

Analytica Anacon India

6th International Trade Fair for Laboratory Technology, Analysis, Biotechnology and Diagnostics
12-14 OCTOBER 2011 | BOMBAY EXHIBITION CENTRE | MUMBAI

Characterisation of Fine Particle Emissions from Small Scale Biomass Combustion

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Content

1. Introduction

Increase biomass utilisation

Small scale comb vs. large scale; i.e. energy prod. Vs. emissions

User, fuel, poor comb., flue gas cleaning

Emission charact OC/EC, PAH

Challenges

2. Situation in Europe

Different devices, emissions

3. Batch combustion/continuous i.e stoves/boilers

4. Detailed Physico-chemical Characterisation

To relate health effects/climate change

5. Single particle analysis

Ash, soot, OC/PAH

Renewable energy need to be increased

- According to EU commission carbon dioxide emissions need to decreased 20 % by 2020
- In addition the share of renewable energy should be increased to 20% on average in EU
- Different countries have their own targets for renewable energy and among them is the Share of Bioenergy from total energy
- Currently bioenergy is considered CO₂ neutral
- As the share of bioenergy is increased also small scale combustion is increased significantly

Emissions from small scale combustion

- The emissions from large power plants are in general well controlled i.e. Efficient combustion and flue gas cleaning
- The produced energy by small scale combustion is only quite low from the total energy production
- However, e.g. the Fine Particle emissions from small scale combustion are significantly higher than the share of energy produced should allow !

Challenges in small scale combustion

- Emissions from small scale combustion are affected by user, fuel, combustion appliance and flue gas cleaning
- Fine particle emissions affect both health and climate
- E.g. Black Carbon has a significant contribution to climate heating
- Heavy metals, PAH and other organics may serve as chemical triggers for health effects
- There is a challenge to decrease significantly the emissions from small scale combustion
 - batch vs. continuous combustion i.e. stoves vs. boilers
- In addition we should identify the most important physico-chemical characteristics of the emissions affecting health and climate

Effects of Fine Particle Emissions

gases

NO_x

SO_x

PAH

other Org



secondary
PM2.5

particles

TSP

PM10

PM2.5

PM1

PM0.1



Air quality

Health effects

Climate change



Health effects



concentration
size
chemistry

Climate change



heating
soot (absorption-IRemission)

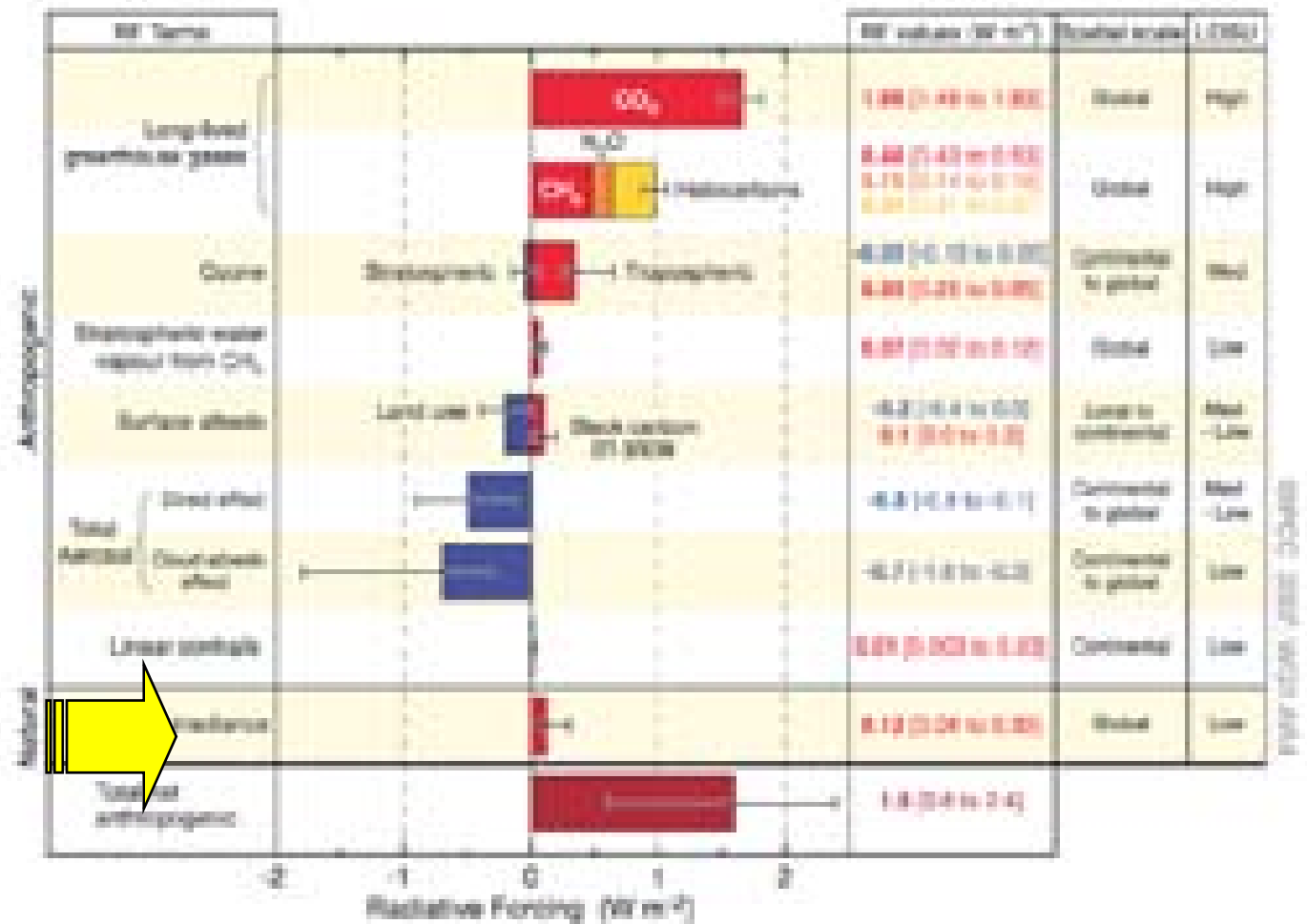
cloud formation

cooling
other PM (scattering)

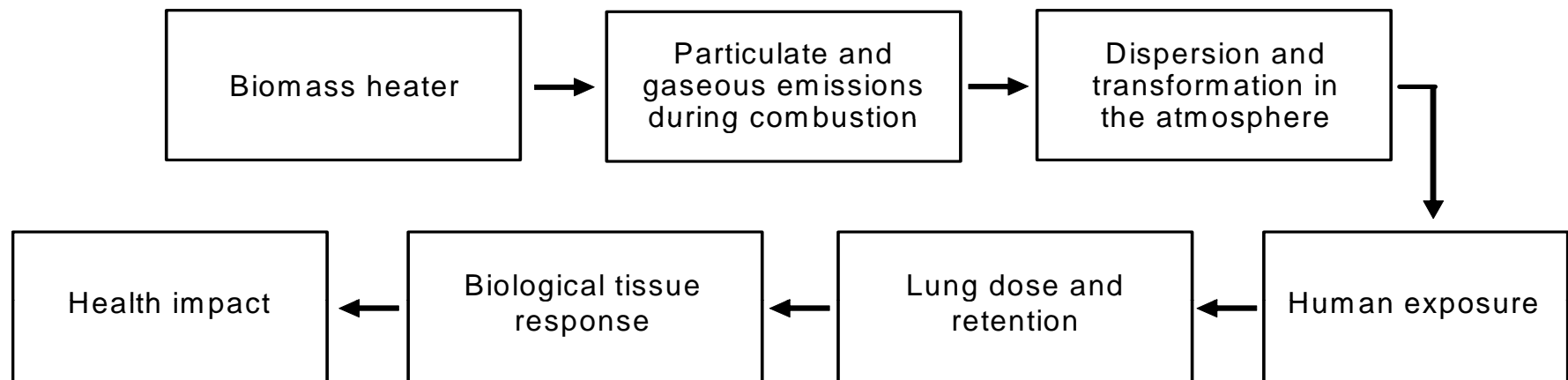


Radiative Forcing Components

The effect of fine particles is the largest uncertainty when assessing the climate change => More need to be known.



Chain of events from heater emissions to health impact



- Biomass combustion contributes substantial proportion of the urban particulate concentrations which are associated with a large health burden across the world
- In Europe approximately 350 000 annual premature deaths occur due to the particulate air pollution
- Health impact of particulate air pollution has also large economic impacts due to worsening of symptoms of cardio-respiratory diseases, hospitalizations, loss of working days, etc.

According to the health effect hypotheses at least the following particle physico-chemical properties should be measured:

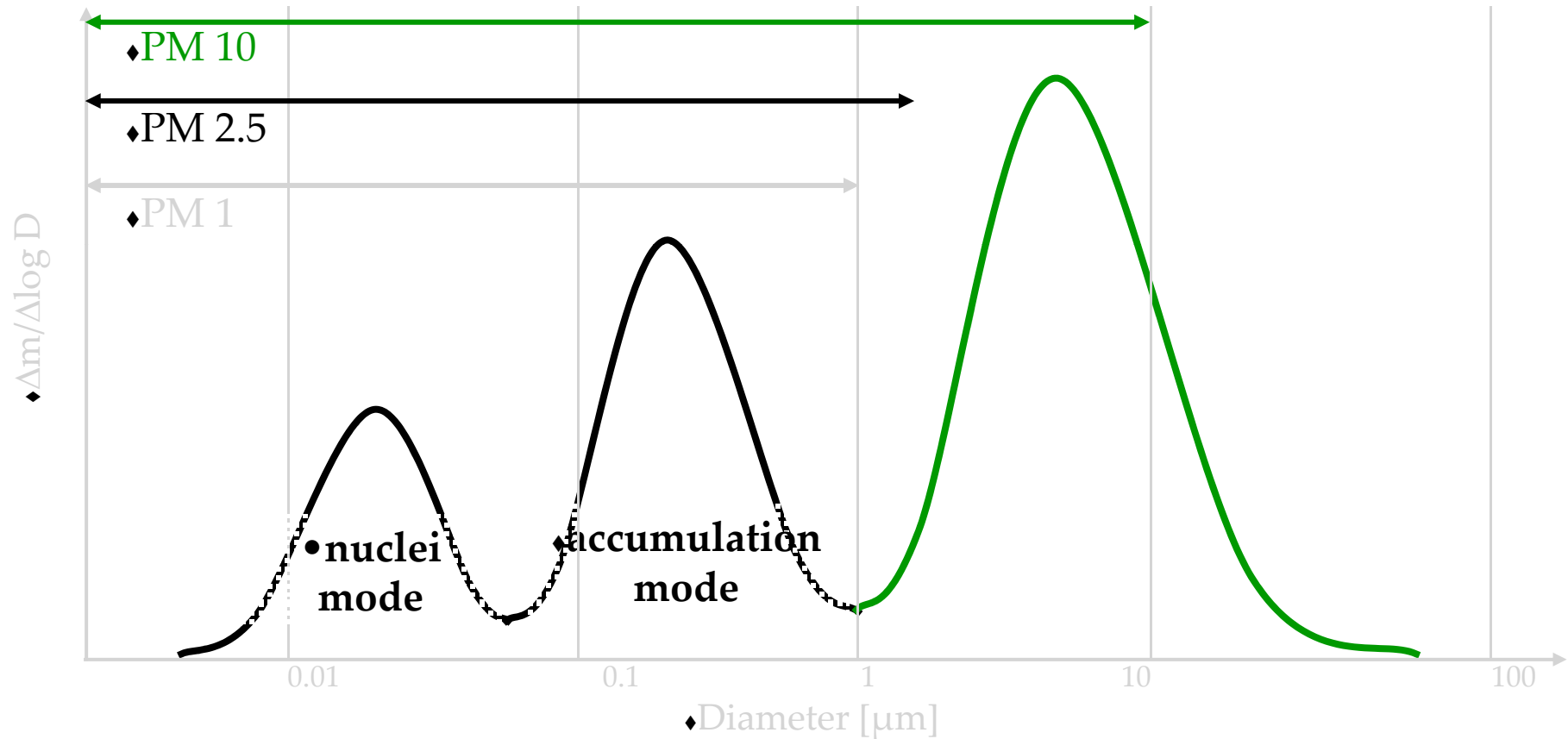
- Health effects and climate change are mainly due to fine and ultrafine particles **not coarse particles ($>10\mu\text{m}$)**
- **PM emission studies should concentrate on PM1**

With correct dilution and cooling it is possible

- particle mass size distribution (multistage impactor)
- particle number size distribution (several instruments)
- elemental composition (EDS-XRF, ICP-MS, PIXE)
- soluble ions (IC)
- soot and organic carbon EC/OC (thermal-optical methods)
- PAHs (GC-MS)
- morphology-single particle analyses (SEM/TEM)
- surface properties (SEM, SIMS, XPS, NSAM, BET...)
- Speciation (LC/GS-MS, AMS, XRD, XPS...)

