Toxicological characteristics of particulate emissions from biomass combustion

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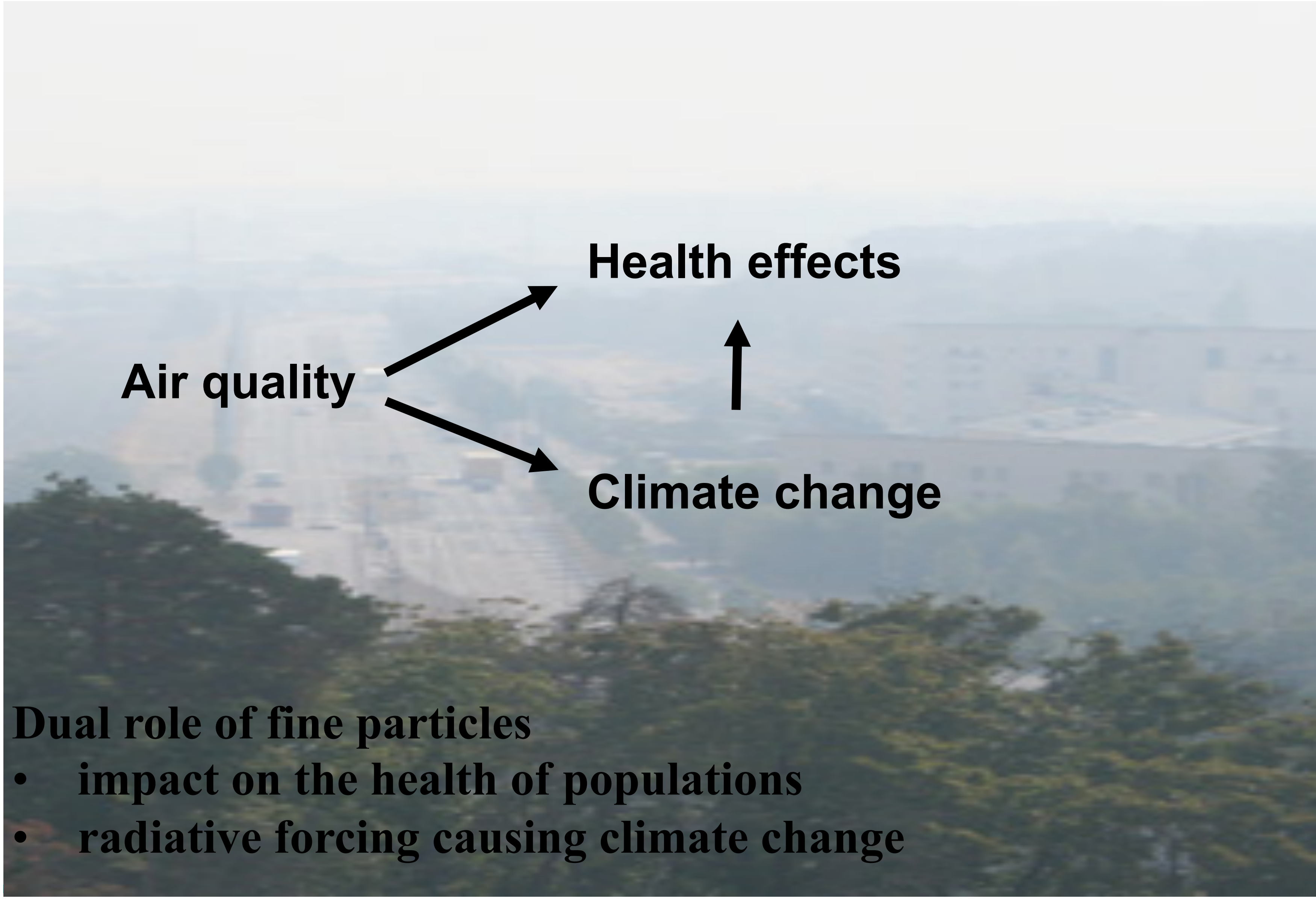


Dual role of fine particles

- **impact on the health of populations**
- **radiative forcing causing climate change**

Particulate air pollution – an issue of public health

In Europe:

- Up to 350 000 **premature deaths** annually
  - 8 months loss of statistical life expectancy

- **large economic impacts**
  - due to worsening of symptoms of cardio-respiratory diseases, hospitalizations, loss of working days, etc.

