Industrial biomass combustion – reached developments and future outlook

Prof. Dr. Ingwald Obernberger





process & particle engineering

Institute for Process and Particle Engineering
Graz University of Technology

TEL.: +43 (316) 481300; FAX: +43 (316) 4813004
E-MAIL: ingwald.obernberger@tugraz.at
HOMEPAGE: http://IPPE.TUGRAZ.AT

TU Graz

SUSTAINABLE ENERGY BIOMASS ASH ECONOMY

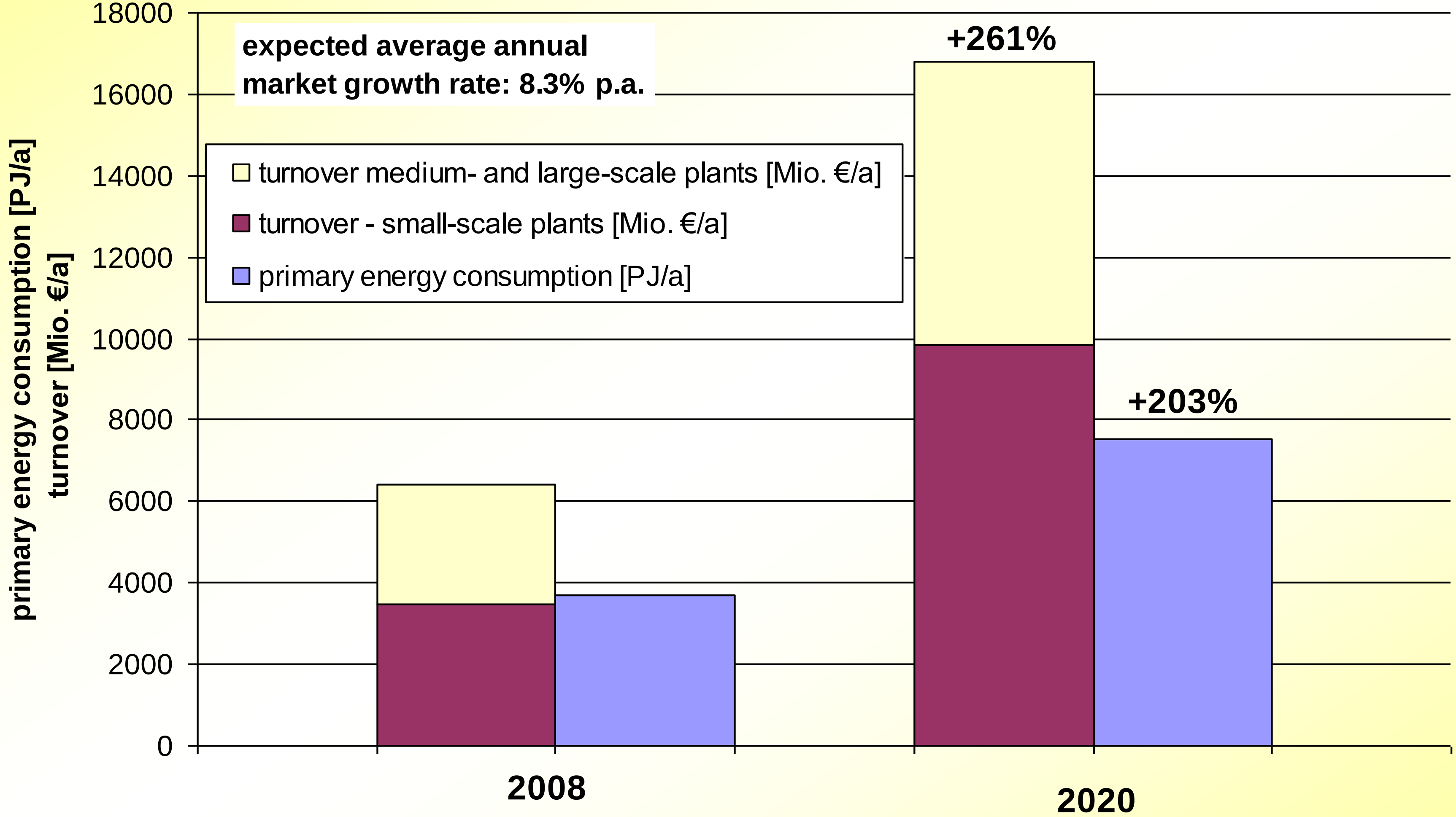
BIOS
BIOENERGIESYSTEME GmbH
Inffeldgasse 21b, A-8010 Graz

Contents

- Thermal biomass utilisation in Europe
- Biomass combustion technologies
- Relevant characteristics of biomass fuels
- Ash formation and ash related problems
  - ash and aerosol formation
  - slagging, deposit formation and corrosion
  - additives to reduce ash related problems
- Gaseous emissions under special consideration of NO_x
- CFD as an efficient tool to design and optimise biomass combustion systems
- Relevant future R&D trends

Institute for Process
and Particle Engineering
Graz University of Technology

Primary energy consumption and total turnover of biomass combustion plants in the EU for 2008 and outlook for 2020



Explanations: small-, medium-, and large-scale plant considered; calculations based on present market and achievement of EU 2020 targets

Biomass combustion technologies – classification by capacity

- **Small-scale biomass combustion systems**
  capacity range: <100 kW_{th}

- **Medium-scale combustion systems**
  capacity range: 100 kW_{th} to 20 MW_{th}

- **Large-scale combustion systems**
  capacity range: >20 MW_{th}

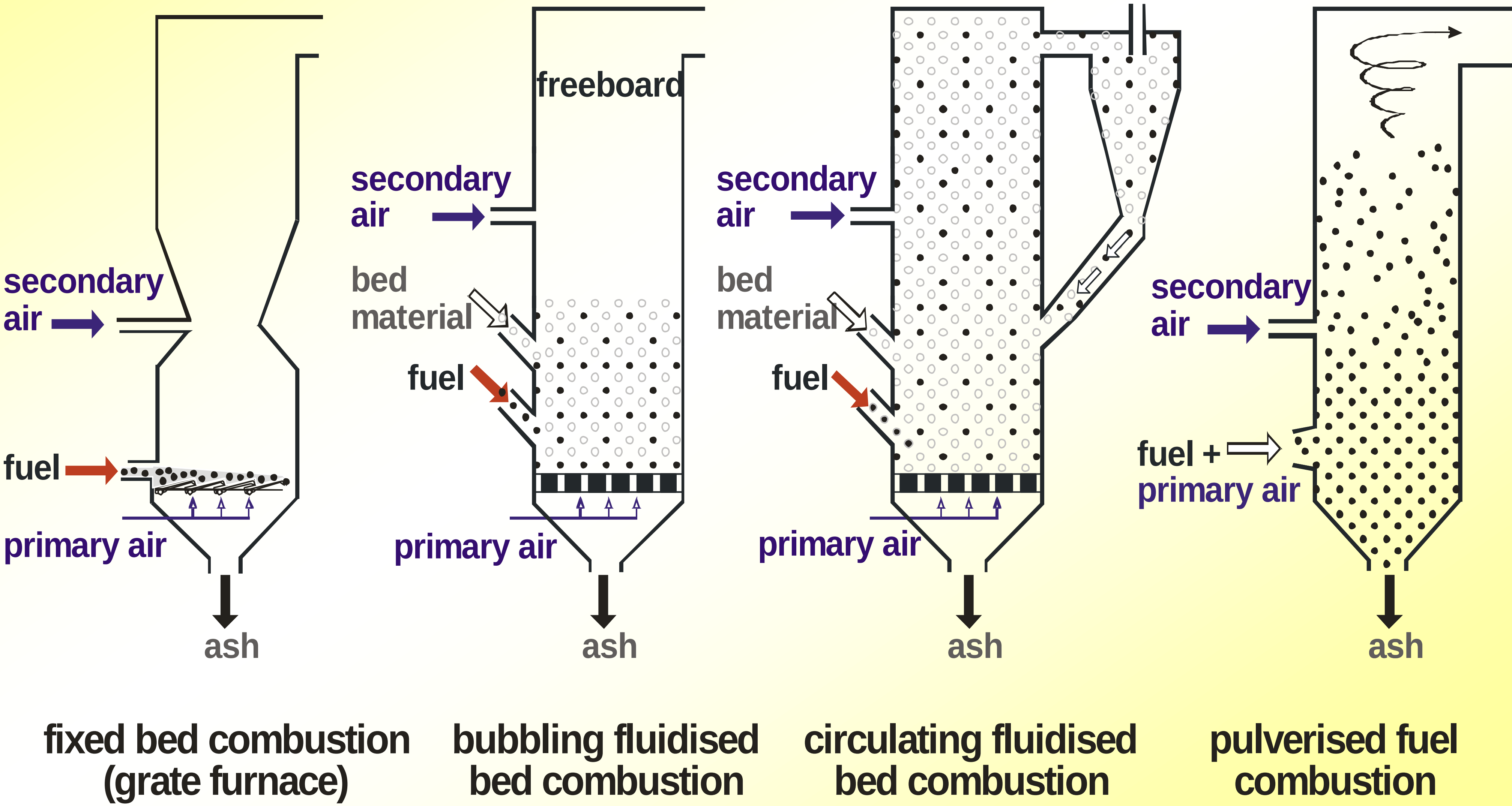
- **Co-firing of biomass in coal fired power stations**
  capacity range: some 100 MW_{th}

Biomass Combustion

- most advanced conversion technology
- market proven applications for a broad range of fuels and plant capacities

Biomass combustion technologies – overview

- fuel
  - bed material



Institute for Process
and Particle Engineering
Graz University of Technology

Medium-scale biomass combustion systems

Application:

