# Chemical and physical properties of biomass combustion aerosols

Jorma Jokiniemi, Jarkko Tissari, Heikki Lamberg and Olli Sippula

University of Eastern Finland

Fine Particle and Aerosol Technology Laboratory

UNIVERSITY OF
EASTERN FINLAND

**ILMARI - Aerosol physics, chemistry and toxicology research unit**

ILMARI research infrastructure offers versatile possibilities for studies on characteristics of emissions and aerosol particles, their atmospheric effects and toxicological properties.

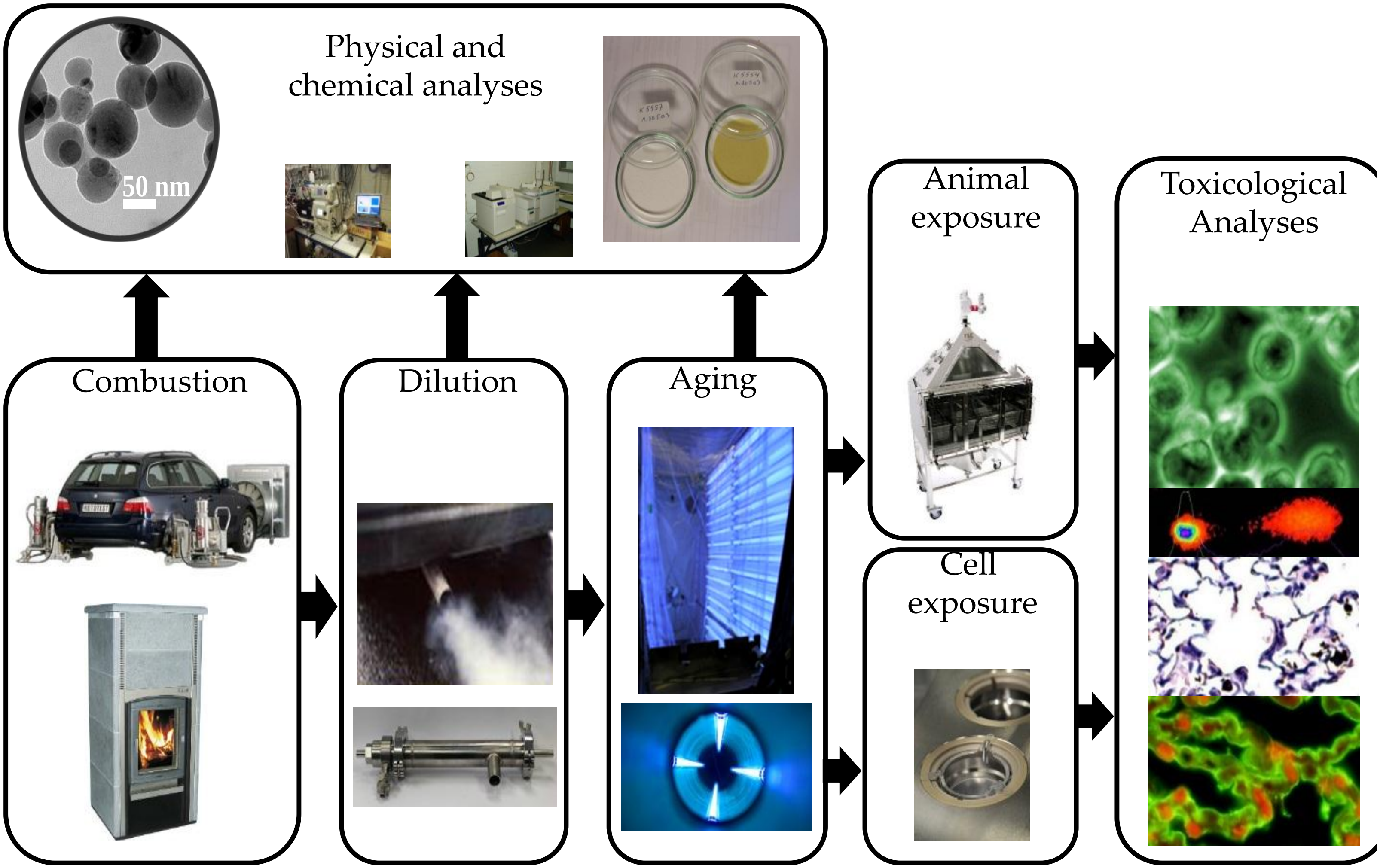



Fig 1. Schema of the ILMARI Research Unit
www.uef.fi/ilmari

# Exposure

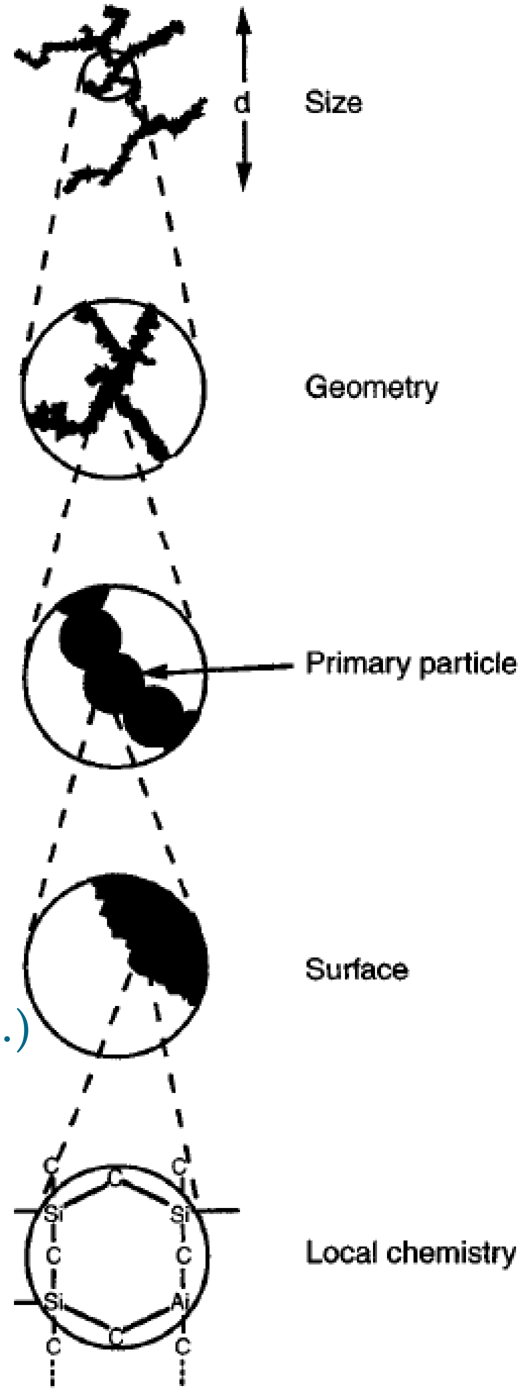
**Properties:**

Combustion particles are usually agglomerates composed of small primary particles
or rods, neeedles, nanotubes…

-Agglomerate size and conc.
(lung deposition)

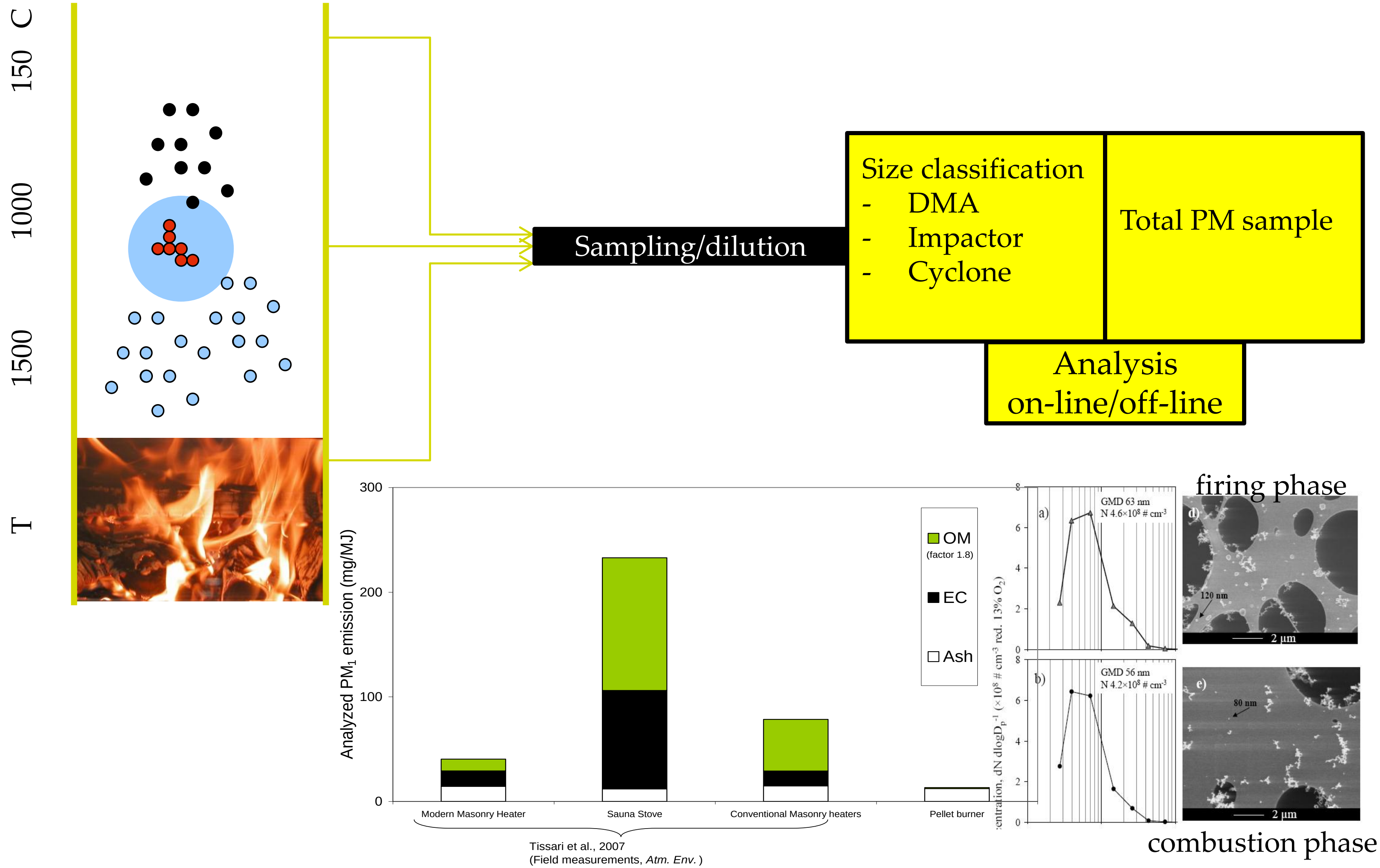
-Primary particle size (translocation…)

**-Surface properties (toxic effects…)**




Schematic structure of an agglomerate in 2-dimensional space.