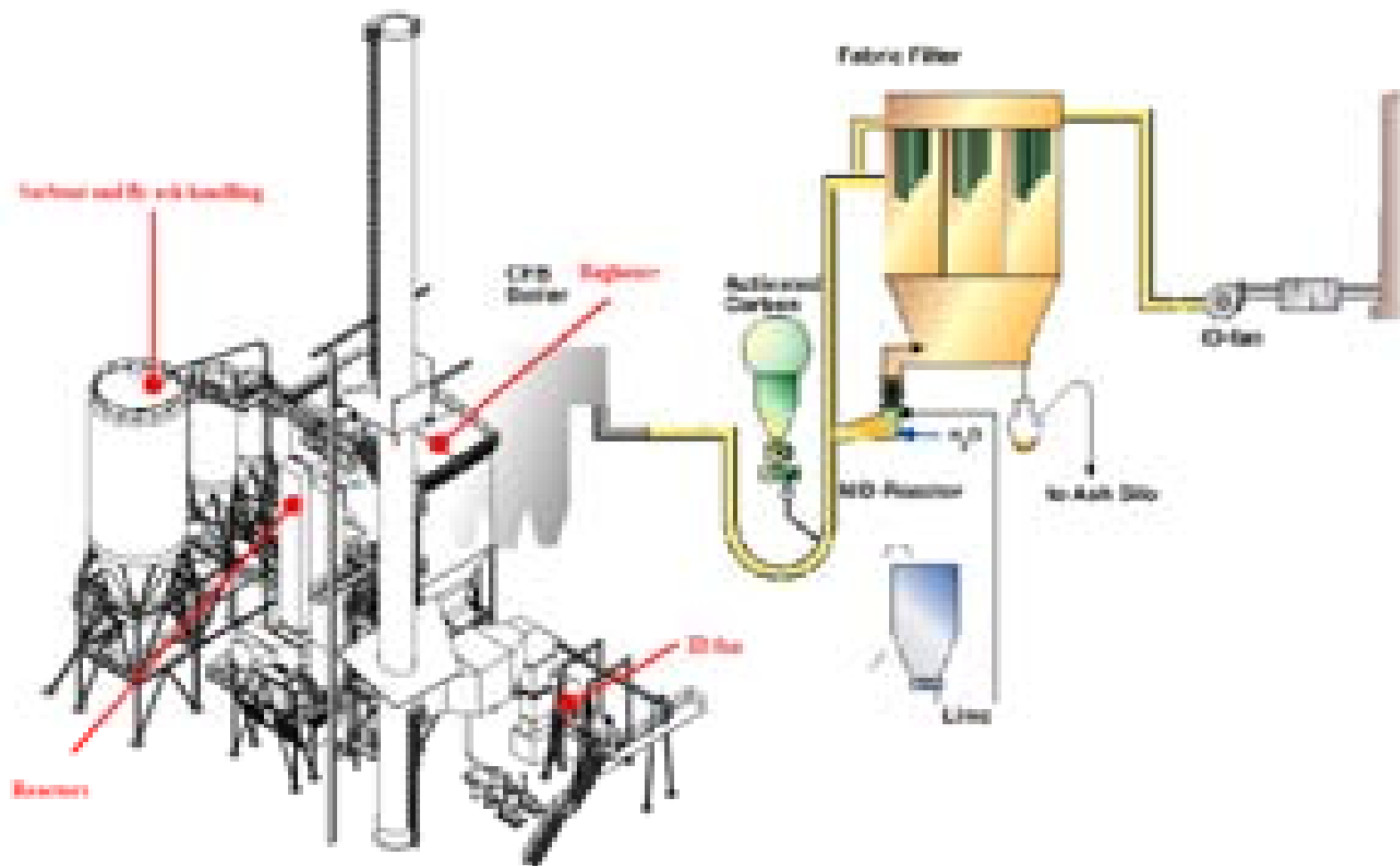
Definitions –

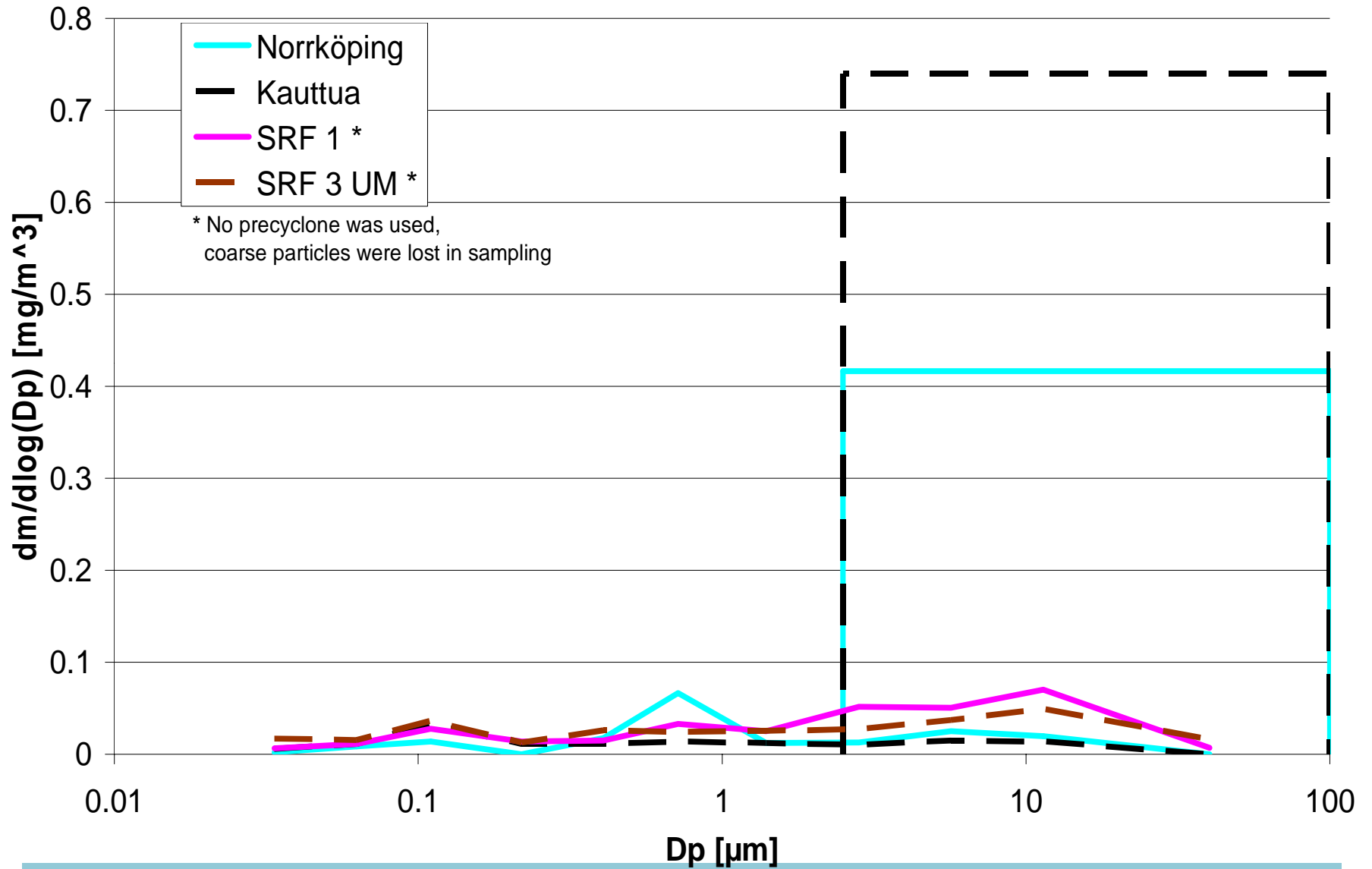
classification of atmospheric aerosols (I)



18 MW GRATE FIRED WASTE INCINERATION PLANT





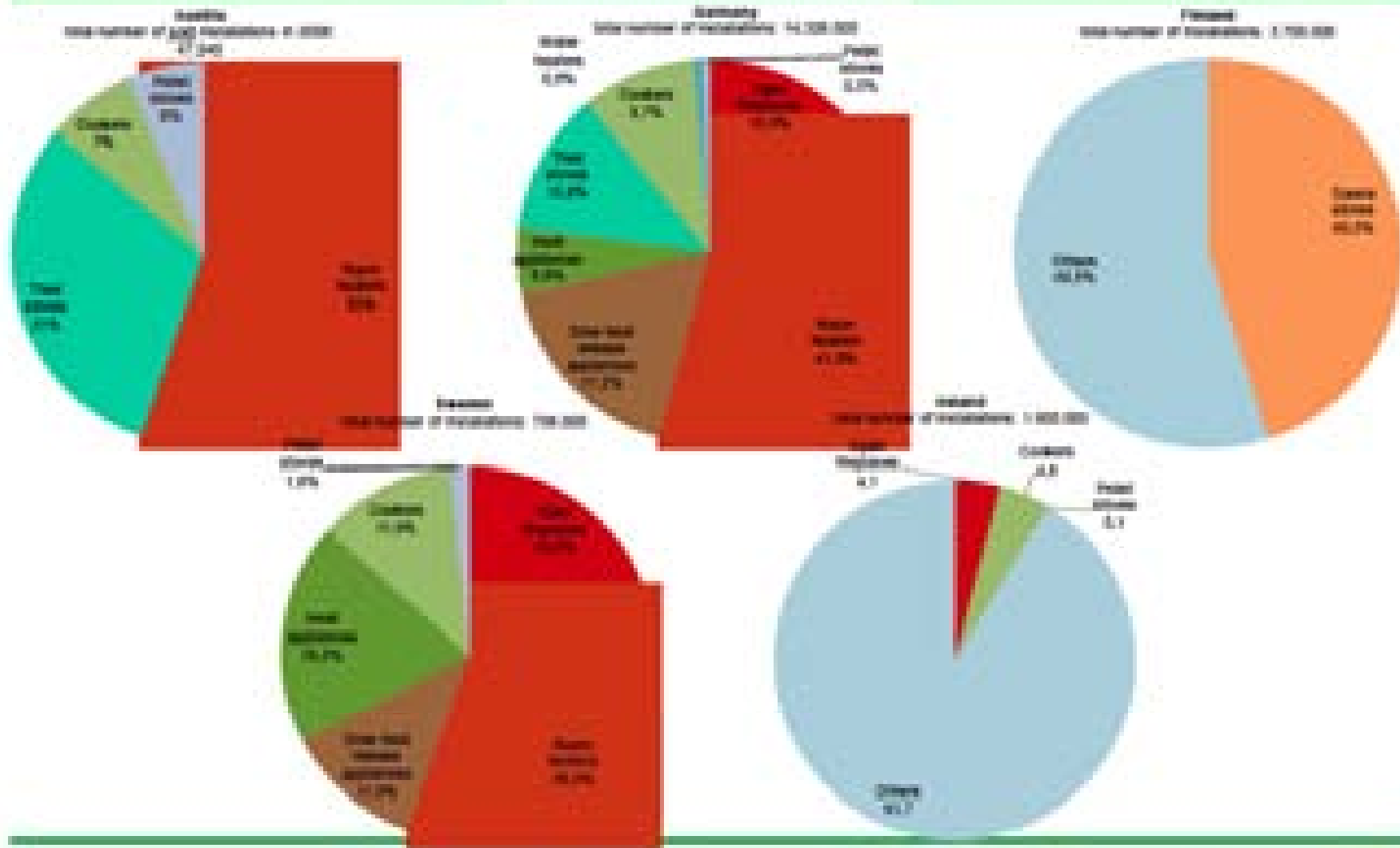


Small scale biomass combustion

- Number of various appliances
- User effect
- Fuel quality
- Emission reduction
 - primary
 - secondary



Distribution of different stove types in the countries



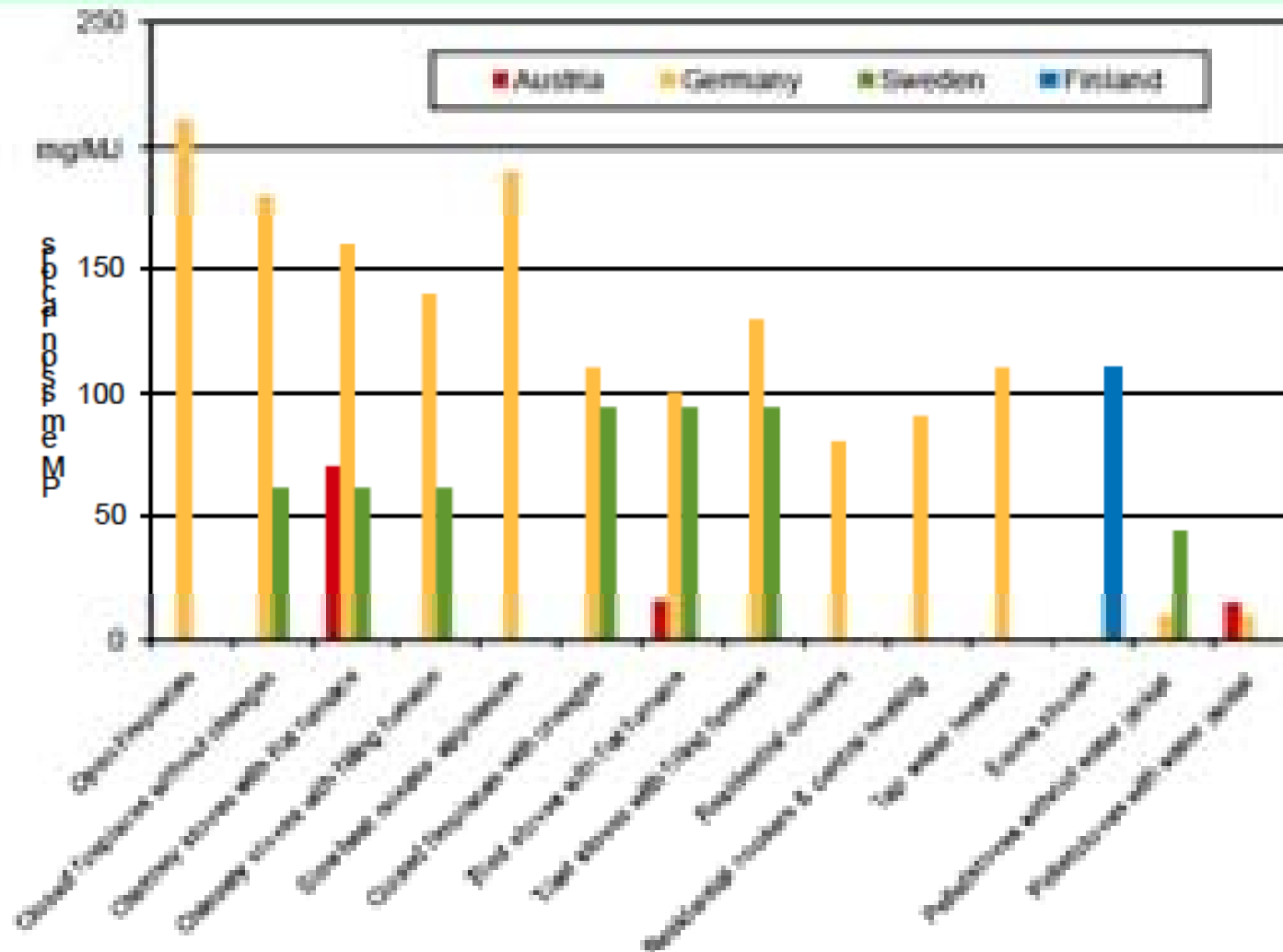
- Dust emission limits in Germany for stoves (all values at 13% O₂, values must be proofed during type testing)

Type of stove	Minimum efficiency %	Emission limit for stoves, when installed			
		after 22.03.2010		after 01.01.2015	
		CO g/m ³	particles mg/m ³	CO g/m ³	particles mg/m ³
Roomheaters with flat furnace	73	2.0	75	1.25	40
Roomheaters with firing furnace	70	2.5	75	1.25	40
Slow heat release appliances	75	2.0	75	1.25	40
Insert appliances (closed operation)	75	2.0	75	1.25	40
Tiled stove inserts with flat furnace	60	2.0	75	1.25	40
Tiled stove inserts with firing furnace	60	2.5	75	1.25	40
Residential cookers	70	3.0	75	1.50	40
Central heating & residential cookers	75	3.5	75	1.50	40
Pellet stoves without water jacket	85	0.4	50	0.25	30
Pellet stoves with water jacket	90	0.4	30	0.25	20

Explanations: source [BImSchV]

