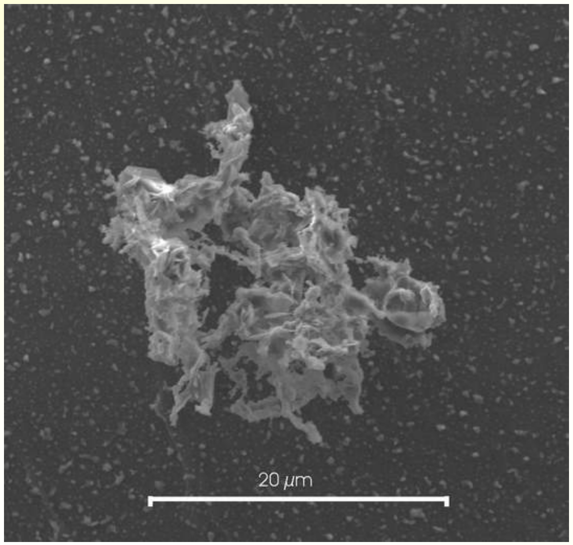
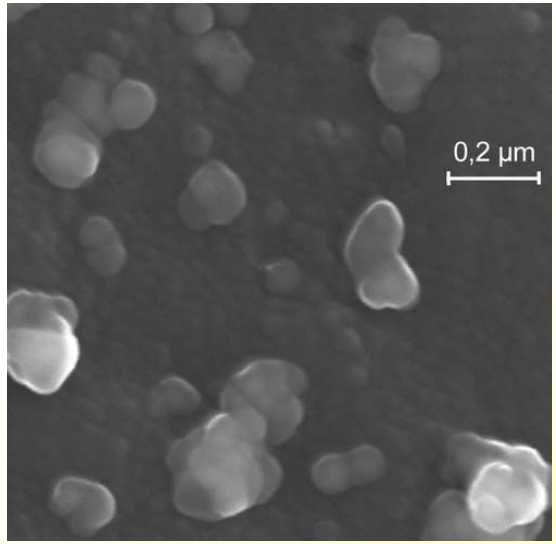
# AEROSOLS AND FLY ASHES FROM FIXED-BED BIOMASS COMBUSTION
# characterisation, formation, precipitation

**Ingwald Obernberger**




**Institute of Chemical Engineering Fundamentals and Plant Engineering**
**Graz University of Technology**
**TEL.: +43 (316) 481300; FAX: +43 (316) 4813004**
**E-MAIL: office@bios-bioenergy.at**
**HOMEPAGE: http://VT.TU-GRAZ.AC.AT**

# Content of presentation

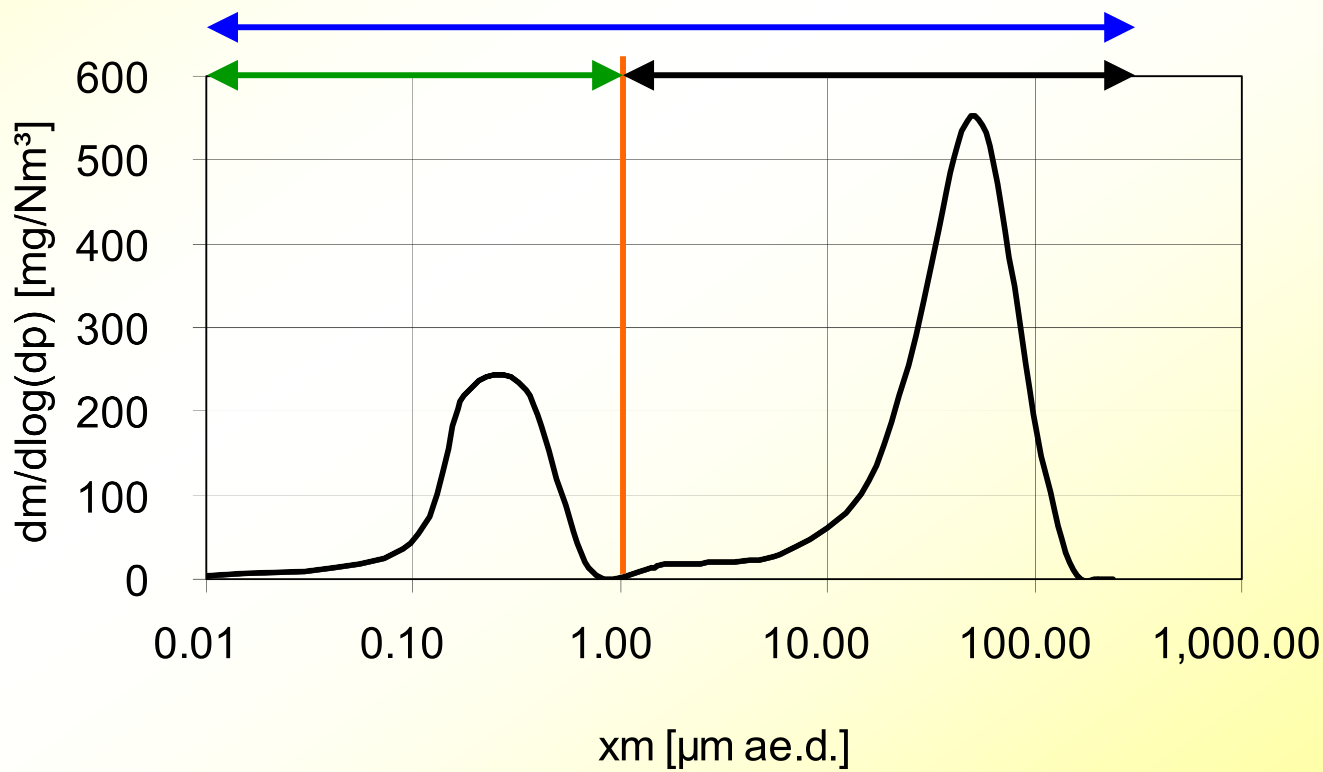
- Definitions, methodology and experimental set-up
- Definition of the fuels used
- Characterisation of aerosols and coarse fly ashes formed during fixed-bed biomass combustion
    - concentration of aerosols and coarse fly ashes in the flue gas
    - particle size distribution of aerosols and coarse fly ashes
    - chemical composition of aerosols and coarse fly ashes
    - shape of aerosols and coarse fly ashes
- Formation mechanisms of aerosols
- Precipitation of aerosols and coarse fly ashes from the flue gas

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Definitions

## Nomenclature for particle fractions used within this presentation

- **aerosols** — **the particle fraction < 1 µm**
- **coarse fly ash** — **particles > 1 µm**
- **fly ash** — **total of aerosols and coarse fly ash**



# Methodology

## Performance of test runs at a pilot-scale combustion unit and a large-scale CHP plant with several biomass fuels at different operational conditions

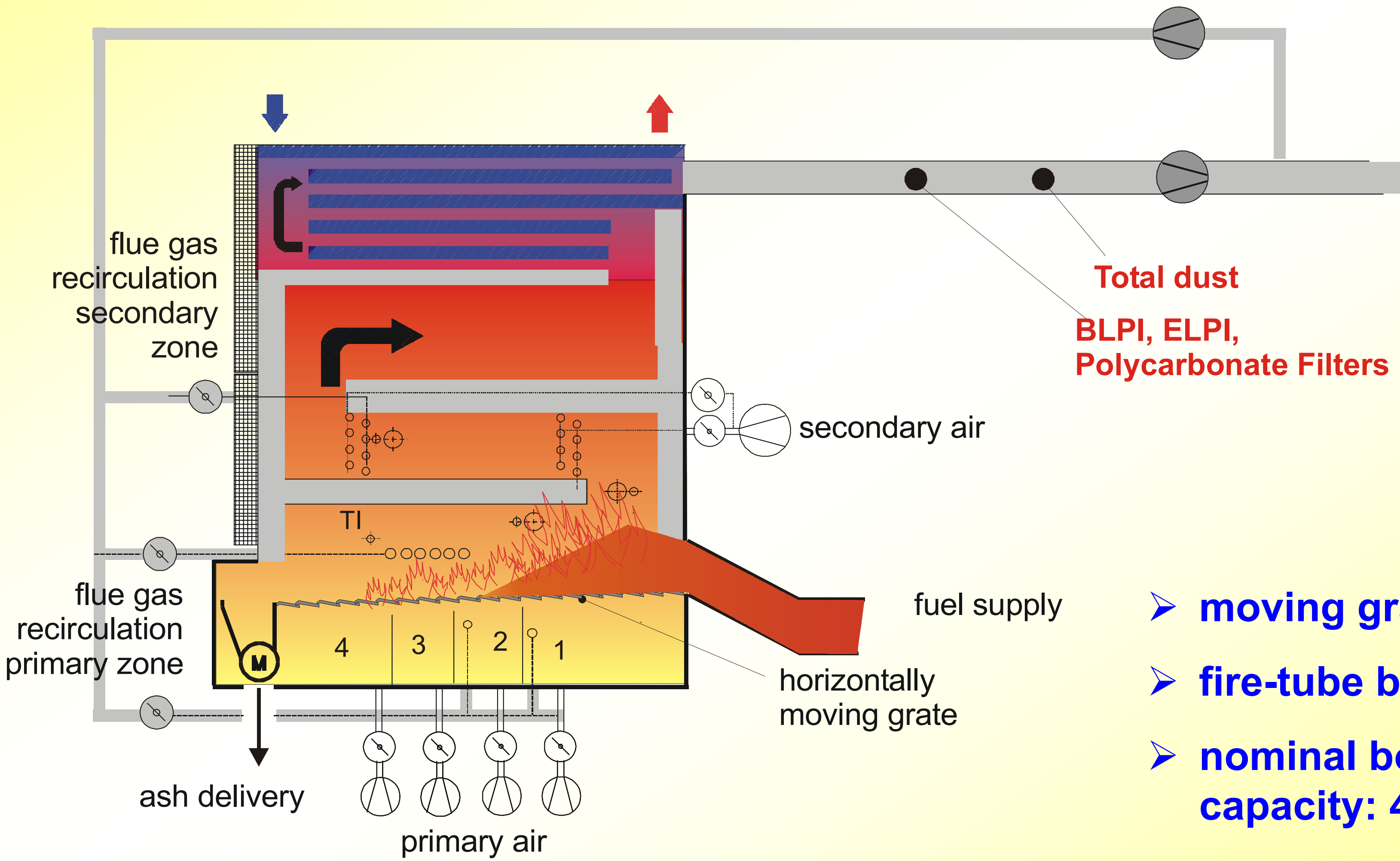
- **Continuous measurements**
  - temperatures in the furnace
  - flue gas temperature at the boiler outlet
  - load of the combustion unit
  - flue gas composition (CO, $O_2$, $NO_x$)
- **Non-continuous measurements**
  - concentration of aerosols and fly ashes in the flue gas using a Berner-type low pressure impactor (BLPI)
  - particle size distribution of aerosols (BLPI)
- **Samples taken during the test runs for subsequent analyses**
  - fuel
  - aerosols and coarse fly ashes
    (sampling with the BLPI, cyclones and polycarbonate filters)

