BIOFLEX!

Clean and flexible use of new difficult biomass fuels in small to medium-scale combustion



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FFG

Swedish Energy Agency

FNR Fachagentur Nachwachsende Rohstoffe e.V.

The National Centre for Research and Development

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Background and intention (I)

- **Small (<500 kW_{th}) to medium-scale (0.5-10 MW_{th}) combustion plants are one cornerstone of the decentralized, sustainable European energy supply**

- **Today, they still show only restricted fuel flexibility**
  - **Small-scale applications:**
    rely on chemically untreated stem wood fuels
    (log wood, wood chips, wood pellets)
  - **Medium-scale applications:**
    rely on high-quality wood fuels as well as
    selected cheaper assortments such as forest residues and waste wood

Background and intention (II)

- **The flexible utilisation of new, "difficult" biomass fuels in such systems is one major challenge for the coming years**
  - **wood from short rotation forestry** (SRF – e.g. poplar and willow)
  - **herbaceous fuels** (e.g. straw)
  - **residues from agriculture and industry** (shells, sludges etc.)
- **Due to their chemical composition, these fuels are challenging in terms of combustion behaviour and emissions**
  - **Elevated ash contents with high levels of e.g. K, Si and P**
    ➔ problems with slagging, deposit formation and fine particulate emissions
  - **Increased S, Cl and N contents**
    ➔ increased gaseous HCl, SO_x and NO_x emissions

Background and intention (III)

- **Small-scale combustion systems:**
  Individually tailored solutions and expensive secondary measures for emission reduction are economically not viable

- **Medium-scale plants:**
  Limited knowledge regarding the problems associated to the utilisation of such challenging biomass fuels so far held back the development of fuel-flexible combustion systems

- **Therefore, the development of cost efficient primary measures for increased fuel flexibility is relevant**

- **Against this background the overall objective of the project was**
  to develop technologies, which facilitate an energetically and economically efficient utilisation of, in terms of combustion properties, challenging biomass fuels in small and medium-scale systems

BIOFLEX! key data and project consortium (I)

BIOFLEX! **Clean and flexible use of new difficult biomass fuels in small to medium-scale combustion**

Duration: **01/2016 – 03/2019**

The project was carried out in the core of the ERA-NET Bioenergy programme "9th Joint Call for Research and Development Proposals of the ERA-NET Bioenergy"

Partners from Sweden

- **RISE – Research Institute of Sweden** (project coordinator)
- **Umeå University (UmU)**
- **Luleå University of Technology (LTU)**
- **Chalmers University of Technology (CTH)**
- **Opcon AB**

BIOFLEX! key data and project consortium (II)

Partners from Austria

BIOS BIOENERGIESYSTEME GmbH

POLYTECHNIK Luft- und Feuerungstechnik GmbH

KWB Kraft und Wärme aus Biomasse GmbH

Partners from Germany

TFZ – Technology and Support Centre of Renewable Raw Materials

AMANDUS KAHL GmbH & Co. KG

Partners from Poland

IEn – Institute of Power Engineering

BTI – Office of Technology and Engineering Jan Gumkowski

Project objectives (I)

- **Improvement of the understanding of ash chemistry with a main focus on ash melting and aerosol formation**
  - **by fundamental research**
  - **accompanied by appropriate experiments**

- **Implementation of ash chemistry and ash transformation into combustion-related modelling**

- **Investigation of the application**
  - **of additives and**
  - **fuel blending**

  in order to improve the combustion quality of challenging feedstocks
  → develop fuel design concepts

Project objectives (II)

- **Further development of combustion technologies for the**
  - **small (<500 kW_{th}) and the**
  - **medium (0.5 – 10 MW_{th}) capacity range**

  towards enhanced fuel flexibility by means of primary measures

- **To perform testing of these measures in appropriately adapted testing plants in cooperation with furnace and boiler manufacturers**

- **Develop guidelines based on the results achieved**
  - **for the design of appropriate fuel-flexible low emission combustion technologies and**
  - **for appropriate fuel design strategies**

Selected results
Biomass fuels investigated

softwood pellets

poplar chips and pellets (poplar from SRF)

wheat straw pellets

grass pellets

sunflower husk pellets

sewage sludge

Selected results - Fuel design concepts (I)

- Fuel design is a general approach of using primary fuel based measures to increase the fuel quality and combustion performance.
- The aim is to induce or promote chemical reactions between the fuels and/or additives to reduce the risk of ash related problems.
- Two possible approaches

  - Fuel blending

  - Fuel additives

Selected results – Fuel design concepts (II)

