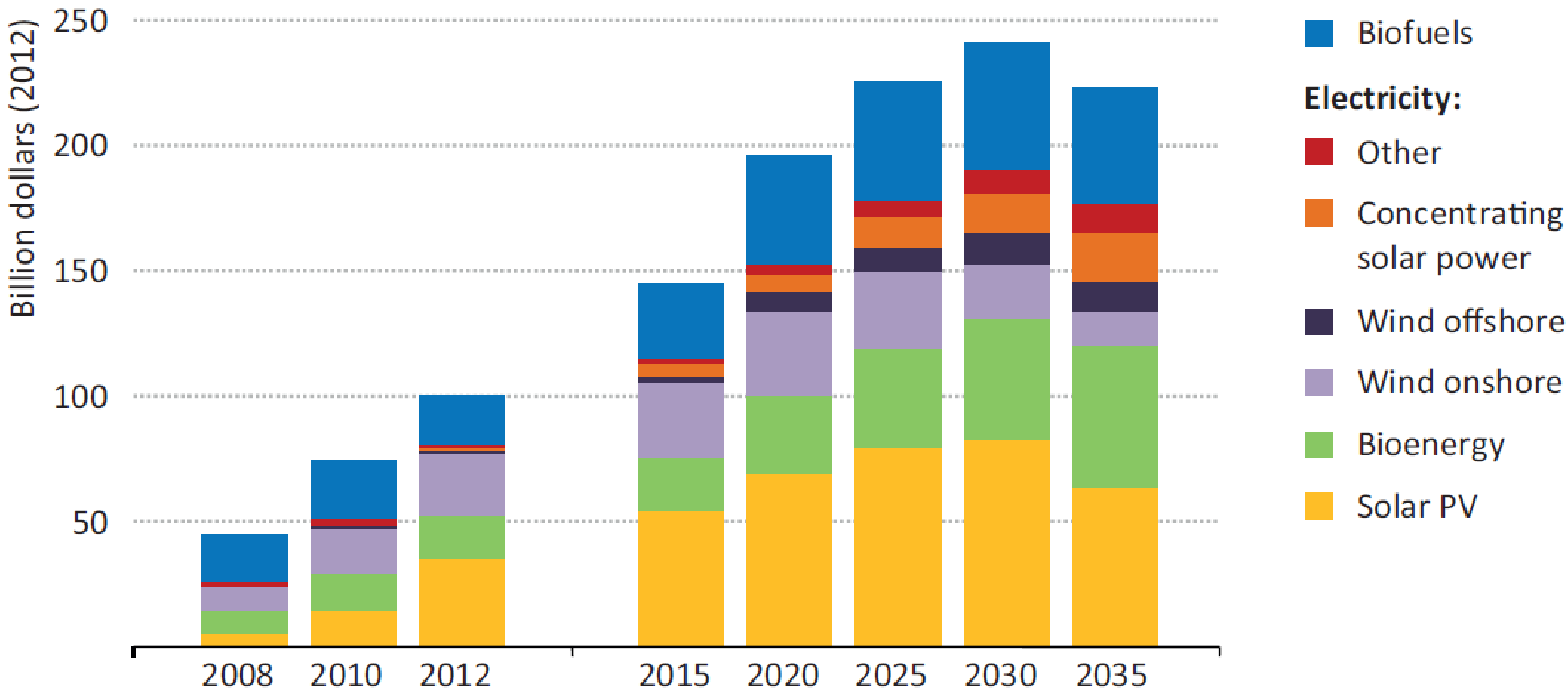
Willingness to invest and install financial support schemes 1/2



It is estimated that the needed investment volume must more that double till 2035 to cover the expected demand.