# Methodology

## Analyses of the samples taken

- fuel
  - moisture content, ash content
  - wet chemical analyses
    (K, Na, Mg, Si, Ca, Cl, S, Pb, Zn)
- aerosols and coarse fly ashes
  - wet chemical analyses of BLPI and fly ash samples
    (K, Na, Mg, Ca, Cl, S, Pb, Zn)
  - SEM/EDX analyses of samples taken with the BLPI and with polycarbonate filters
  - Determination of the particle size distribution of coarse fly ashes by sedimentation

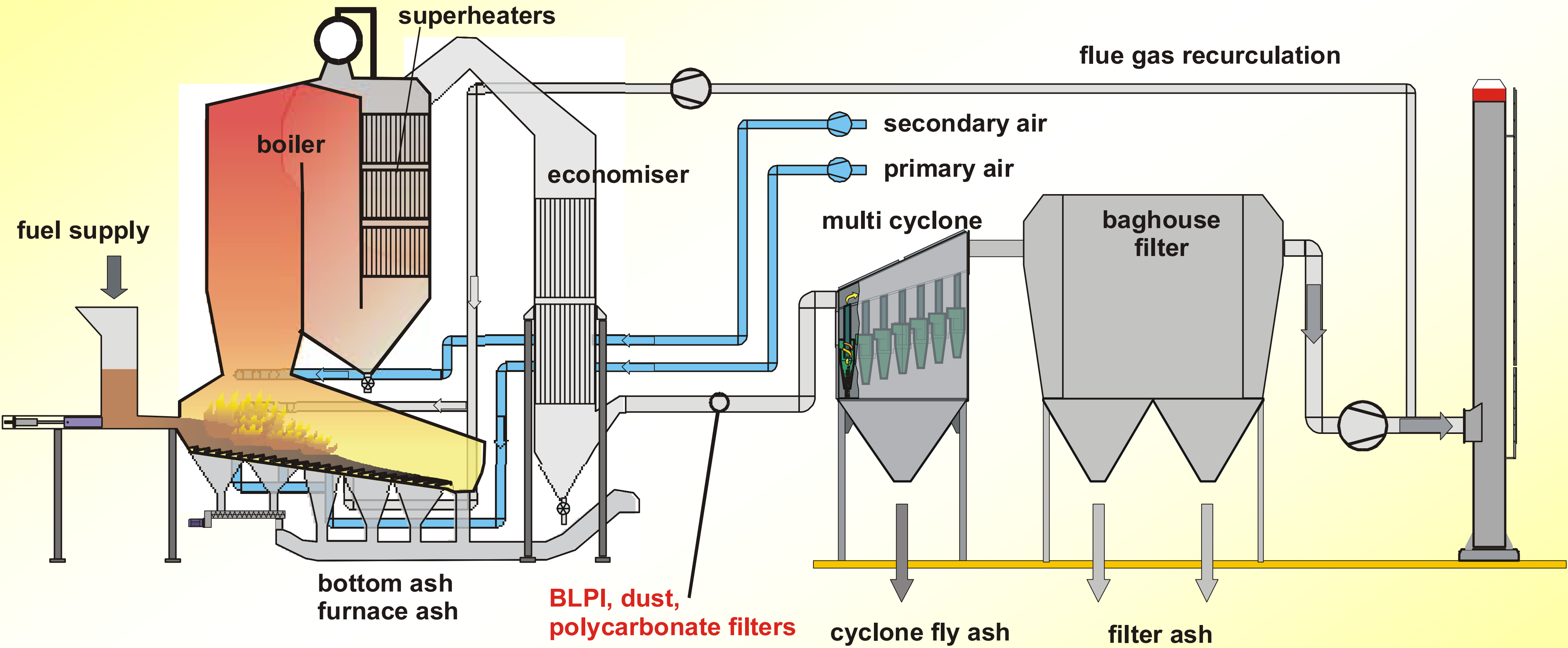
# Pilot-scale combustion unit




- **moving grate**
- **fire-tube boiler**
- **nominal boiler capacity: 440 kW$_{th}$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Large-scale CHP plant




- **moving grate**
- **nominal boiler capacity: 45,000 $kW_{th}$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Characterisation of fuels

| | | Softwood | | Hardwood | | Bark | | Waste wood | |
|---|---|---|---|---|---|---|---|---|---|
| | | mean | std.dev. | mean | std.dev. | mean | std.dev. | mean | std.dev. |
| moisture | wt.% w.b. | 41.5 | 20.2 | 18.8 | 15.9 | 54.6 | 6.1 | 29.6 | 12.0 |
| ash content | wt.% d.b.naf | 0.3 | 0.04 | 0.7 | 0.2 | 5.9 | 1.1 | 4.7 | 0.9 |
| Si | mg/kg d.b. | 349 | 27 | 370 | 356 | 4,865 | 3,185 | 8,211 | 3,896 |
| Ca | mg/kg d.b. | 834 | 151 | 1,865 | 786 | 13,326 | 2,101 | 7,430 | 3,092 |
| Mg | mg/kg d.b. | 113 | 20 | 305 | 19 | 869 | 94 | 929 | 580 |
| K | mg/kg d.b. | 435 | 135 | 1,097 | 91 | 2,493 | 472 | 1,027 | 246 |
| Na | mg/kg d.b. | 4.6 | 2.1 | 27.9 | 6.4 | 151 | 127 | 979 | 507 |
| S | mg/kg d.b. | 38.0 | 5.7 | 114.7 | 7.6 | 347 | 43 | 1,015 | 152 |
| Cl | mg/kg d.b. | 75.6 | 37.6 | 35.0 | 16.4 | 194 | 44 | 1,569 | 1,210 |
| Zn | mg/kg d.b. | 10.0 | 1.4 | 6.1 | 2.4 | 86.5 | 23.9 | 2,334 | 4,162 |
| Pb | mg/kg d.b. | 0.4 | 0.1 | 0.9 | 0.6 | 3.0 | 0.7 | 433 | 264 |

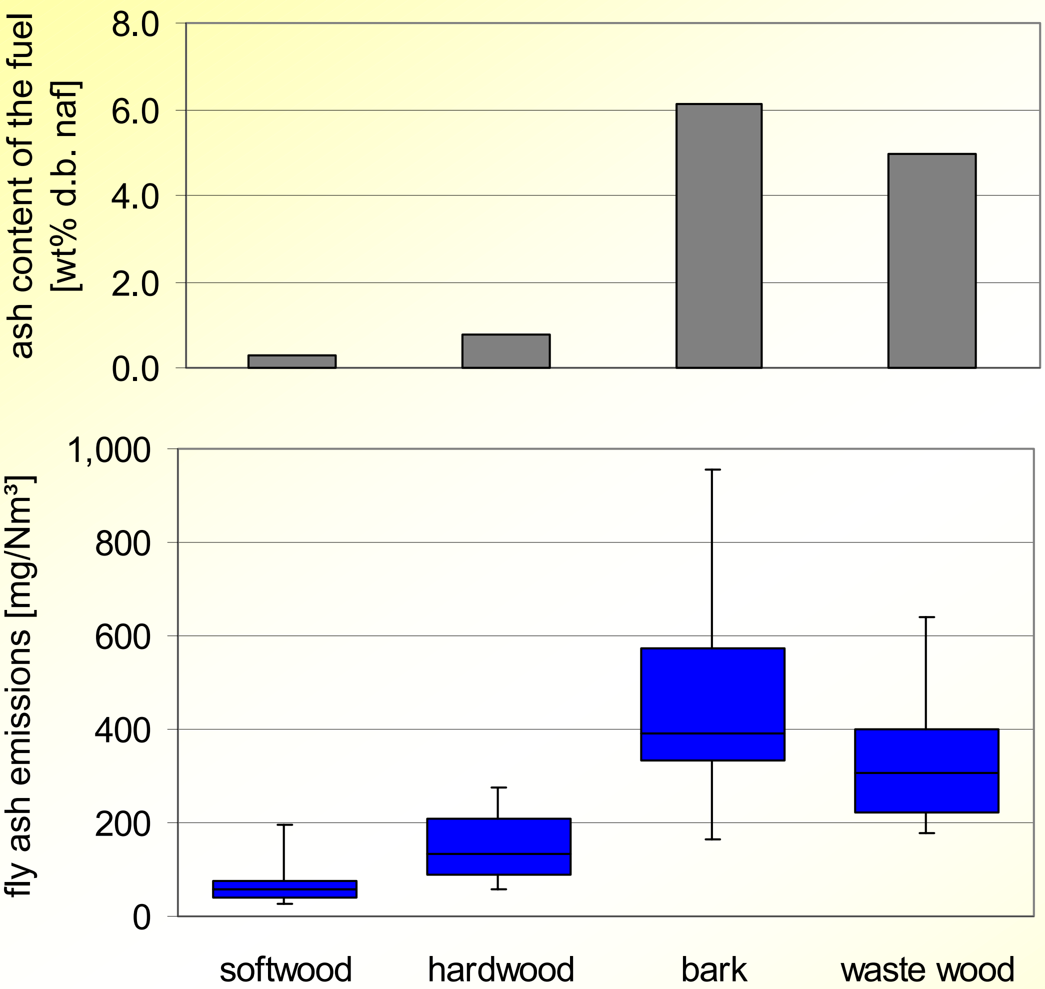
highest concentration

2nd highest concentration

std.dev. … standard deviation; d.b. … dry basis; w.b. … wet basis; naf … non ash free