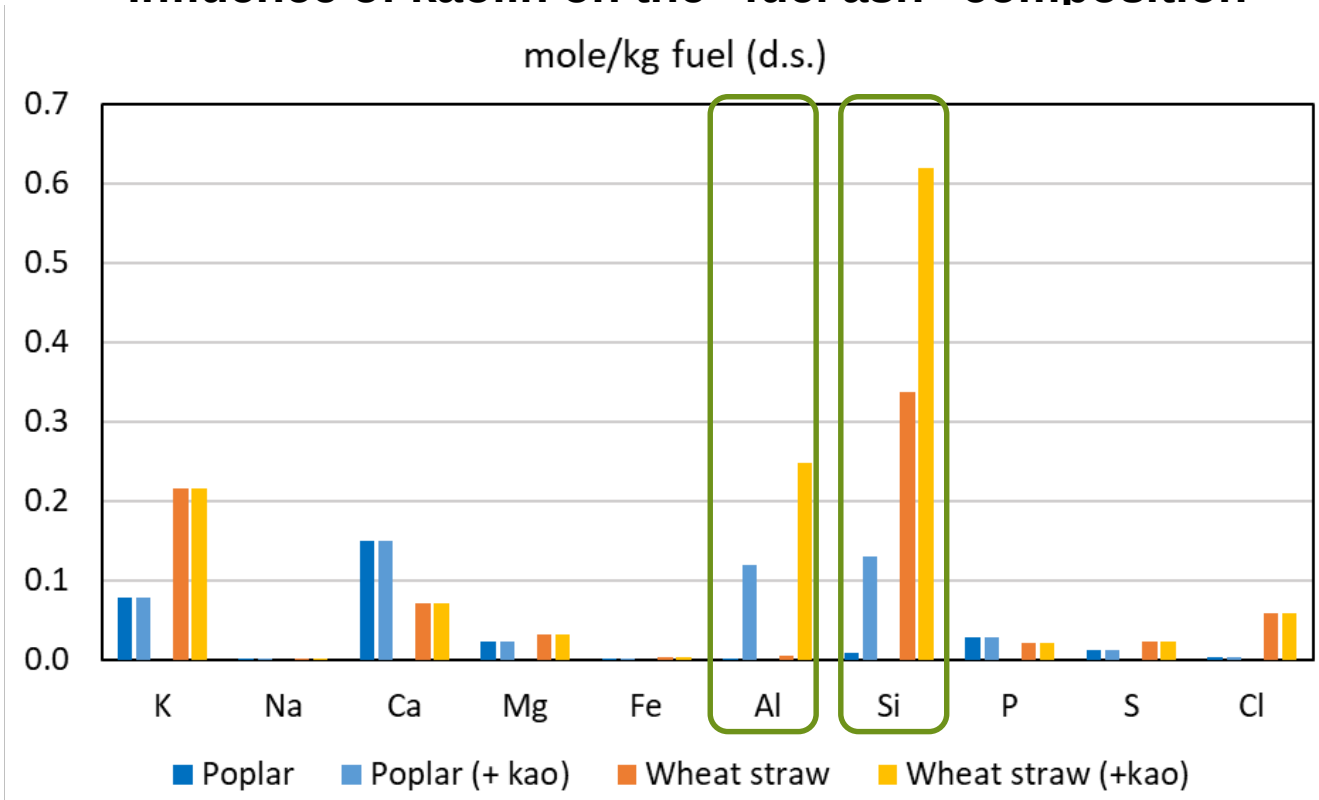
- **Additives can be sorted into some main groups, depending on their chemical composition, namely additives containing**
  - **Calcium**
  - **Phosphorus**
  - **Sulfur**
  - **Aluminum**
  - **Aluminum-Silicates**

The clay **kaolin** has been selected for BIOFLEX!
(main component is the mineral kaolinite [$Al_2Si_2O_5(OH)_4$])

- **Additivation of challenging biomass fuels has been studied**
  - **in combustion experiments in small-scale boilers and**
  - **at single-pellet lab-scale furnaces**