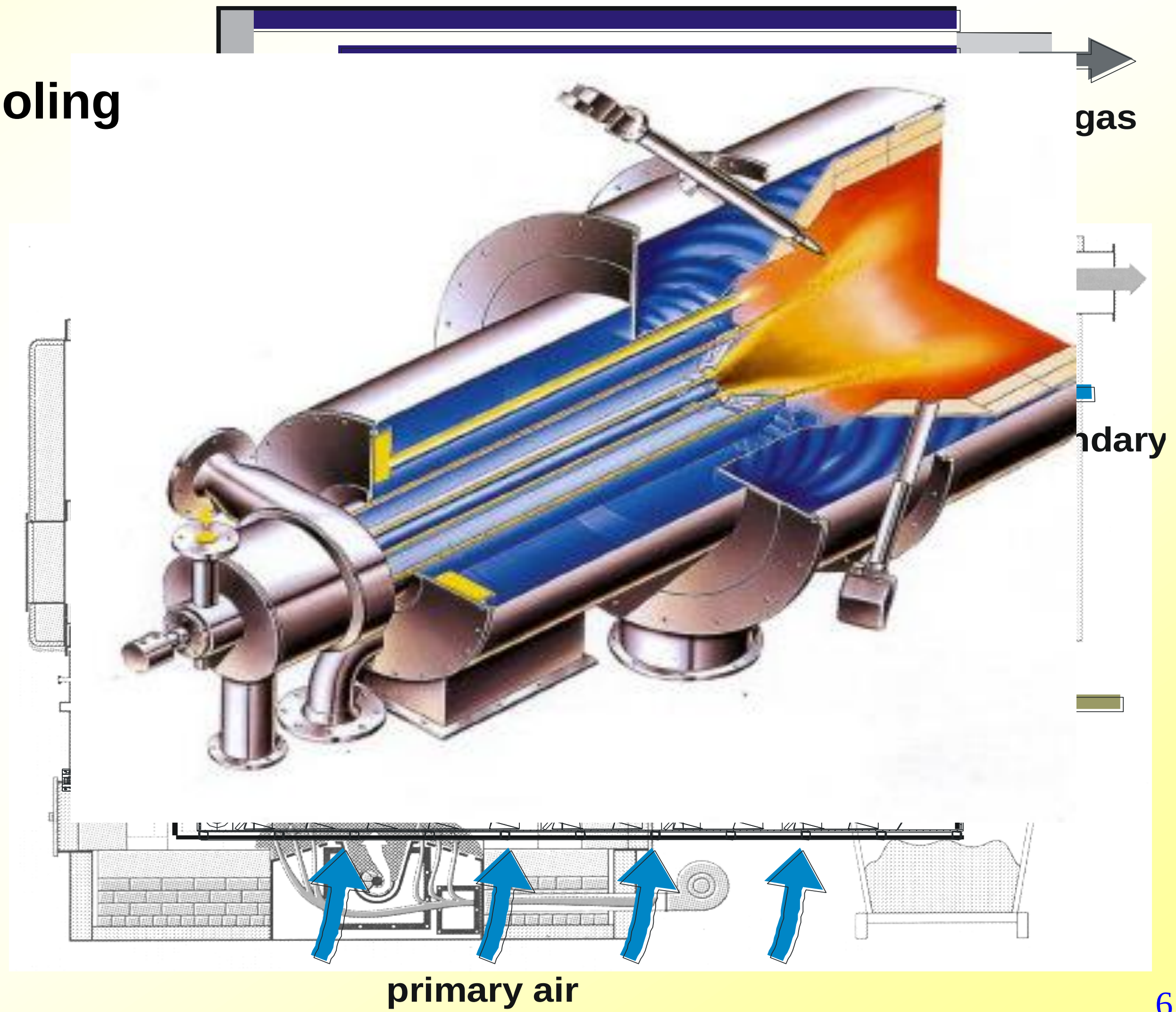
- district heating
- process heating and cooling
- CHP production

Fuels used:

- wood chips
- bark
- forest residues
- waste wood
- straw

Technologies:

- underfeed stokers
- grate-fired systems
- dust burners



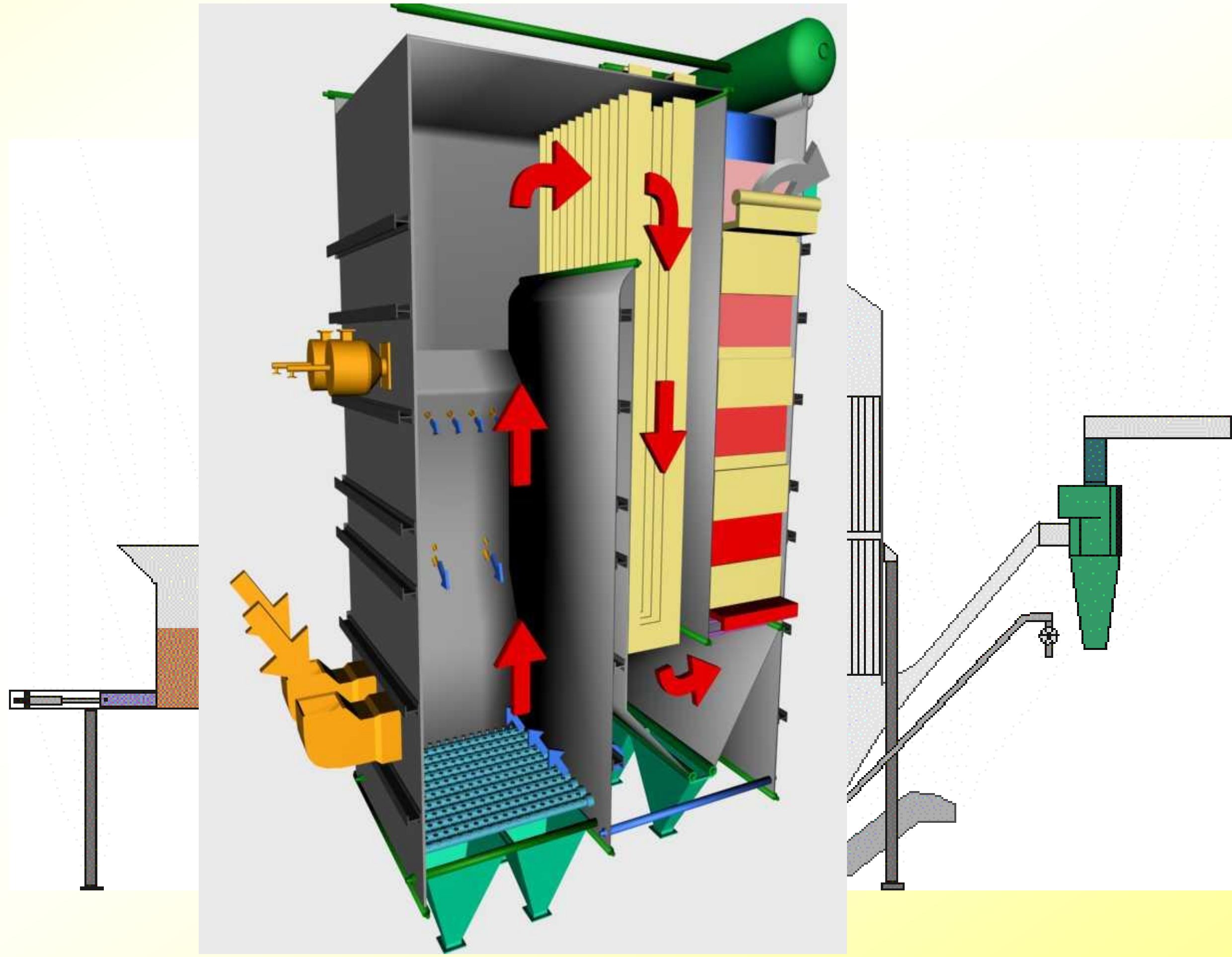
Large-scale biomass combustion systems

Application:

- CHP production
- power production

Fuels used:

- bark
- forest residues
- waste wood
- straw, cereals
- fruit stones, kernels, husks, shells



Technologies:

- grate-fired systems
- fluidised beds

Combustion relevant characteristics of solid biomass fuels – physical properties

Properties	Effects
Moisture content	Storability, dry matter losses, NCV, self-ignition, plant design
NCV, GCV	Fuel utilisation, plant design
Volatiles	Thermal decomposition behaviour
Ash content	Dust emissions, ash manipulation, ash utilisation / disposal, combustion technology
Ash melting behaviour	Operational safety, combustion technology, process control system, hard deposit formation
Fungi	Health risks
Bulk density	Fuel logistics (storage, transport, handling)
Particle density	Thermal conductance, thermal decomposition
Physical dimension, form, size distribution	Hoisting and conveying, combustion technology, bridging, operational safety, drying, formation of dust
Amount of fines	Fuel feeding, particle entrainment
Abrasion resistance (wood pressings)	Quality changes, segregation, fine parts

Institute for Process
and Particle Engineering
Graz University of Technology

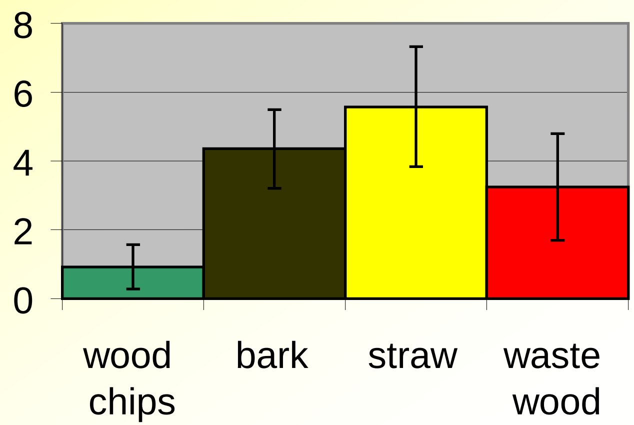
Combustion relevant characteristics of solid biomass fuels – chemical properties

Properties	Effects
Carbon (C)	GCV
Hydrogen (H)	GCV, NCV
Oxygen (O)	GCV
Chlorine (Cl)	HCl-, PCDD/F emissions, corrosion
Nitrogen (N)	NO_x-, N_2O emissions
Sulphur (S)	SO_x emissions, corrosion
Fluor (F)	HF emissions, corrosion
Potassium (K)	Corrosion (heat exchangers, superheaters), lowering ash melting temperature, formation of aerosols, ash utilisation (plant nutrient)
Sodium (Na)	Corrosion (heat exchangers, superheaters), lowering ash melting temperature, formation of aerosols
Magnesium (Mg)	Increase of ash melting temperature, ash utilisation (plant nutrient)
Calcium (Ca)	Increase of ash melting temperature, ash utilisation (plant nutrient)
Phosphor (P)	Ash utilisation (plant nutrient), ash melting, aerosol formation
Heavy metals	Emissions, ash utilisation, formation of aerosols

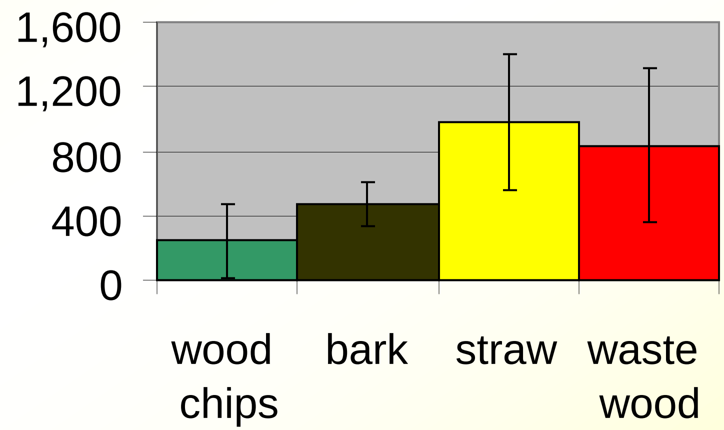
Institute for Process
and Particle Engineering
Graz University of Technology

Chemical compositions of different solid biomass fuels – ash, S, Cl, K

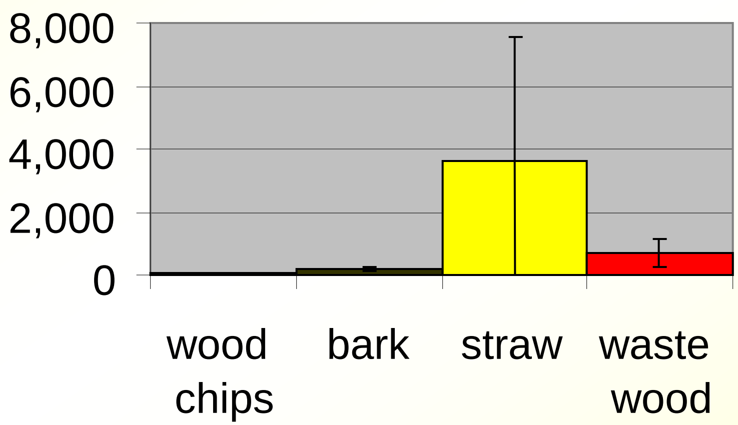
ash content wt% (d.b.)