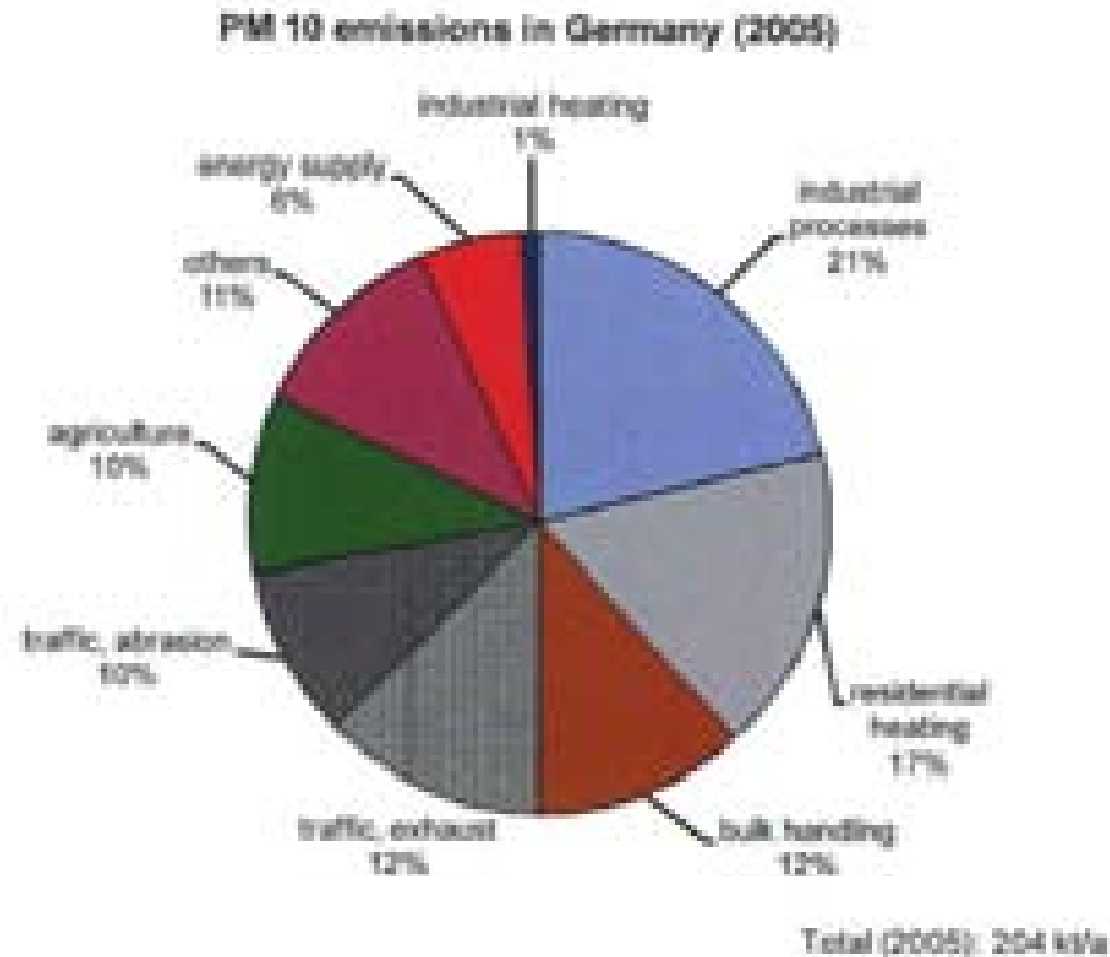


PM emission factors for different stoves in the countries



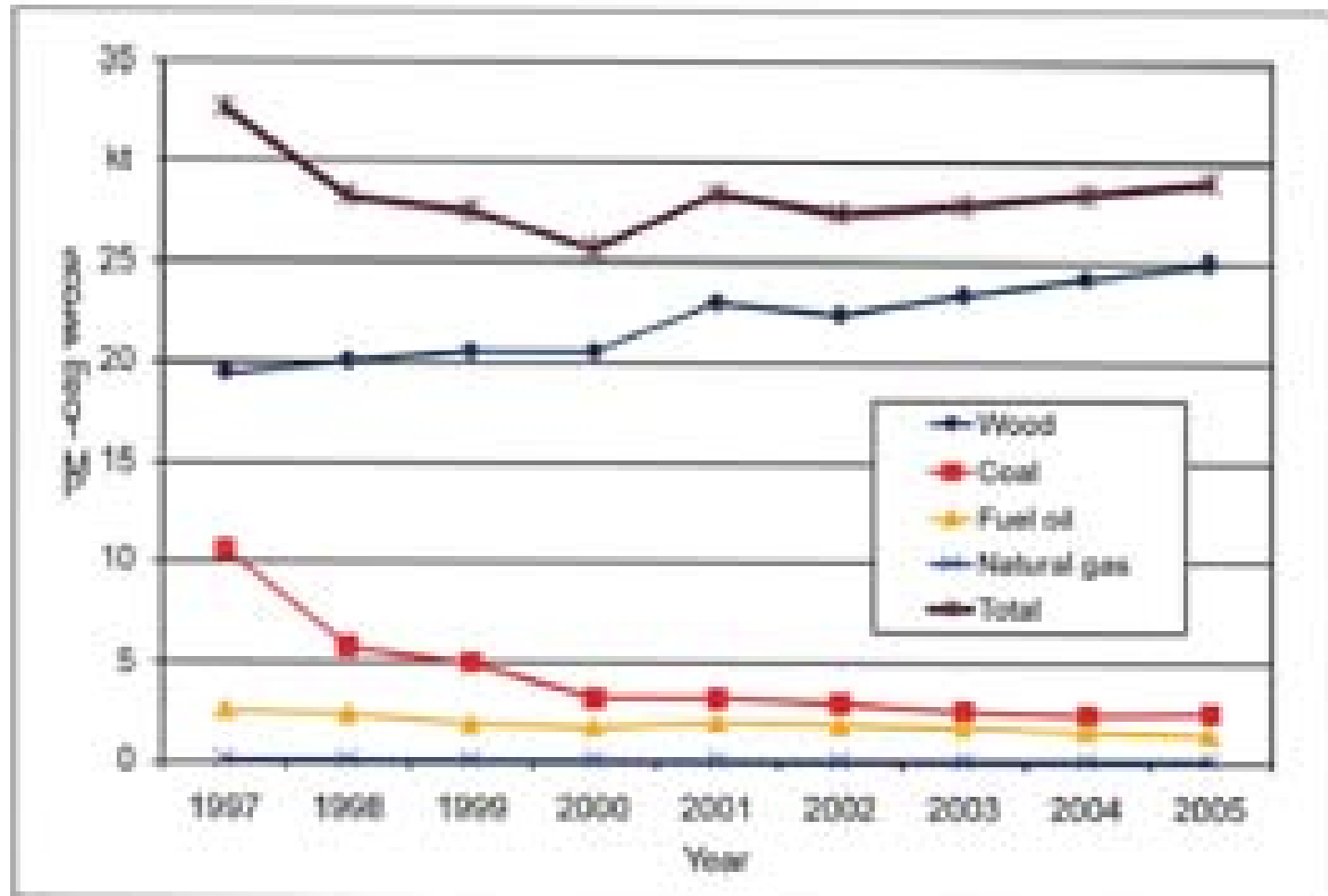
Background in Germany

■ Situation of particle emissions in Germany (2005)



Explanations: source [Umweltbundesamt Germany]

■ Trends of particle emissions in Germany



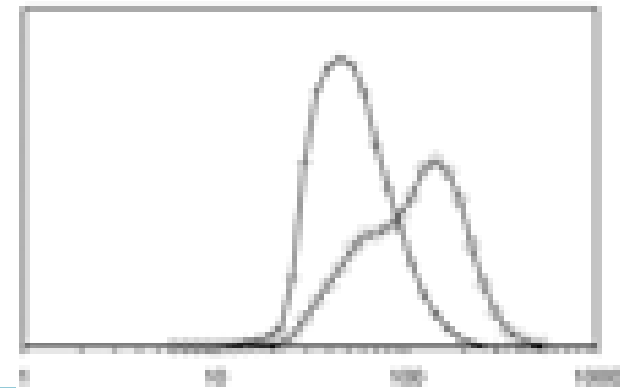
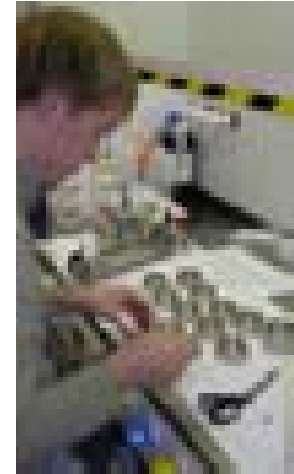
Explanations: source [Umweltbundesamt Germany]

MEASUREMENT METHODS

Dilution in the emission measurement in small-scale biomass combustion

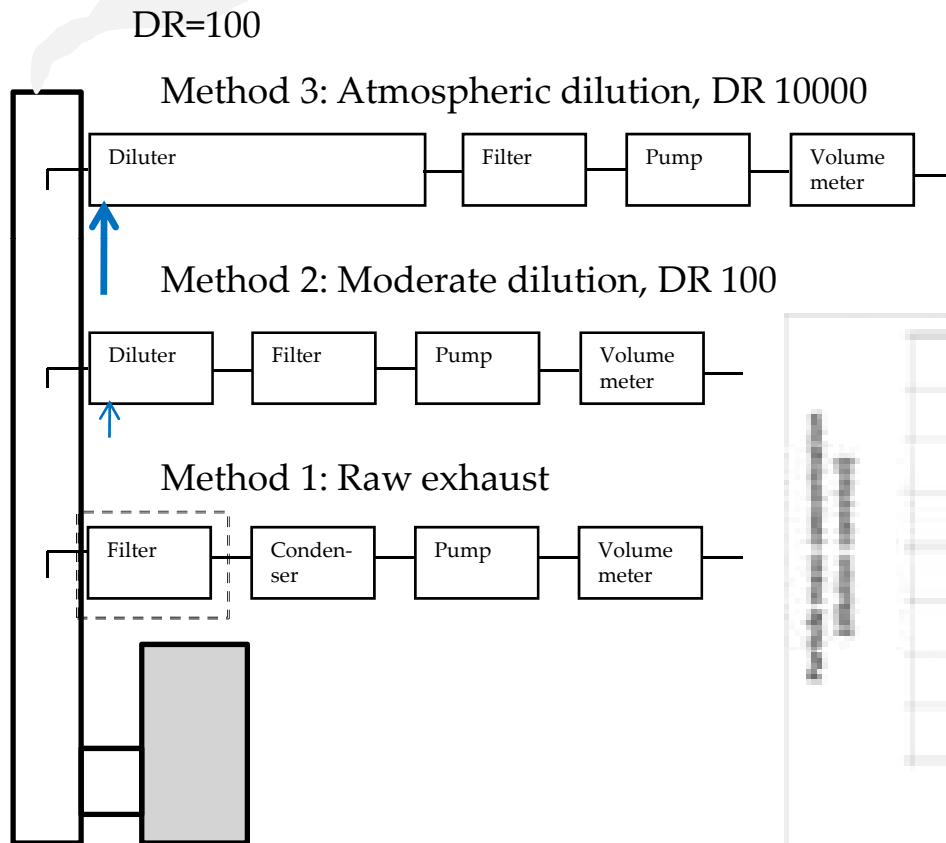
Which particle properties we want to measure and what for?

- To test whether the combustion appliances meet emission requirements
 - particle mass
- To develop cleaner appliances
- To assess the impact on air quality and climate
 - mass, size, number, composition, optical properties
- To assess health effects
 - exposure: mass, size, number
 - composition, toxicology
 - responses in animals and humans
 - epidemiology

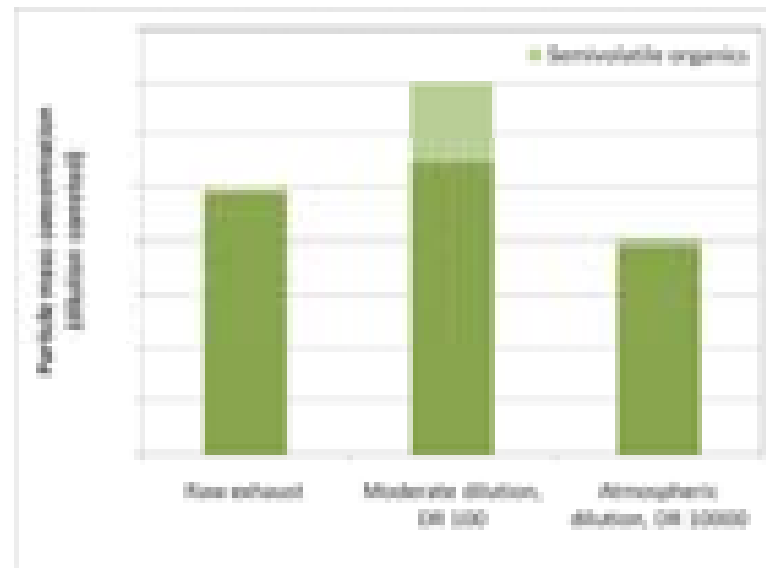


Select the method, select the results?

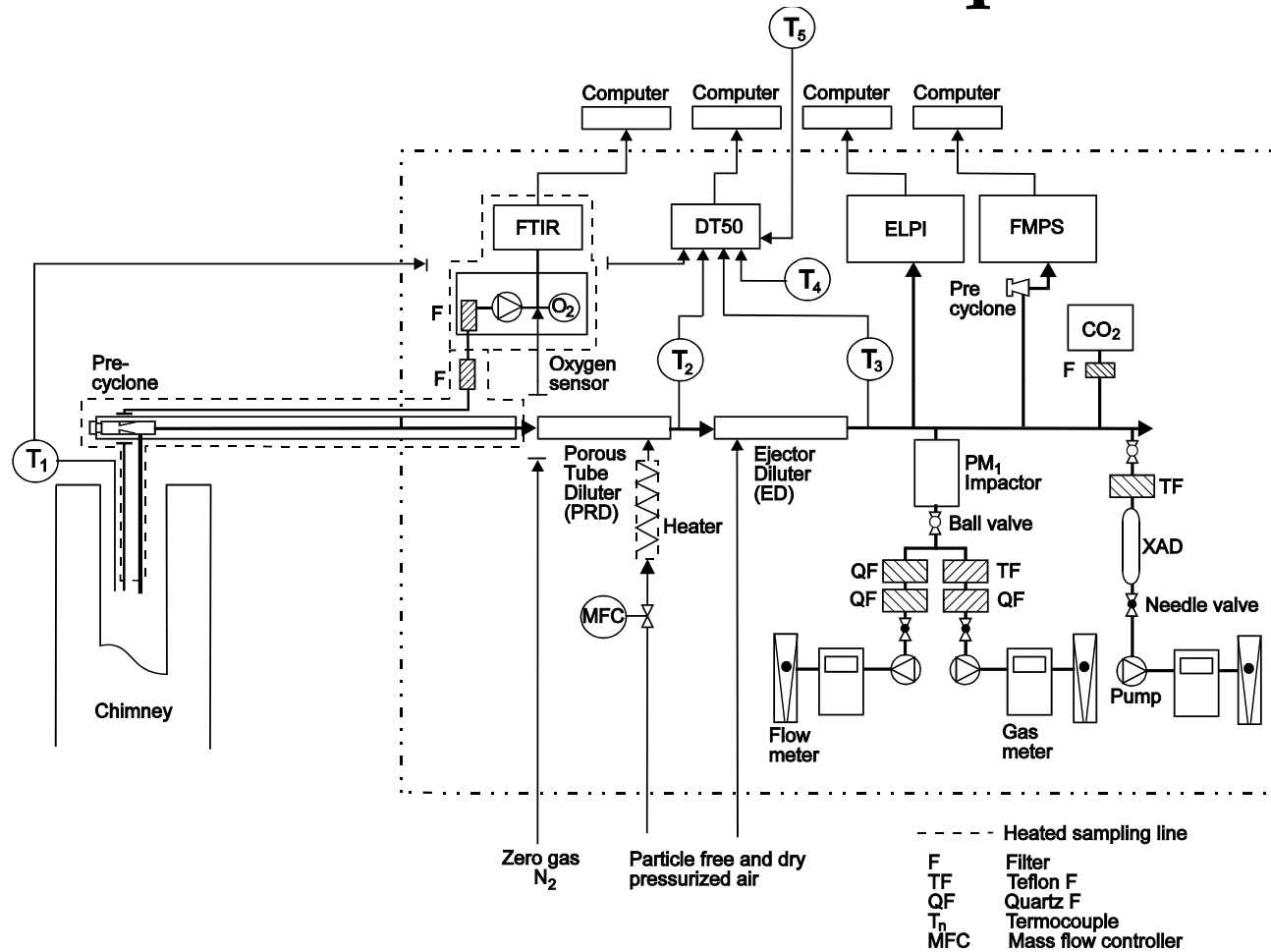
DR=10000



Also particle number and size?