Scanning down to view ever higher magnification

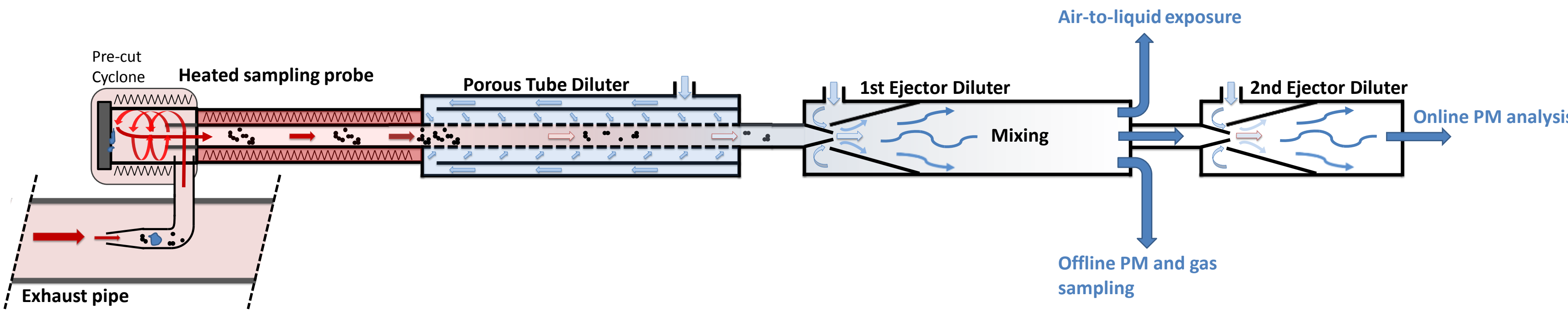


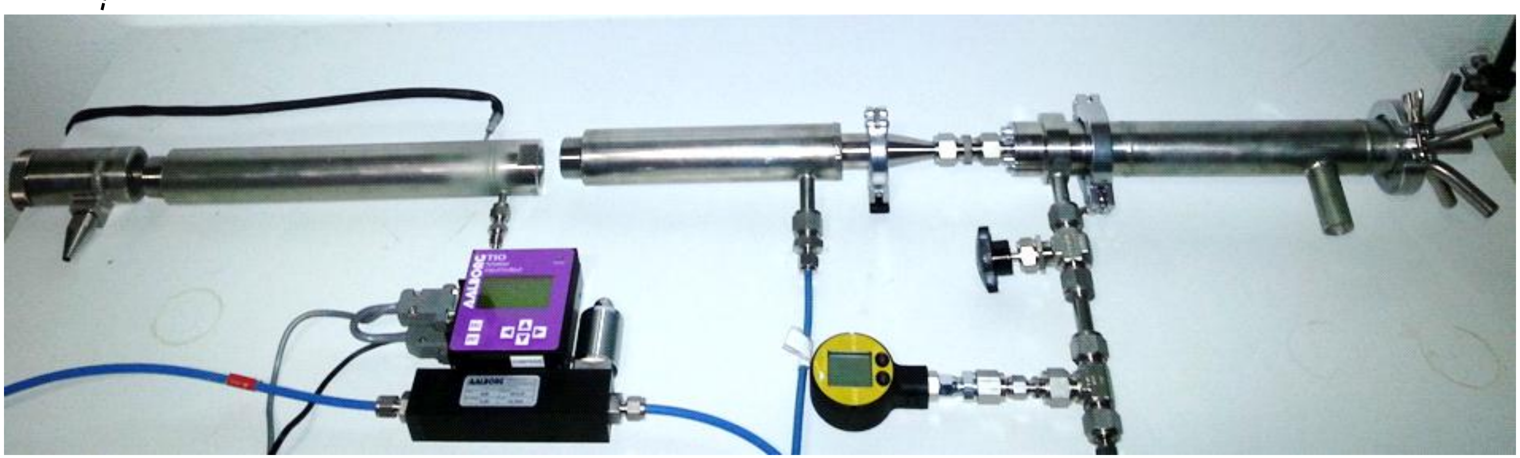

# Combustion aerosol sampling and physico-chemical properties

# Sampling and dilution techniques

Compact and fully adjustable diluting sampling setup for combustion exhaust measurements

– Based on the combination of porous tube diluter and ejector diluter



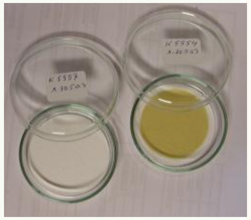



Tissari et al. (2008) *Energy & Fuels;* Sippula et al. (2012) *Aerosol Science & Technology*

# • Measurements & Analyses

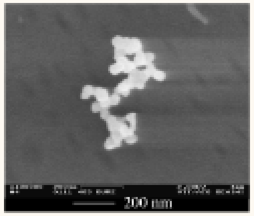
## PM Chemical composition:

- **Thermal-optical carbon analysis**, TOC (Sunset)
- **GC-MS** (Agilent)
- **TEM-EDS** (Jeol)
- **SEM-EDS** (Zeiss)
- X-ray diffraction, **XRD** (Bruker)
- **ICP-MS** (w. Eurofinns)
- **Ion chromatography** (w. Eurofinns)
- **Raman spectroscopy**: (Bruker)
- **Sp-AMS-ToF** (Aerodyne)



## PM Physical properties:

- Scanning mobility particle sizer, **SMPS** (TSI)
- Fast mobility particle sizer, **FMPS** (TSI)
- Electrical low pressure impactor, **ELPI** (Dekati )
- Dekati low pressure impactor, **DLPI** (Dekati), PM10 impactors (Dekati)
- Nanoparticle surface area monitor, **NSAM** (TSI)
- Tapered element oscillating microbalance, **TEOM** (Thermo Scientific)
- Aerosol particle mass analyzer, **APM** (Kanomax)



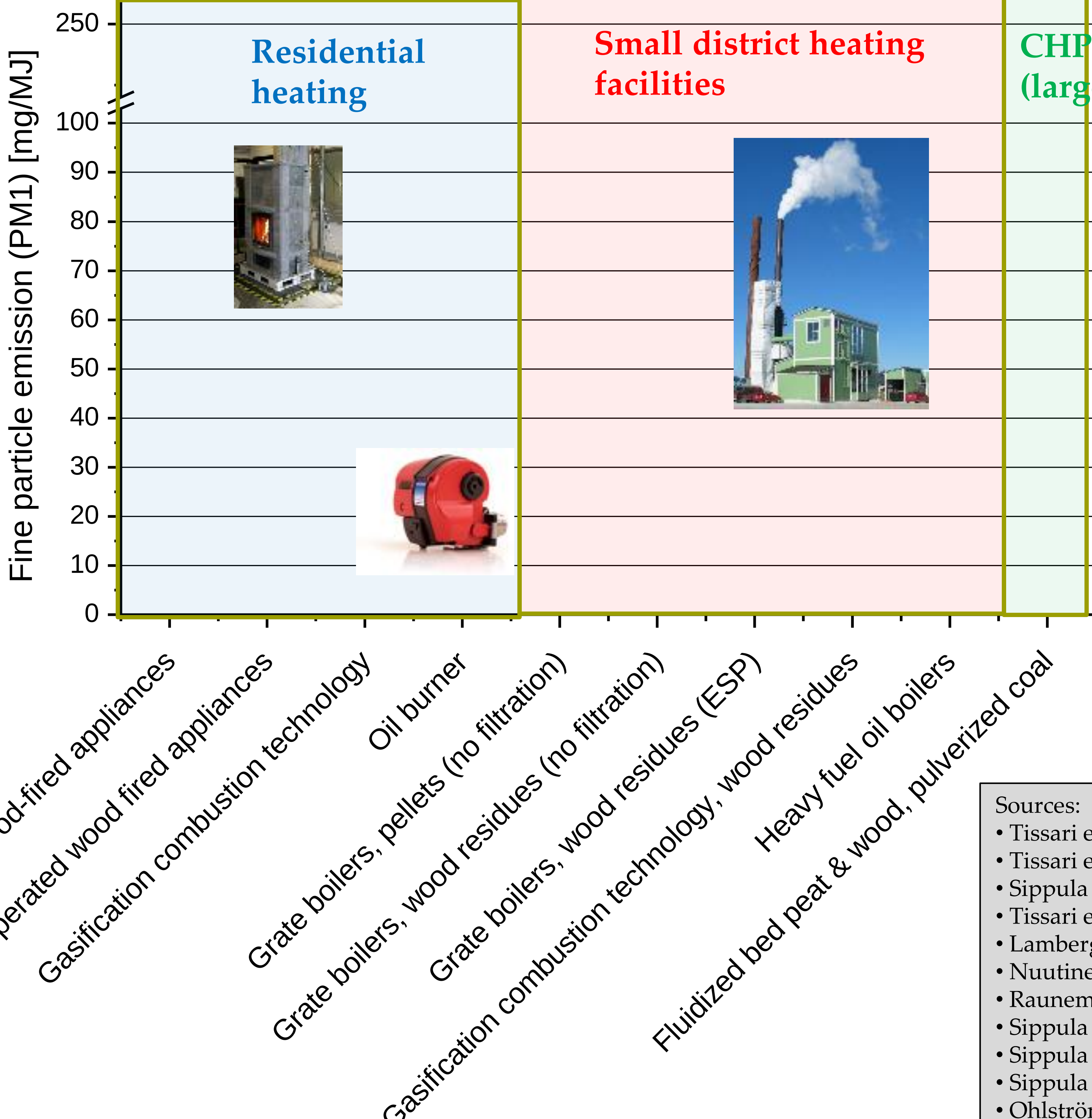

## Gas-phase composition:

- **FTIR** (Gasmet) Multicomponent analyzer
- ABB single component gas analyzers (O2, CO, NO, NO2, THC)
- **PTR-ToF** (Ionicon) w. Physics department
- **GC-MS** (Agilent)