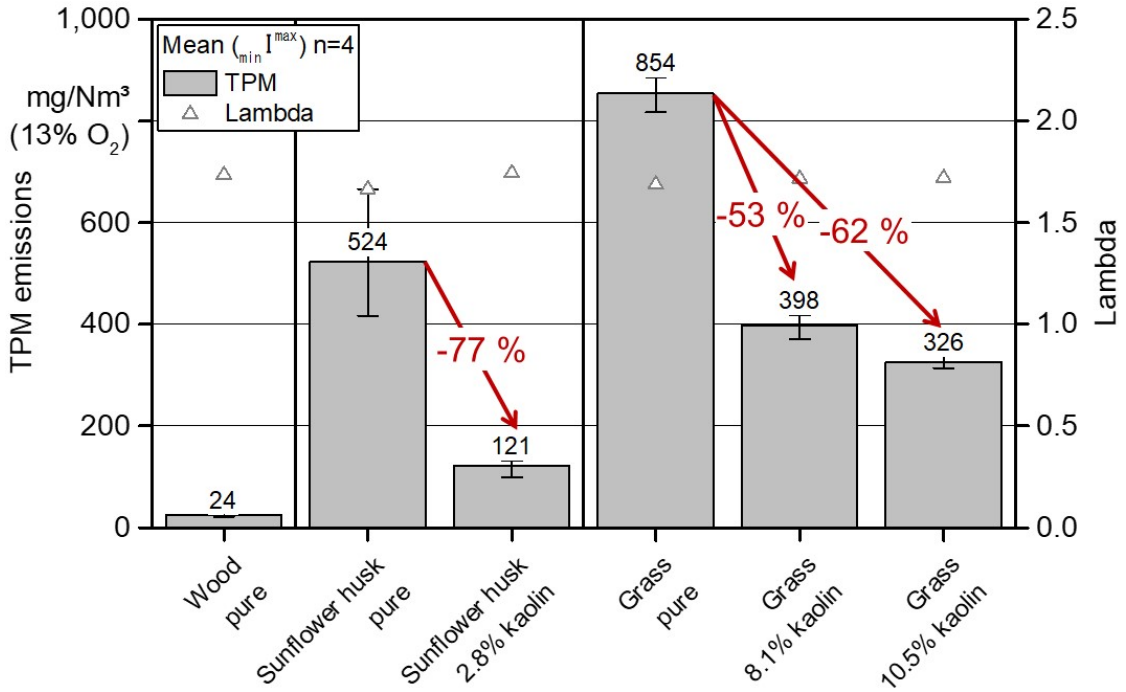
Selected results – Fuel design concepts (III)

Influence of kaolin on the "fuel ash" composition



- Kaolinite has a porous structure
- Kaolinite is very capable of incorporating (react with) alkali vapours in biomass ashes by forming high-temperature stable K/Al-silicates
- It thereby reduces slagging problems and particulate matter emissions