- No obvious threshold value for particle levels below which no adverse health effects occur.

(EU/CAFÉ 2000, Directive 2008/50)

Why worry about biomass combustion emission?

In order to slow down the climate change the use of renewable energy in EU will be increased up to 20% of the total energy consumption by 2020

- **This may lead to an increase in harmful effects on human health**

- **No health-based guidelines for regulating source specific emissions**

- Only little is known on which constituents of emissions are behind the reported harmful health effects

Chemical composition of **biomass combustion particles** is different from fossil fuel combustion

Health risks may differ

from other particles of similar size

What do we NOT know ?

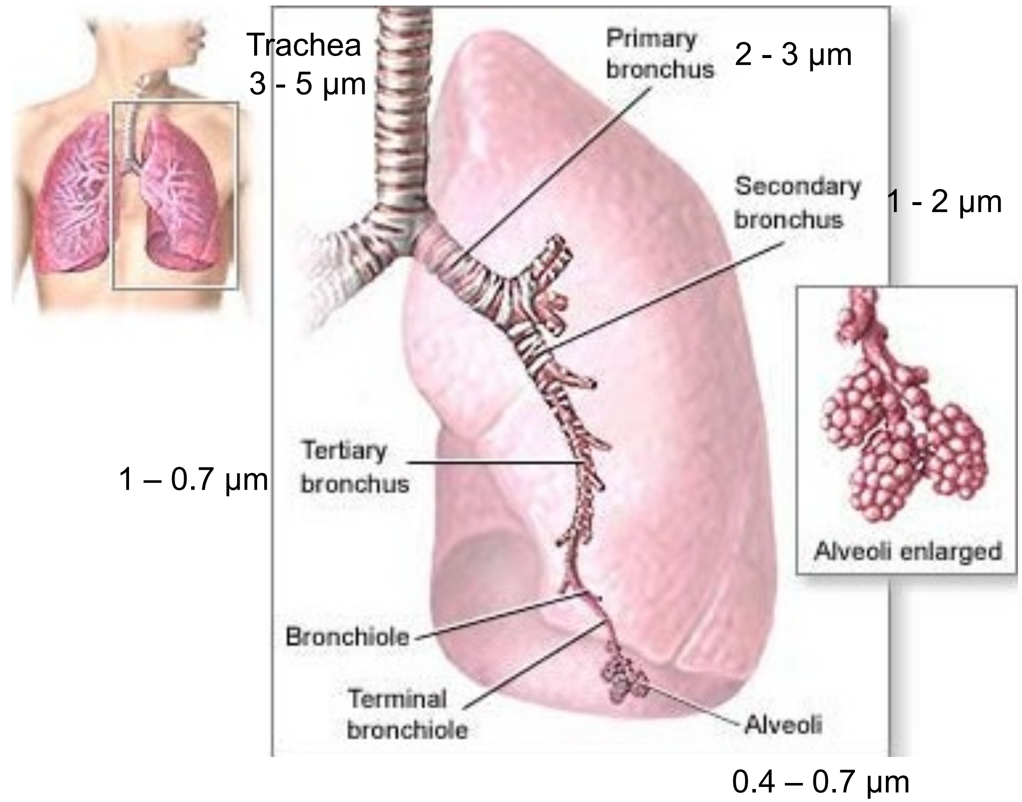
- causal compounds behind the health effects and their effective doses
- spesific sources of the harmful emissions
- how the atmospheric transformation and other components of the complex ambient mixture affect the potency of the different emissions in the atmosphere

Why the fine particles are so dangerous?