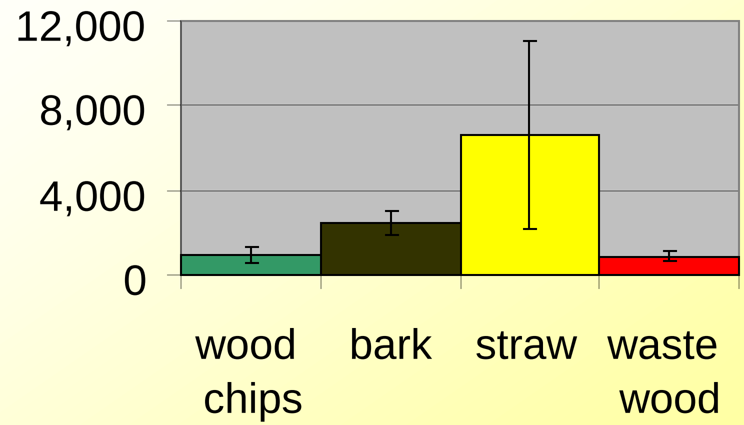
S mg/kg (d.b.)



Cl mg/kg (d.b.)



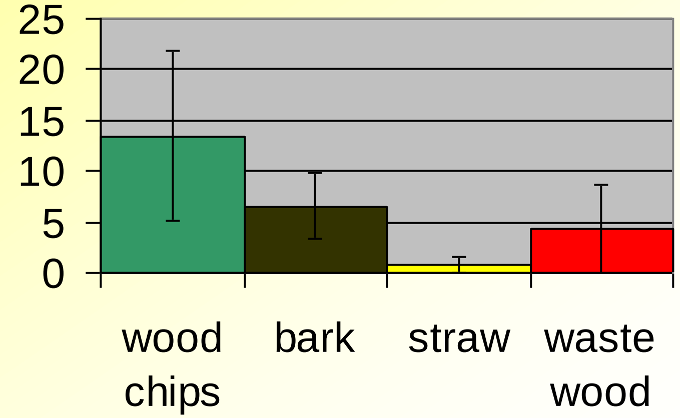
K mg/kg (d.b.)



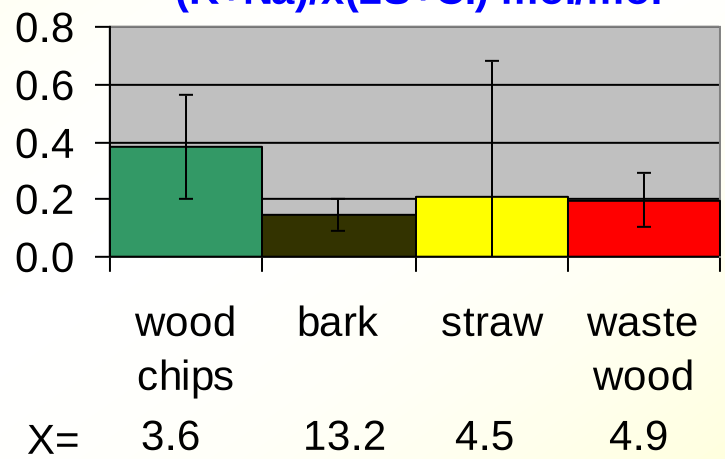
mean values and standard deviations; d.b. … dry basis

Institute for Process
and Particle Engineering
Graz University of Technology

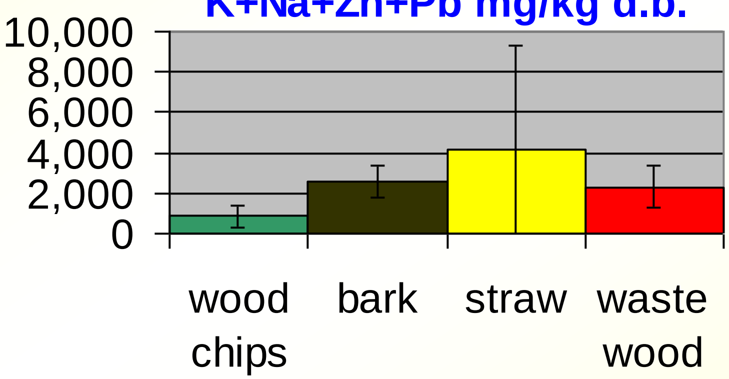
Evaluation of different biomass fuels – relevant fuel indexes



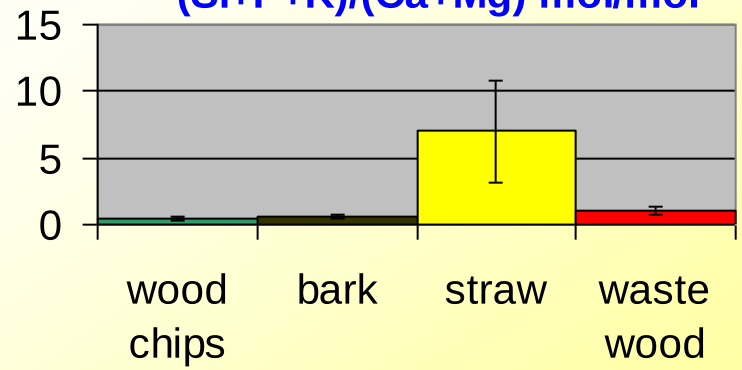
Indicator regarding corrosion risks



Indicator regarding the embedding of S and Cl in the ashes as well as SO_2/HCl emissions



Indicator regarding aerosol formation



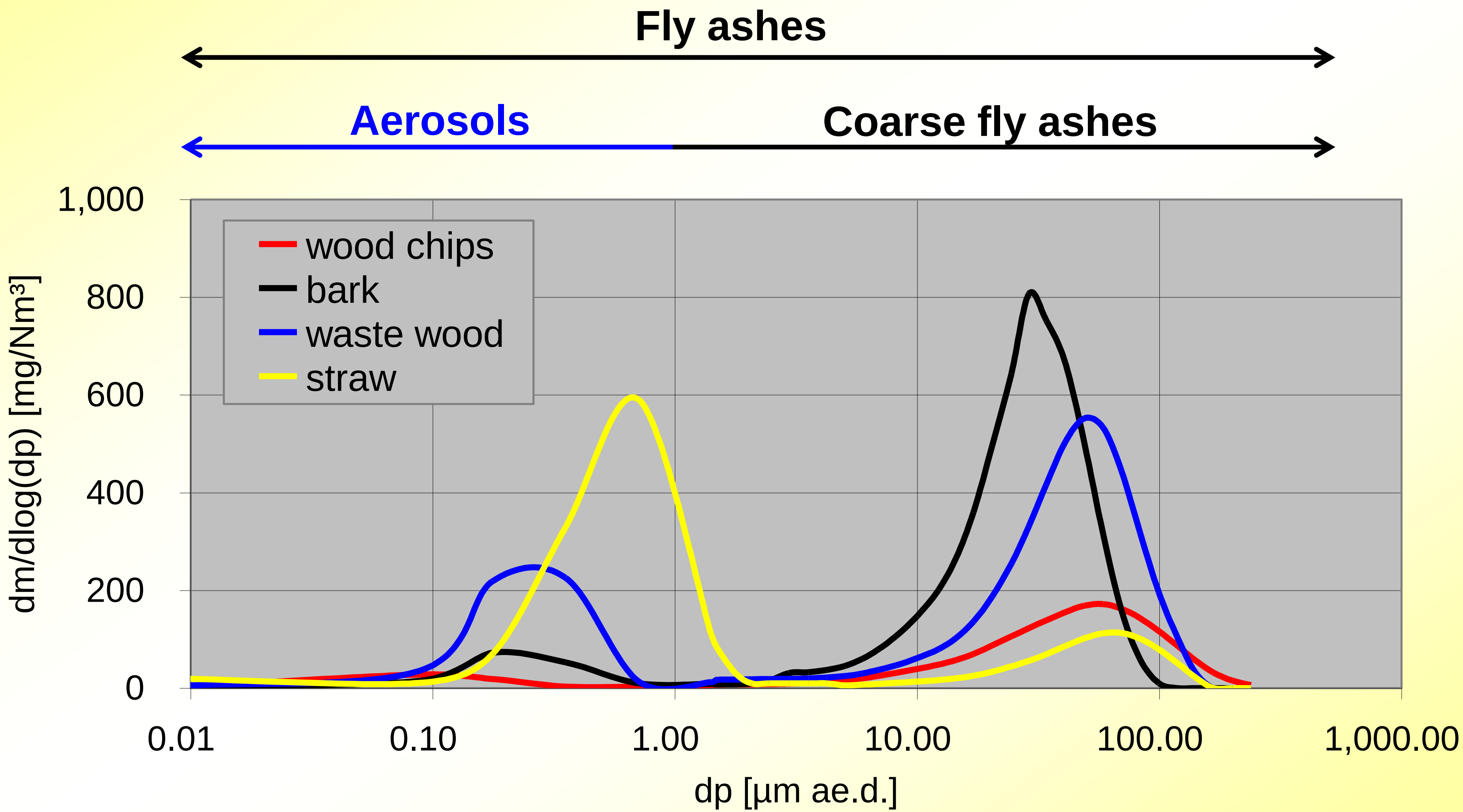
Indicator regarding ash melting behaviour

Ash related problems in biomass combustion processes

- Fine particulate emissions
- Ash melting / slagging and fouling
- Corrosion
- Additives to reduce ash related problems