## Modeling:

- Computational Fluid Dynamics (CFD, Ansys)
- Thermodynamic Equilibrium (FactSage)
- Aerosol Dynamics Modeling (KCAR-code)

**Emission factors:**




Sources:

- Tissari et al., 2009
- Tissari et al., 2003
- Sippula et al., 2007
- Tissari et al., 2008
- Lamberg et al., 2009
- Nuutinen et al., 2009
- Raunemaa et al., 2005
- Sippula et al., 2009a
- Sippula et al., 2009b
- Sippula et al., 2009c
- Ohlström et al., 2006

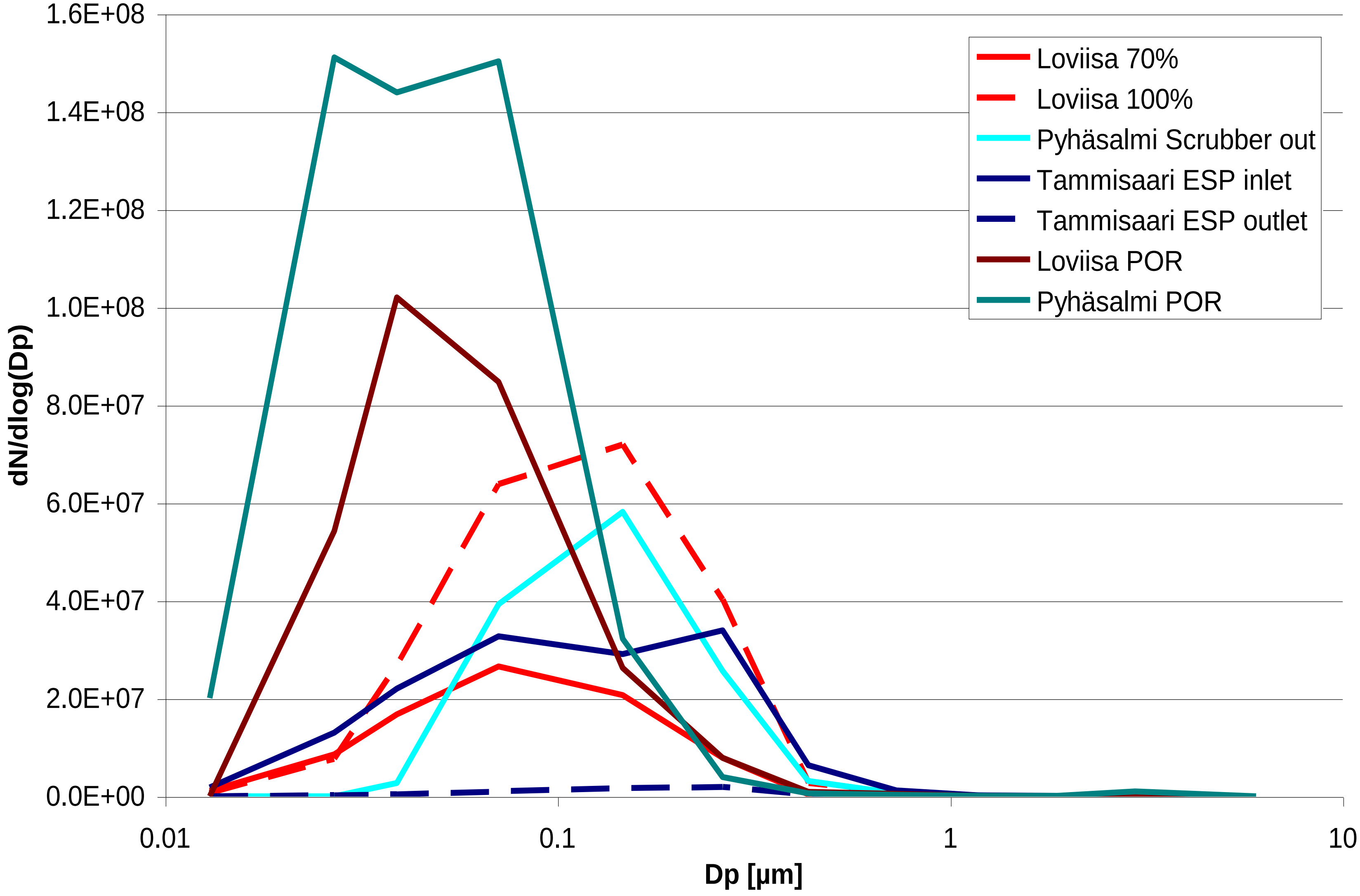
# Methodologies: Combustion units

**Field measurements**

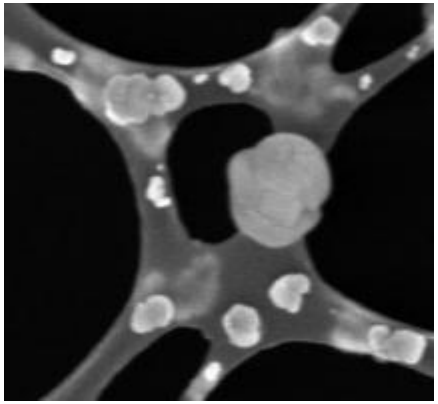
**Grate fired heating plants 1-15 MW**

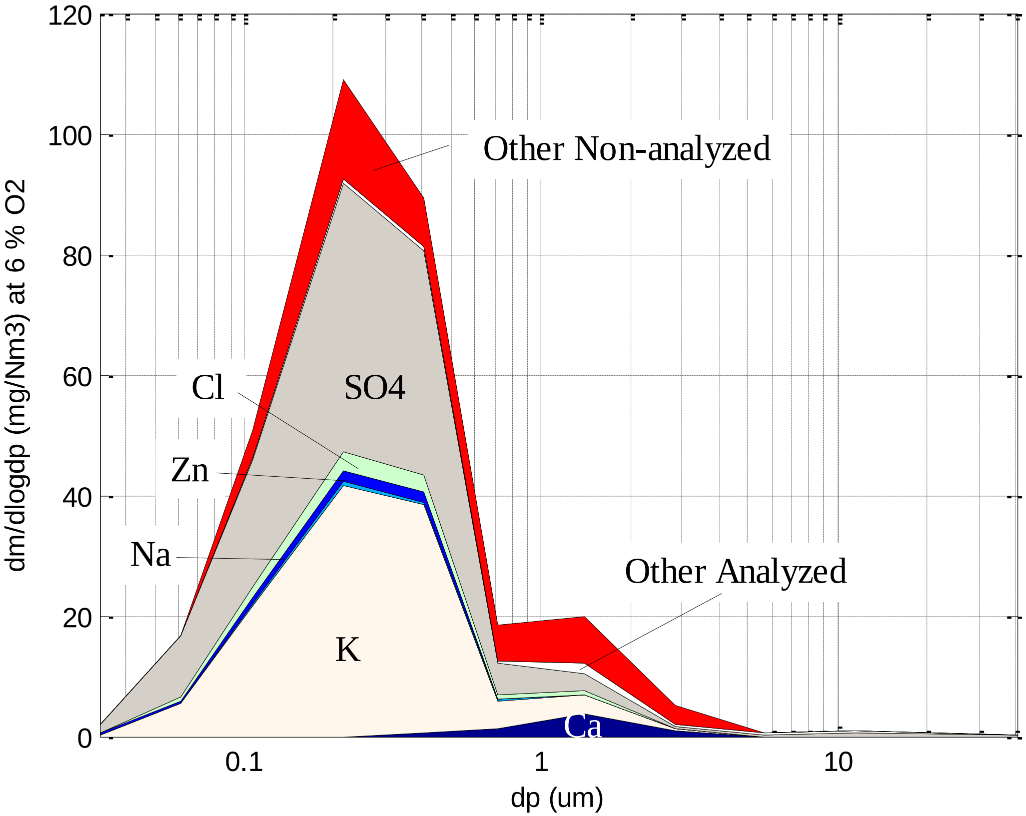
Sippula et al. (2014) *Environ. Sci. Technol*