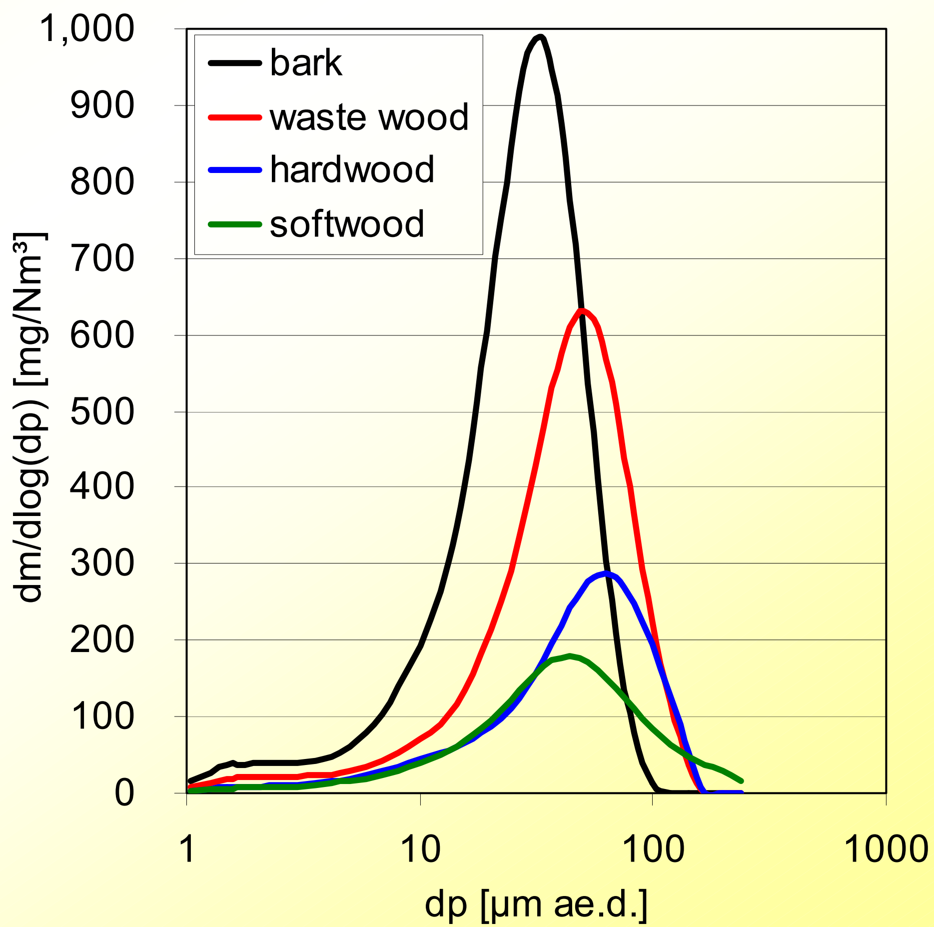
Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# PSD of coarse fly ashes and total fly ash concentrations in the flue gas at boiler outlet

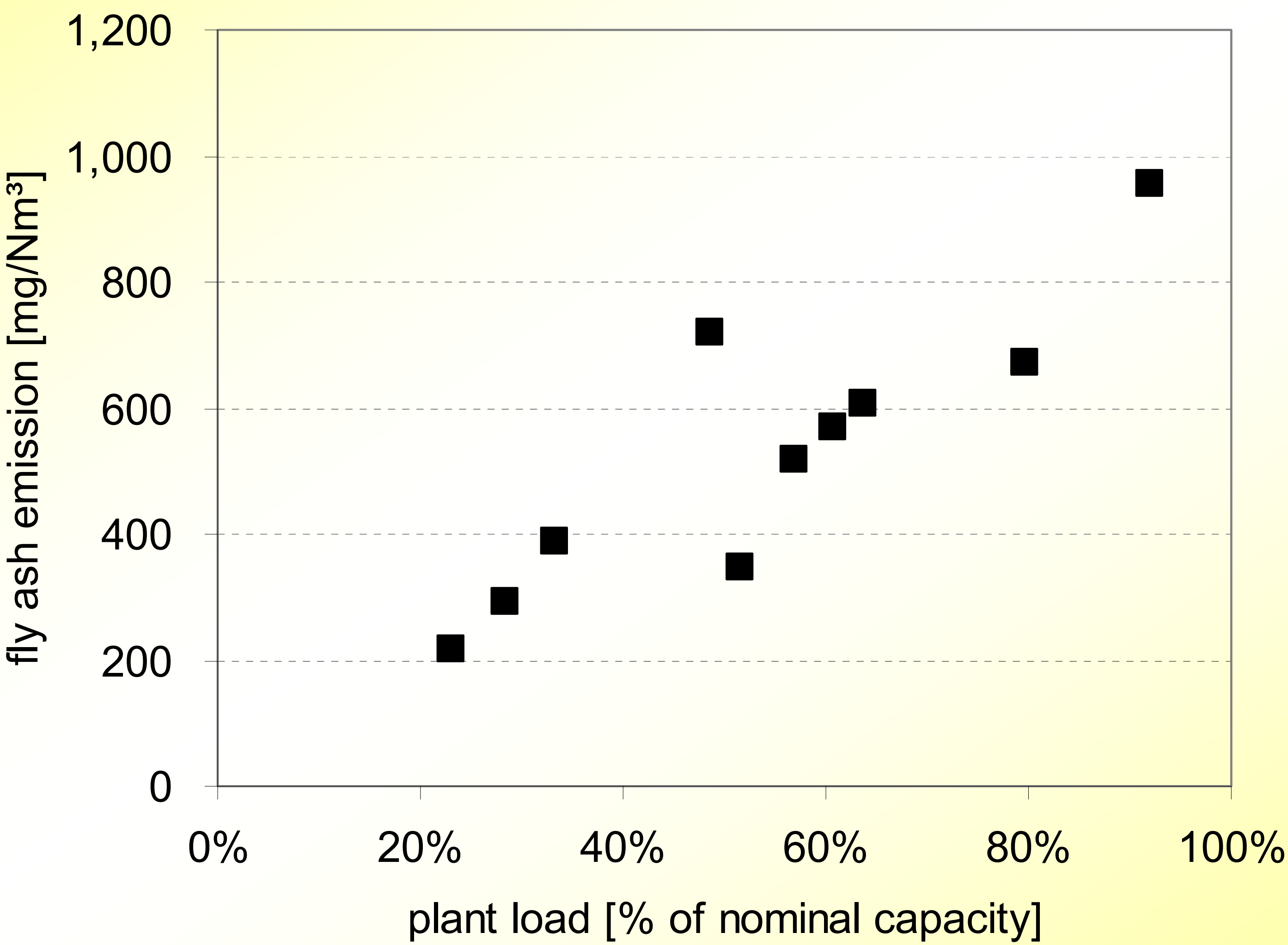



Concentrations related to dry flue gas and 13 vol.% $O_2$

PSD determined at the pilot-scale combustion unit at nominal load



# Fly ash concentrations in the flue gas vs. plant load - bark

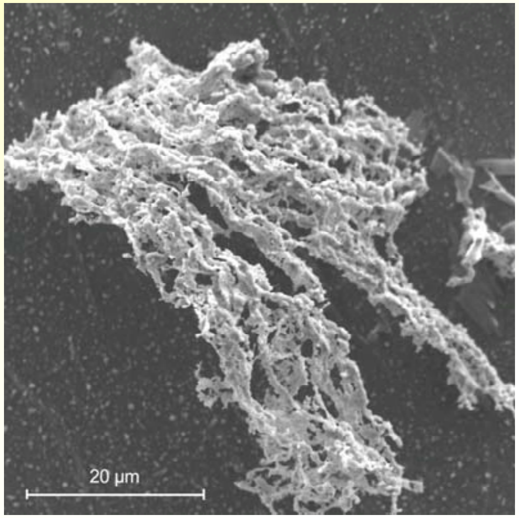


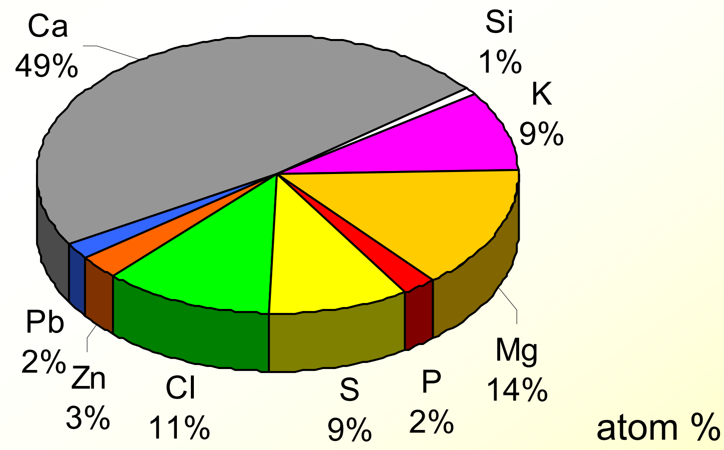

**Concentrations related to dry flue gas and 13 vol.% $O_2$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

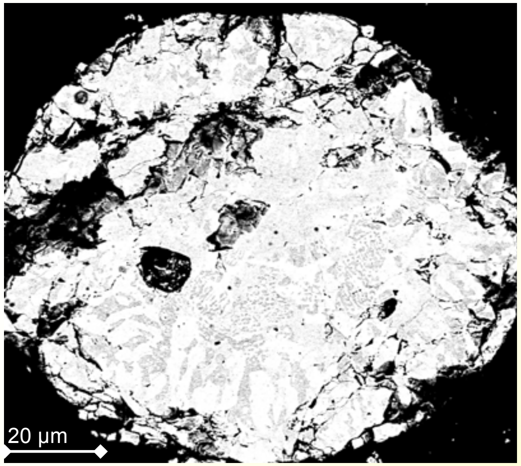
# Shape and chemical composition of coarse fly ashes

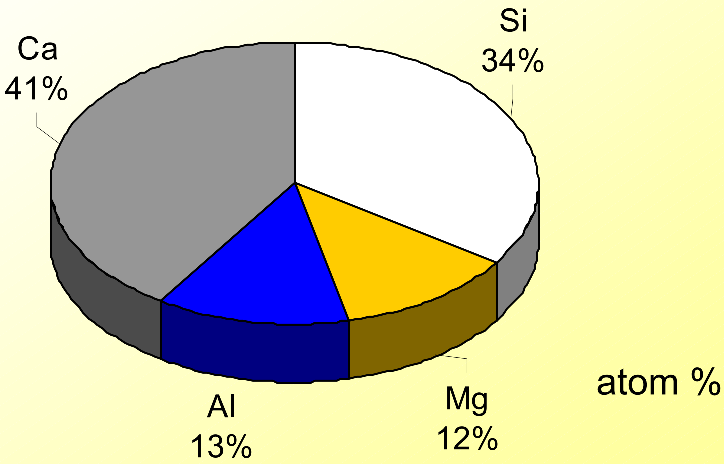
**Coarse fly ash particle from the combustion of hardwood**