Institute for Process
and Particle Engineering
Graz University of Technology

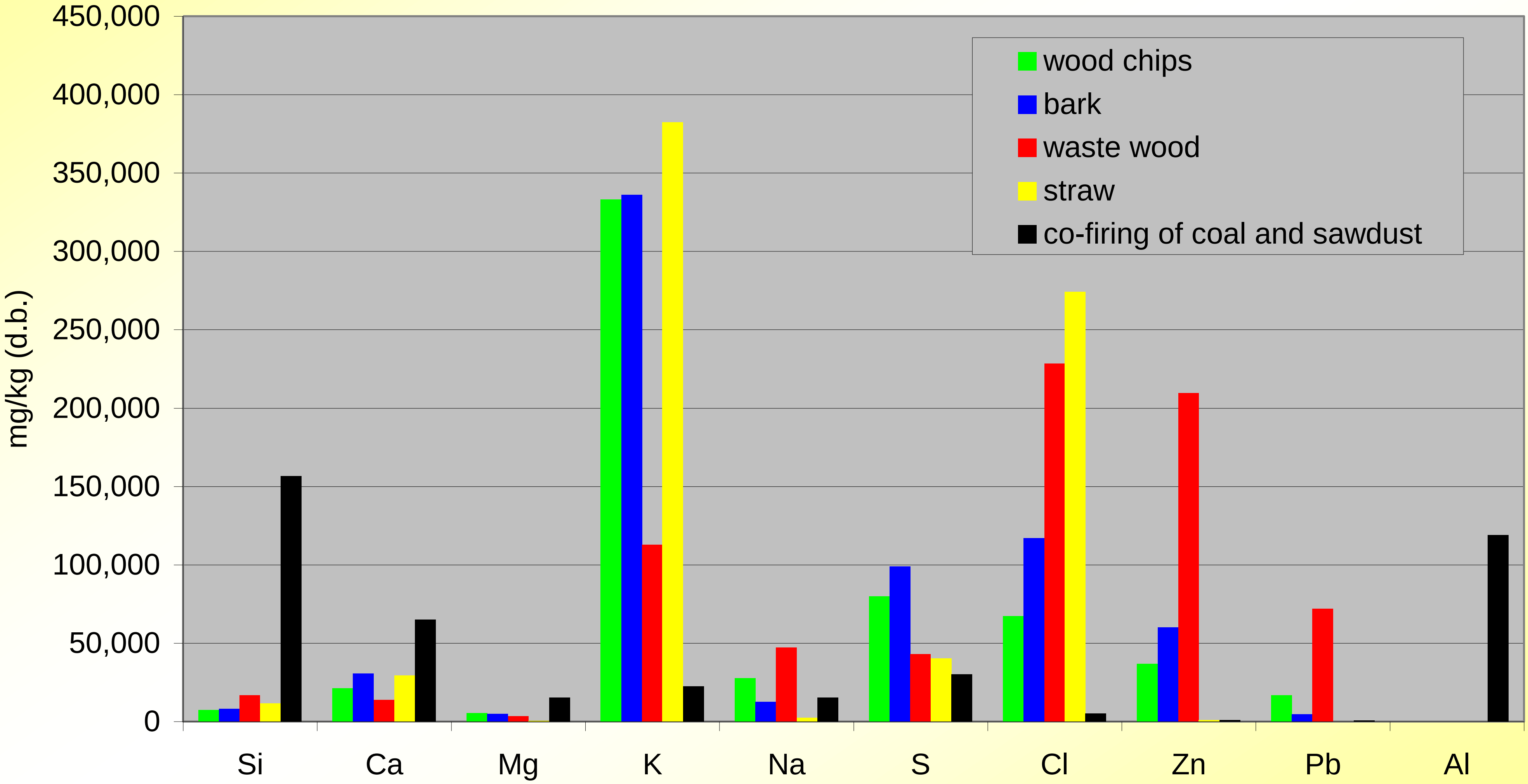
Particle size distributions of fly ashes from biomass combustion



Data related to dry flue gas and 13 vol.% O_2; results from grate-fired combustion systems

Institute for Process
and Particle Engineering
Graz University of Technology

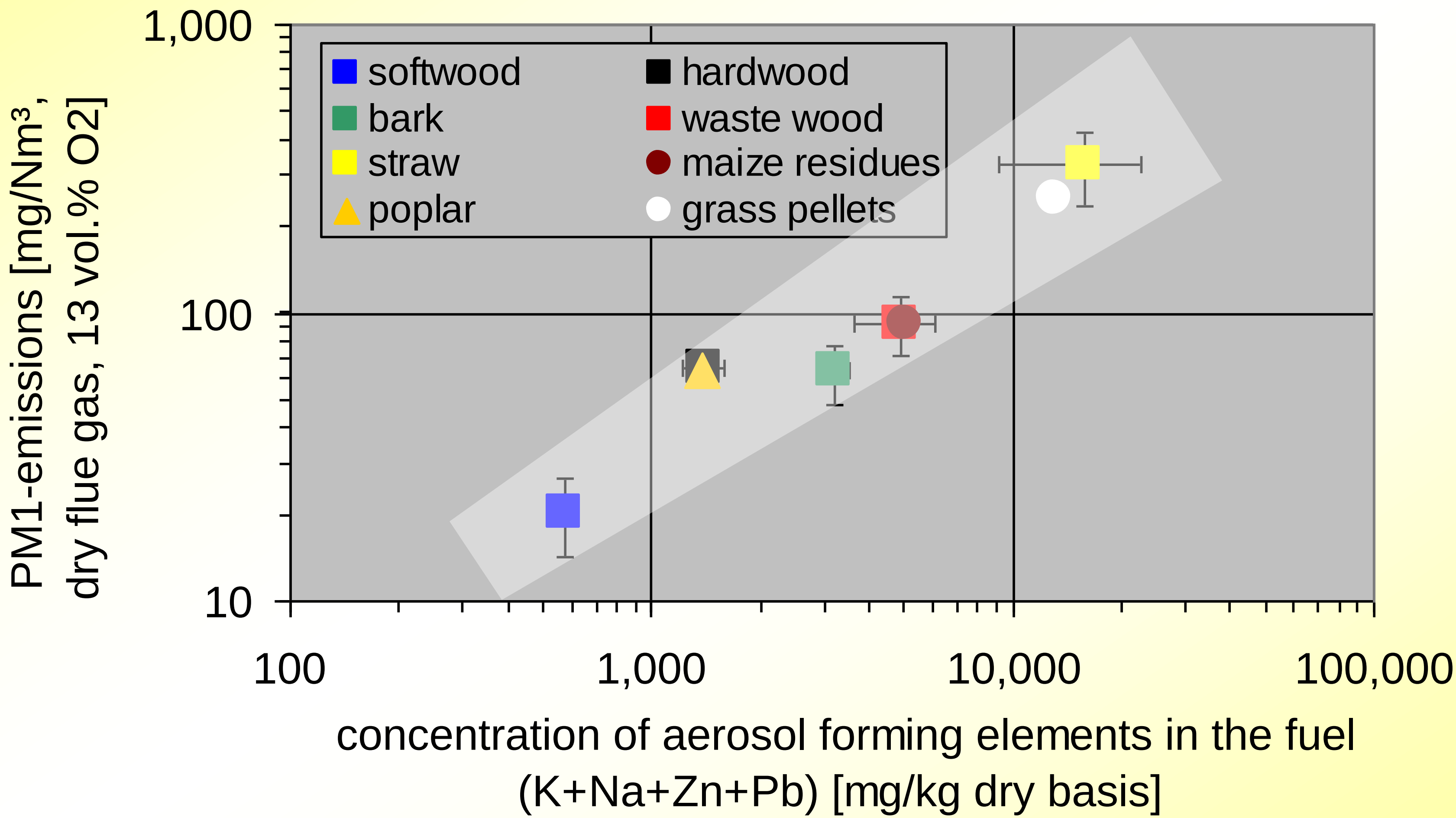
Typical compositions of aerosols from biomass combustion and co-firing of biomass (sawdust)



Data related to dry flue gas and 13 vol.% O_2; results from real-scale test runs

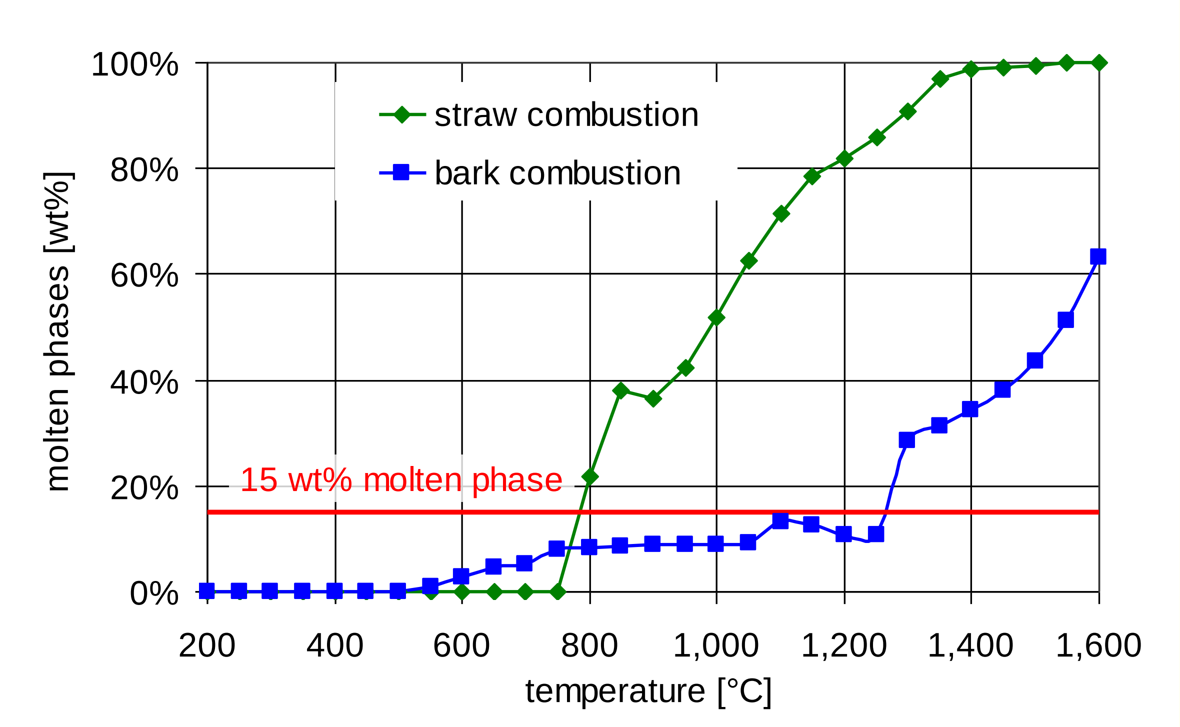
Institute for Process
and Particle Engineering
Graz University of Technology