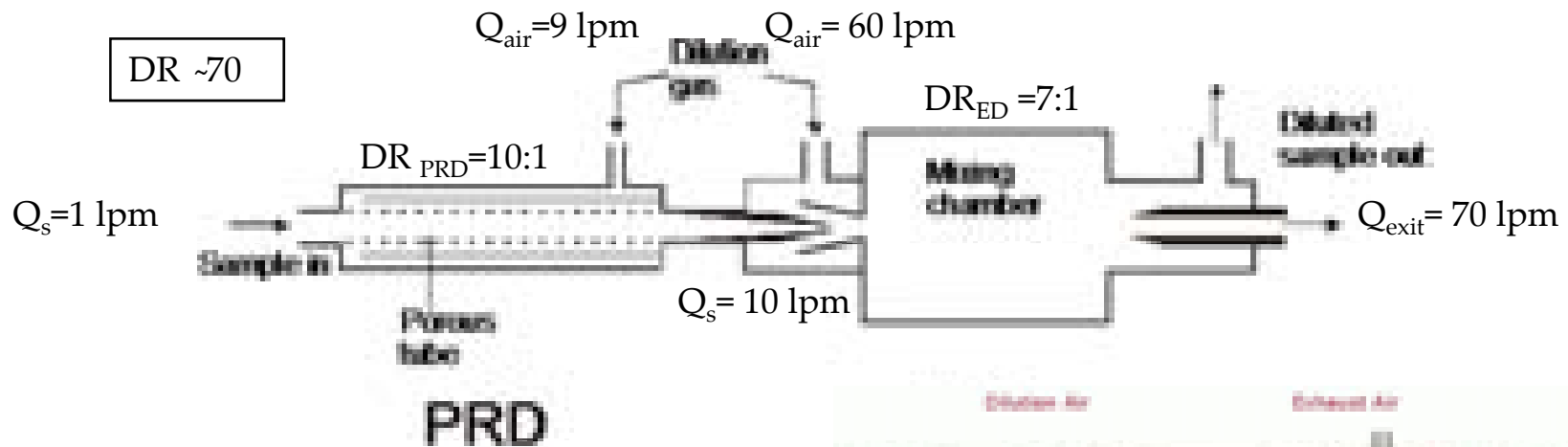
Field measurement technique



Tissari et al. (2007) *Atmos. Environ.* 41:8330-8344

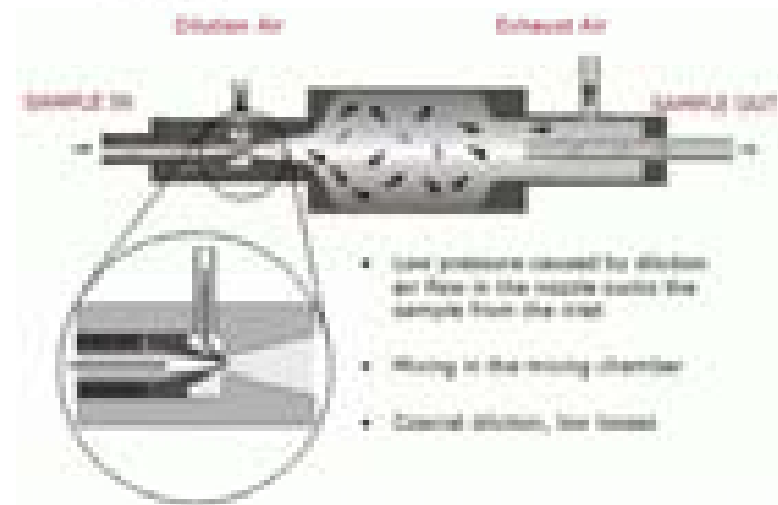
Dilution in practice

Lyyränen et al AST 2004, 38(12)

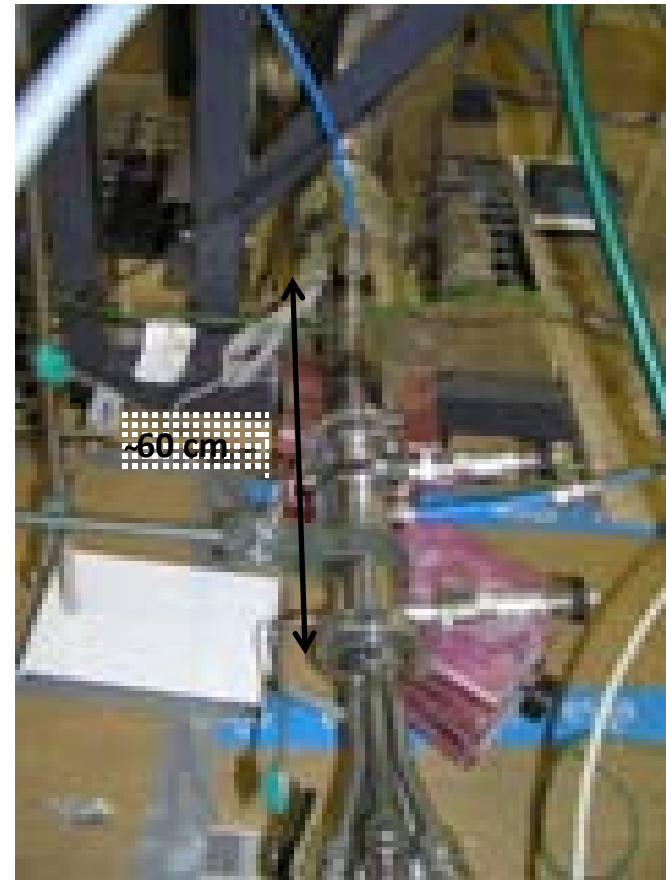


- Real-time monitoring of CO_2 is a must

$$DR = \frac{CO_2(\text{rawgas}) - CO_2(\text{background})}{CO_2(\text{dilutedgas}) - CO_2(\text{background})}$$

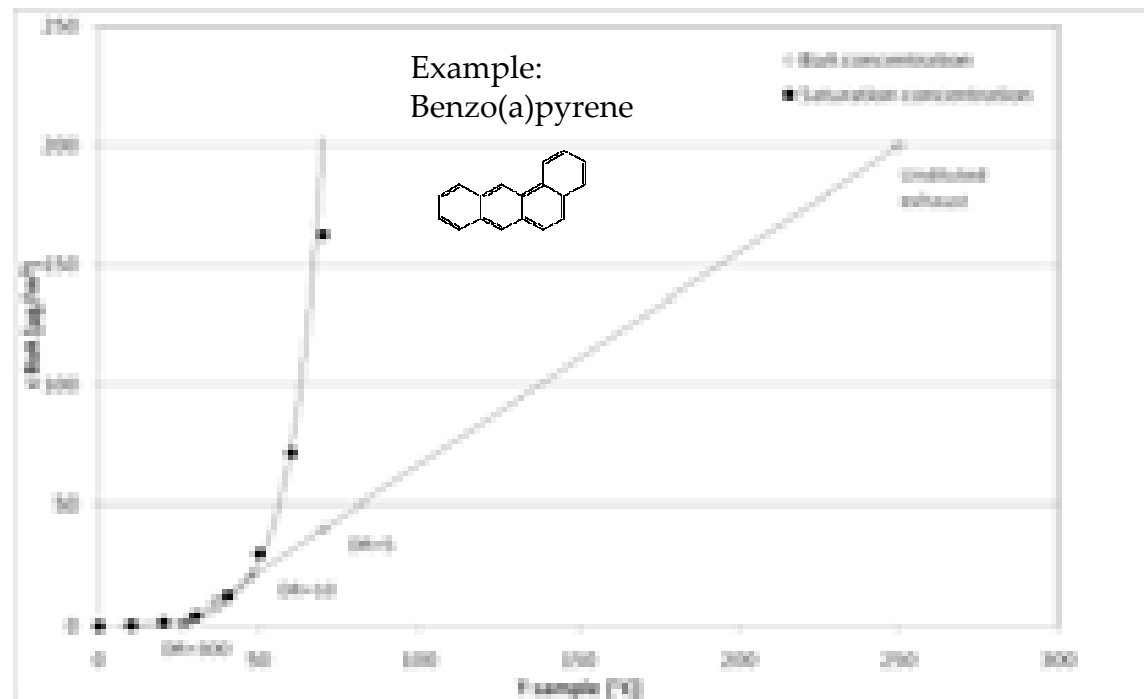


Combination of porous tube diluter (PRD) and ejector diluter (ED)



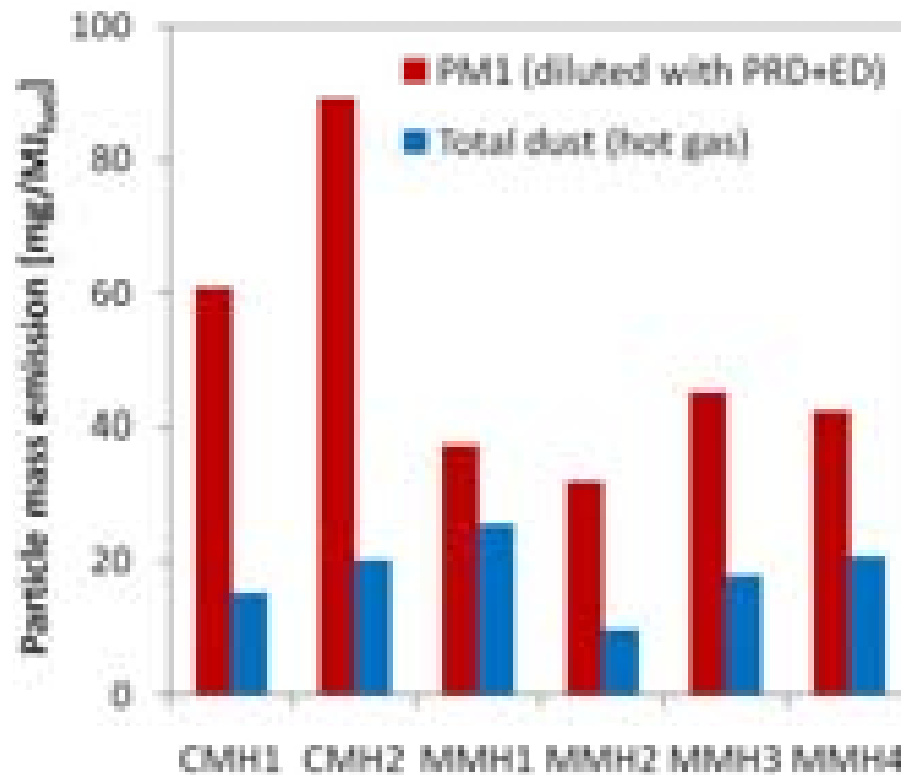
Dilution affects aerosol properties

- In incomplete wood combustion, large amount of organic species are formed
- The semivolatile species condense on the particles in dilution



Hytonen et al. AST 2009, 43(442)

How does the method affect the results?

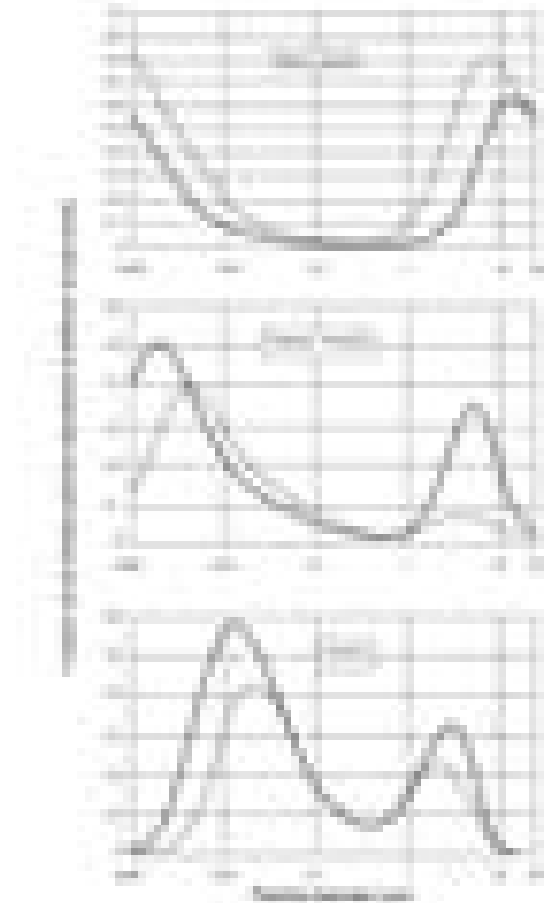


CMH=conventional masonry heater

MMH=modern masonry heater (sec. combustion air)