**Coarse fly ash particle from the combustion of bark**

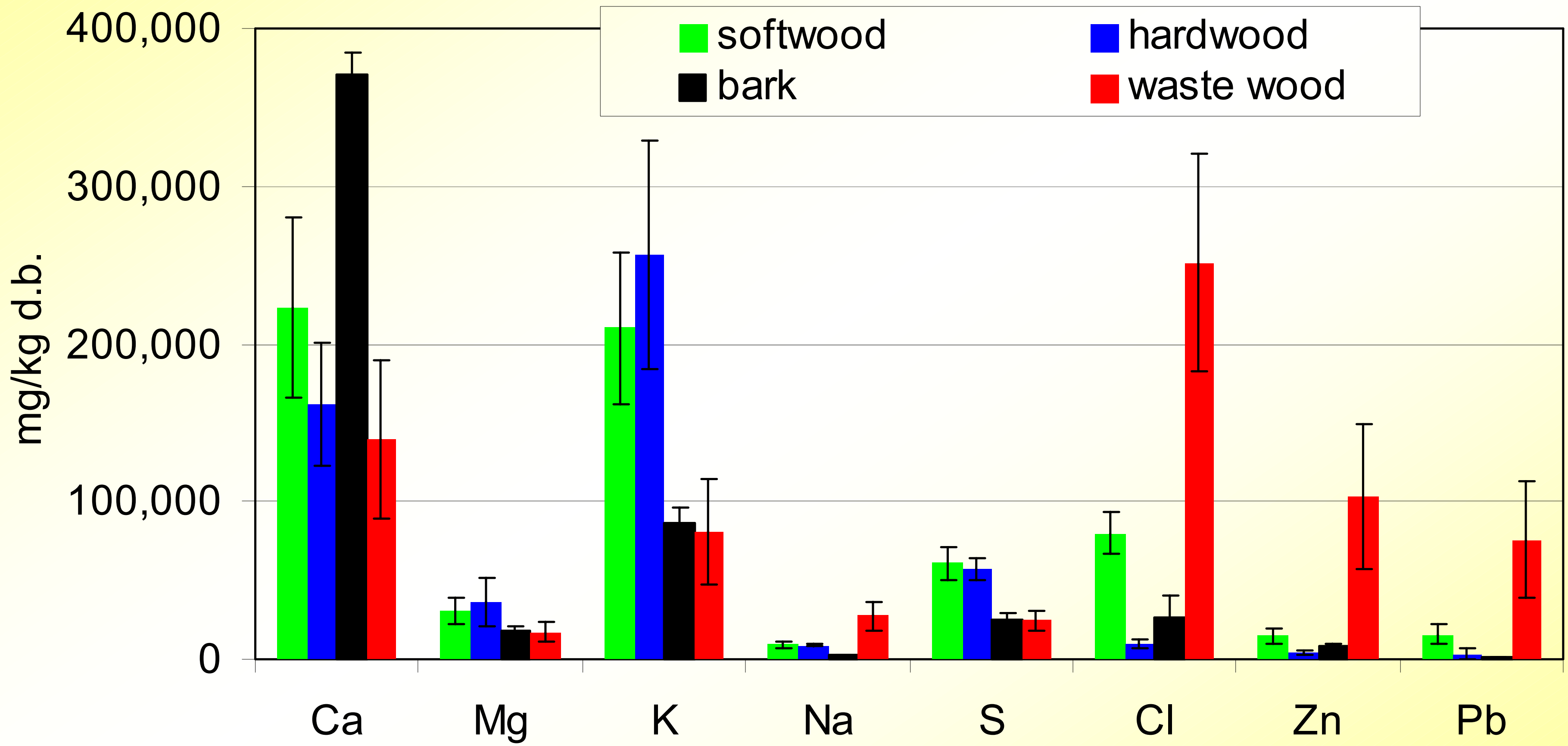



**Results from EDX-analyses; data normalised to 100% not considering $O_2$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

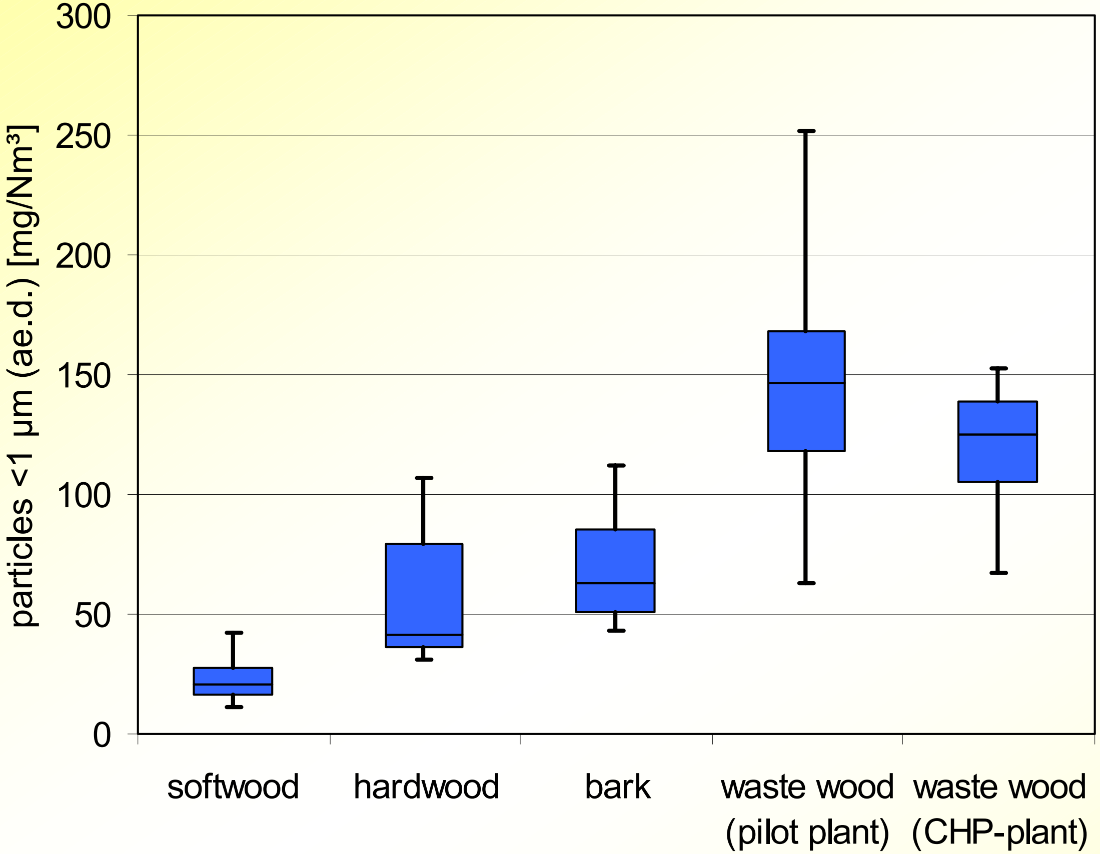
# Chemical composition of the fly ashes

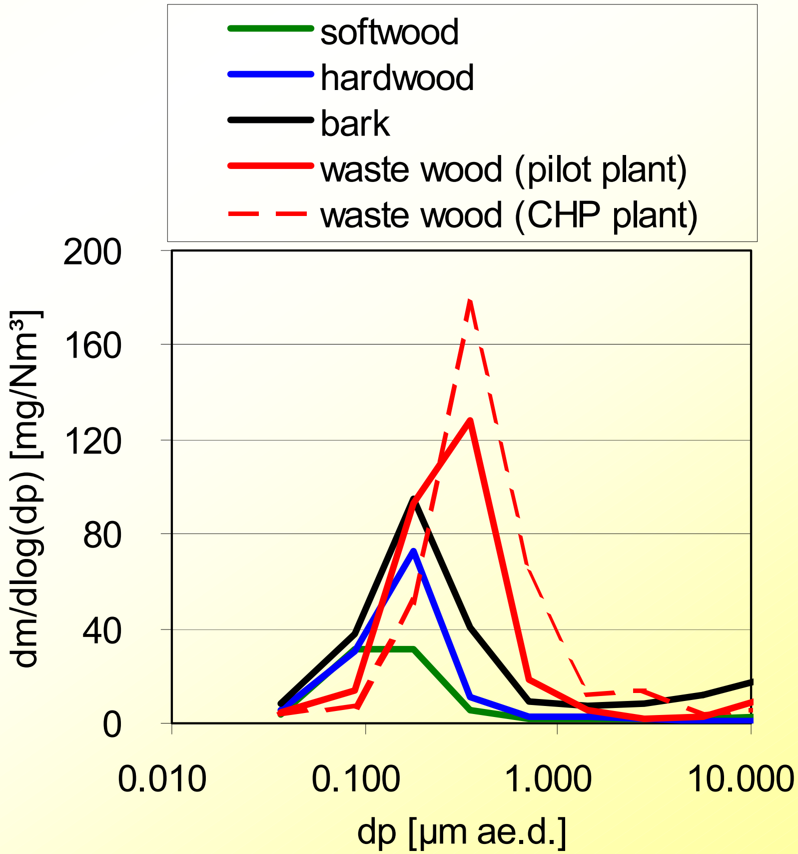



**d.b. … dry basis; sampling with silica filters, therefore no Si-analyses were performed**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# PSD and concentrations of aerosols in the flue gas at boiler outlet