# ELPI, number size distributions

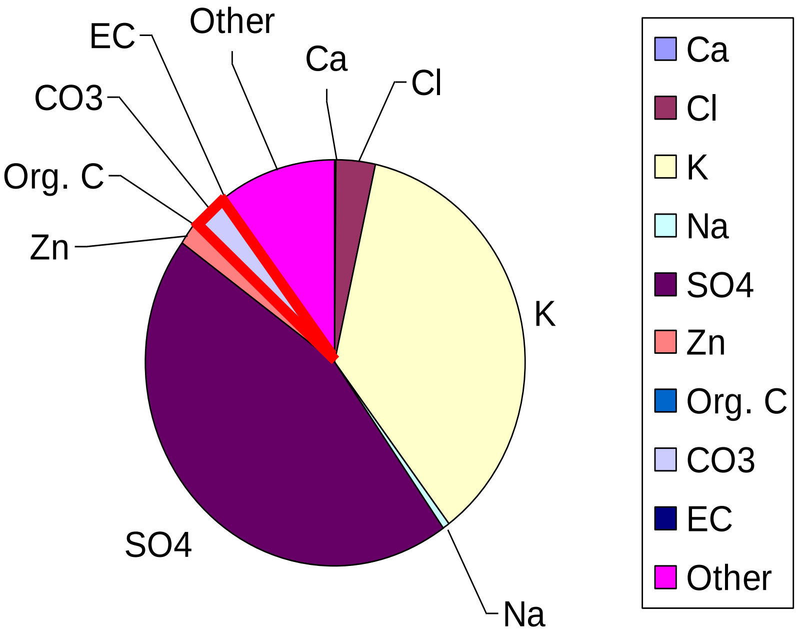


# Chemical composition: Grate boiler, wood residues



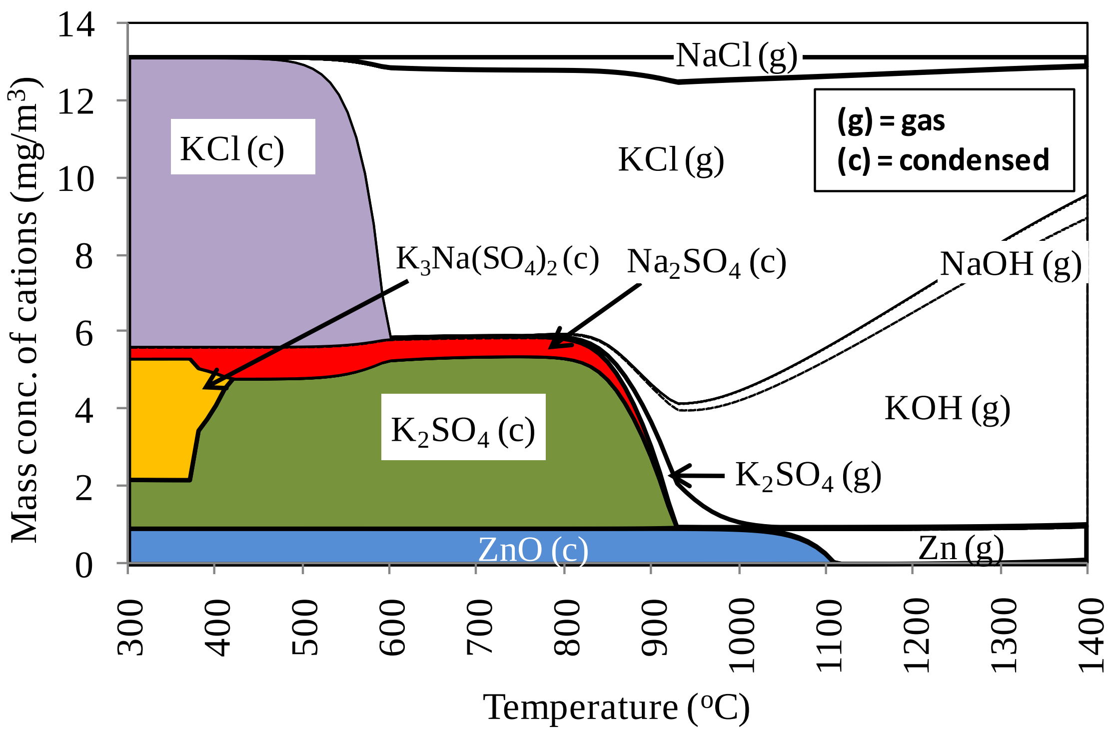


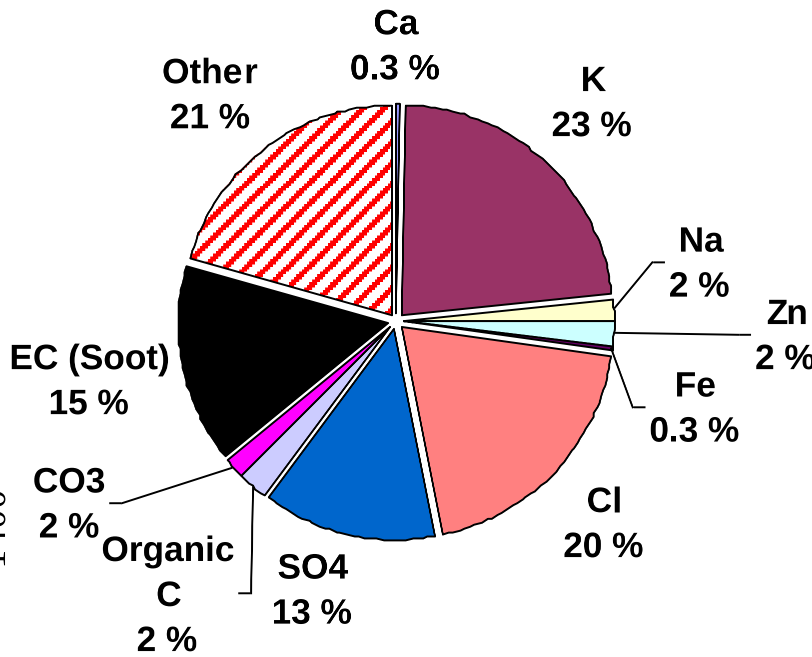

## PM1.0 chemical composition:



# PM1 Chemical Composition:
## Grate boiler (0.5 MW), Stem-bark pellets

**Thermodynamic equilibrium calculation (FactSage)**



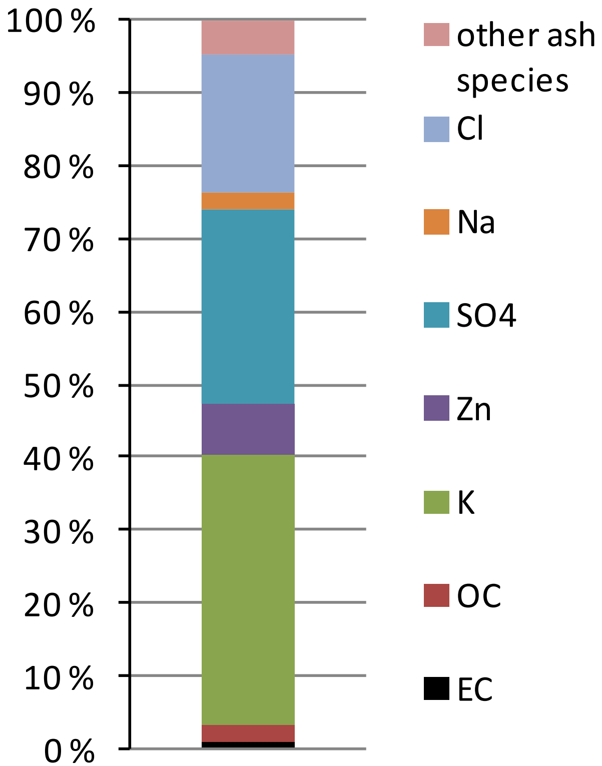



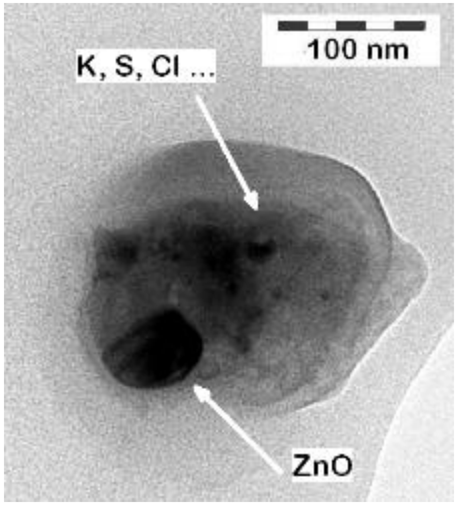
**Modern continuously operated small-scale wood boiler:**

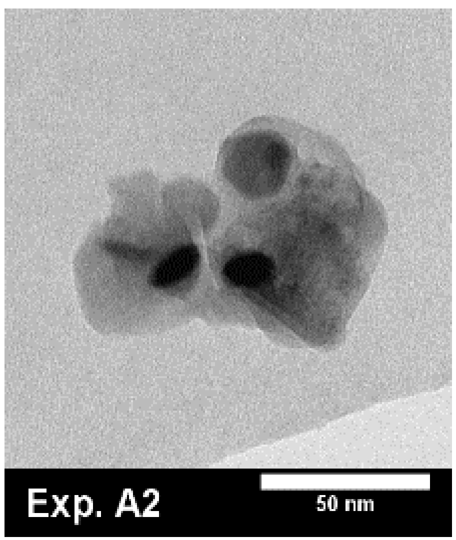
**Modern medium scale biomass boiler**

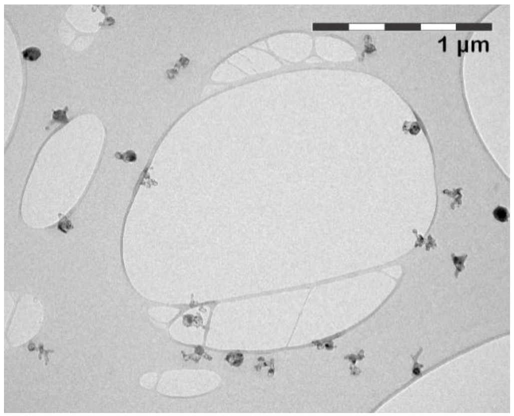
# Physical and chemical properties of PM from wood combustion