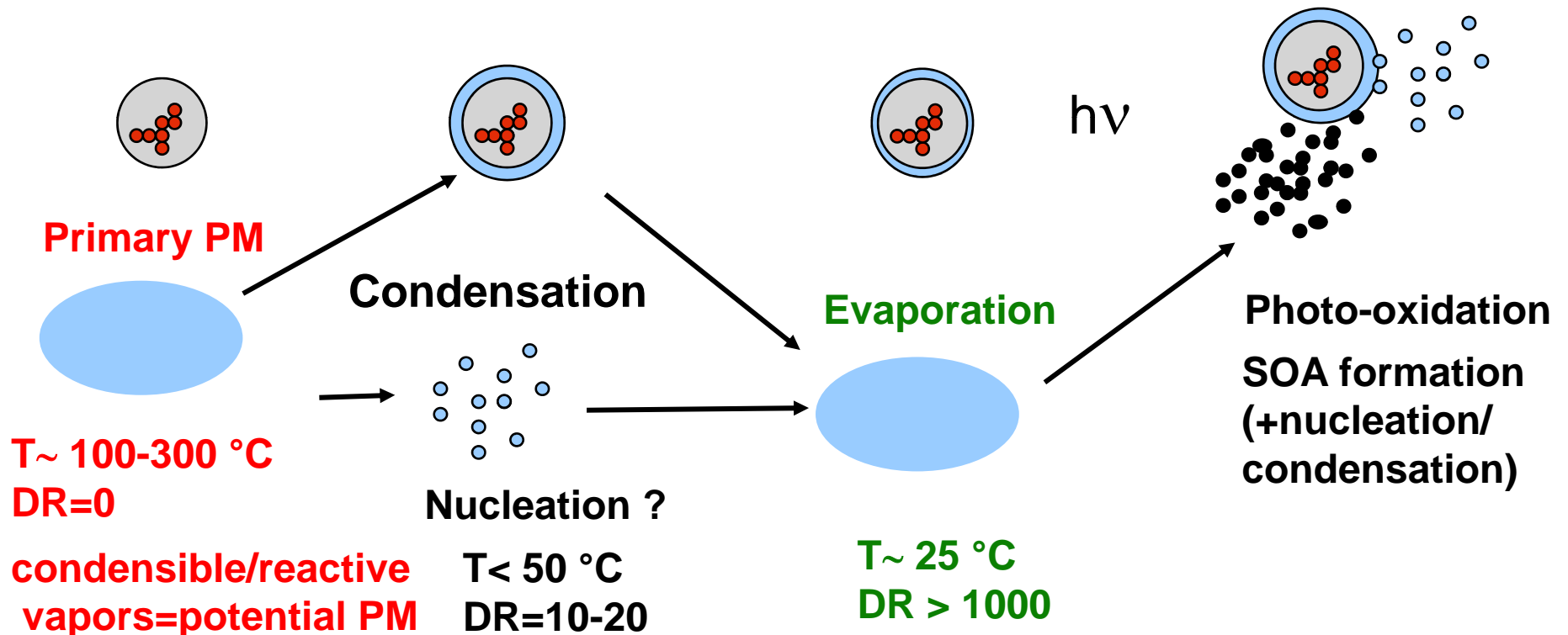
Total dust measurement and dilution

- In dilution, coarse particles are lost
 - Bends, narrowings etc exist
 - Maintaining isokinetic flow is challenging
- Relevance of coarse particles for health and environment?
 - Particles over 10 μm are not considered inhalable
 - Mimicking atmospheric conditions in the sample is probably more relevant
 - early stage DR 10-1 000
 - final stage DR 1 000-100 000



PM_{tot} = primary PM + potential PM (gas + vapour)

1. In-stack
2. Emission and rapid dilution/cooling
3. Fresh atmosphere
4. Aged atmosphere



EMISSION REDUCTION

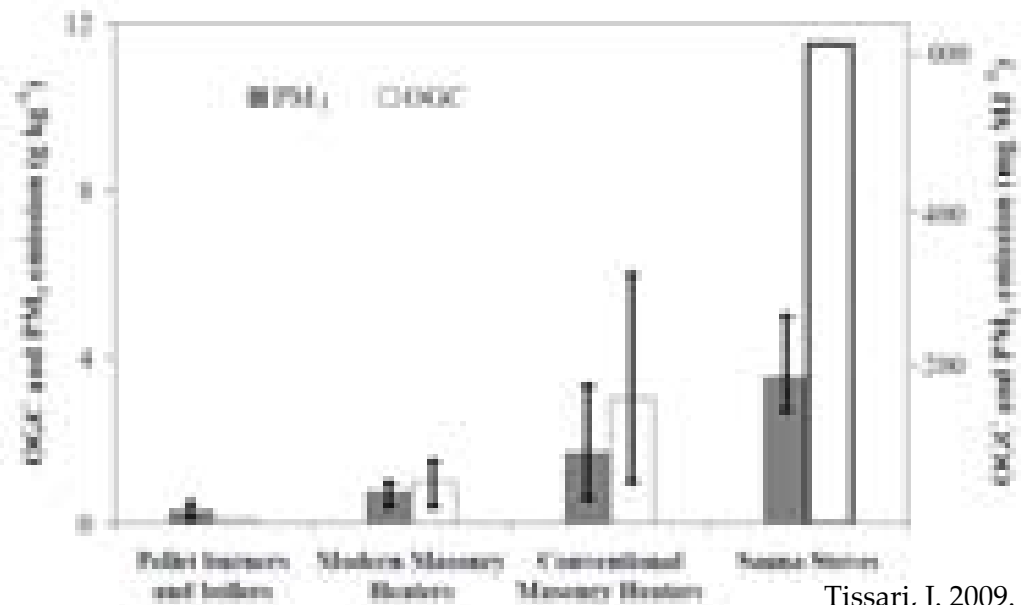
Primary measures

- user
- fuel
- appliance



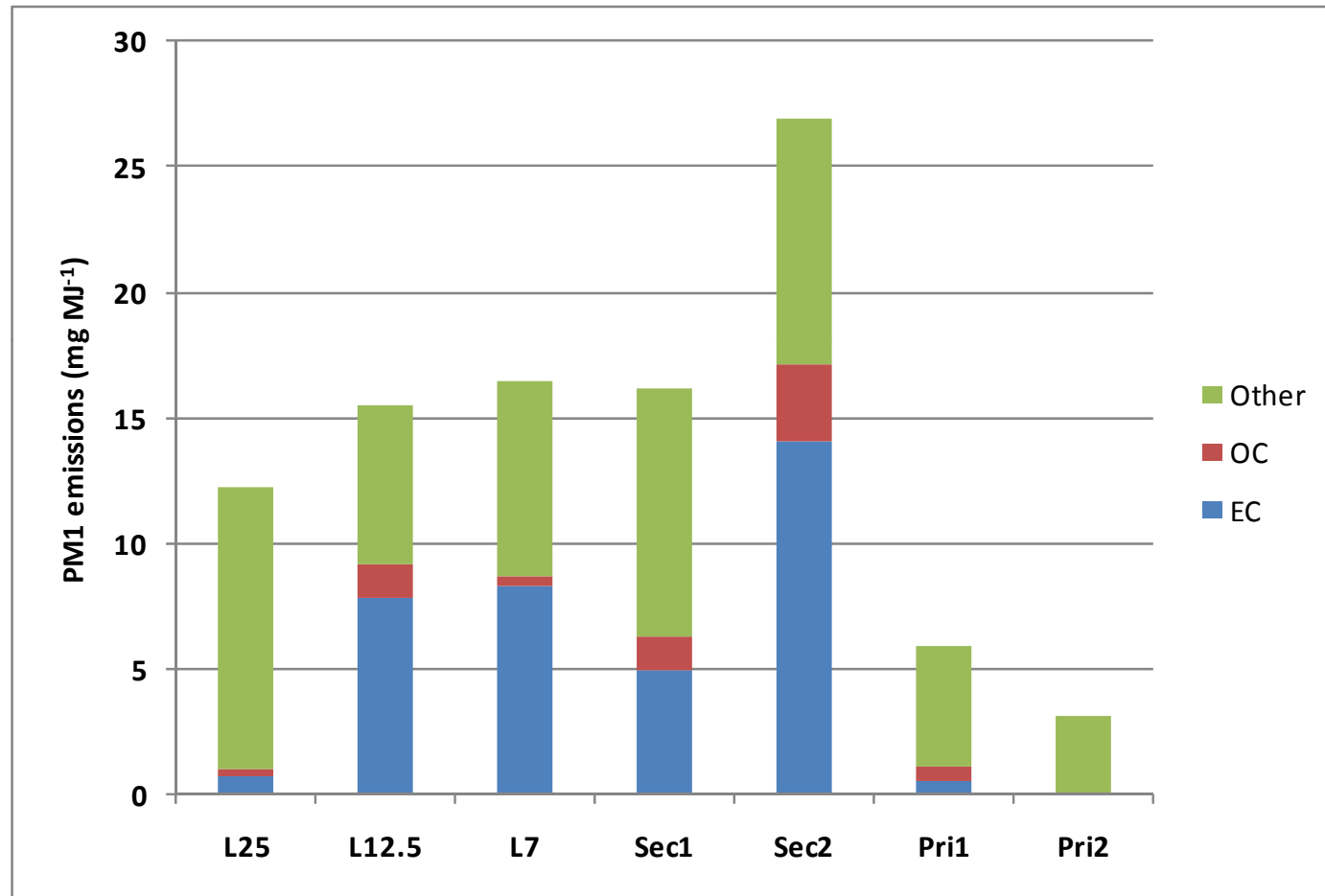
Pellet combustion

- Good controllability and efficiency
- Stable fuel quality
- Relatively low emissions
- However, higher emissions compared to light fuel oil (Johansson et al. 2004)



Effect of air-staging

see also 9C3 Lamberg et al. EAC2011



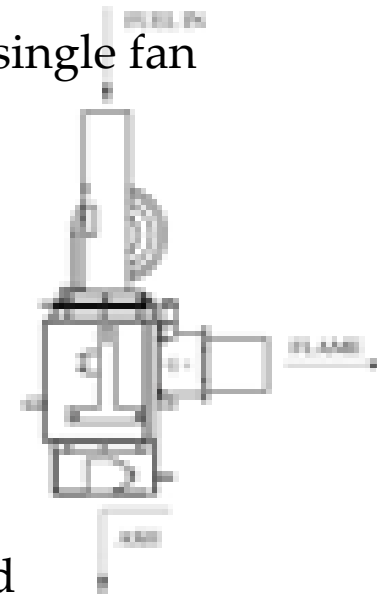
Primary air flow/Secondary air flow:

0.58 0.65 0.54 0.73 0.91 0.16 0.05

Pyro-Man Burner – 15 kW

Features

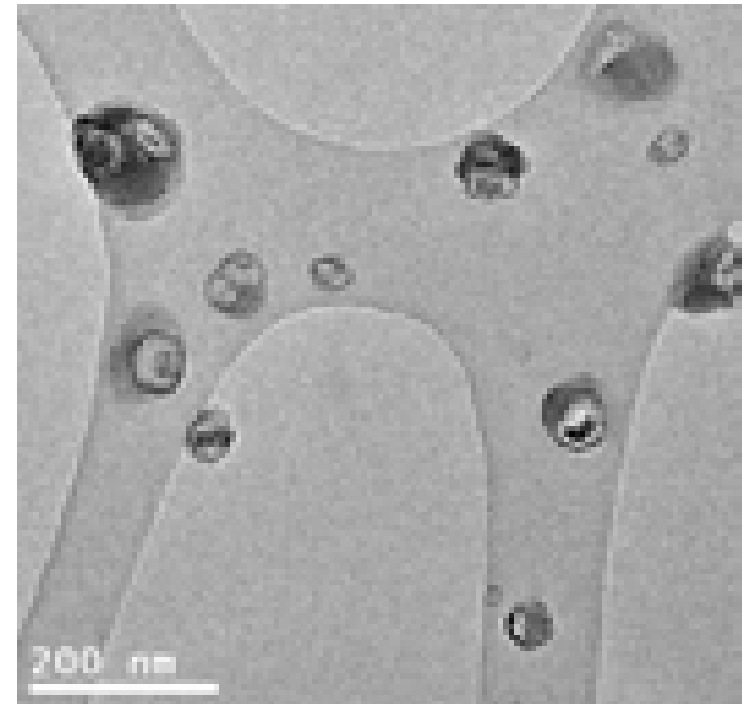
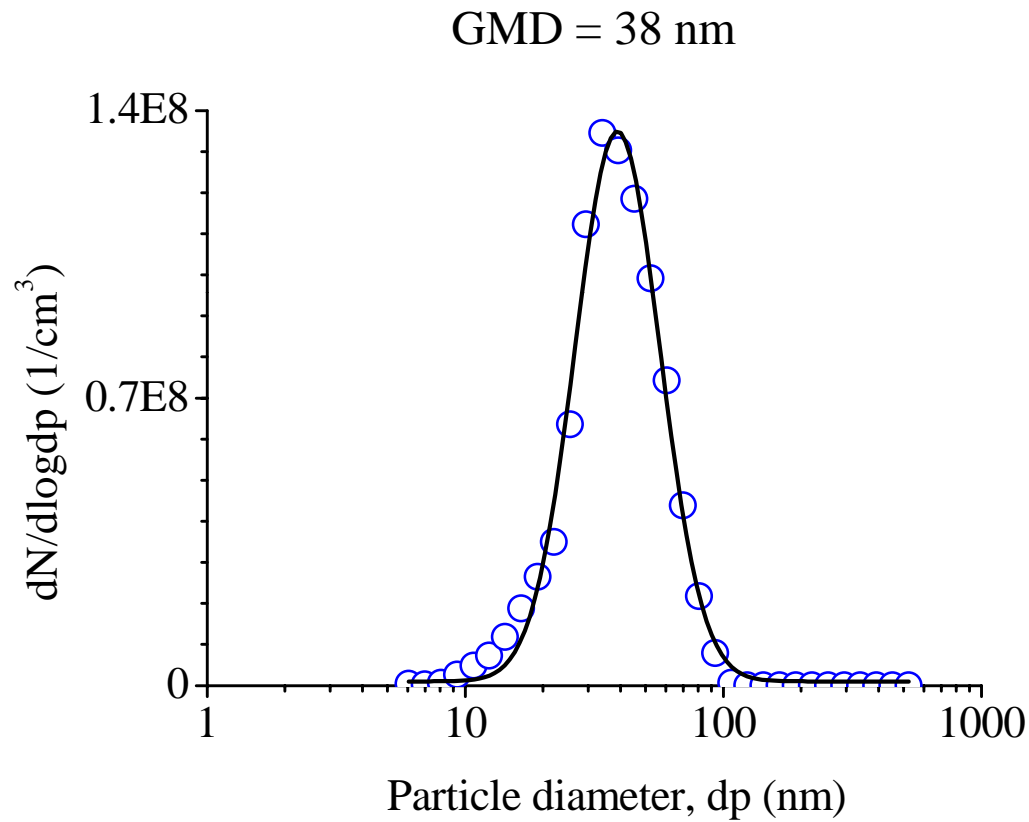
- Small scale fixed-bed counter-draft gasifying pellet burner
- Designed to replace oil burner using the old boiler system
- Staged primary/secondary/tertiary air feeding with a single fan
- Fully computer controlled
- Fuel bed ignition with electric heater
- First gasifies the wood pellet and
Then burns produced syngas in a ceramic burner head



Emission measurement results

- PM1 emission 1,4 – 2,4 mg/MJ (27- 43 mg/kg)
- TSP 1,8-2.0 mg/MJ
- CO – 4,8 to 6 mg/MJ
- NO – 120-140 ppm / 60-80 mg/MJ
- Particle number emission 1.8×10^{13} /MJ.