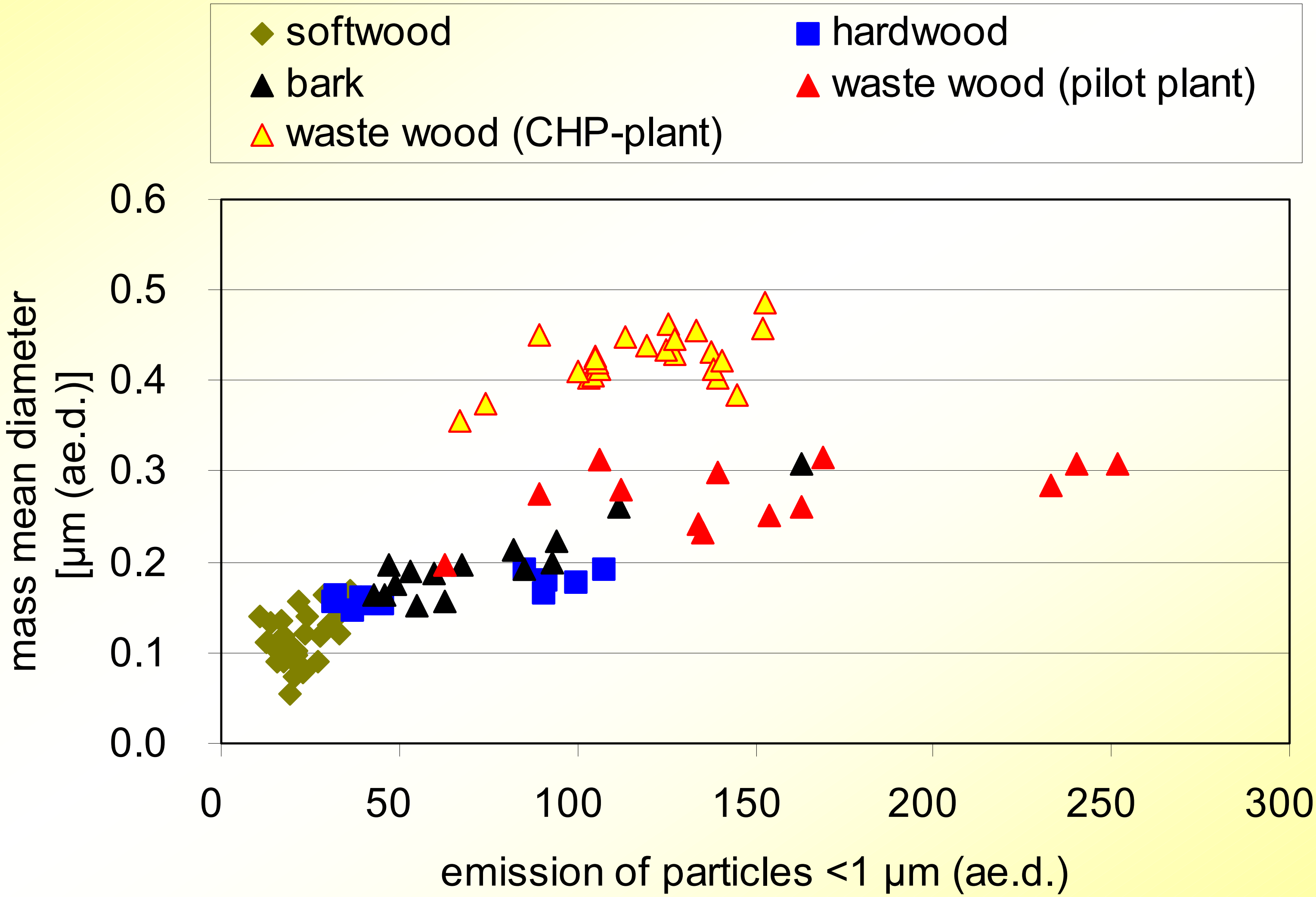



**Concentrations related to dry flue gas and 13 vol.% $O_2$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

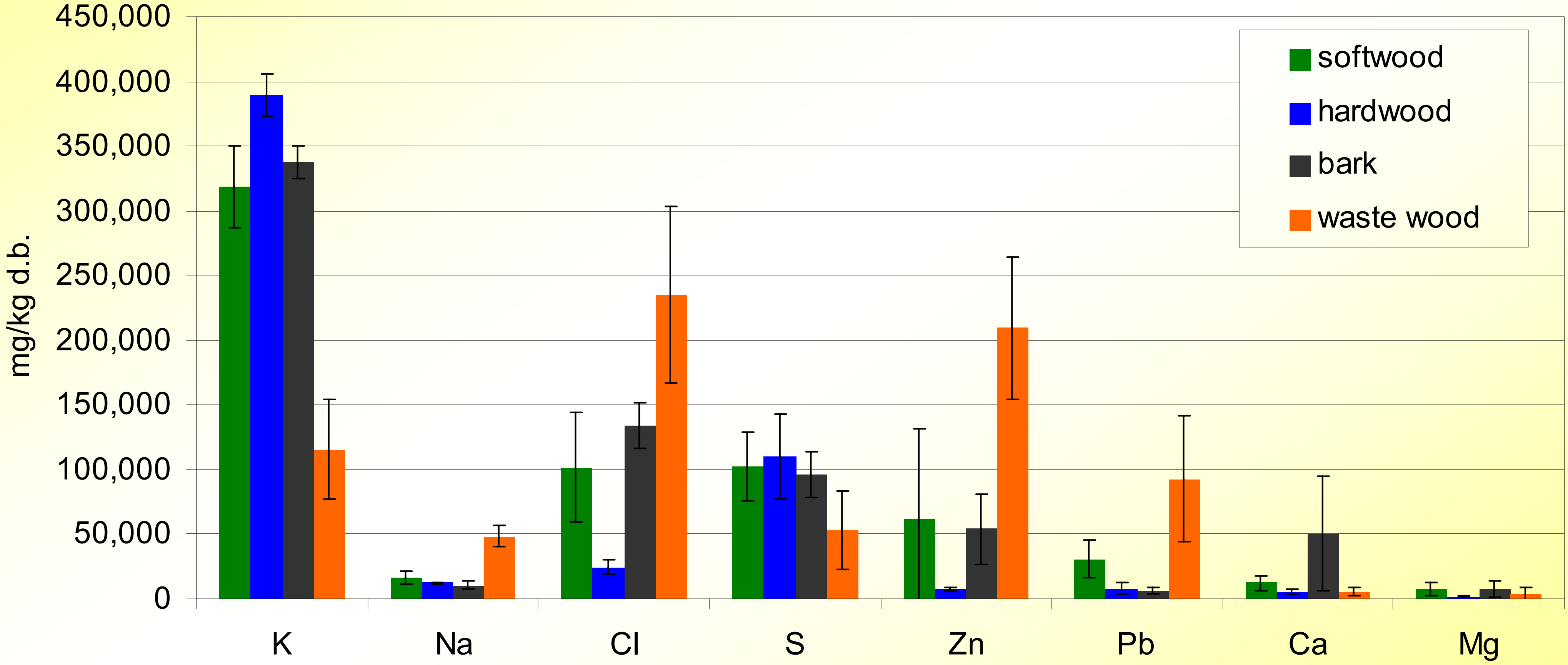
# Mean diameter of the aerosol fraction versus aerosol emissions




**Concentrations (mg/Nm$^3$) related to dry flue gas and 13 vol.% $O_2$**

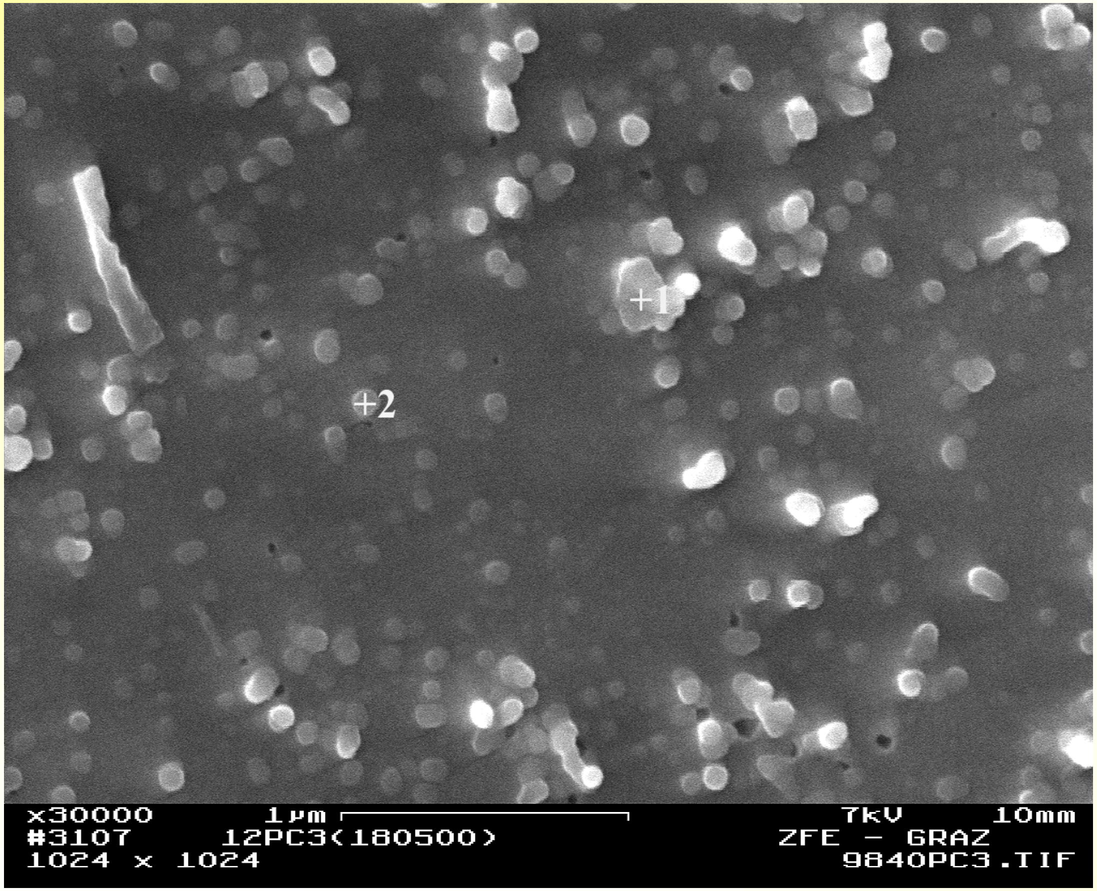
Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Chemical composition of aerosols

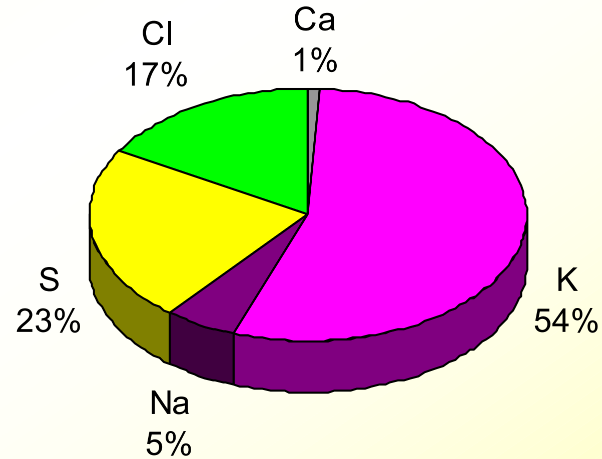


Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

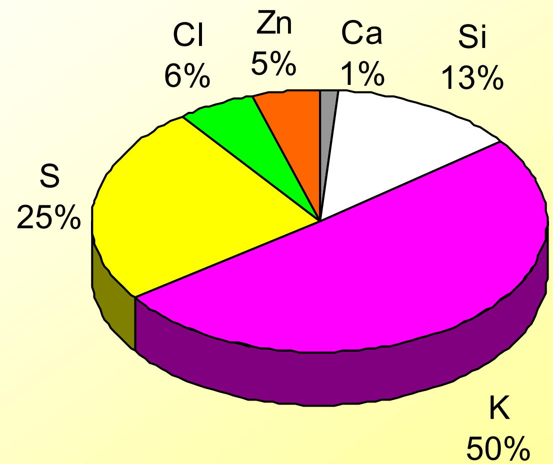
# Chemical composition of aerosols SEM/EDX analyses - softwood