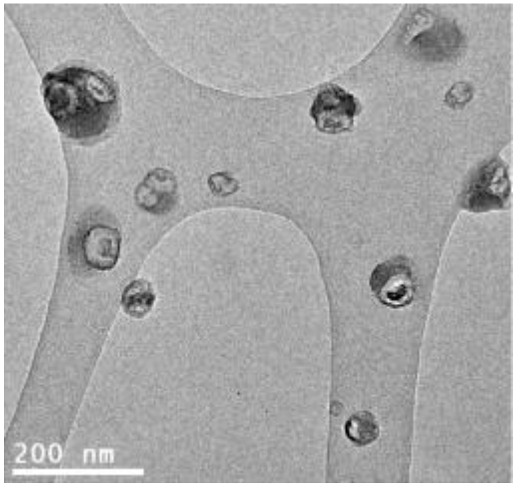
**Fine particle (PM1) composition:**



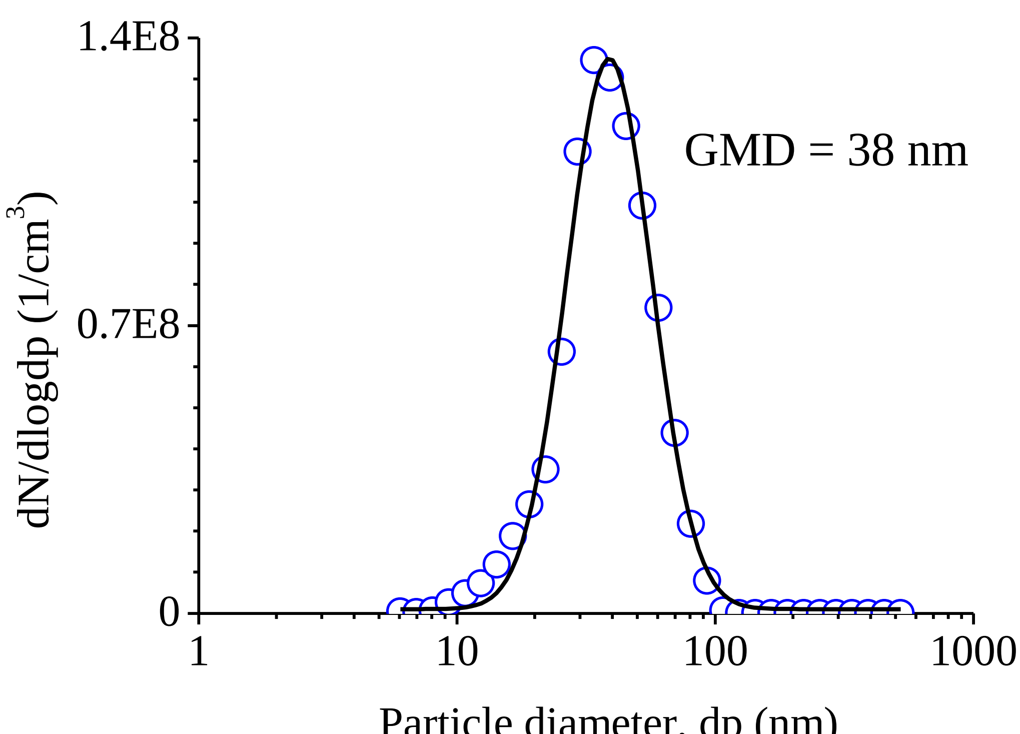

Leskinen et al. (2014) *Atmos. Environ.*

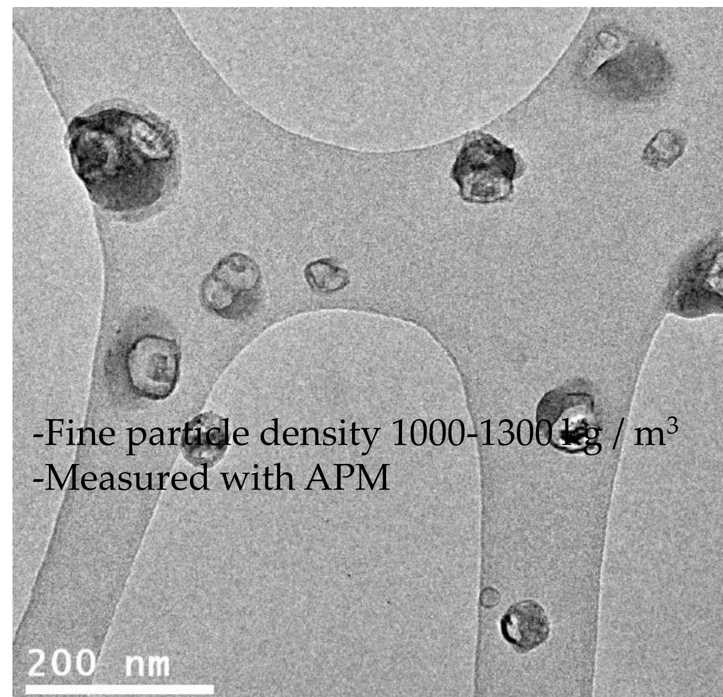
Torvela et al. (2014) *Atmos. Environ.*

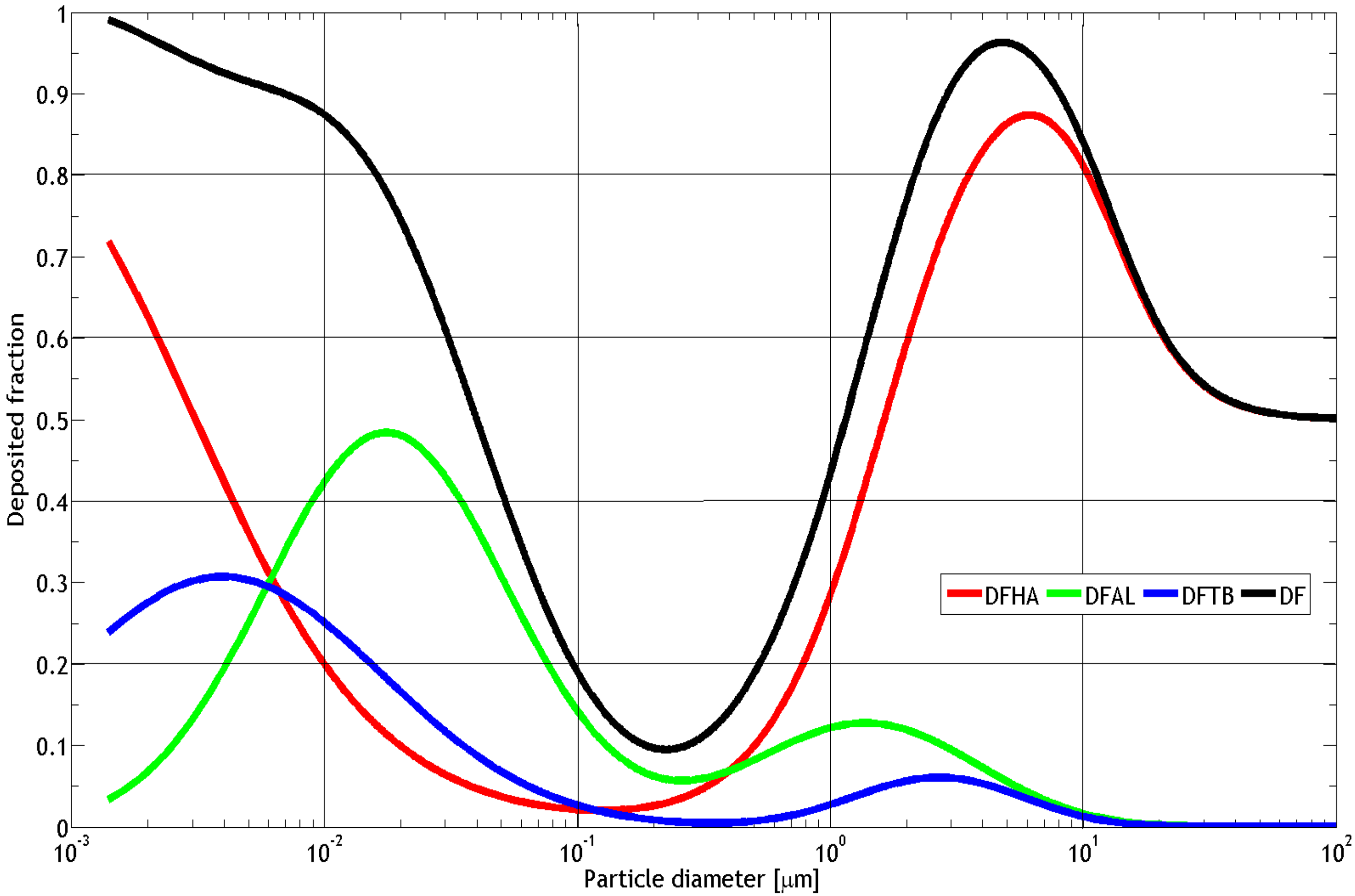
**Gasification-combustion**

- Small scale fixed-bed counter-draft gasifying pellet burner
- Desinged to replace oil burner using the old boiler system
- Staged primary/secondary/tertiary air feeding with a single fan

## Particle size distribution



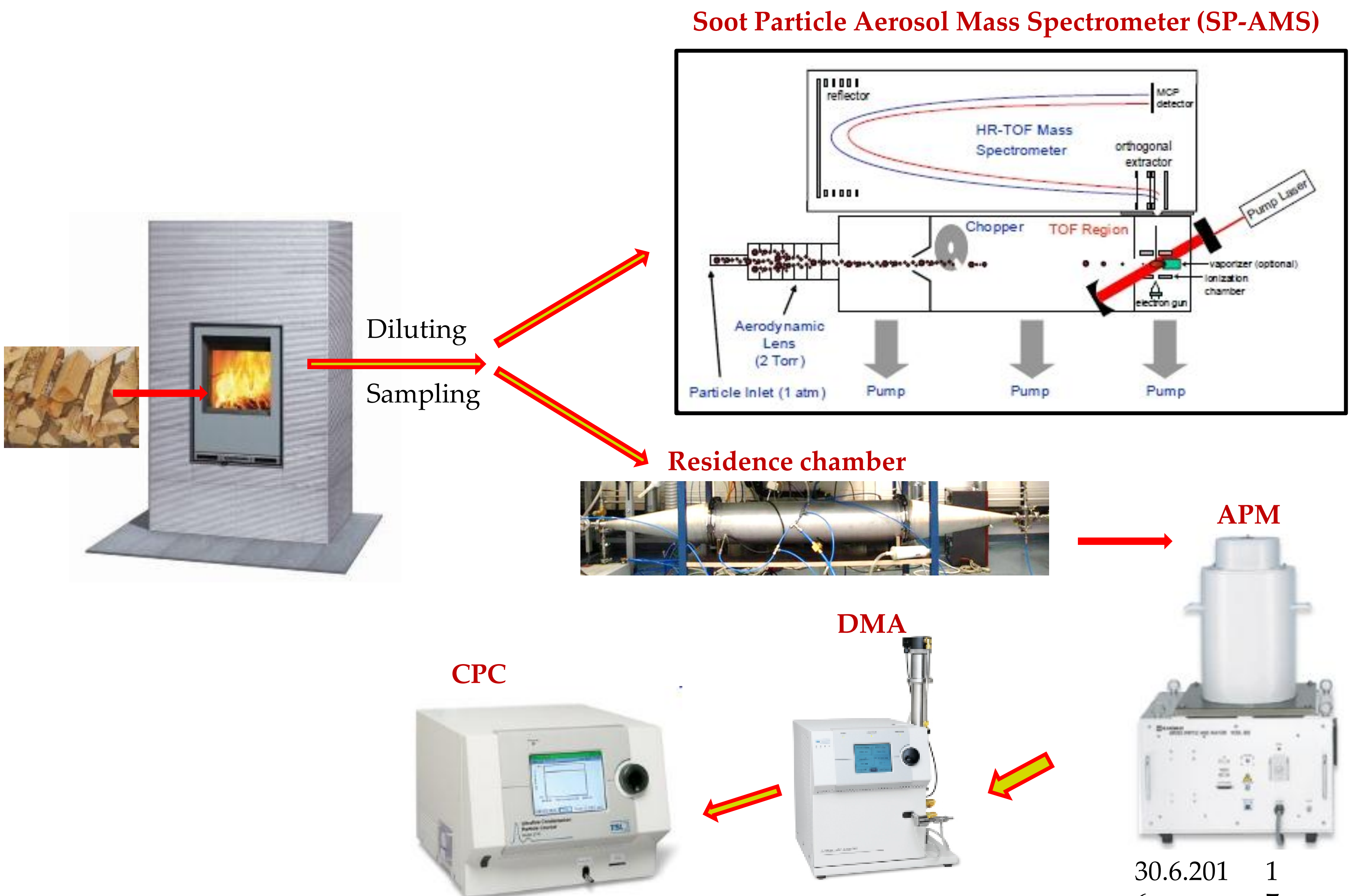






Inhalation exposure: Lung Total Deposition Fraction ((=DF); Head-Airways Deposition Fraction (DFHA); Alveoli area Deposition Fraction (DFAL) ja Thetra-Bronchial Deposition Fraction (DFTB) as a function of particle size