Selected results –
Combustion trials with sunflower husk and grass pellets

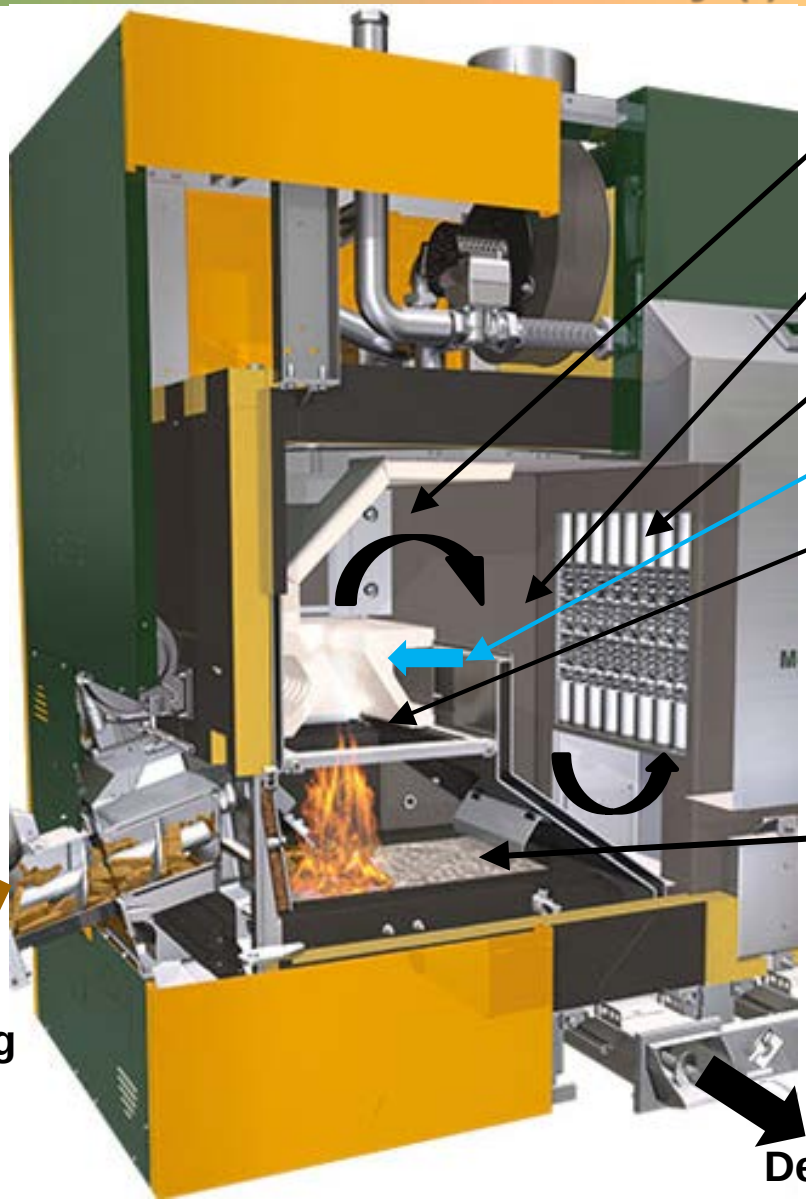


TPM … total particulate matter

- **For all BIOFLEX!-fuels, kaolin addition reduced PM emissions and slagging problems**
- **Further effects**
  - Decrease of CO and OGC emissions
  - Slight increase of NO_x emissions
  - Increase of HCl and SO_x emissions

Selected results – CFD-based adaptation of the KWB Multifire boiler towards increased fuel flexibility (I)

SCZ ... secondary combustion zone



Insulated first section of the SCZ

Radiative boiler section as second part of the SCZ (=post combustion chamber)

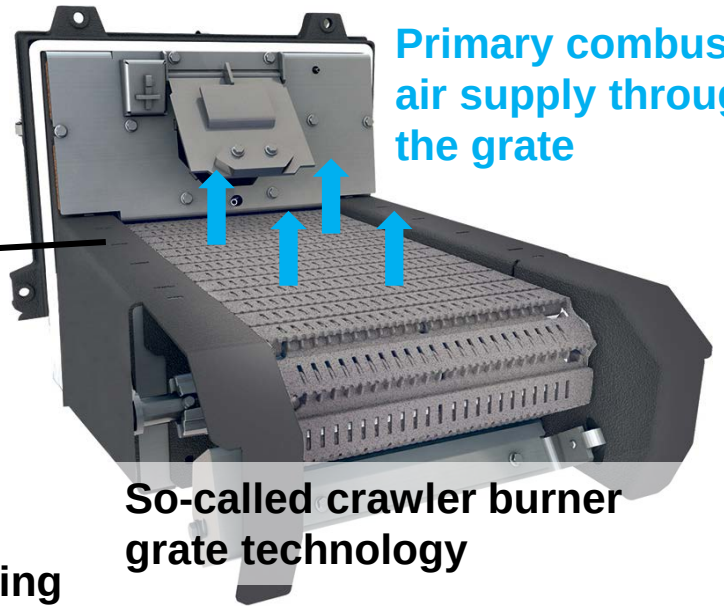
Convective heat exchanger section

Secondary combustion air

Insulated primary combustion zone

Fuel feeding

De-ashing



Primary combustion air supply through the grate

So-called crawler burner grate technology

Selected results – CFD-based adaptation of the KWB Multifire boiler towards increased fuel flexibility (II)