**Particle 1**
**(atom%)**



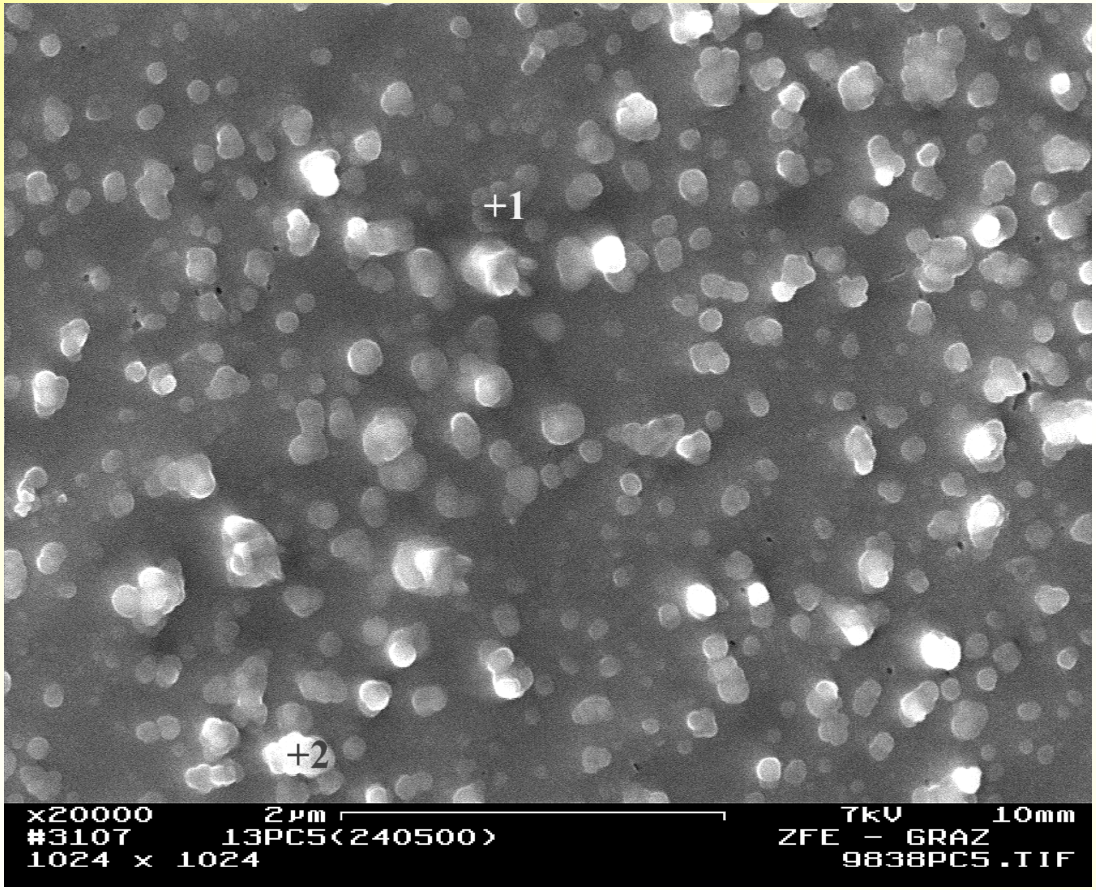

**Particle 2**
**(atom%)**



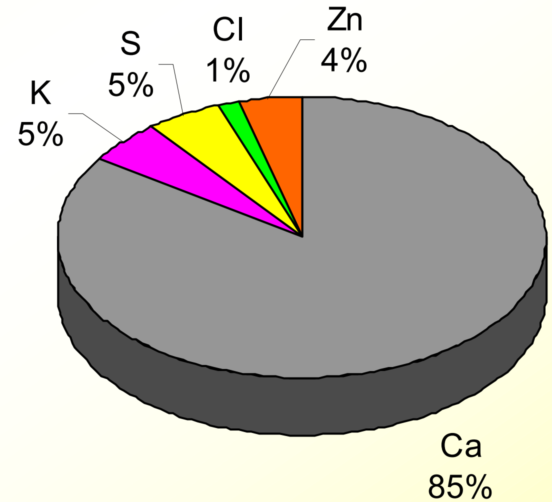

**Results from EDX-analyses; data normalised to 100% not considering $O_2$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

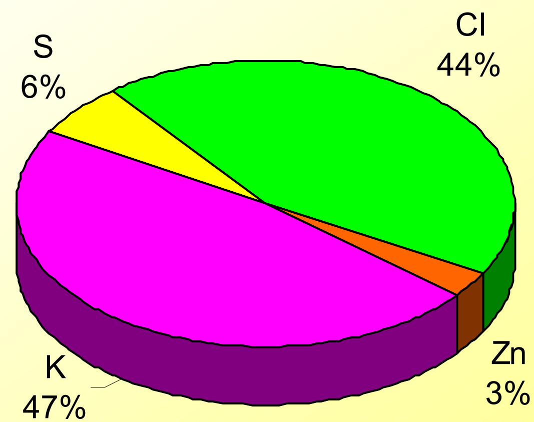
# Chemical composition of aerosols SEM/EDX analyses - bark




## Particle 1
(atom%)



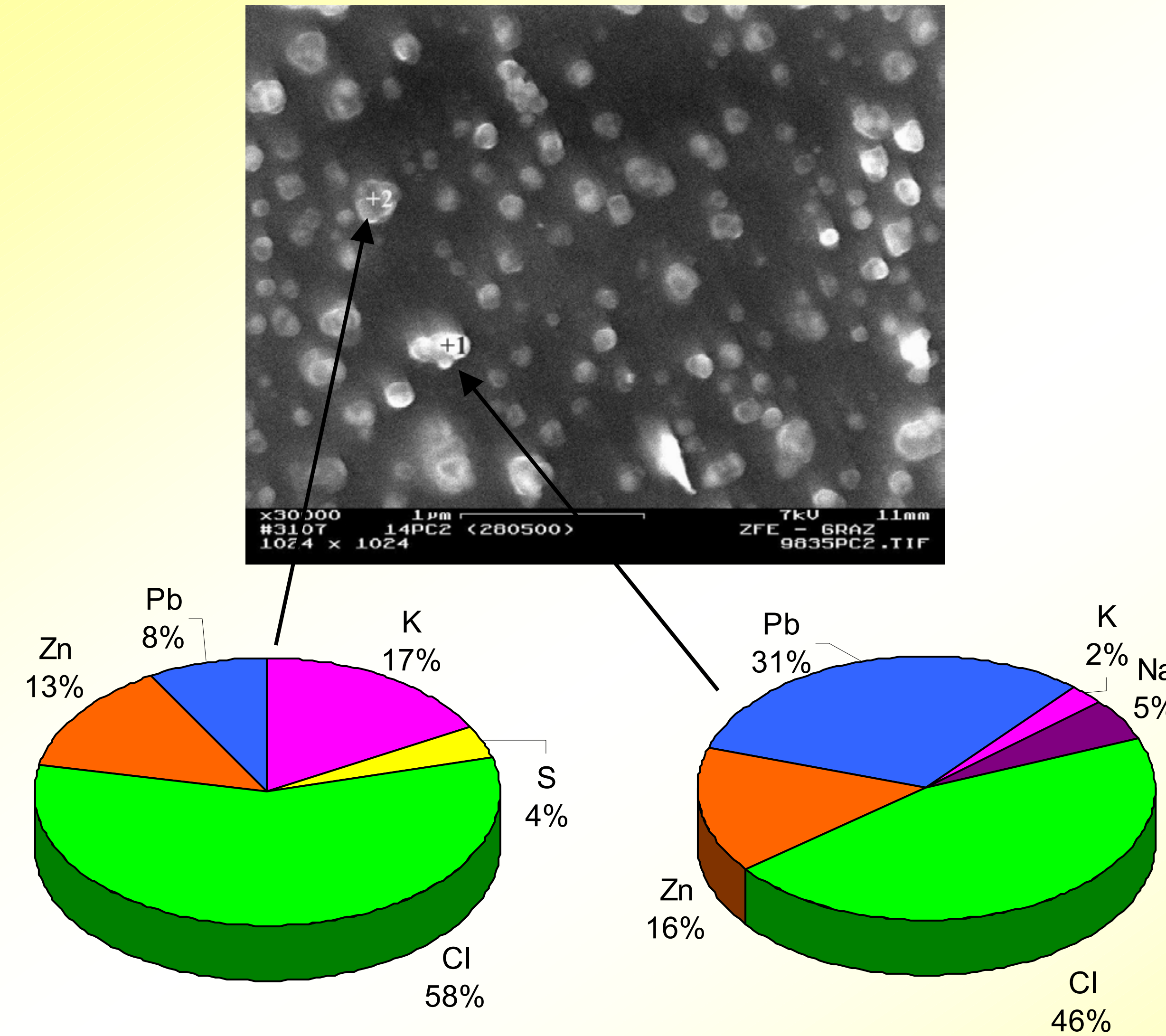

## Particle 2
(atom%)

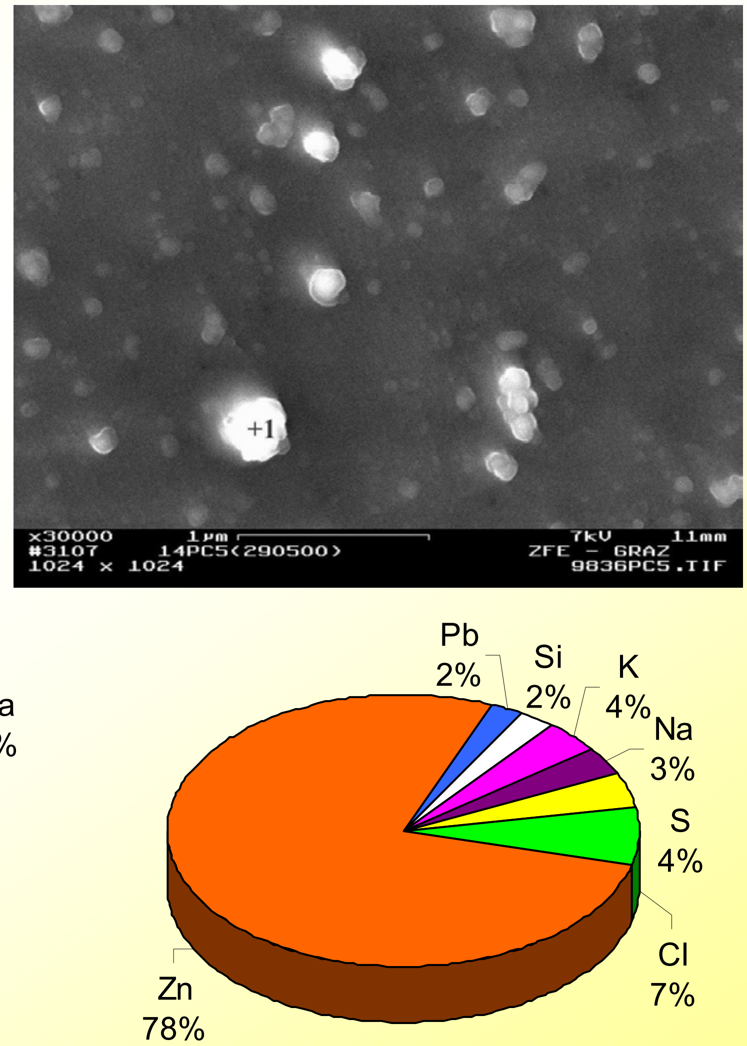



Results from EDX-analyses; data normalised to 100% not considering $O_2$

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Chemical composition of aerosols SEM/EDX analyses – waste wood