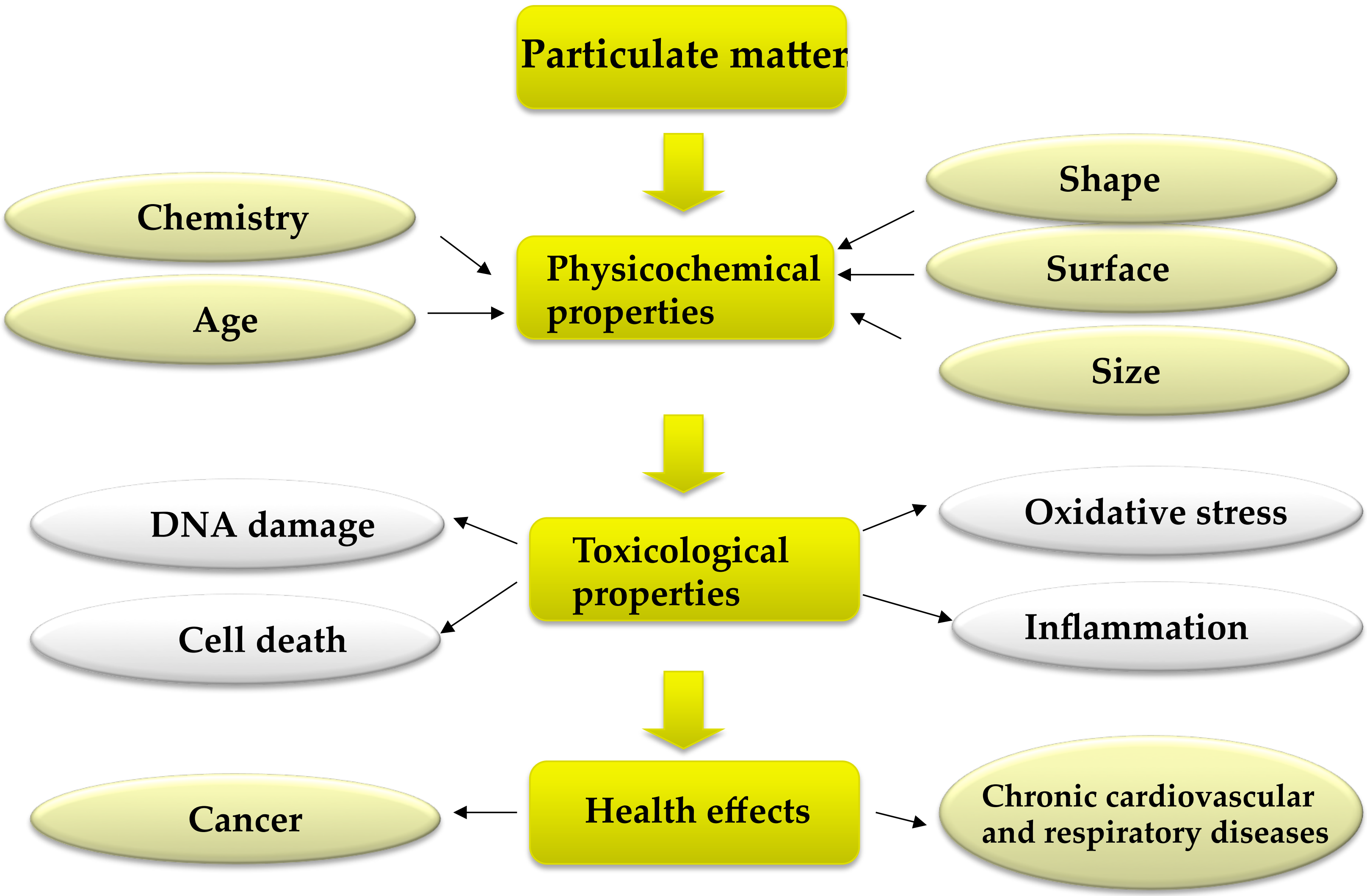
Penetration deep in the airways

- PM less than 0.1um have the largest reactive surface
- Transition metals and their oxidized forms
- Reactive organic compounds (e.g. uncompleted combustion)
- Age of the particles (fresh PM more harmful than aged)
- Poor water solubility

Activation of wide variety of mechanisms leading to adverse health effects



Mechanisms behind the health effects?