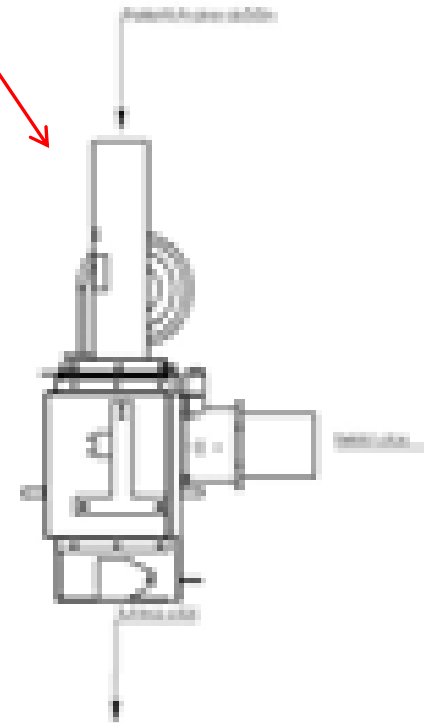
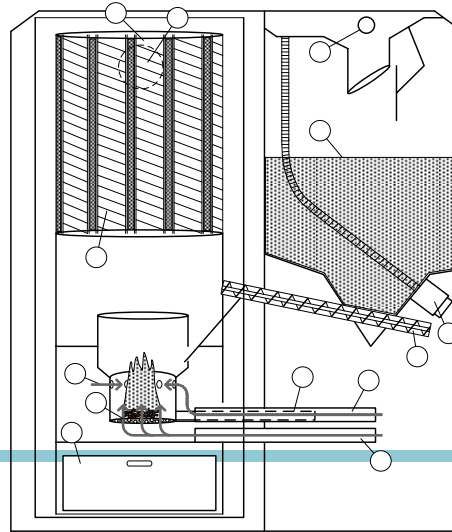
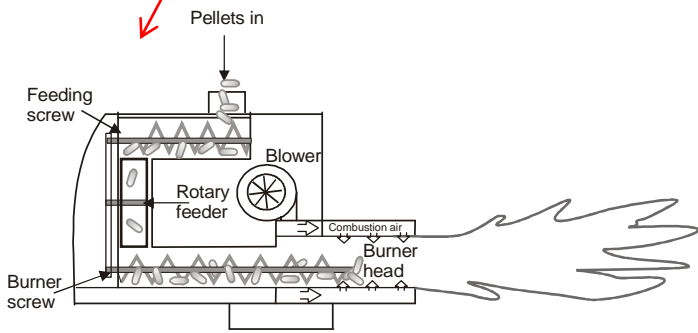
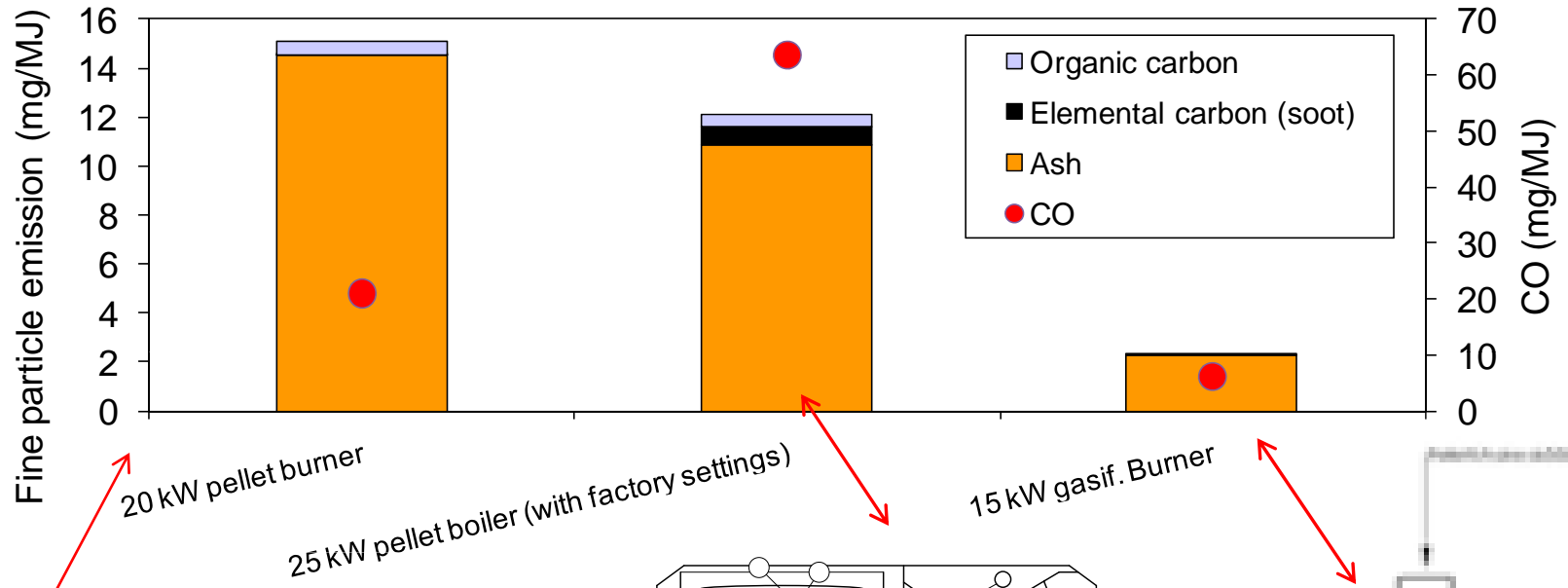
Particle size distribution



-Fine particle density 1000-1300 kg / m^3
-Measured with APM

Comparison of technologies: Residential scale

(Tissari et al., 2008,
Lamberg et al., 2009,
Nuutinen et al., 2010)



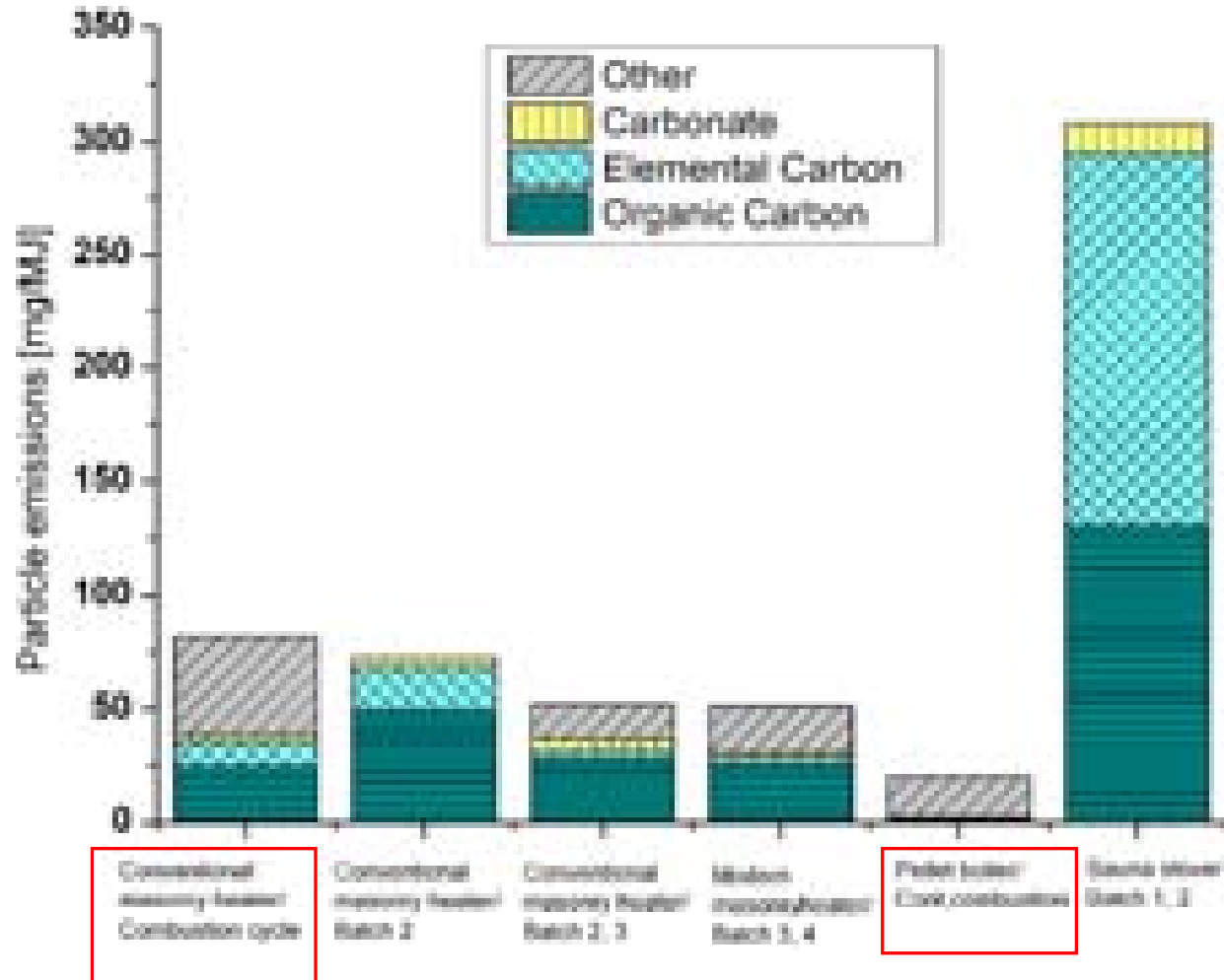
EMISSIONS

- PM1
- PAH
- Size distribution

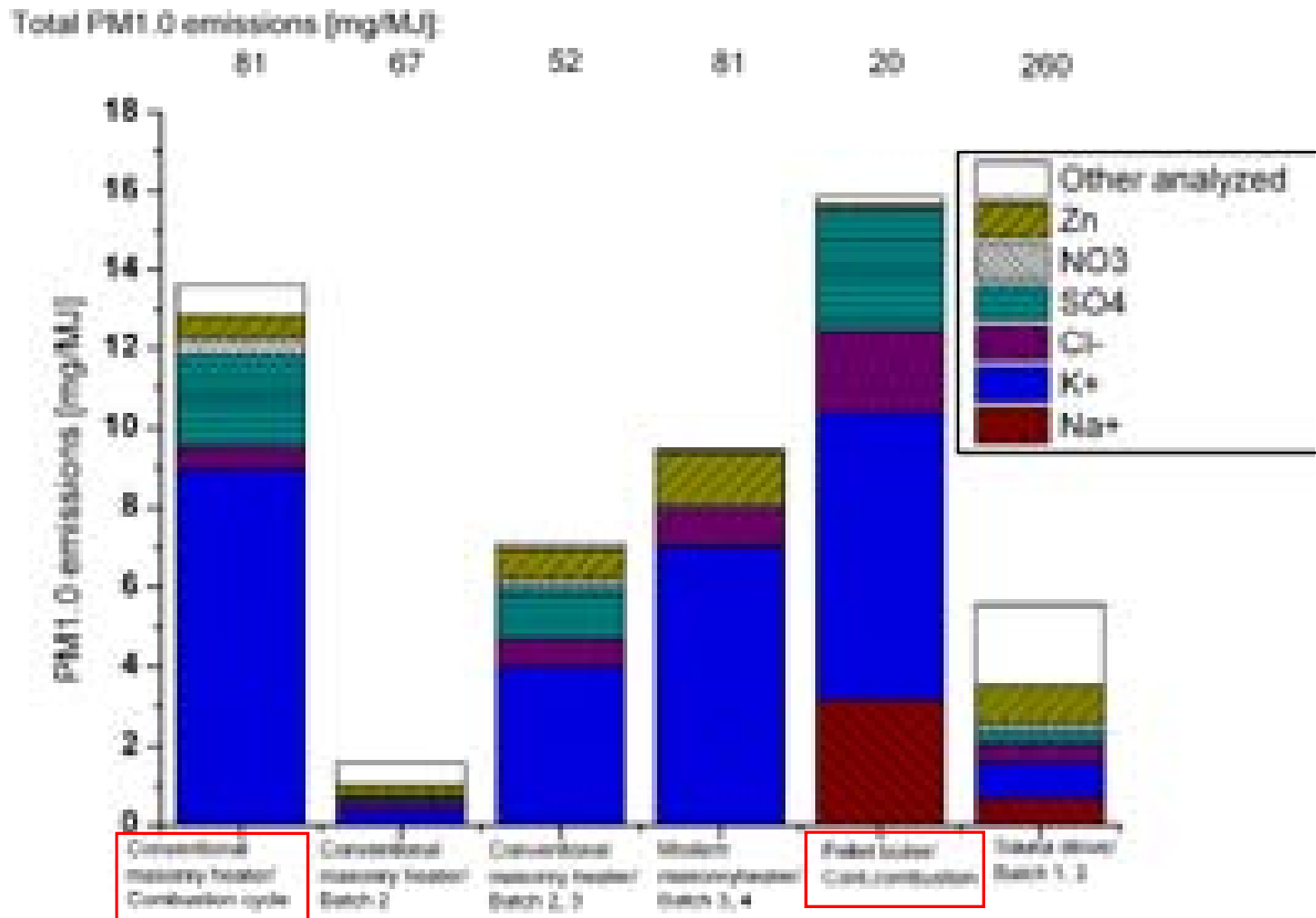


Chemical properties and PM_{1.0} emissions

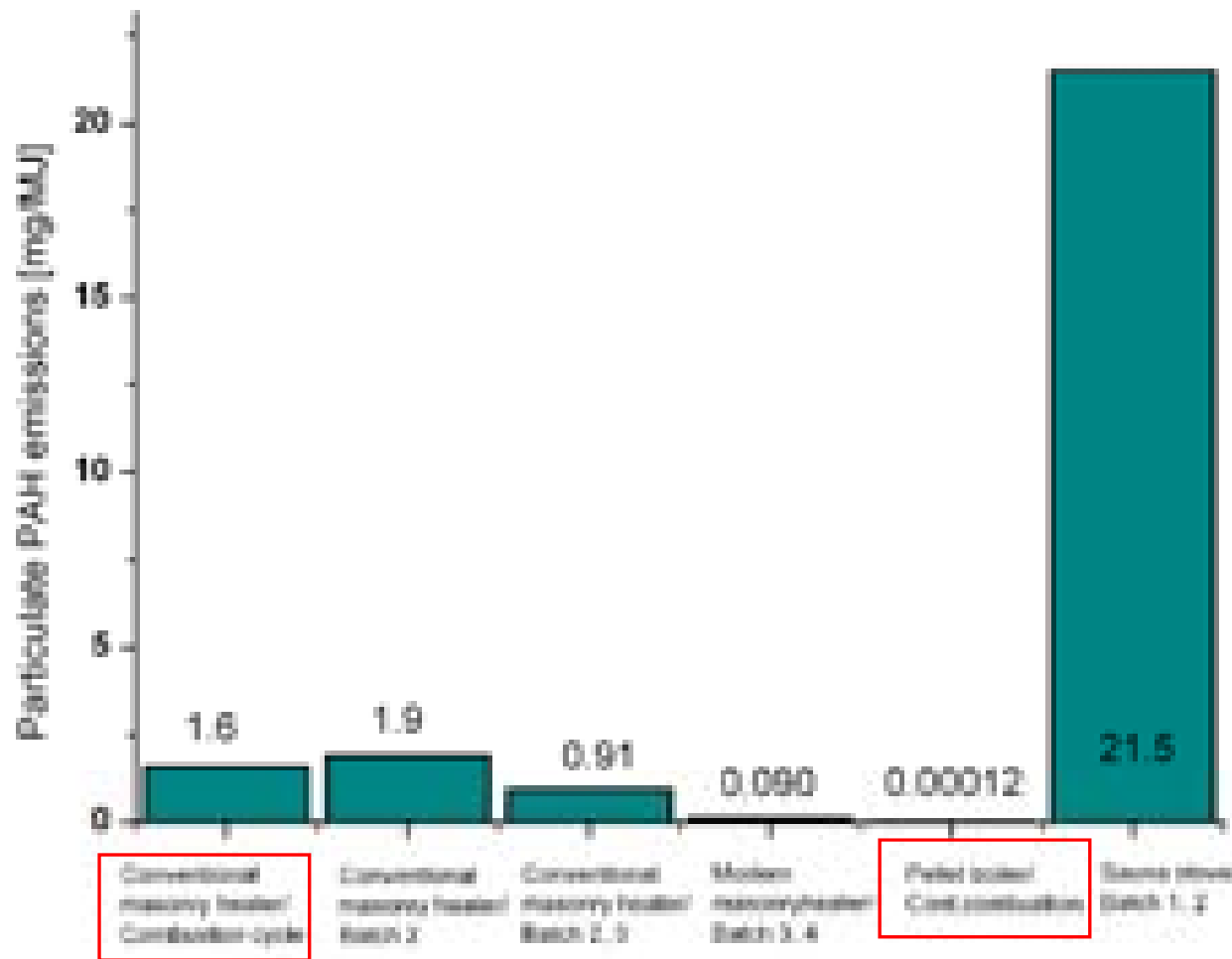
- PM_{1.0} emissions from 47 mm PTFE filters