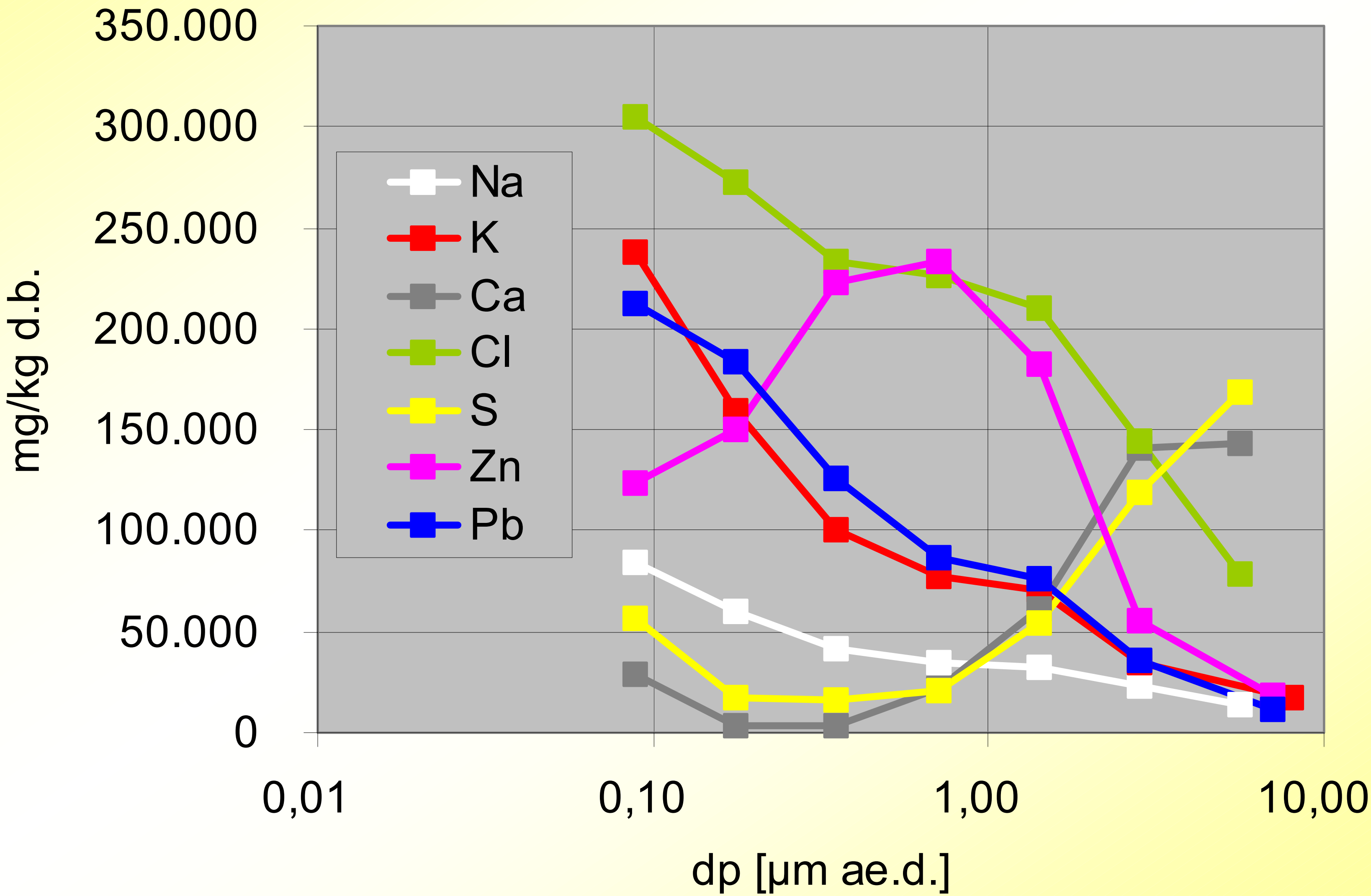



**Results from EDX-analyses (atom%); data normalised to 100% not considering $O_2$**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Chemical composition of aerosols versus particle size – waste wood



# Conclusions - coarse fly ash formation

## Characteristics of coarse fly ash emissions at the boiler outlet

- **particle size: up to 200 µm (ae.d.) with a peak at 30 - 70 µm (ae.d.)**
- **concentration: from about 100 mg/Nm³ up to 1,000 mg/Nm³**
- **chemical composition: Ca, Si, Mg and K are the matrix elements**

## Parameters influencing fly ash formation

### Parameters identified during the test runs

- **ash content of the fuel**
- **load of the combustion unit**
- **operation mode** (combustion air distribution over the fuel bed)

### Other known parameter

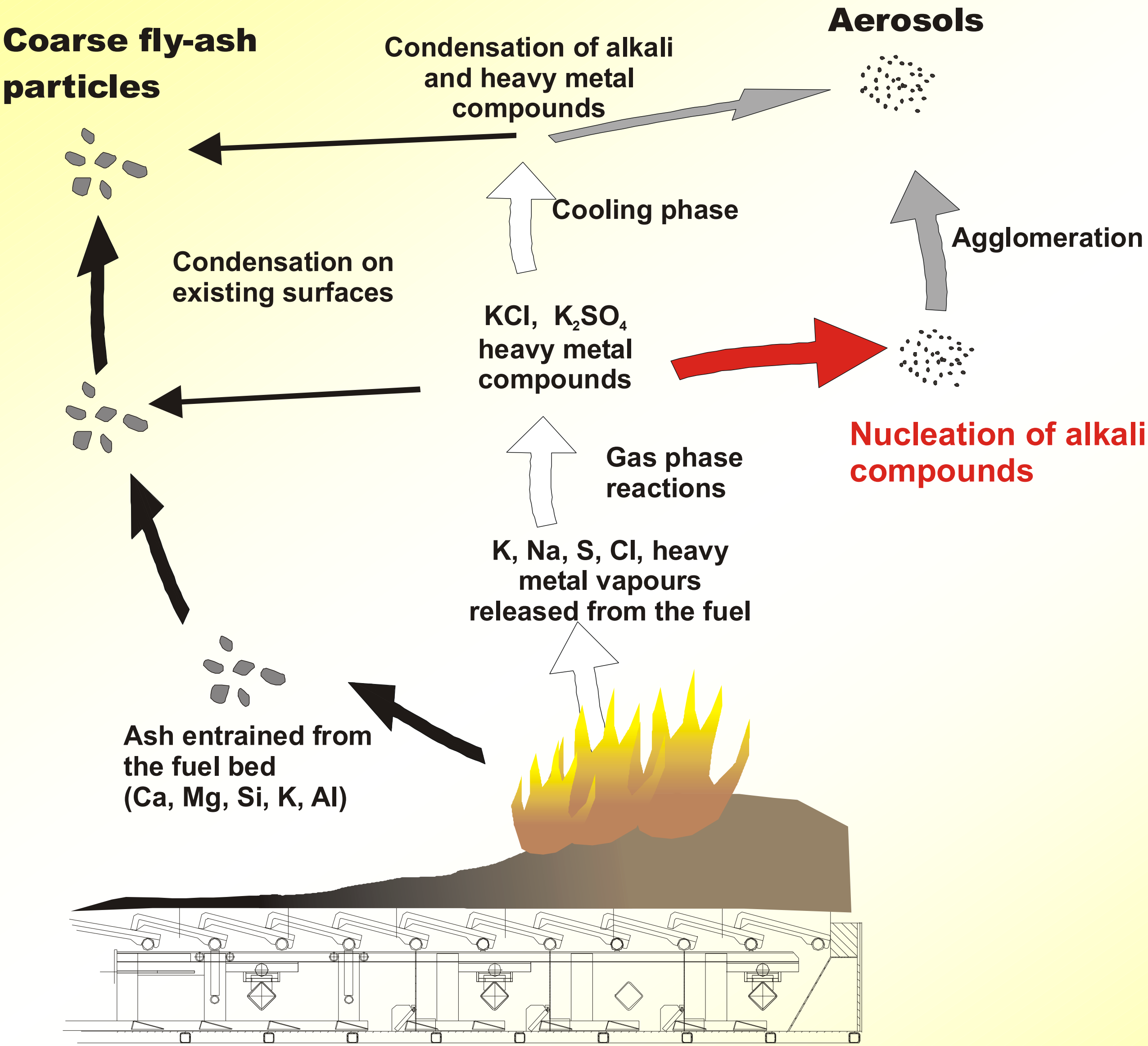
- **combustion technology**
- **furnace and boiler technology**

# Conclusions - aerosol formation

- **With increasing mass of aerosols formed the peak diameter of the particle size distribution also increases.**
  This indicates, that if the time/temperature history of the particles is comparable, the particle number concentration always remains in the same order of magnitude.
- **The peak of the resulting particle size distribution may change if the time-temperature profile is changed.**
  e.g.: different geometries or types of furnaces and boilers
- **The amount of aerosols formed as well as their chemical composition mainly depend on the chemical composition of the biomass fuel used.**
- **Three different processes concerning aerosol formation in fixed-bed combustion of woody biomass have been identified.**
  These processes indicate the location in the furnace / boiler where aerosol formation (nucleation) mainly takes place, which is of relevance regarding possibilities to influence aerosol formation.