source: World Energy Outlook, IEA 2013

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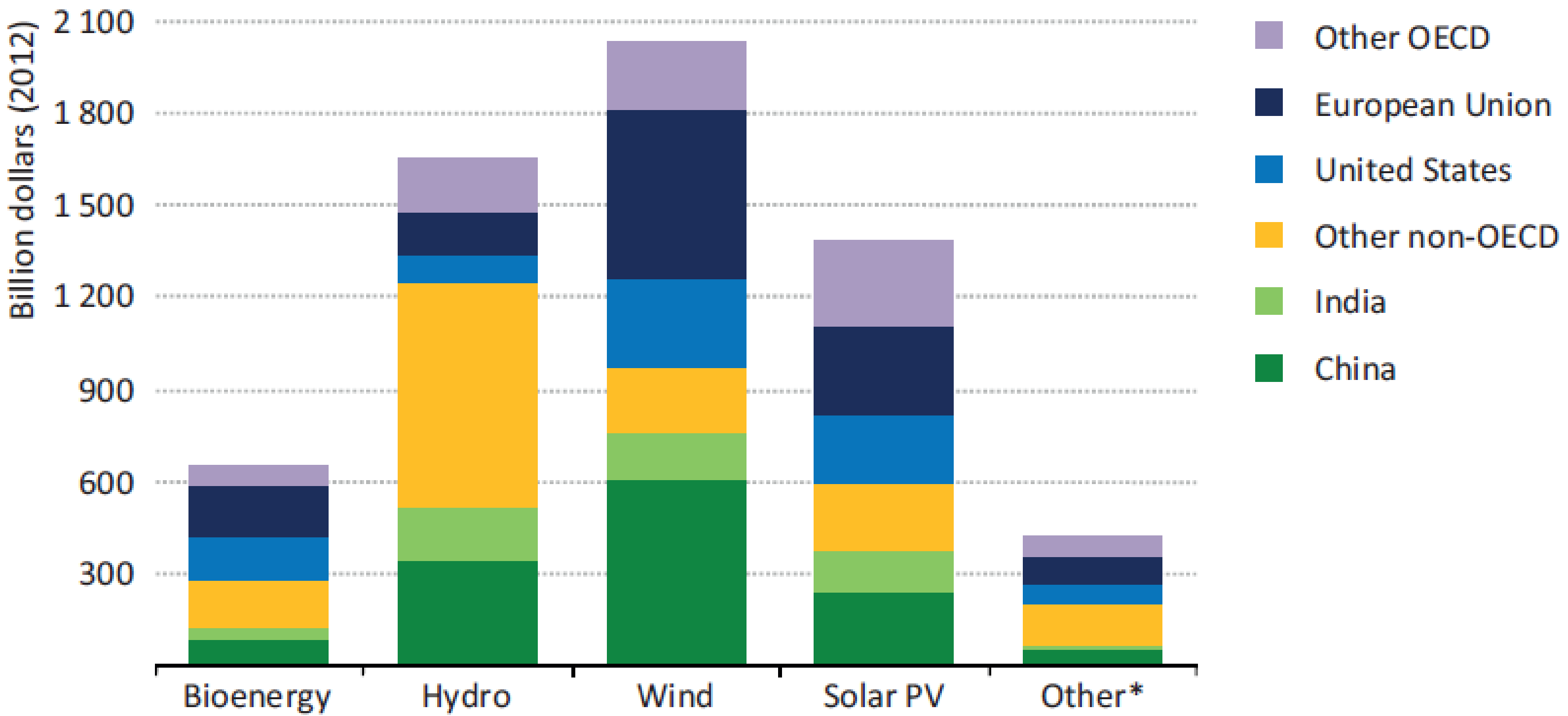
Willingness to invest and install financial support schemes 2/2



* Other includes geothermal, marine and solar CSP.