Chemical properties: anions and cations



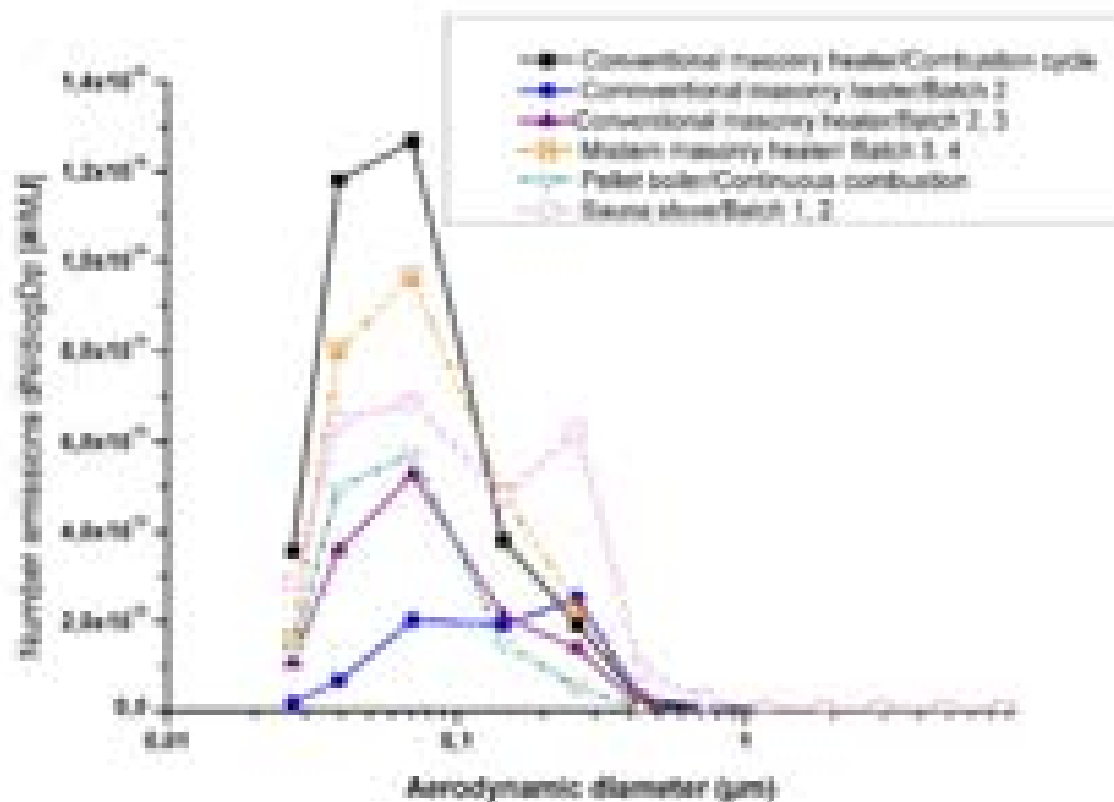
Particulate PAH emissions



- Conventional masonry heaters on a same level
- pellet boiler clearly the lowest
- sauna stove the highest
- CMH vs. MMH

Physical properties

- Measured using Electrical Low Pressure Impactor (Dekati Ltd.)
- second mode becomes more visible when combustion conditions get worse
- number emissions/GMD do not clearly correlate with combustion conditions



	GMD [nm]	Ntot [1/MJ]
Conventional masonry heater/combustion cycle	63	8.3E+13
Conventional masonry heater/Batch 2	140	1.9E+13
Conventional masonry heater/Batch 2, 3	73	3.4E+13
Modern masonry heater/Batch 3, 4	74	6.8E+13
Pellet Boiler/Cont. combustion	61	3.5E+13
Sauna stove/Bad combustion	105	6.7E+13

DETAILED PHYSICO-CHEMICAL CHARACTERISATION

Needed

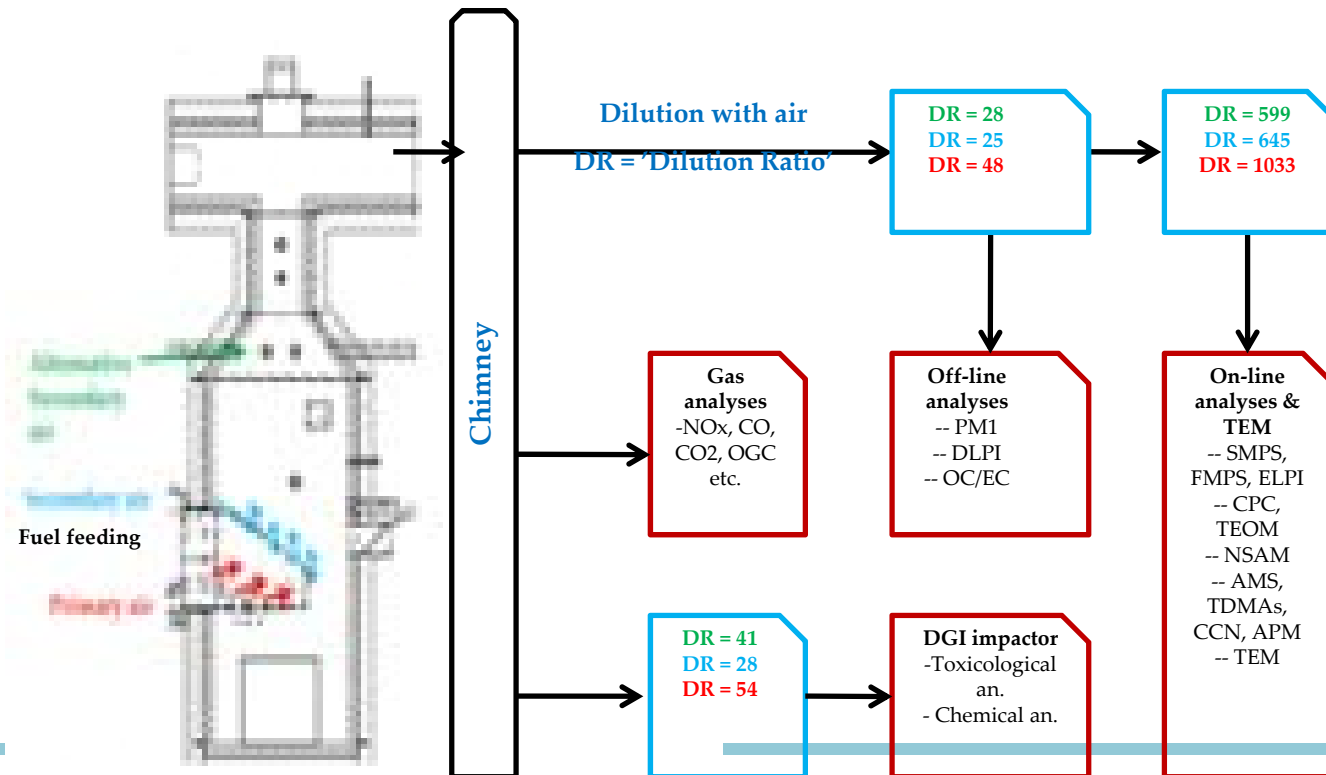
- To relate toxicological effects
- To better understand their effects on climate

Towards single particle analysis

Experimental setup

- A 40 kW grate combustion reactor with adjustable air flows and staging of combustion air, with multi step dilution.
- Three wood chip combustion setups: **optimal** (low CO and organics), **variable** (elevated CO), and **poor** (high CO and organics).

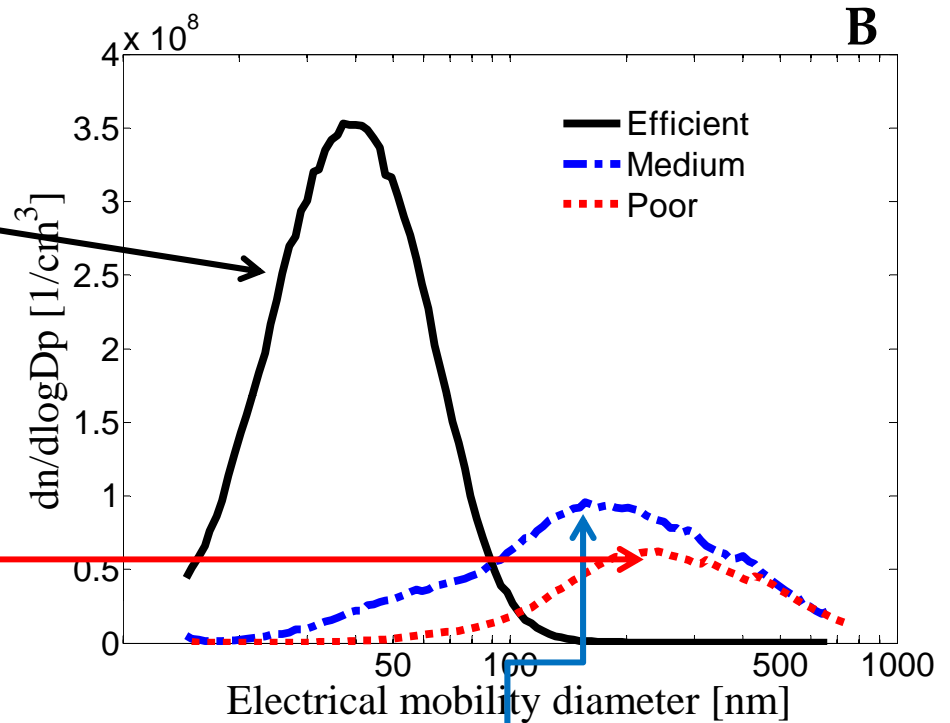
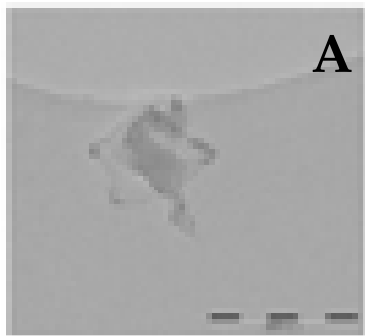
	Fuel feeding [kg/h]	Primary air [l/min]	Secondary air [l/min]
Optimal	7	300 – 320	400 – 430
Variable	5	300 – 330	0
Poor	7-8	200 - 230	0



Properties of the particles

Optimal combustion:

- Ash containing particles in the size range of 10-200 nm
- Multi-element non-spherical particle type
- No soot particles.



Poor combustion:

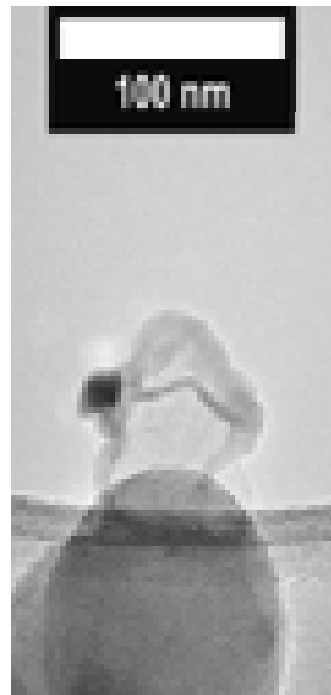
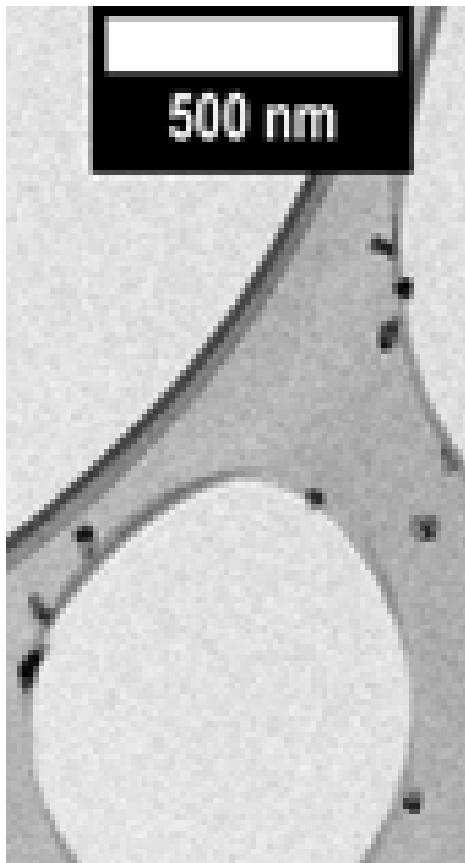
- Large chained soot agglomerates in the size range from 50 nm to $1\mu m$
- Elemental analysis show K, S and O with the soot particles
- Primary particles spherical with graphite layers (EC)

Variable combustion:

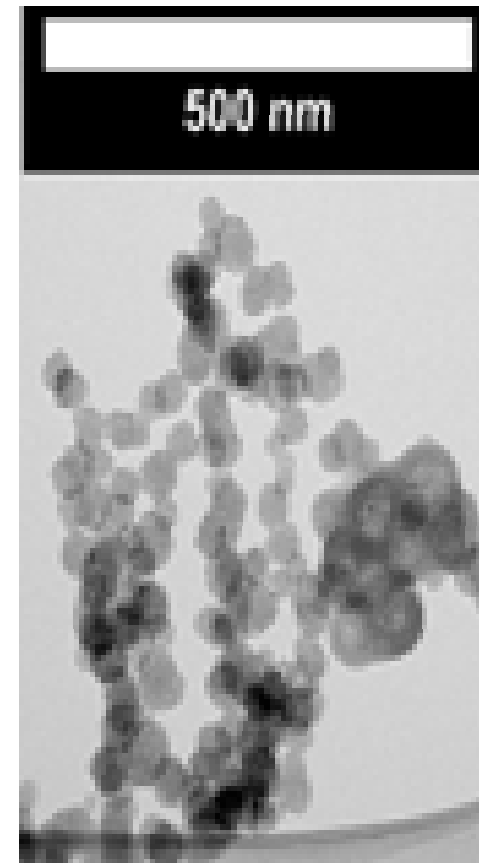
- Both ash and soot containing particles in the wide size range from 10 nm to $1\mu m$.
- Ash mostly in separate phase, but some loosely attached with soot
- Particles consisted of wide range of elements and had different morphologies

TEM-EDS results

In general, soot and ash particles were found as separate particles suggesting different formation routes for the two fine particle types.