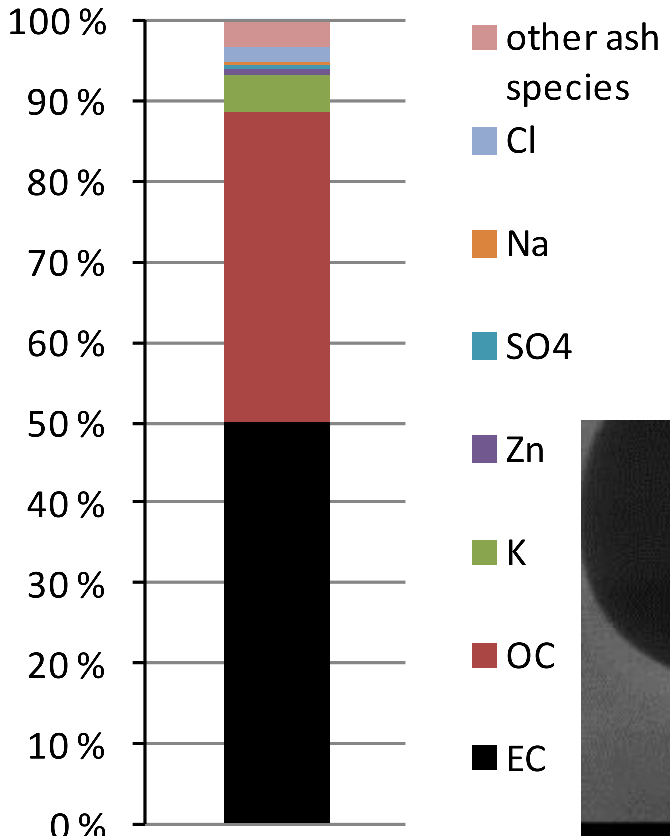
# Batch-wise operated, wood log fired closed fireplace, stoves & boilers

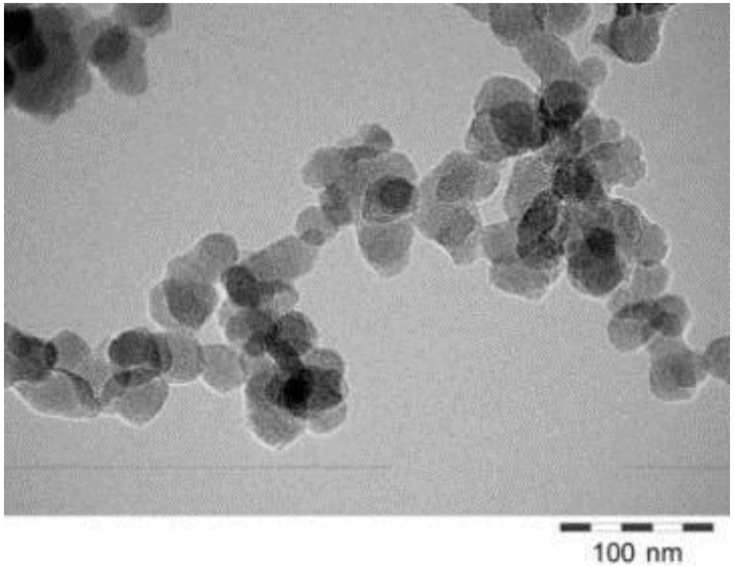
# Variation of fine PM properties in residential wood combustion

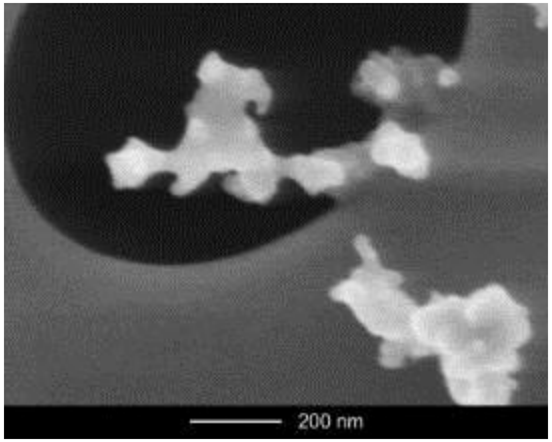


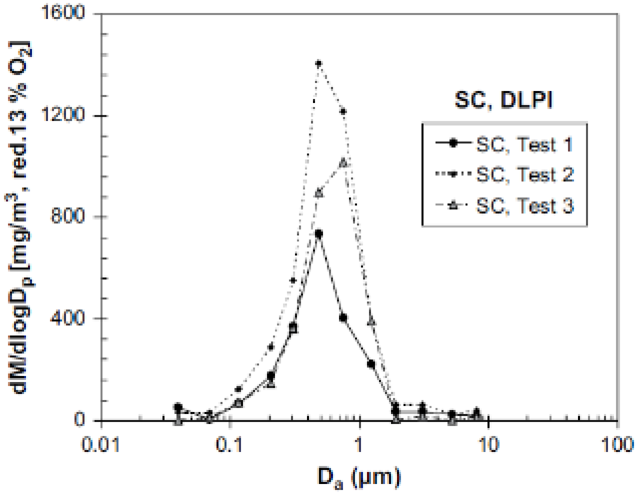
# Physical and chemical properties of PM from wood combustion

**Fine particle (PM1) composition:**



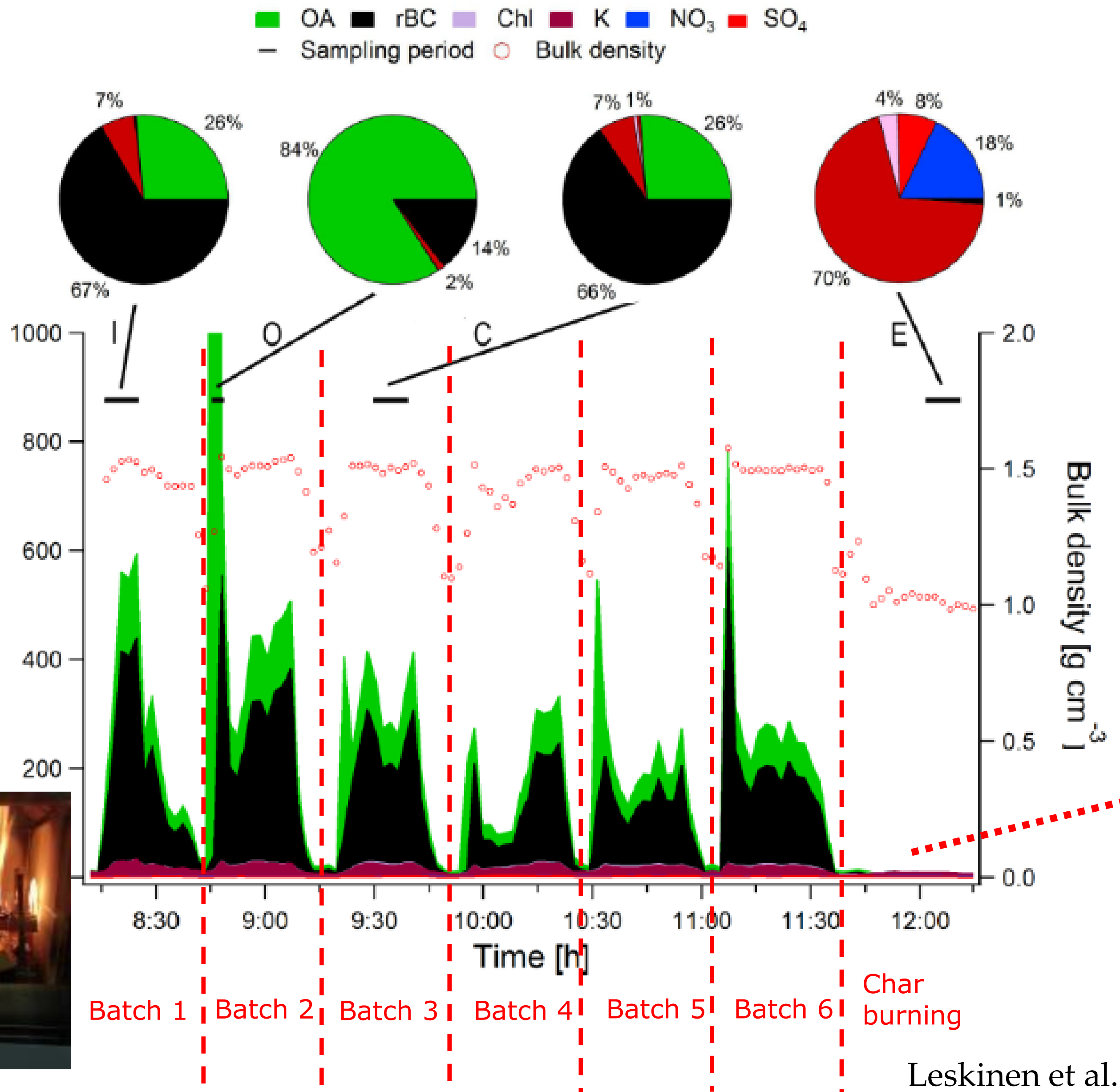




Tissari et al. (2009) *Atmos. Environ.*

Leskinen et al. (2014) *Atmos. Environ.*

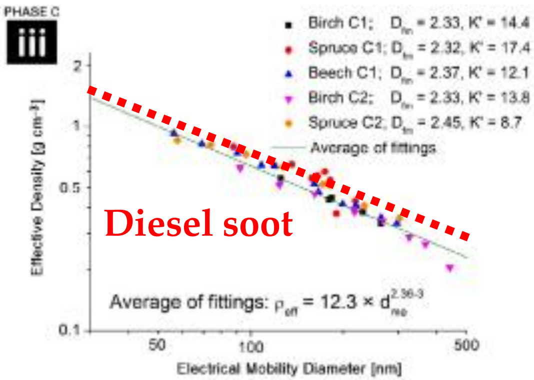
# Variation of fine PM chemical composition in wood combustion