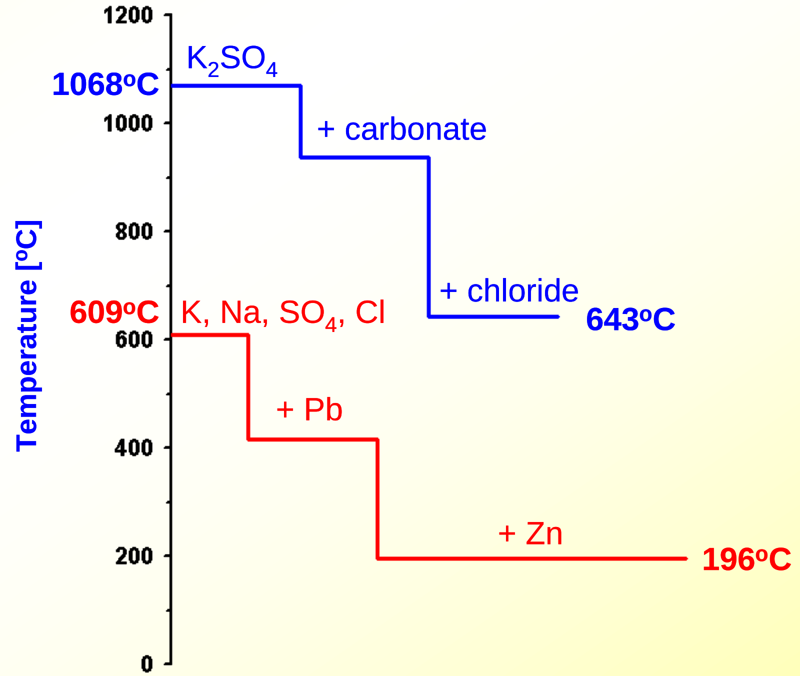
PM_1-emissions – evaluation based on the fuel index K+Na+Zn+Pb



PM_1 emissions downstream the boiler (before any dust precipitation device) measured in real-scale plants

Prediction of ash melting – results from TGA-DSC analyses and thermodynamic equilibrium analyses





Formation of molten phases – results from thermodynamic equilibrium analyses (left) and the influence of heavy metals on the melting temperatures of Cl-containing ash mixtures (right)

- **Appropriate fuel selective design and process control relevant**
- **Utilisation of new prediction tools important**
- **Furnace cooling relevant (flue gas recirculation, grate, walls)**

Institute for Process
and Particle Engineering
Graz University of Technology

Ash related problems in biomass combustion processes – corrosion

- Solid phase reactions involving alkali metal and heavy metal chlorides

  $2KCl(s) + SO_2(g) + 0.5\ O_2(g) + H_2O(g) \rightarrow K_2SO_4(s) + 2HCl(g)$

  → highly relevant (active oxidation)

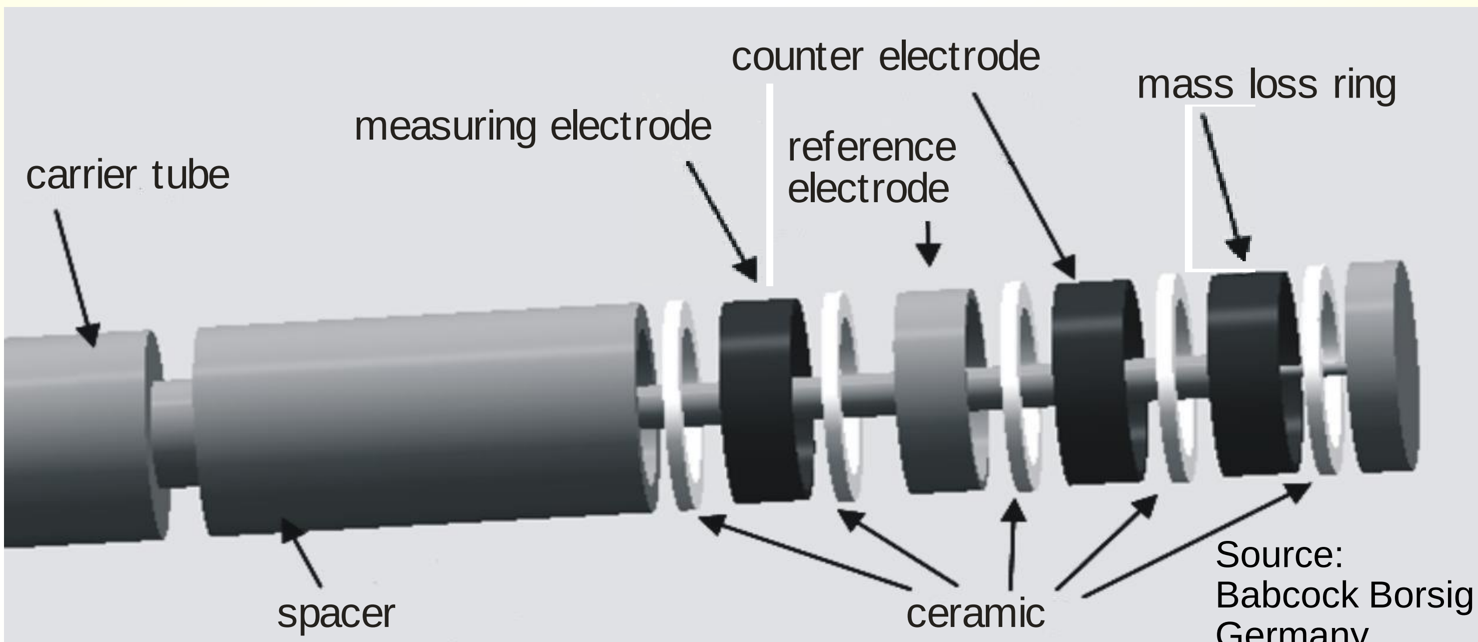
- Reactions involving molten alkali metal and other chlorides

  → relevant

- Fuel selection relevant
- Highest allowable temperatures on boiler tube surfaces and inlet temperatures of flue gas in convective boiler section relevant
- Boiler cleaning relevant
- Utilisation of additives interesting
- Development towards increased steam parameters as a driving force
  → straw: 540 °C
  → wood chips: higher than 540°C

On-line corrosion probe measurements

- Water and air cooled corrosion probe exposed to flue gas
- Current-voltage metering and the measurement of material loss allows to calculate the corrosion rate
- Different superheater materials can be investigated
- Subsequent SEM/EDX analyses of measurement rings
- Can be applied in lab-scale applications as well as real-scale plants



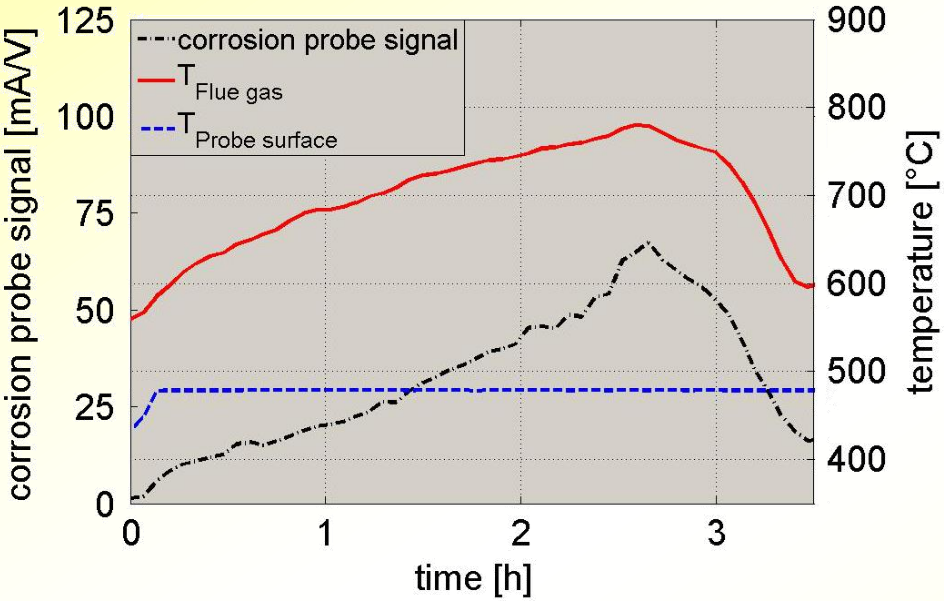
Source:
Babcock Borsig Steinmüller GmbH
Germany

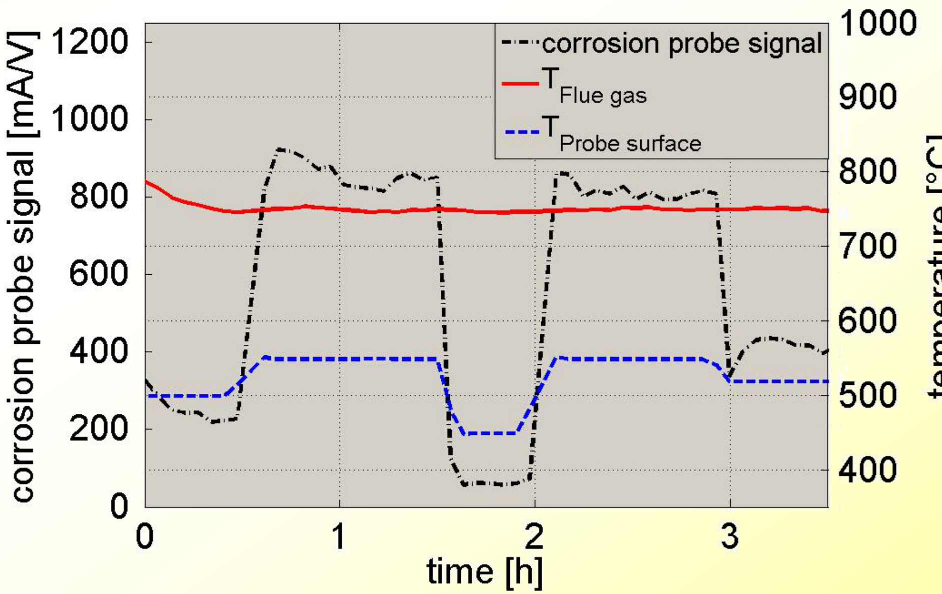
Institute for Process
and Particle Engineering
Graz University of Technology

Corrosion risks – evaluation based on corrosion probe measurements

Signals gained from online corrosion probes show a strong dependence on:

- the flue gas temperature
- the probe surface temperature





Results of online corrosion probe measurements at a 50 kW biomass furnace connected with an electrically heated drop tube; fuel: wheat straw pellets