- **Based on CFD simulations the following adaptations have been proposed:**

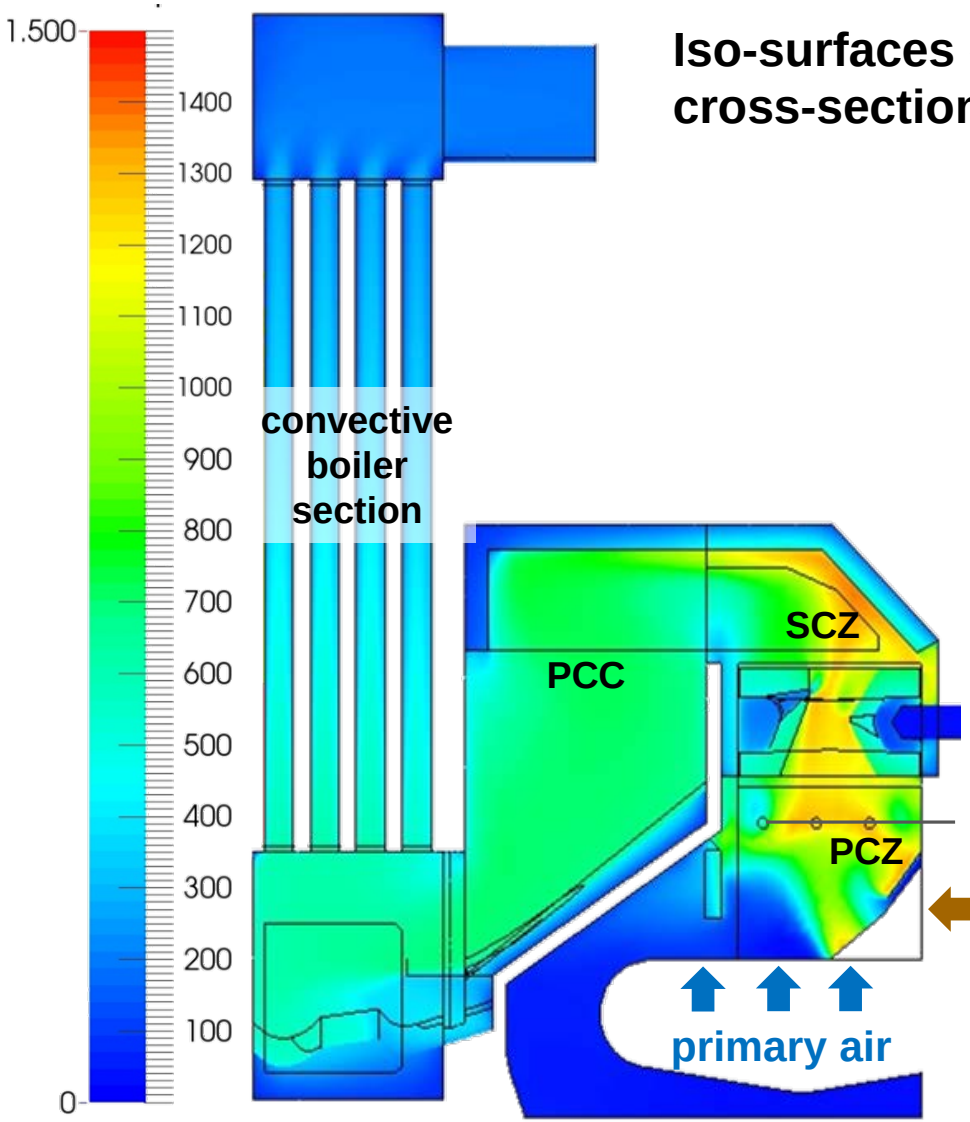
  - **Modification of the air staging concept** towards lower primary air ratios (target value for the air ratio below the grate: about 0.5)
    → reduction of the fuel bed temperatures (avoid ash melting and slagging)
    → reduce ash entrainment with the flue gas

  - **Implementation of flue gas recirculation** above the fuel bed
    → achieve a better mixing of the flue gases and a controlled temperature in the primary combustion zone

  - Adaptations regarding the **secondary air injection** and the **insulation of the secondary combustion chamber**
    → improve the gas phase burnout (minimisation of CO, OGC, organic PM and soot emissions)

  - Modification of the **process control system**
    → implement and maintain the air and flue gas recirculation ratios defined based on the CFD simulations at continuous operation conditions

Selected results – CFD-based adaptation of the KWB Multifire boiler towards increased fuel flexibility (III)