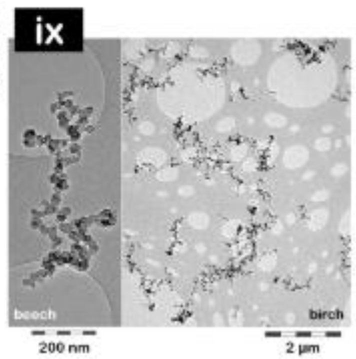



Leskinen et al. (2014) *Environ. Sci. Technol*

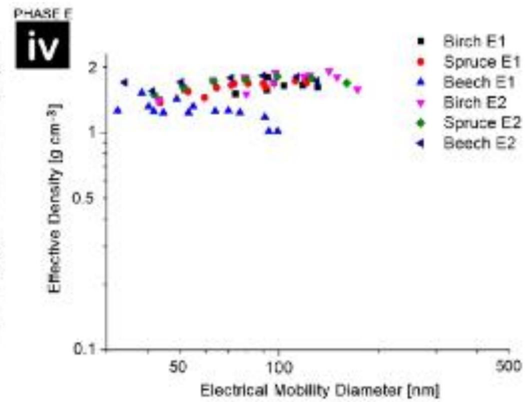
# Physical and chemical properties of PM from wood combustion

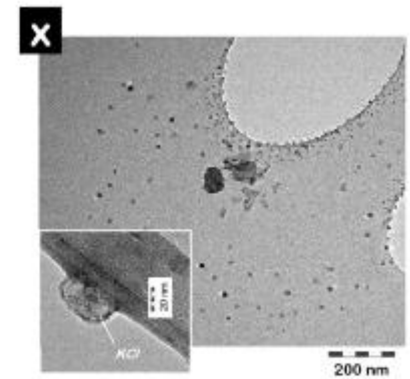
**Main combustion phase:**



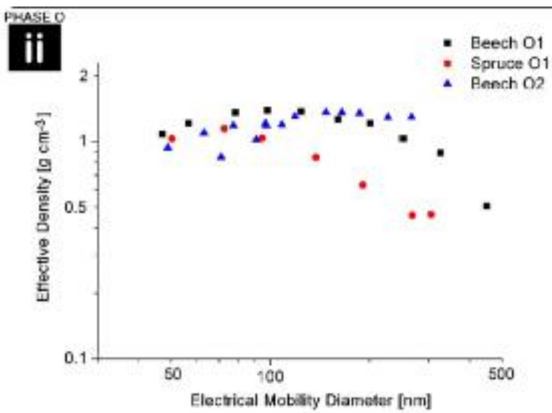



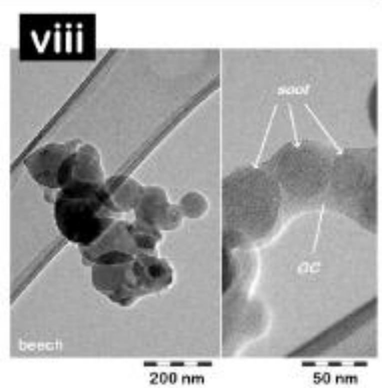

**Char combustion phase:**




**Organic rich combustion (High OC/EC):**



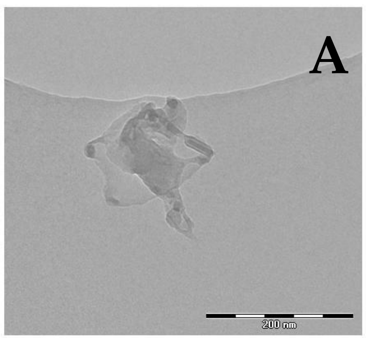



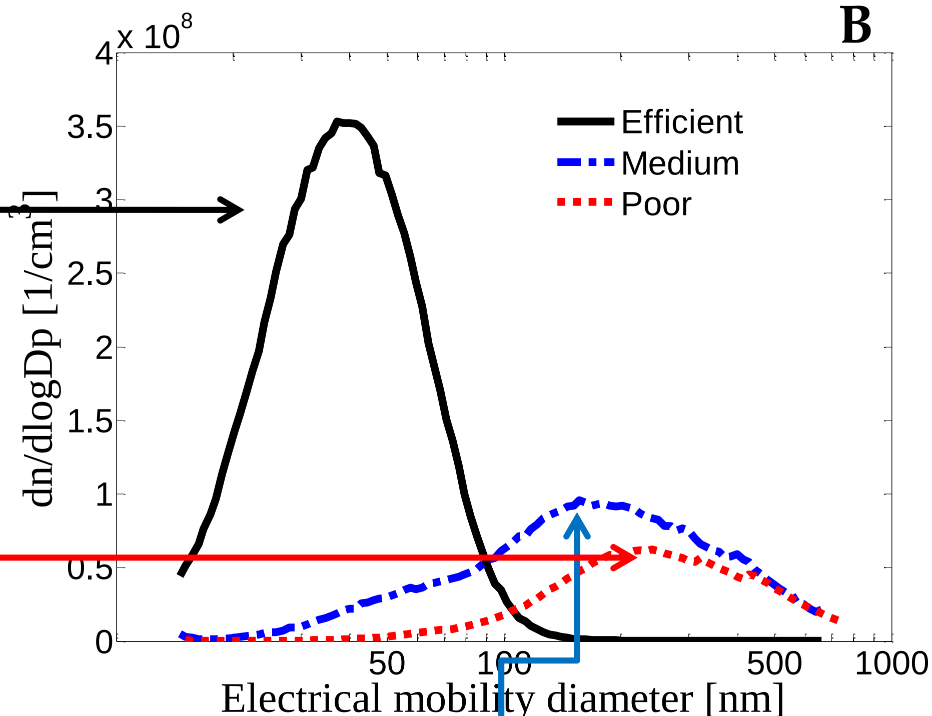

Leskinen et al. (2014) *Environ. Sci. Technol.*, 48, 13298-13306.

# Conclusions on the formation and properties of biomass combustion emission fine and nanoparticles

**Efficient combustion:**

- Ash containing particles in the size range of 10-200 nm
- Multi-element non-spherical particle type (see image A) most typical
- No soot particles.
- May contain e.g. ZnO core 10-30 nm




**Poor combustion:**

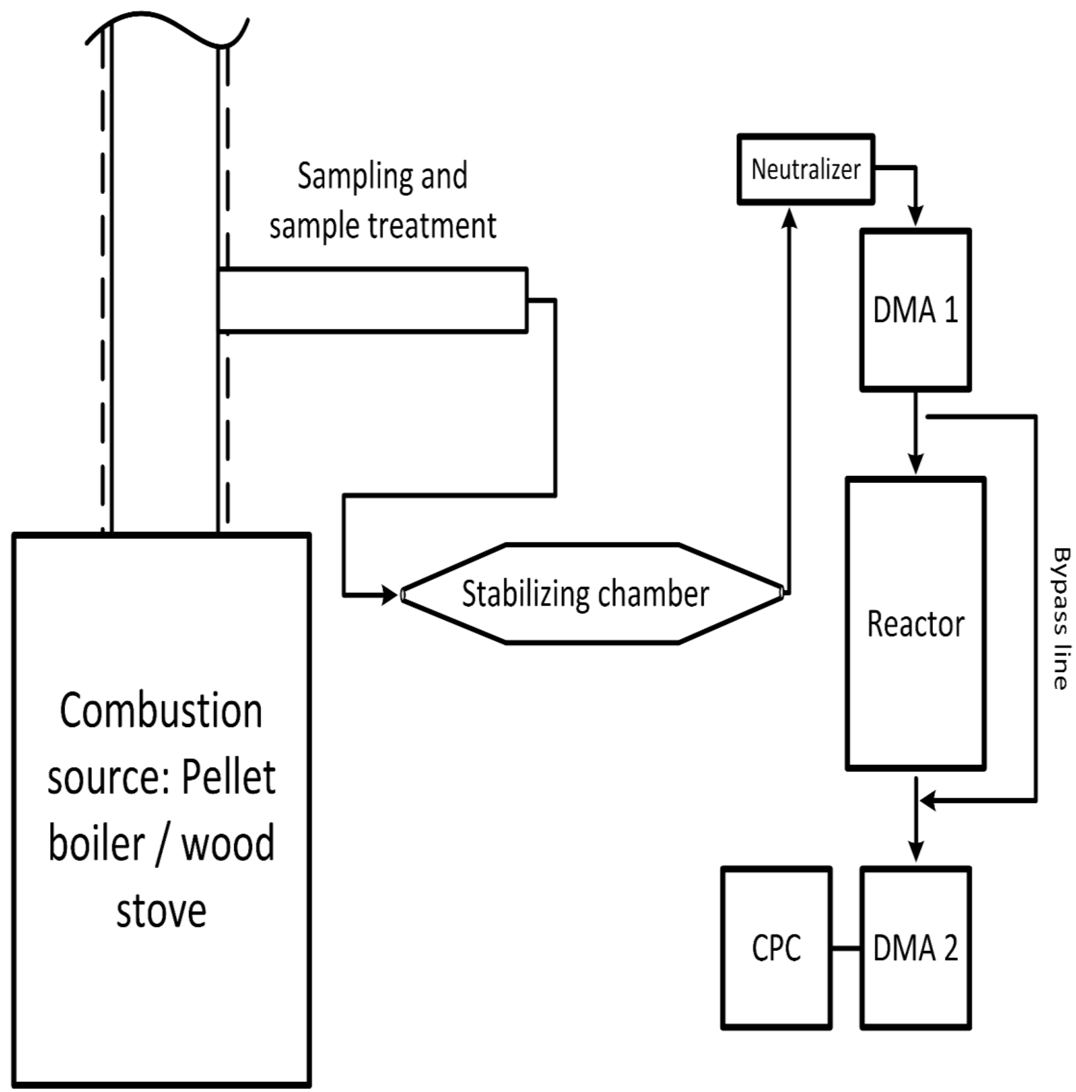
- Large chained soot agglomerates in the size range from 50 nm to 1µm
- Elemental analysis show K, S and O with the soot particles
- Primary particles spherical with graphite layers (EC)