Increasing renewable energy installations need large investments, financial support schemes and favourable frameworkconditions to be competitive to the fossil energy supply

source: World Energy Outlook, IEA 2013

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Market survey summary: Black & white pellets

- **Supply:**
  - USA Southeast & Northwest Russia: major cost effective suppliers for Europe
  - Canada and Brazil with further biomass potential of wood and bagasse
  - Asia (e.g. India, China): bamboo, palm oil residues

- **Demand:**
  - Asia Pacific: Especially Japan after Fukushima, South Korea
  - South Africa: Plans to substitute coal by 10%
  - US: co-firing schemes emerging

  => white pellets have not been established, chance for torrefied fuels
  - Europe:
    - major market in large scale appliances, depending on policy (switch from coal to biomass, due to low CAPEX), growing demand mostly in UK
    - residential grade pellets (white) strongest markets in Germany, Italy, Austria, growing demand in heating market

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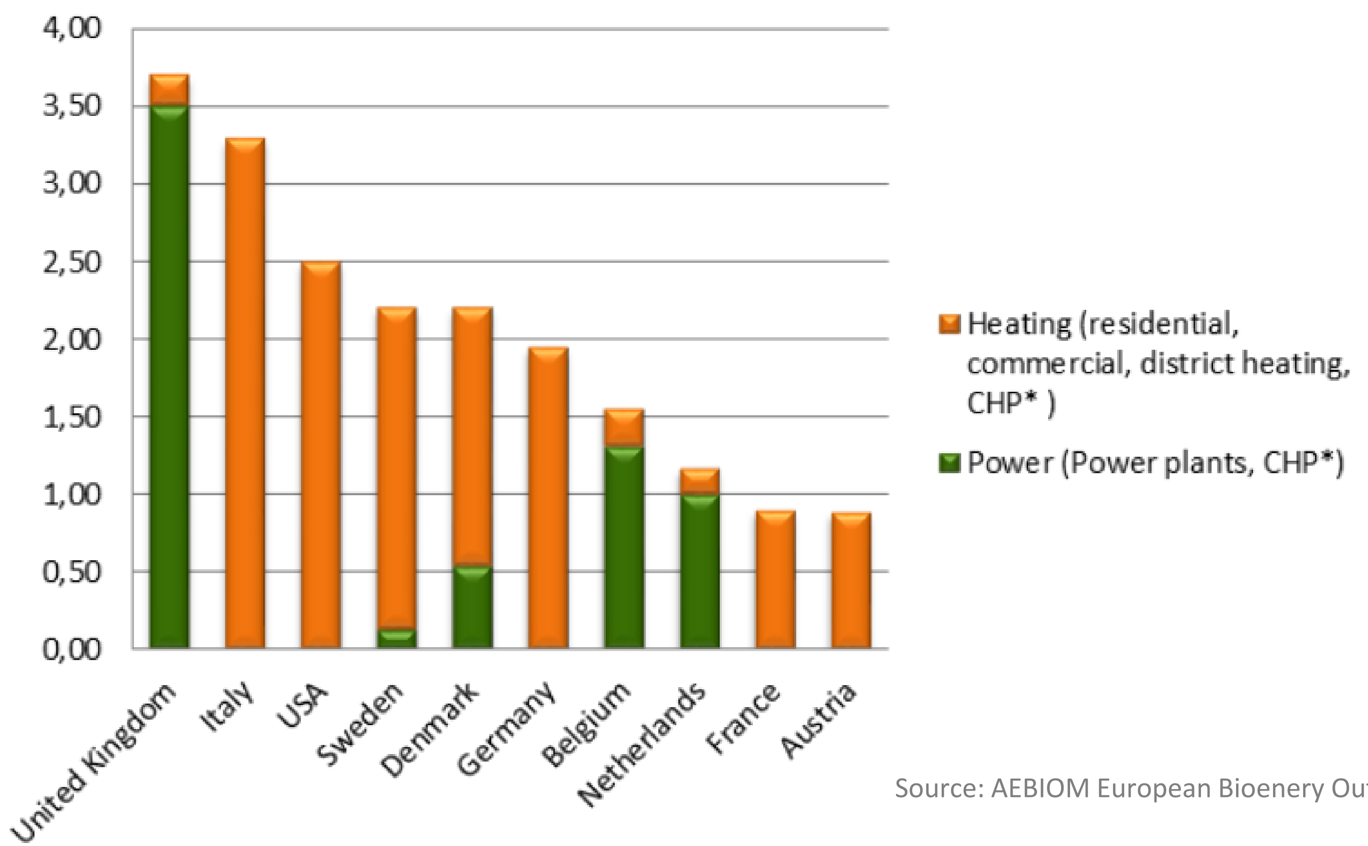
Market survey summary: Black & white pellets

=> competition between white and black pellets?