Impacted ash on soot particle

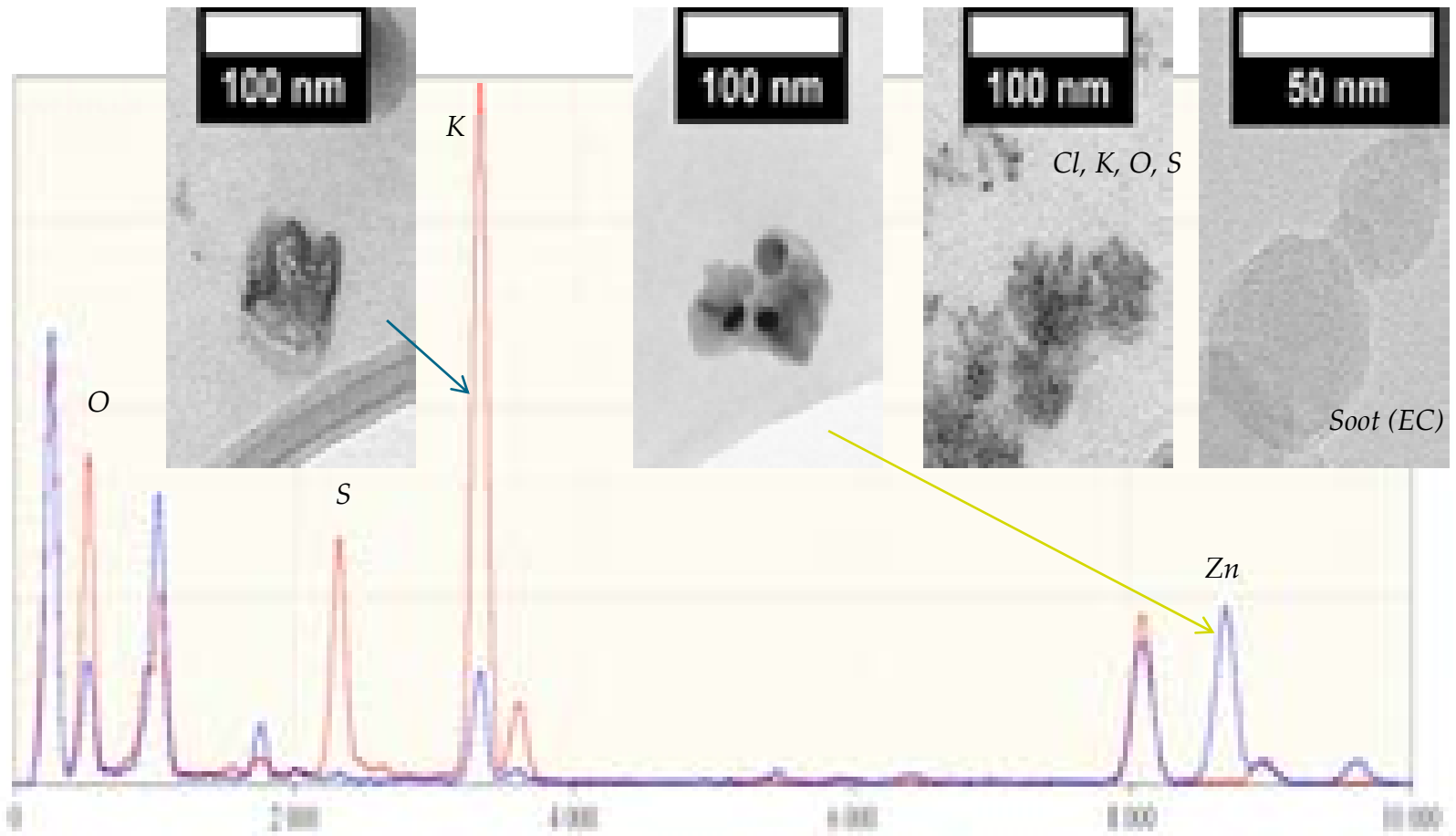


SOOT (>150 nm)

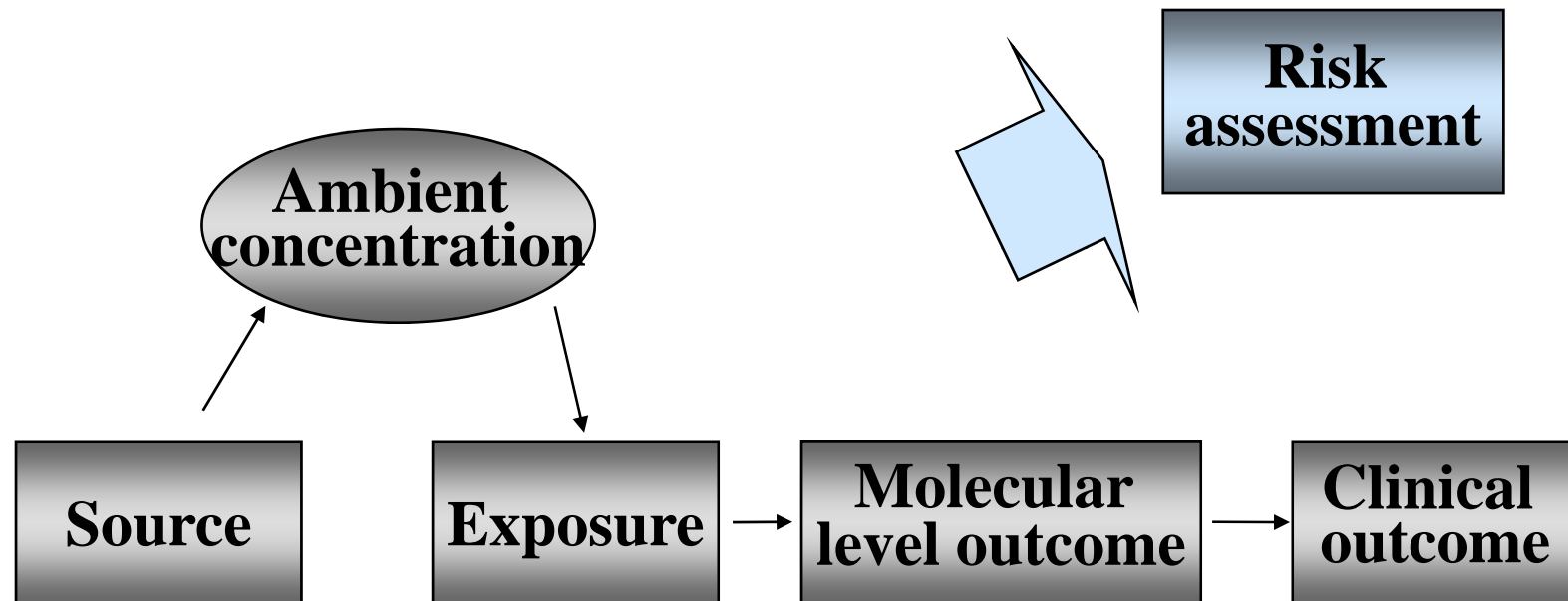
see also 4P180 Torvela et al. EAC2011

Size classified TEM samples: typical EDS spectra and particle morphologies

Variable



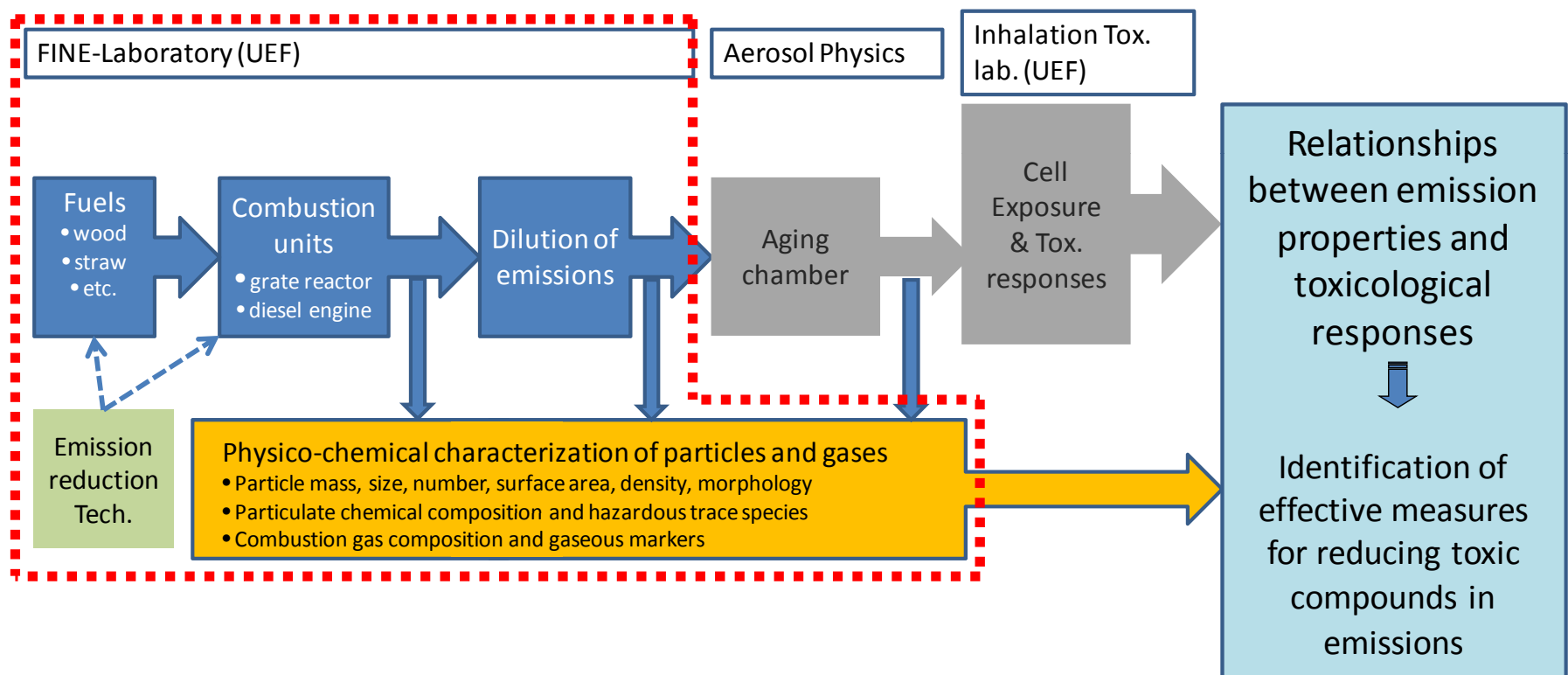
The chain of events from emissions to health impact

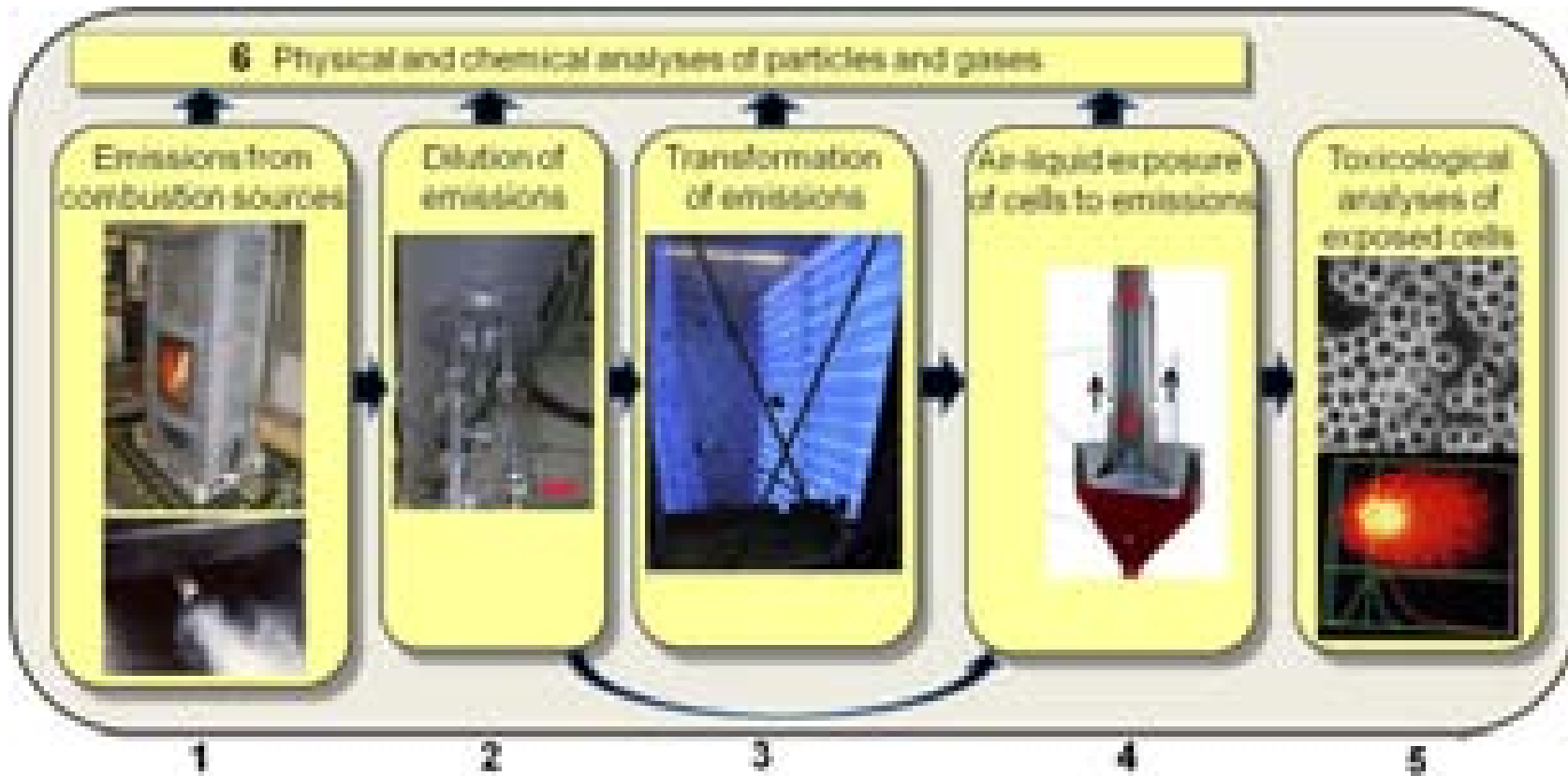


Highly multidisciplinary, broad research area



Combustion experiments combined with emission aging studies and toxicological collections





Analysis of the whole chain from emission sources (1) via dilution (2) and transformation (2), their physical and chemical characterization (6) to health related toxicological responses in cell lines (4-5).

An illustration of the new research set-up for on-line exposure to fresh and aged combustion aerosols at the University of Eastern Finland
see also 5C2 Leskinen et al. EAC2011.



CONCLUSIONS

- **Emission reduction from small scale combustion is needed**
 - primary measures
 - secondary measures
 - measurement methods
 - legislation

- **The relation of PM physico-chemical properties and health/climate effects is not well understood**



Thank you for attention!

Acknowledgements

This work was supported partly by: Univ. Of Eastern Finland, Tekes and Academy of Finland