$T_{Flue\ gas}$ … flue gas temperature at the measurement position

$T_{Probe\ surface}$ … surface temperature of the corrosion probe

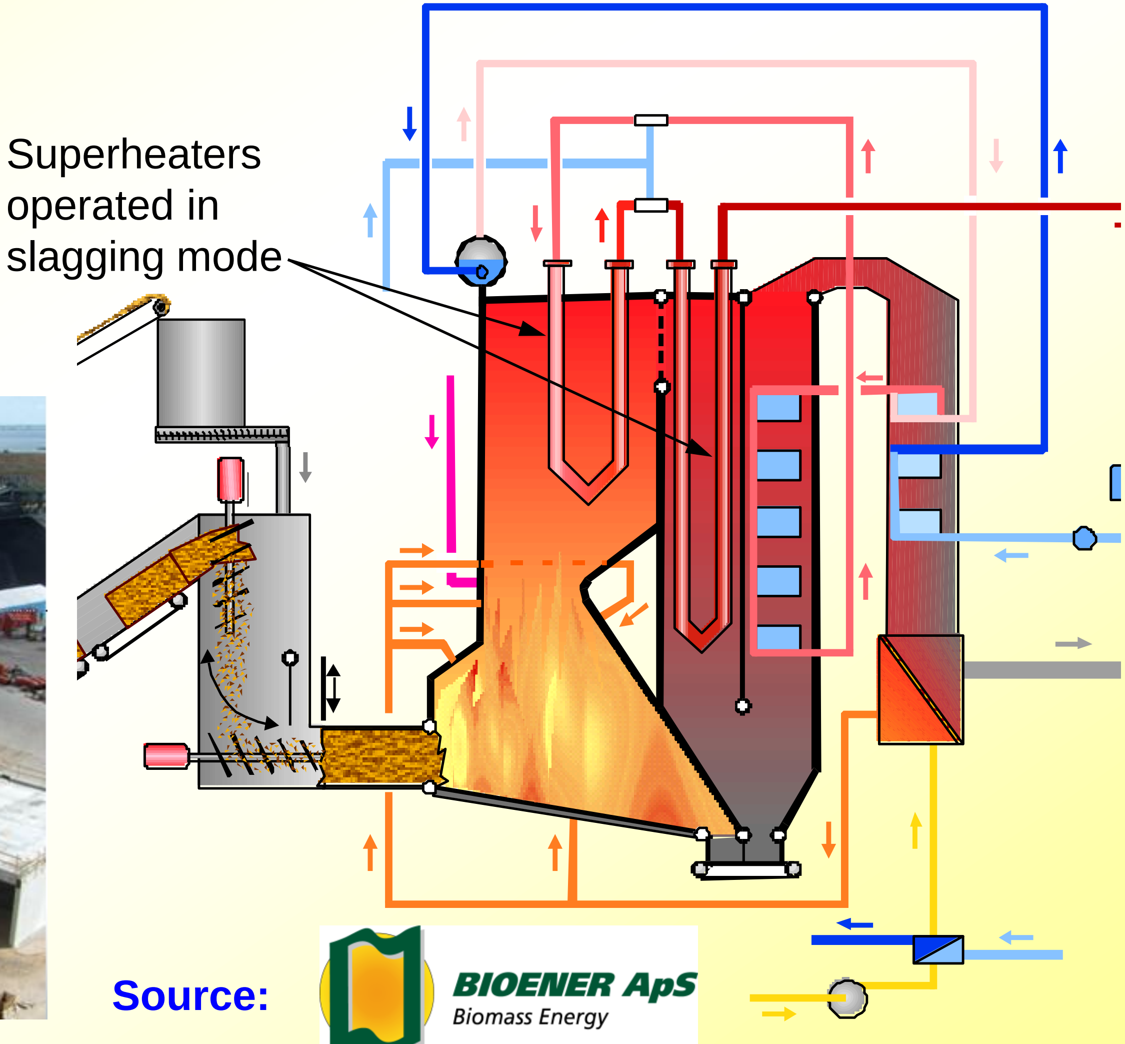
Probe material: 13CrMo4-5

Institute for Process
and Particle Engineering
Graz University of Technology

Ash related problems – case study for appropriate technological solutions (I)

CHP plant Maribo-Sakskøbing (Denmark)

Main fuel:	Wheat straw
Steam pressure:	92 bar
Steam temperature:	542 °C
Power output (gross):	10.6 MW
Thermal output:	20 MW
Electric efficiency (gross):	31.7 %
Thermal plant efficiency:	60 %
Total plant efficiency:	91.7 %



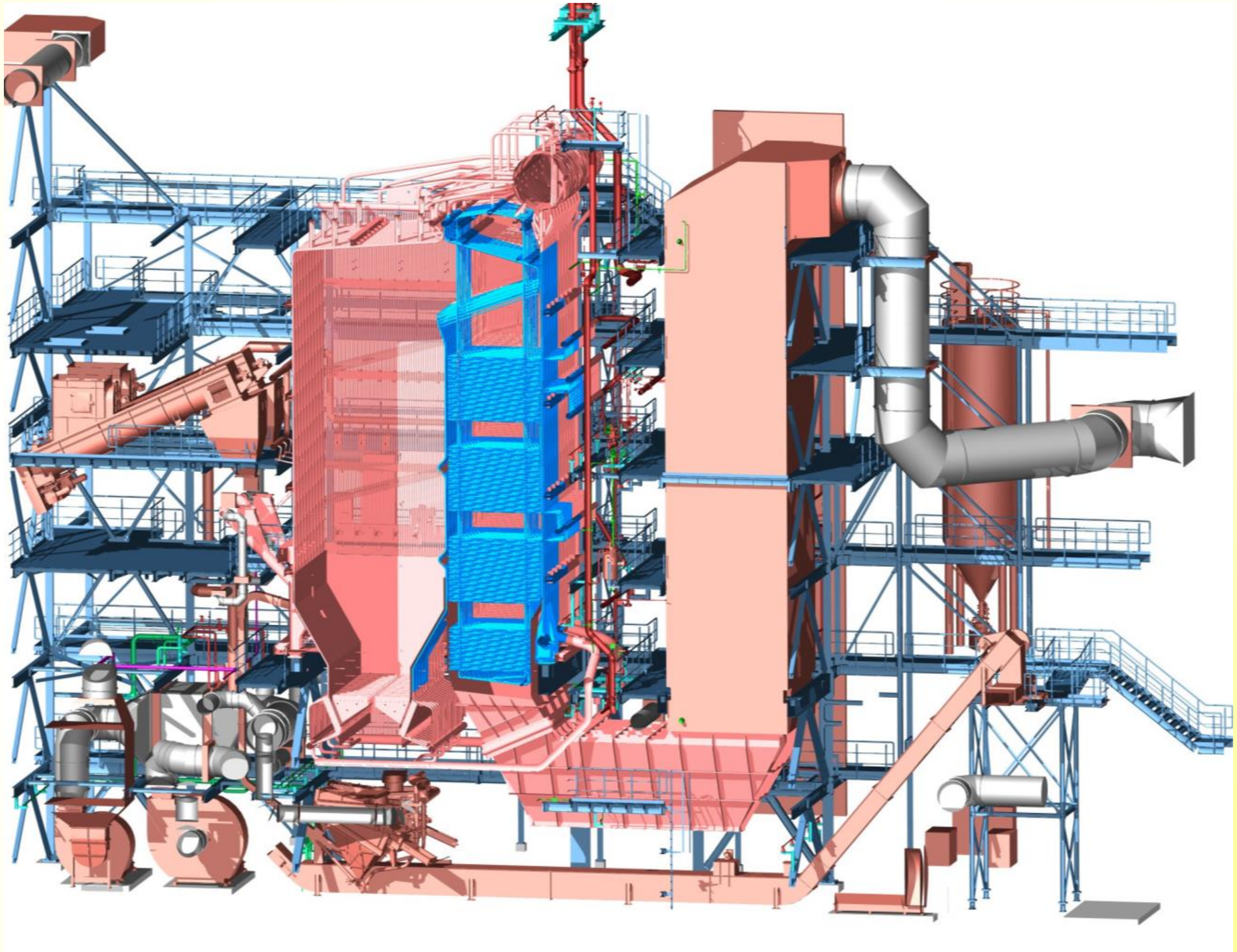
Source: BIOENER ApS Biomass Energy

Institute for Process
and Particle Engineering
Graz University of Technology

Ash related problems – case study for appropriate technological solutions (II)

CHP plant Bern (Switzerland)

Main fuel:	waste wood
Combustion technology:	bubbling fluidised bed
Steam pressure:	75 bar
Steam temperature:	485 °C
Power output (gross):	7.0 MW
Thermal output:	28.4 MW
Electric efficiency (gross):	26.5 %
Thermal plant efficiency:	64.1 %
Total plant efficiency:	90.6 %



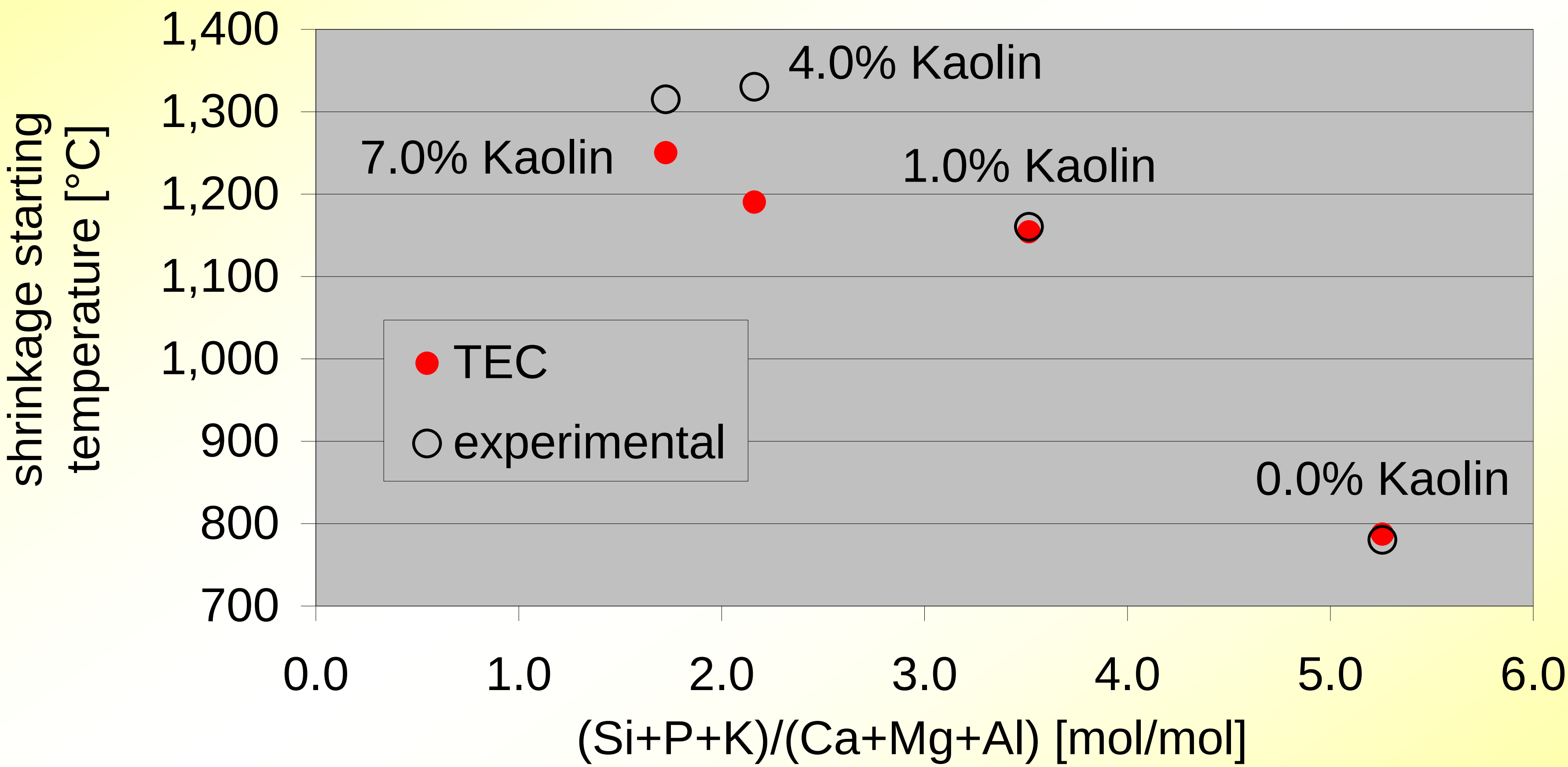
Source: BERTSCH BERTSCHenergy Kessel- und Energietechnik Apparatebau