Top ten wood Pellet consuming countries by end-use in 2013 [in millions of tonnes]



Source: AEBIOM European Bioenery Outlook 2014

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What interest have end users on torrefied material? SECTOR-survey (WP2) in 2012/13:

- **Security of supply:** sufficient and continuous fuel availability in a competitive market ➲ 2012/13 only limited torrefied material could be tested before, **within SECTOR 160 tons of torrefied pellets were produced for further tests**
- **Define fuel properties**: replacement of wood pellets cofiring by use of torrefied material (expected cofiring ratios, higher energy density) ➲ **SECTOR drafted Fuel specificaton to ISO/TC 238, 17225-8, meanwhile new fuel parameter could be defined** (e.g. degree of torrefaction, grindability)
- **Demonstrate full-scale tests** / availability of experiences and test results to convince strategic decision makers to start midterm contract negotiations; expected information of demonstration tests:
  - Densification of torrefied material: energy density of pellets
  - Large scale co-firing and co-gasification tests: heating value, reactivity, handling
  - (co-)milling and outdoor storage tests: grindability, investments in parallel conveying system necassary?, risks of self heating and off-gasing (CO and VOC emissions), durability, water uptake / leachability
  - Overall cost and sustainability analysis along the whole value chain

➲ **SECTOR published Vattenfall-cogasification test results and will perform cofiring test by Helen Limited in autumn**

source: adapted by E. Alakangas, VTT

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Helen Limited - potential user

- What: heat and electricity
- What from: coal
- Where: Helsinki, Parrukatu 1–3
- When: 1974
- How much: electricity 220 MW, heat 420 MW

→Cofiring tests within SECTOR (79 t torrefied material)

Hanasaari power plant B, nominal output 321 MW

Source: www.helen.fi, openstreetmap

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Trigger Points I: Market Barriers

- **Price competitiveness:**
  - Torrefied biomass vs. coal + emission certificates
  - Torrefied biomass vs. conventional biomass + infrastructure
- **Size of torrefied biomass production for cofiring/cogasification**
  - Start up needs to be large scale, however up-scaling poses technical and financial problem
  - Even production of test material for relevant share of cofiring over longer periods is difficult in demo plants
- **Establishment of business relations**
  - Power producers need prove of reliable supply in terms of quality and quantity
  - Producers need long term contract for investing in large scale
- **Still unclear legal regulations**
  - e.g. REACH and sustainability requirements

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Trigger Points II: Technical Challenges

- quality and quantity of input biomass
- process control for varying qualities and different fuels to achieve constant quality of output streams
- integration of densification
- component availability (prototype production, adaptation of equipment from other sectors necessary)
- minimisation of logistical and end-use risks
- determination of standardised fuel properties/qualities (ISO/TC 238)

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Trigger Points III: Biomass potentials and availability

- **Biomass resources are limited** and an **increasing competition** with material use is seen about high quality fractions (especially round wood)
- The energetic **use of large potentials are often very inefficient** (especially in non-developed countries)
- The **cultivation of energetic biomass plants (e.g. SRC) is limited according to the area potential** (→food & fodder cultivation, natural protection etc.) and expensive
- New market actors compete about available amounts (Bioeconomy)
- **However:** Worldwide are still available biomass potentials , especially in the sector of agricultural and forestry residues as well as organic waste
- **But:** Biomass qualities and risks/benefits are often unknown
  - Agro-biomass contains higher amounts of chlorine, potassium and sodium (corrosion, emission and ash problems must be solved) → torrefaction process does influence such incredience rarely)
  - Experiences with untreated agro-biomass showed that cofiring ratio 10 to 20% should be possible
  - fuel prices can become competitive by efficient logistic concepts