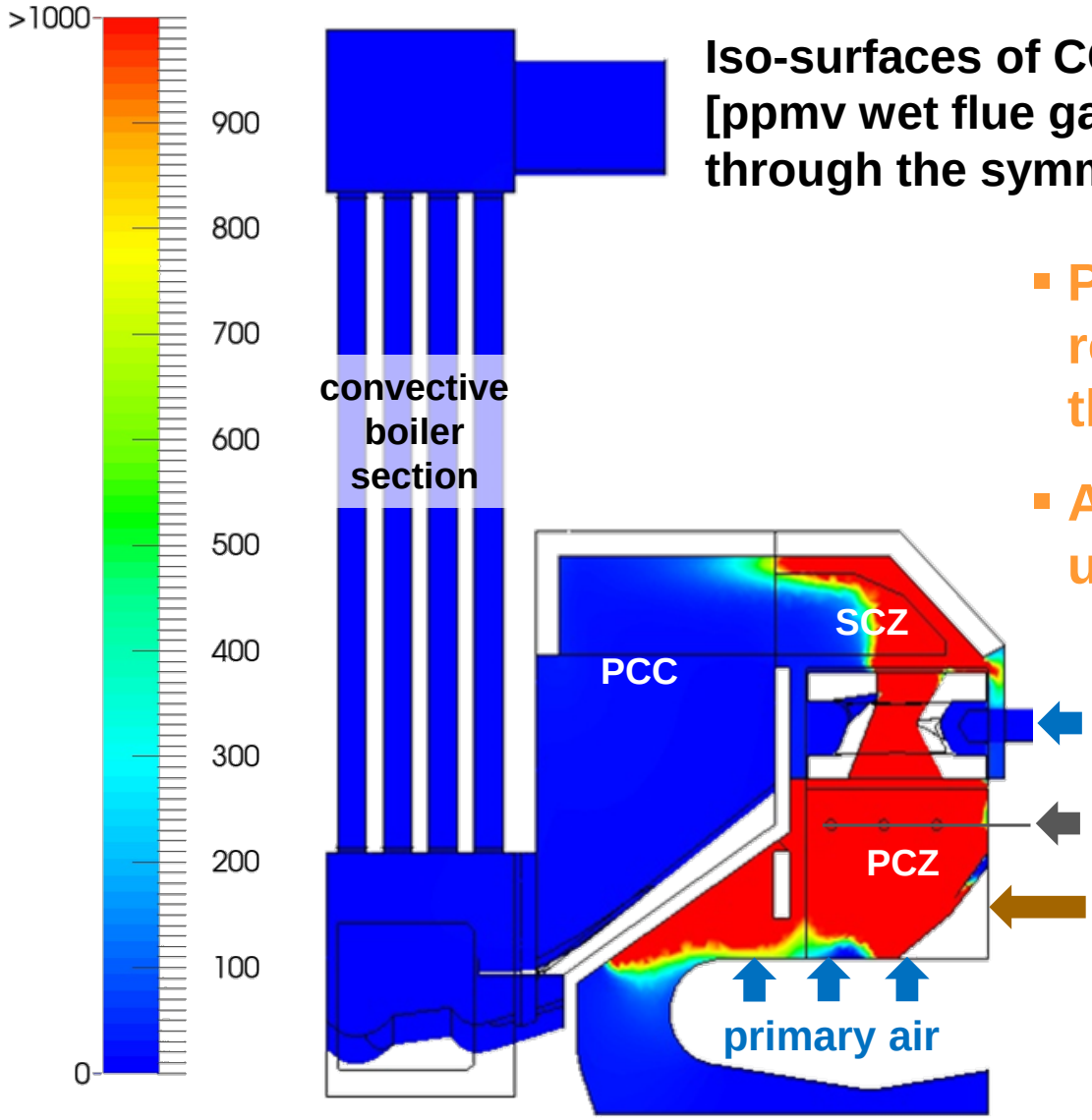


Iso-surfaces of flue gas temperature [°C] in a cross-section through the symmetry plane

- **Moderate temperatures in the grate near zone**
- **High temperatures in the secondary combustion zone**

PCZ ... primary combustion zone
SCZ ... secondary combustion zone
PCC ... post combustion chamber

Selected results – CFD-based adaptation of the KWB Multifire boiler towards increased fuel flexibility (IV)



Iso-surfaces of CO concentrations [ppmv wet flue gas] in a cross-section through the symmetry plane

- **Pronounced zone with reducing atmosphere above the fuel bed in the PCZ**
- **Almost complete CO burnout upstream the PCC**

PCZ ... primary combustion zone
SCZ ... secondary combustion zone
PCC ... post combustion chamber

Selected results – CFD-based adaptation of the KWB Multifire boiler – test runs with wheat straw pellets (I)

Grate during test run

Grate after test run

Clean grate after test run

Ash in ash box

- Ash-rich wheat straw pellets form “ash pellets” on the grate
- The ash pellets were easily disintegrated by the de-ashing screw
- No slagging on the grate was observed
- Self-cleaning of the grate worked properly
- No ash deposit formation on the furnace walls