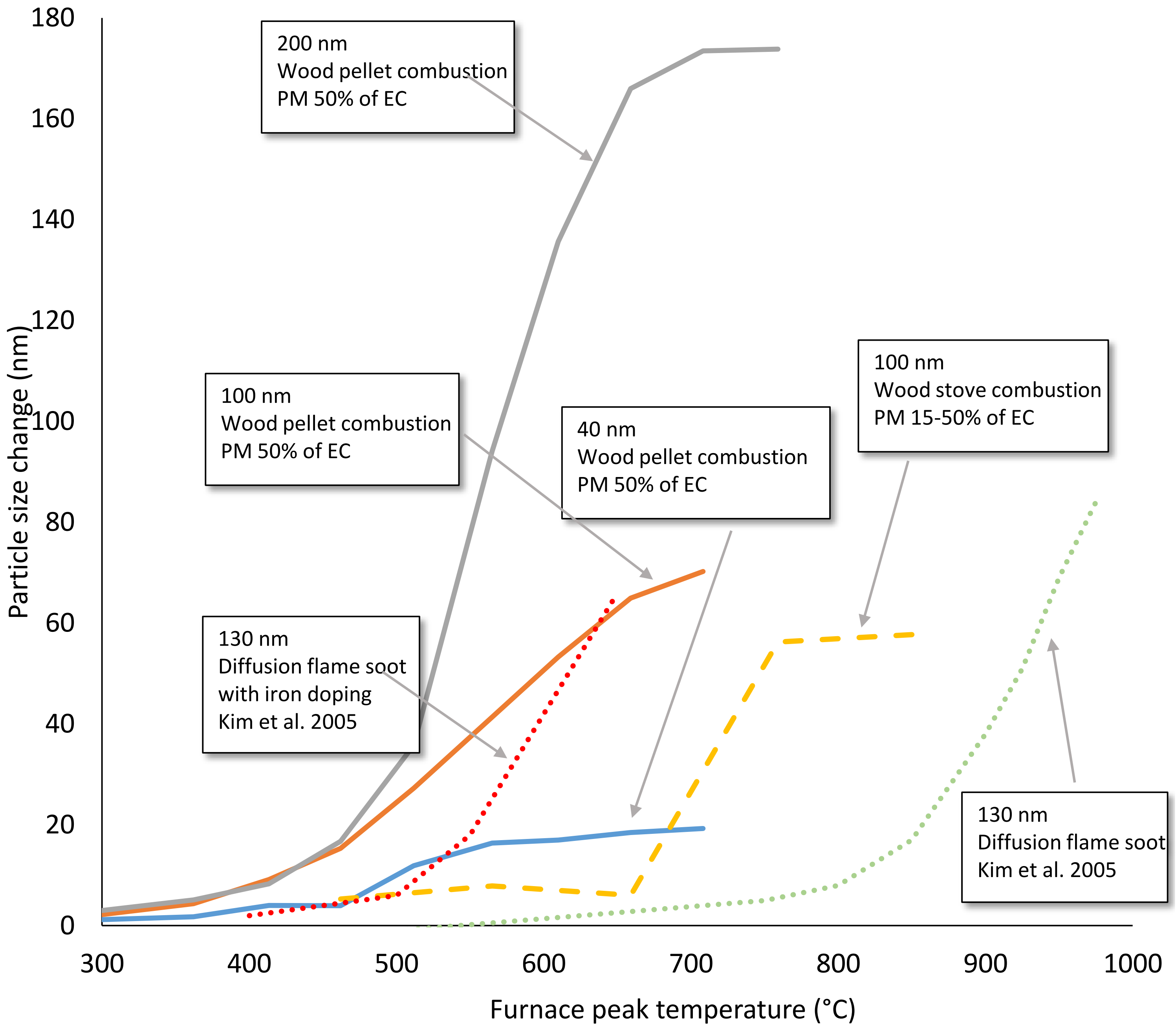
**Medium combustion:**

- Both ash and soot containing particles in the wide size range from 10 nm to 1 µm.
- Ash mostly in separate phase, but some loosely attached with soot
- Particles consisted of wide range of elements and had different morphologies

**RWC soot oxidation: experimental setup and new results,**

**Lamberg, Sippula, Tissari, Jokiniemi**





200 nm
Wood pellet combustion
PM 50% of EC
100 nm
Wood pellet combustion
PM 50% of EC
40 nm
Wood pellet combustion
PM 50% of EC
100 nm
Wood stove combustion
PM 15-50% of EC
130 nm
Diffusion flame soot
with iron doping
Kim et al. 2005
130 nm
Diffusion flame soot
Kim et al. 2005
Particle size change (nm)
Furnace peak temperature (°C)
0
20
40
60
80
100
120
140
160
180
300
400
500
600
700
800
900
1000

# SOA Photochemical flow tube reactor

- **Similarity with PAM tube**
  - 254 nm UV lamps (70 W) with adjustable power
  - External O3 feeding
  - Outlet divided to "ring flow" and center-flow
- **Flow field optimized with a diffuser inlet**
  - Design aided with 3D CFD simulations (Ansys Fluent) ar trace gas experiments
  - Very low particle losses: *for 50 nm particles 1-10% losses (in PAM-tube ~ 60 %)*
- **Stainless steel, volume 100 dm³ , vertically positioned**
  - Typical flow rates 50-200 lpm -> 0.5-2 min residence time
- **Adjustable OH-exposure**
  - ~ $10^9$–$10^{12}$ molec cm$^{-3}$ s
  - Online monitoring of photochemical age via D9-butanol according to Barmet et al. (2012)
- **Other "nice-to-know"**
  - Possibility to develop the setup for low temperatures (< 0 °C)
  - Possibility to use different dilution techniques and conditions
  - Possibility to implement photochemistry models in the 3D CFD model
  - Tested so far with :
    - Toluene precursor
    - Small-scale wood combustion
    - Modern gasoline engine

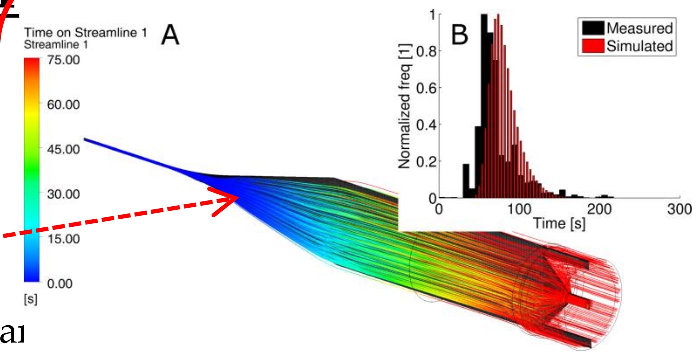
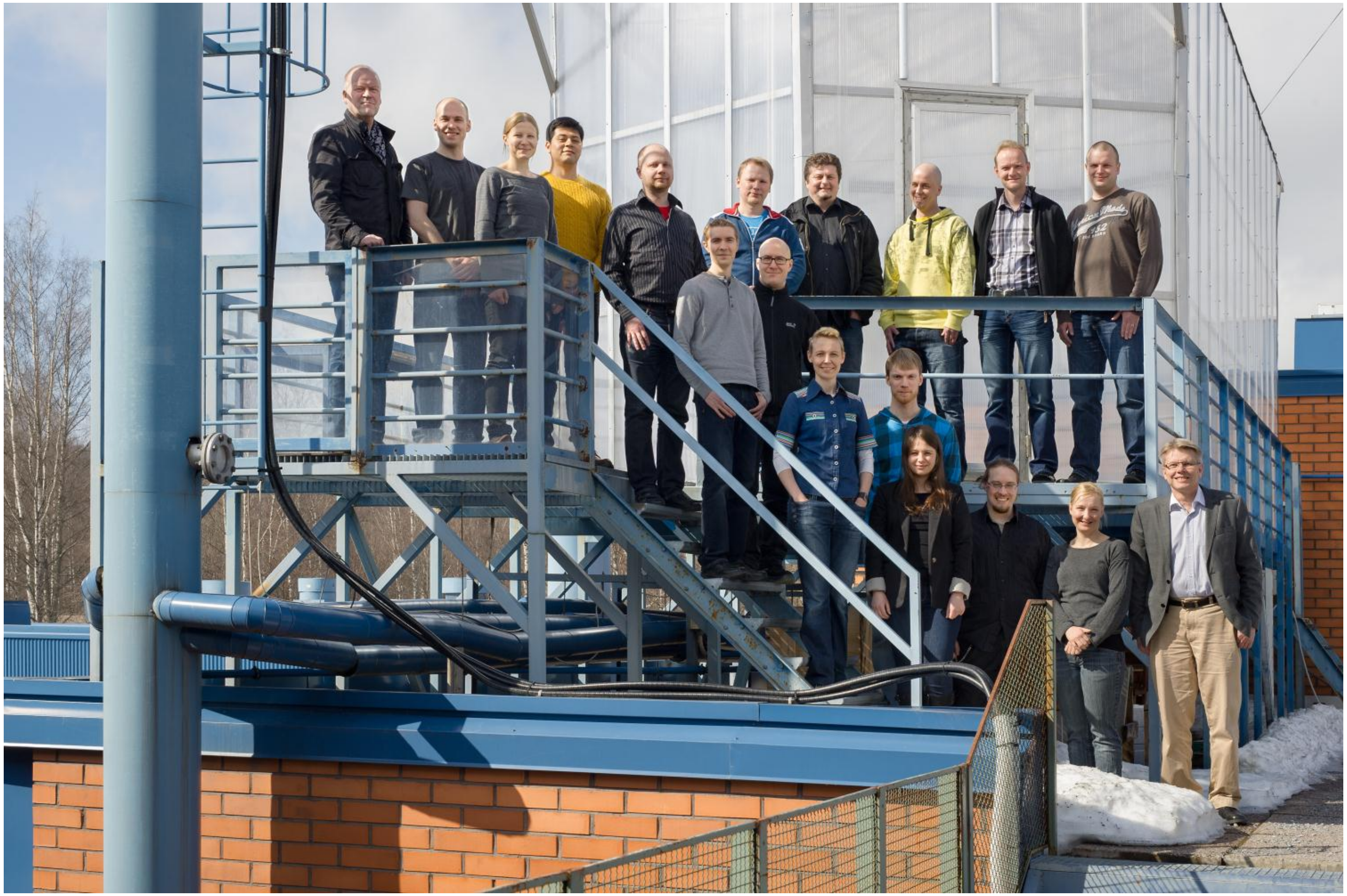



**Fig. A)** Numerically simulated streamlines and **B)** the simulated and measured residence times of $CO_2$ trace gas in the photochemical flow tube reactor

**For more information on SOA visit Poster 24 Sippula et al. and Hear Leskinen et al. talk tomorrow morning**

# Thank You for Attention



www.uef.fi/fine