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How to ensure relevance of results for medium to long term future investments? - Strategy Development

- **Tackle the price competitiveness**
  - Regulatory framework: support schemes, quotas and/or effective emission trade
  - Reduction of cost through industry integration, further development, large scale implementation /upscaling technology
- **Tackle the needed installed capacity problem**
  - Focus on smaller markets, diversified markets (e.g. heat, CHP)
  - Support of small distributed plants with lower capacity
- **Establishment of business relations**
  - Support of one best practice example, buffering risks
- **Tackle the unclear regulation**
  - Acceleration of fuel quality standard / specification and regulation development (e.g. REACH registration or not, sustainability)

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What can be done in SECTOR additionally?

- **Support of Strategy Development**
- **Policy consulting**
  - Knowledge transfer to organisations with direct contact to decision makers like RHC-EP, AEBIOM (input to EU SET-Plan, EIBI) and also large NGO's
  - Policy Workshop in June (16./17.06.2015)
  - Articles in specific journals such as Parliament, International Innovation
- **Technology advancement in the market**: availability, price effects through knowledge sharing
  - Further publications (also peer reviewed to reach science)
  - Support of IBTC
  - Cooperation with IEA task 40 /32
- In general: **initiation of further R&D based projects on trigger points**

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CONCLUSIONS - STRATEGY AND PERSPECTIVES FOR MARKET IMPLEMENTATION

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Conclusions - Strategy and perspectives for market implementation

- Torrefaction **technologies are manifold on the start but only few developers are able to provide a commercial offer for the realisation of a full scale plant.**
- **Barriers to market implementation:**
  - Low price for coal and CO_2-emission allowances vs high biomass price
  - When cofiring / co-gasification, then power plant operators see advantage in use of established / commodity biofuel ➲ white pellets
  - Existing investments of power plant operators in white pellet application (nearly same delivery costs per GJ, outside storage advantage of torrefied fuel covers not additional cost and disadvantage of dirty handling)
  - Project funding of commercial torrefaction plants to supply cofiring plants
- **Prospective markets currently:**
  - Countries in which supporting schemes exists for biomass cofiring or the use of 100% biomass fuels in large scale applications (e.g. UK, NL, BEL)
  - Countries in which the large scale biomass use starts now; thus appropriate infrastructure and plant modification to torrefied material can directly installed (e.g. Asia, South Africa) ➲ lower CAPEX

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SECTOR Production of Solid Sustainable Energy Carriers from Biomass by Means of TORrefaction

Conclusions - Strategy and perspectives for market implementation

- **Attractive markets perspectives:**
  - **Heating /CHP market**, due to the higher willingness ... users → However, when introducing into small ... market a separate delivery structure for ... be established (no direct fuel supply from produ... parallel to the white pellets distribution network) ➲ n... transport and storage facilities for black & white pellets
  - **High value applications**, e.g. bioeconomy sector, 2nd generation biofuels

➲ Delivery of limited high quality material to high end use applications

- **Improving the market frame conditions for the application of torrefied biomass**
  - Attractive and stable EU and national policies ➲ SECTOR/BioBoost Policy WS 16./17.06.2015
  - Transparent and fixed sustainability requirements for solid biomass
  - Handling of REACH requirements ➲ SECTOR contribution, MSDS-development in cooperation with IBTC
  - Adaption of national regulations (e.g. German emission standards to integrate torrefied fuels; boiler type license to apply torrefied fuels)

➲ SECTOR contributes to shorten the time to market implementation

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thank you very much for your attention

SECTOR contacts : Strategy and perspectives for market implementation

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