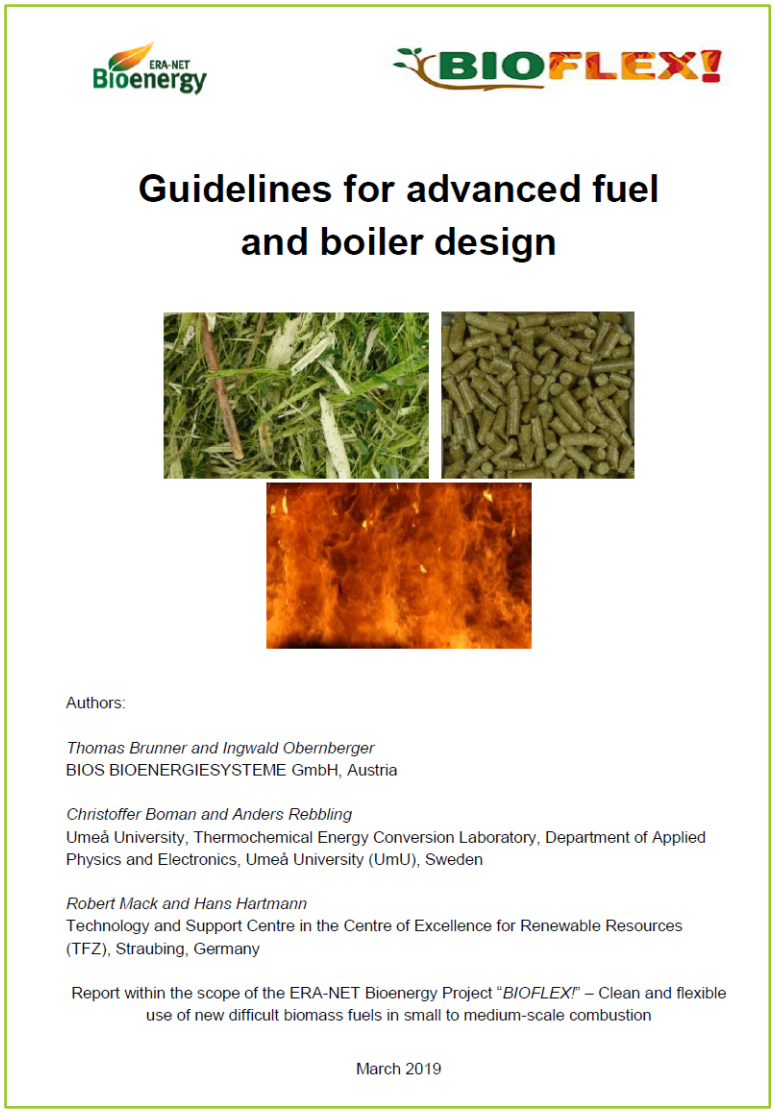
Selected results – CFD-based adaptation of the KWB Multifire boiler – test runs with wheat straw pellets (II)

	from to	Evaluation period 08:24:00 16:24:00 mean	 s	Settings proposed by CFD	Emission limit acc. to 1. BImSchV
Flue gas temperature at boiler outlet	[°C]	176.24	5.02		
Boiler load	[kW]	41.72	1.85		
O_2	[vol% d.b.]	7.80	0.88		
CO_2	[vol% d.b.]	12.97	0.90		
CO (dry FG, 13 vol% O_2)	[mg/Nm³]	**11.18**	4.46		250
NO_x as NO_2 (dry FG, 13 vol% O_2)	[mg/Nm³]	**395.76**	23.01		500
OGC (FID) (dry FG,13% O_2)	[mg/Nm³]	0.01	0.04		
SO_x as SO_2 (dry FG, 13 vol% O_2)	[mg/Nm³]	72.46	2.34		
HCl (dry FG, 13 vol% O_2)	[mg/Nm³]	95.57	4.48		
Fine particulate emissions (PM_1)	[mg/Nm³]	55.88	2.85		
TSP	[mg/Nm³]	**74.33**	2.96		20
Total air ratio	[-]	1.60	0.10	1.60	
Primary air ratio	[-]	0.65	0.05	0.54	
Flue gas recirculation ratio	[-]	0.18	0.01	0.20	
Combustion efficiency related to the NCV of the fuel	[%]	88.60			

w.b. ... wet basis; d.b. ... dry basis; mean ... mean value; s ... standard deviation

- ➔ **Air staging and flue gas recirculation settings proposed based on the results of the CFD simulations could be achieved**
- ➔ **Emission limits (German 1. BImSchV) for CO and NO_x could be kept while for TSP the emission limit was exceeded**

Selected results – Guidelines for advanced furnace/boiler and fuel design (I)



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BIOFLEX!

Guidelines for advanced fuel and boiler design

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Report within the scope of the ERA-NET Bioenergy Project "*BIOFLEX!*" – Clean and flexible use of new difficult biomass fuels in small to medium-scale combustion