Additives applied in biomass combustion systems

Purpose	Additive	State-of-application
Alkaline metal catchers to reduce aerosol formation	Kaolin	R&D
Sulphation of chlorides to reduce corrosion	ChlorOut (ammonium sulphate)	Demonstration
Additives to increase ash melting temperatures	Ca-based Mg-based	R&D
Additives to reduce SO_2- HCl- and PCDD/F-emissions	Limestone Sodium bicarbonate Activated charcoal	State-of-the-art
Additives for NO_x emission reduction	Urea NH_3	State-of-the-art

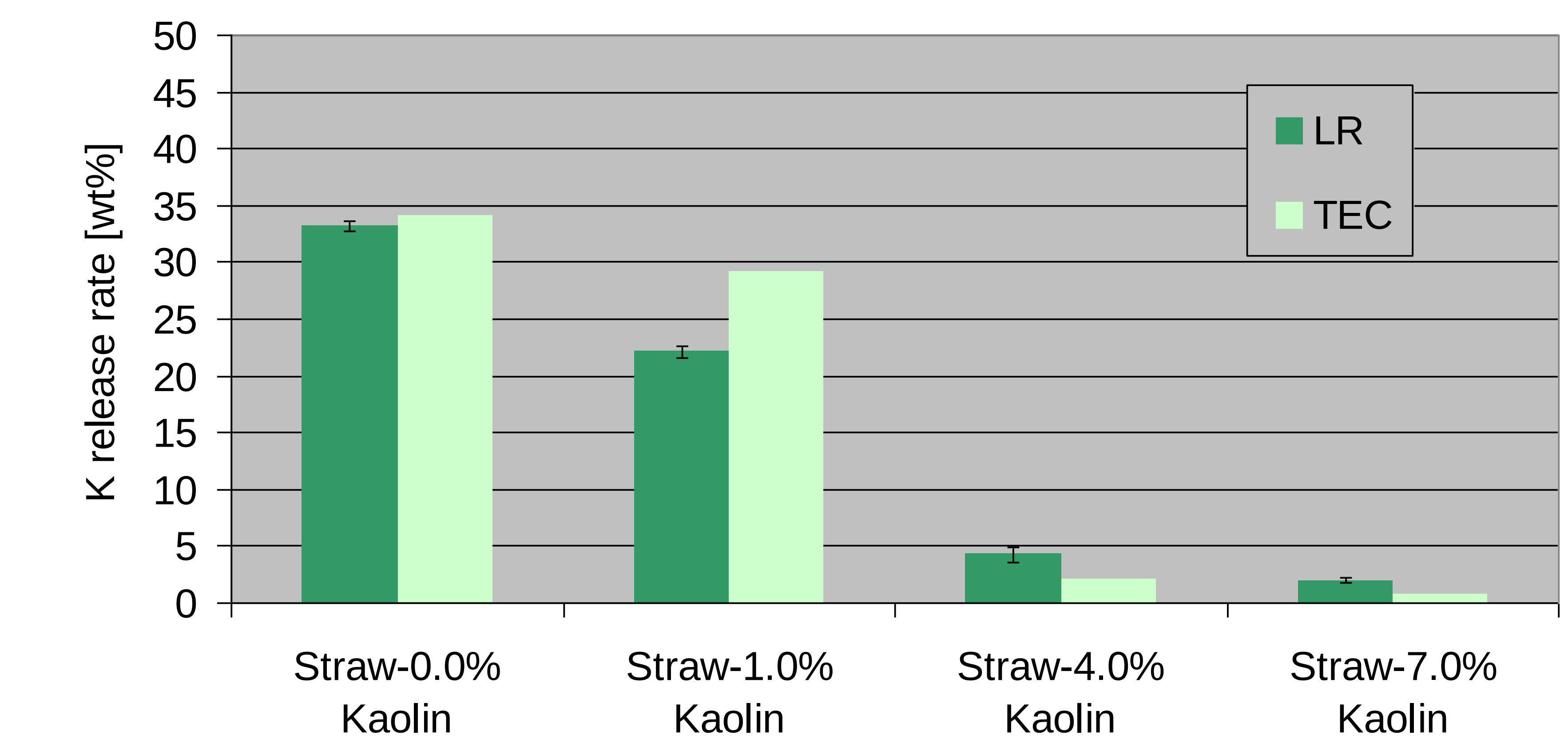
Institute for Process
and Particle Engineering
Graz University of Technology

Additive utilisation – effect of kaolin addition to wheat straw on ash melting properties



TEC... thermodynamic equilibrium calculations
The shrinkage starting temperature from TEC was estimated at 30 wt% molten fraction
Experimental: shrinkage starting temperature according to CEN/TS 15370-1

Additive utilisation – effect on the K release



LR ... lab-reactor, TEC ... thermodynamic equilibrium calculation
TEC release estimated at 1250°C

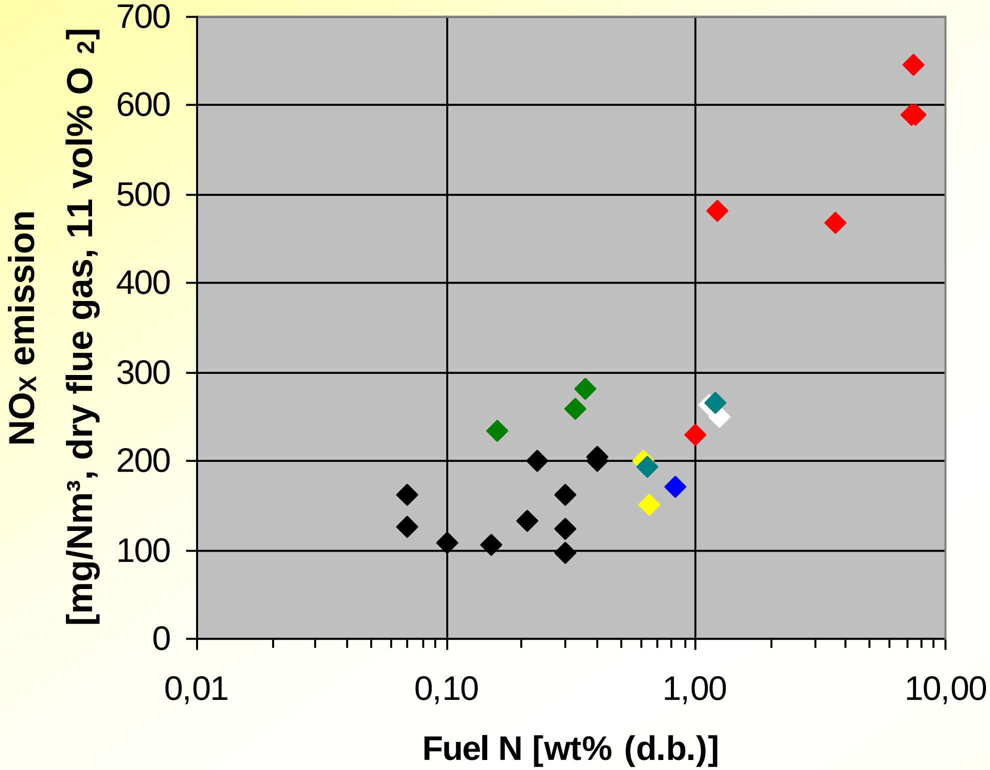
$$Release_{LR,X,\%} = \left(1 - \frac{c_{X,Output(d.b.)} \cdot m_{Output(d.b.)}}{c_{X,Input(d.b.)} \cdot m_{Input(d.b.)}}\right) \cdot 100\%$$

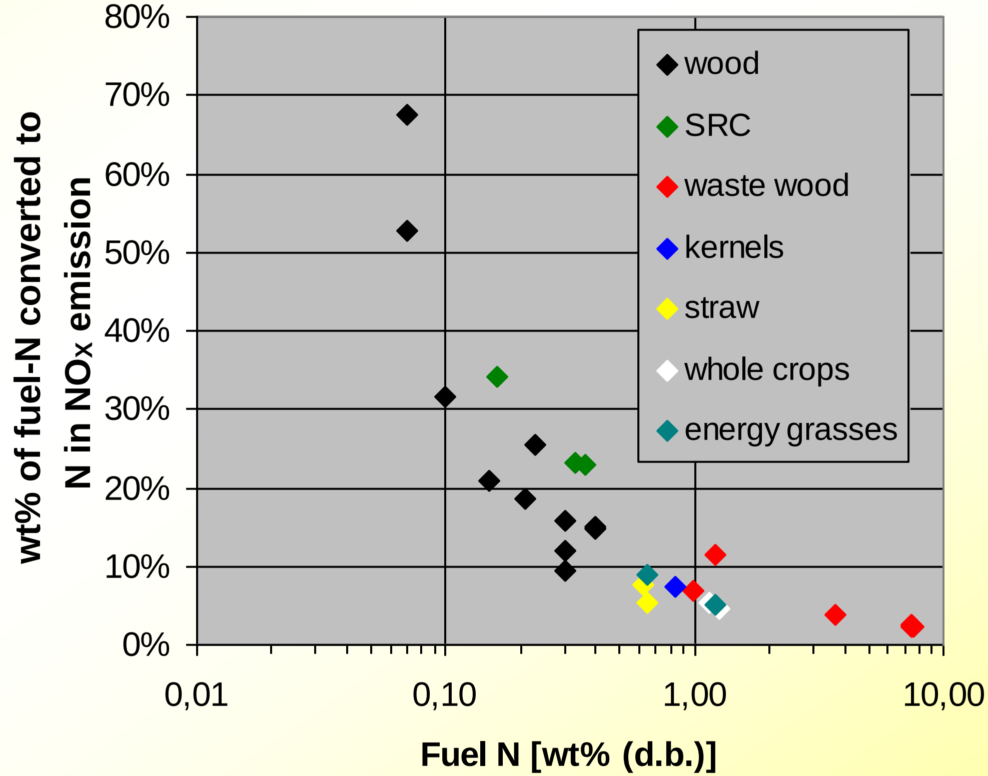
$c_{x,\ Input(d.b.)}$ ... concentration of element x in the fuel [mg/kg d.b.]