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Aerosol formation processes - wood chips

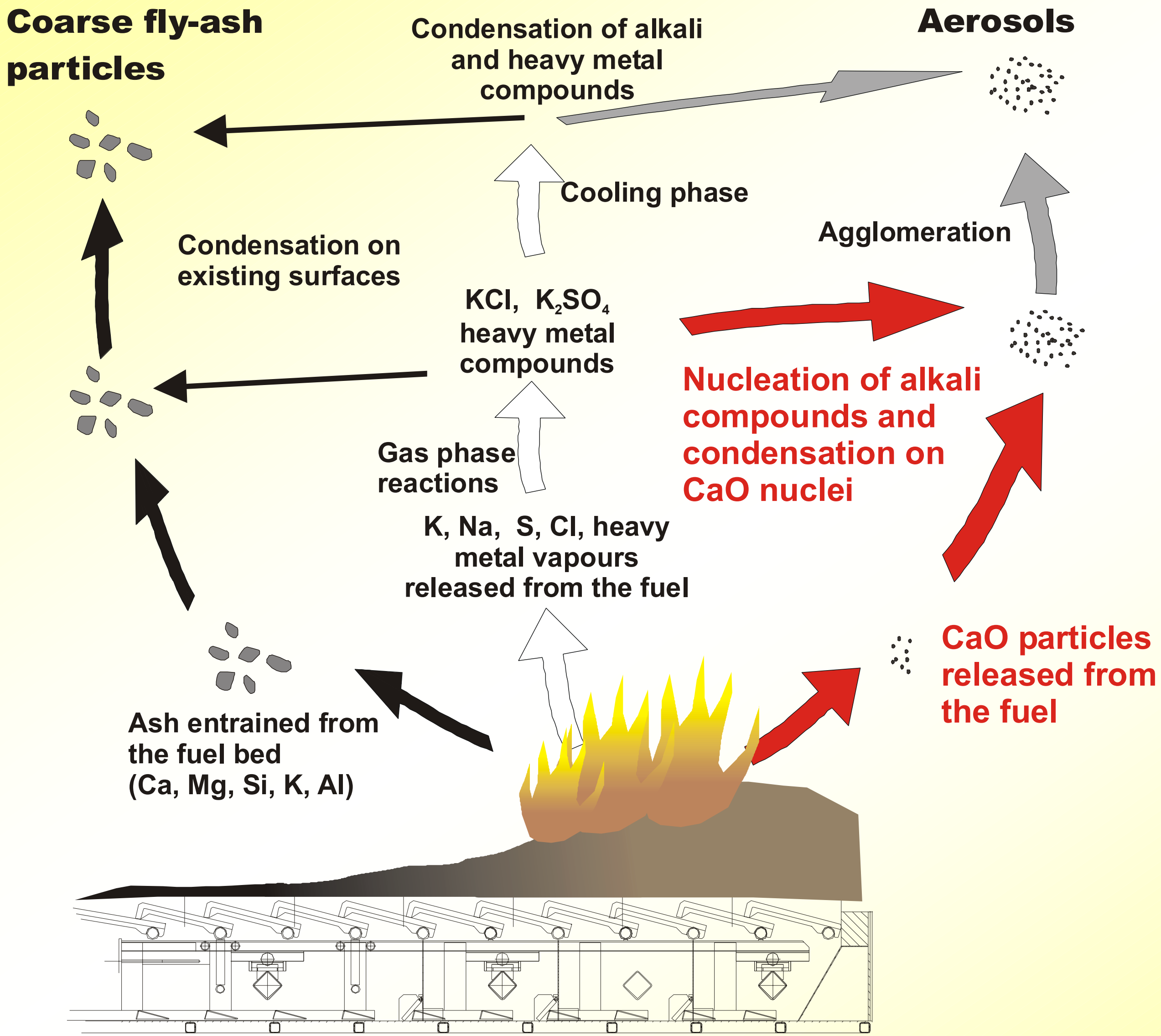


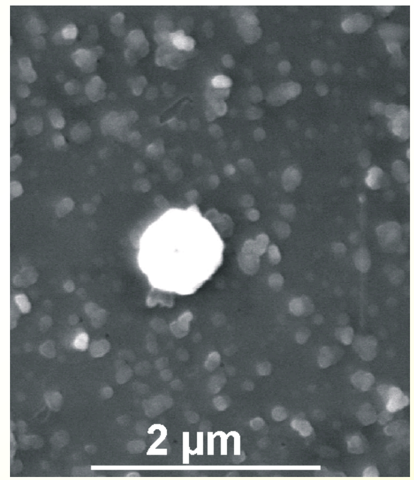

**Most relevant mechanism**

**nucleation of alkali metal salts dominating**

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Aerosol formation processes – bark




| | atom% |
|---|---|
| Si | 0.7 |
| Ca | 36.3 |
| Na | 0.2 |
| K | 2.2 |
| Zn | 1.8 |
| Si | 2.2 |
| Mg | 1.5 |
| Cl | 0.6 |
| O | 53.1 |

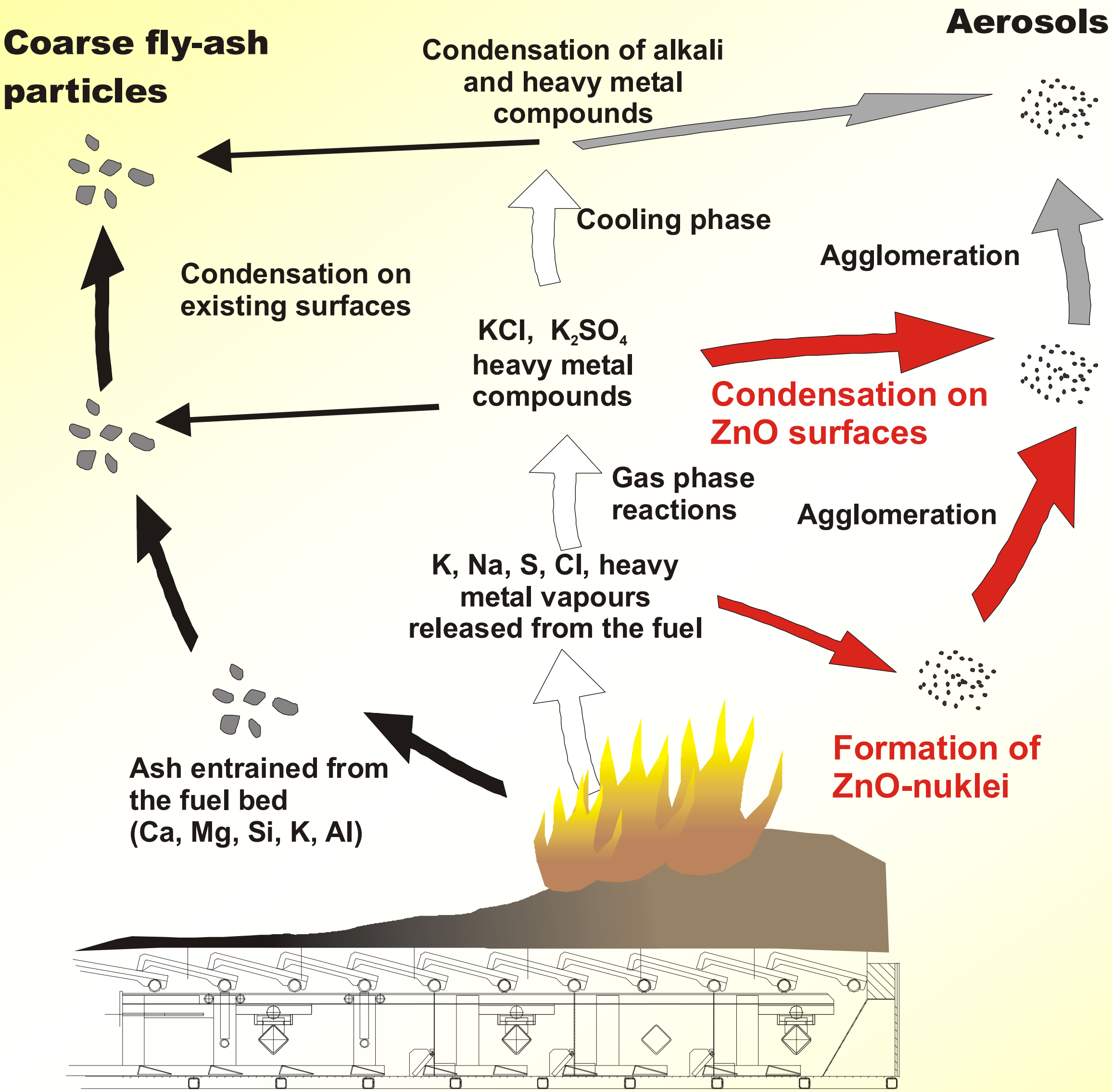
## Most relevant mechanisms

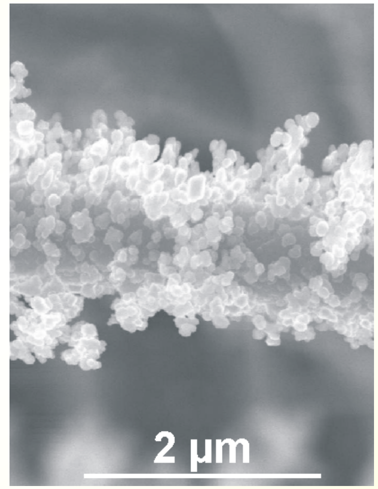
Ca-nuclei present

condensation on Ca-nuclei and nucleation of alkali metal salts as competing processes

Institute of Chemical Engineering
Fundamentals and Plant Engineering
Graz University of Technology

# Aerosol formation processes - waste wood




| | atom% |
|---|---|
| Zn | 30.5 |
| Si | 7.1 |
| Ca | 3.4 |
| S | 1.1 |
| K | 1.0 |
| O | 54.9 |

ZnO particles sampled directly in the furnace on a hot gas Si-filter

**Most relevant mechanisms**

nucleation of ZnO dominant

alkali metals and heavy metal vapours (specially Pb) condense on ZnO-surfaces

# Summary - aerosol and fly ash emissions at the boiler outlet

## Results from test runs at the pilot-scale combustion unit

| | | aerosols | fly ashes |
|---|---|---|---|
| softwood | mg/Nm³ | 11 – 43 | 26 – 197 |
| hardwood | mg/Nm³ | 31 – 107 | 58 – 274 |
| bark | mg/Nm³ | 42 – 112 | 162 – 958 |
| waste wood | mg/Nm³ | 62 - 251 | 176 - 640 |

All concentrations related to dry flue gas and 13 vol.% $O_2$.

Measurements performed at different loads between 30 and 100% of the nominal boiler capacity.

# Conclusions - aerosol precipitation

## Applicability of technologies for aerosol and fly ash precipitation

| | | multi-cyclone | flue gas cond. unit | dry ESP | wet ESP | baghouse filters |
|---|---|---|---|---|---|---|
| cut size | [µm] | ~5 | | ~0.1 | ~0.1 | ~0.1 |
| separation efficiency | [%] | 85 - 95 | 50 - 90 | 95 – 99.9 | 95 – 99.9 | 99 – 99.9 |
| Chemically untreated hardwood, softwood and bark | | | | | | |
| emissions < 150 mg/Nm³ | | X | X | X | X | X |
| emissions < 50 mg/Nm³ | | | X | X | X | X |
| emissions < 20 mg/Nm³ | | | | | X | X |
| emissions < 10 mg/Nm³ | | | | | | X |
| Waste wood | | | | | | |
| emissions << 10 mg/Nm³ | | | | | | X |

cond. … condensation

# Conclusions - aerosol precipitation

For medium- to large-scale combustion units economically sound dust precipitation technologies with high efficiencies are available.

For small-scale systems no efficient low-cost system (only multi-cyclones) are available.

# Outlook

- **Investigations concerning the release behaviour of aerosol forming elements from different biomass fuels.**
  The investigations have shown, that a reliable prediction of aerosol formation is only possible if the release behaviour of the relevant aerosol forming elements is known.
- **Advanced modelling of aerosol formation and behaviour in biomass combustion units.**
- **Development of an efficient and cost effective aerosol precipitation technology for small-scale applications.**