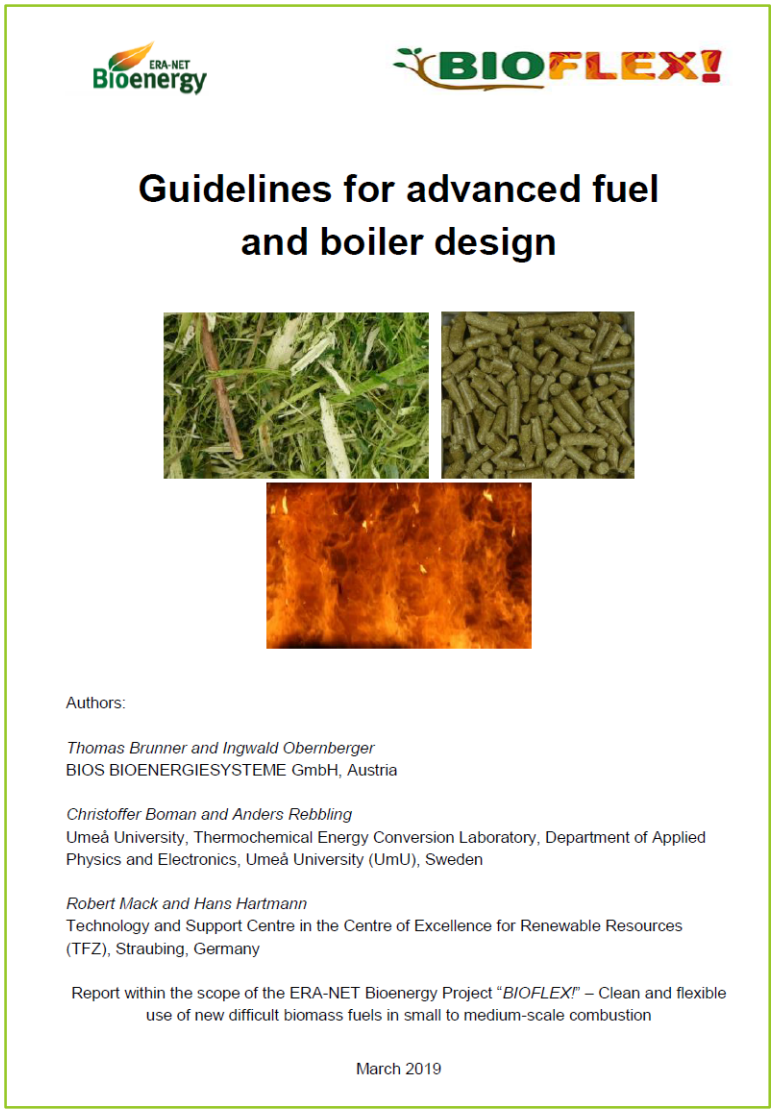
March 2019

Fuel design

- **Basic knowledge about interactions and correlations between fuel properties and their impact on**
  - Emissions (e.g. PM and NO_x)
  - Slag formation
  - Ash chemistry and fuel design related aspects
- **Utilisation of fuel additives based on clay minerals (kaolin) and examples for successful applications**
- **Technological aspects and calculation procedures for kaolin additivation**

Download: https://bioflex-eranet.eu/

Selected results – Guidelines for advanced furnace/boiler and fuel design (II)



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Furnace/boiler design

- **Technical and operational measures to design a furnace, which can cope with challenging fuels**
- **Deeper view on how to generally handle fuels with elevated fuel ash content**
  - grate design
  - avoidance of ash melting (temperature control)
  - advanced air staging and flue gas recirculation concepts
  - layout of de-ashing systems
- **Small-scale boilers and medium-scale systems**
- **Practical examples for plant design**

Conclusions (I)

- The project has increased the fundamental understanding of ash transformation issues in combustion

- The application of additives and fuel blending have been investigated in order to make the new feedstock better applicable in small to medium-scale biomass combustion systems
  - Appropriate new concepts for fuel blending, additive selection as well as fuel/additive mixing ratios have been worked out

- Ash transformation concepts have been implemented in novel combustion-related modelling approaches
  - The ash chemistry has been coupled to the combustion modelling to enable predictions of slagging and alkaline release
  - The model has been validated with results of the combustion tests performed (at lab-scale reactors and small-scale boilers)
  - The concept could serve as a powerful tool for future applications in the prediction of the behaviour of ash components in a fuel bed

Conclusions (II)

- Combustion technologies for small and medium sized grate-fired boilers have been further developed by means of primary measures such as
  - Advanced air staging concepts
  - Improved control systems
  - CFD optimised combustion chamber design

- A prototype burner for pulverized straw and sewage sludge has been developed and evaluated by CFD simulations and combustion experiments.

- Testing and experimental prove of concept of the measures proposed has been conducted in appropriately adapted testing plants in cooperation with furnace and boiler manufacturers.

- Based on accompanying techno-economic analyses it has also been shown that the resulting concepts are economically affordable and commercially competitive in comparison with conventional wood combustion systems as well as with fossil fuel fired systems.

Conclusions (III)

- **Based on the results gained, guidelines for the design of suitable low emission combustion technologies and for appropriate fuel design for new challenging biomass fuels have been worked out and presented.**

- **Downloads on https://bioflex-eranet.eu/**
  - **Guidelines for advanced furnace/boiler and fuel design**
  - **Presentations from our final international project workshop**
    28th of February 2019, side event of the World Sustainable Energy Days 2019, Wels, AT

Thank you for your attention

Project webpage: https://bioflex-eranet.eu/

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