$c_{x,\ Output(d.b.)}$ ... concentration of element x in the ash [mg/kg d.b.]

Institute for Process
and Particle Engineering
Graz University of Technology

Gaseous emissions - NO_x





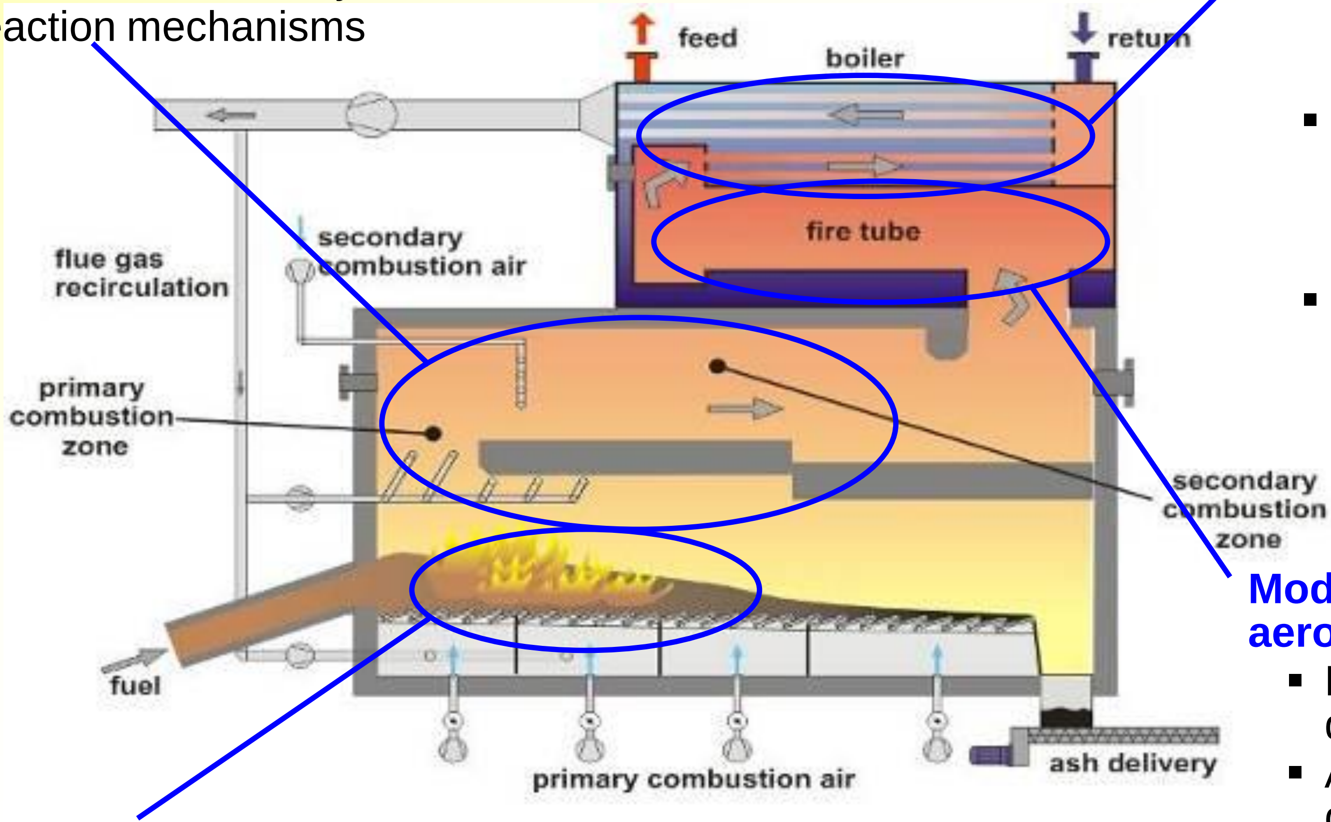
- **Fuel selection relevant**
- **Primary measures especially relevant (air staging / fuel staging)**
  CFD optimised plant design relevant
- **Combination of primary and secondary measures (SNCR, SCR) if needed**

Institute for Process
and Particle Engineering
Graz University of Technology

CFD simulation of biomass combustion plants – model overview

Models for gas phase combustion and NO_x formation
- Turbulence models
- Turbulence-chemistry interaction models
- Reaction mechanisms

Finite cell model for convective heat exchangers
- For fire tube boilers, water tube and steam boilers, thermal oil boilers
- Consideration of flow, heat transfer, pressure distribution; calculation of tube surface temperatures
- Link with ash deposit model (in progress)



Models for ash deposit and aerosol formation
- Direct wall condensation, deposition of fly ash particles
- Aerosol formation and deposition
- Erosion
- Deposit growth and influence on heat transfer

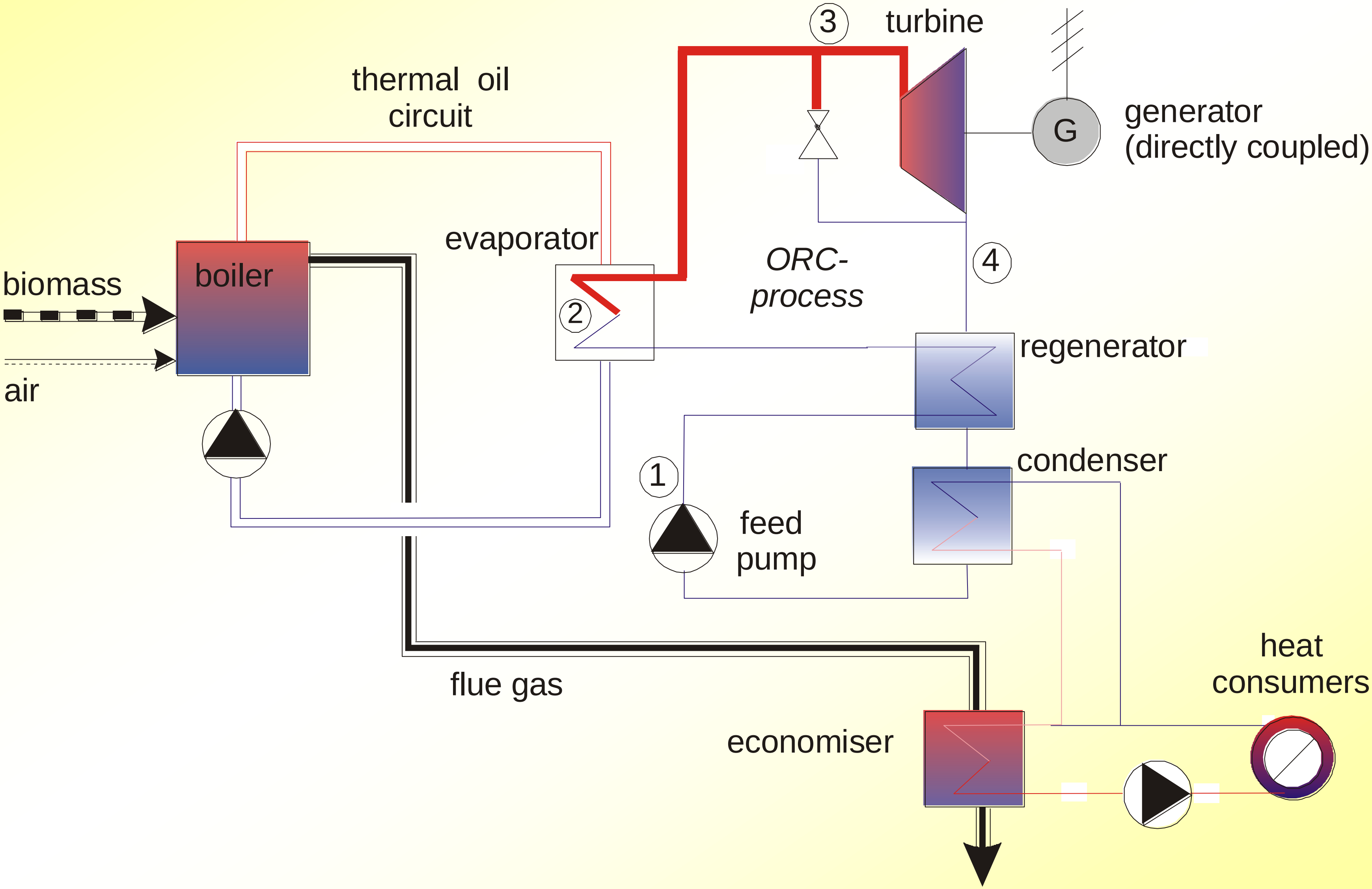
Models for solid biomass conversion
- Single particle conversion and volatiles release
- Multiphase modelling for particle-particle and particle-gas interactions in packed beds (and entrained flows)

Ongoing research and future R&D topics

State of science		Future R&D
conventional biomass fuels (wood fuels, straw)	→	**new biomass fuels** annual crops, short rotation plants, waste materials from the agricultural and the food industry, etc.
modern biomass combustion technologies	→	**next generation biomass combustion systems** towards zero emission technologies towards fuel flexible technologies
conventional CHP technologies	→	**advanced highly efficient systems** towards increased steam parameters towards higher availability
single model development	→	**virtual biomass conversion plant**


Thank you for your attention
Prof. Dr. Ingwald Obernberger
Inffeldgasse 21b, A-8010 Graz, Austria
TEL.: +43 (316) 481300; FAX: +43 (316) 4813004
Email: ingwald.obernberger@tugraz.at
HOMEPAGE: www.bios-bioenergy.at, www.IPPE.TUGRAZ.at

ORC process - standard scheme



Institute for Process
and Particle Engineering
Graz University of Technology

Biomass CHP plant based on an ORC process (400 kW$_{el}$)

Energy balance of a biomass CHP plant based on ORC technology