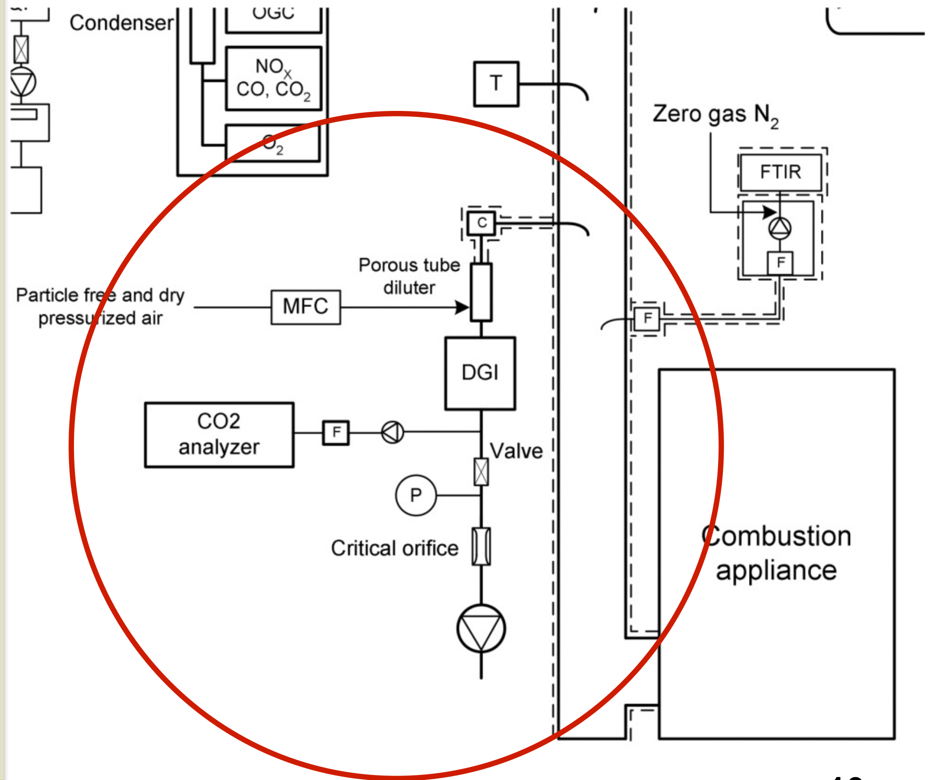
Multidiciplinary approach

- To define the Chemistry-Toxigology-Health connection, examing the toxicity of the entire PM mixture is important, since interactions between various chemical components may lead to unpredictable responses

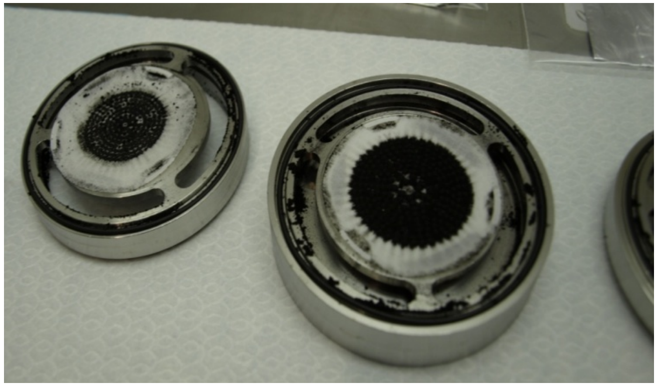
- To gain comparable data, harmonised sampling methods and analysis of physicochemical and toxicological characteristics need to be studied in both in field studies and experimental settings focussing on
  - complex mixture of urban air particulate matter (PM)
  - source specific PM emissions

Particle collection
(University of Eastern Finland, FINE)

- Particle samples were collected to filters with a Dekati Gravimetric Impactor (DGI)
  - sample diluted with porous tube diluter
    - DR 13-26



Sample preparation



1. Weighing of filters
2. Methanol extraction (sonication)
3. Evaporation of additional methanol
4. Dispensing the particle suspension to glass tubes on mass basis
5. Drying under nitrogen flow
6. Storing at -20 °C

Before exposure of cells:

6. Dissolving particles to DMSO and water
7. Sonication for 30 minutes

Exposure to particulate matter

Cell lines:

- Mouse RAW264.7 macrophages,
- Human BEAS-2B cells

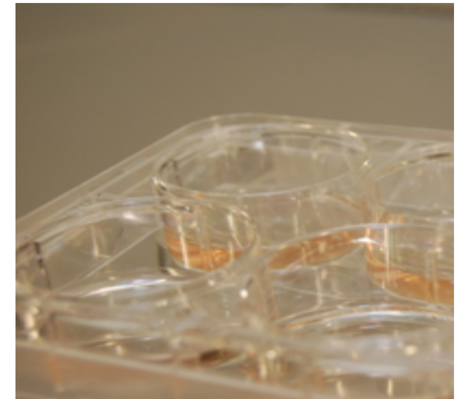
They are target cells in PM induced immunotoxicity

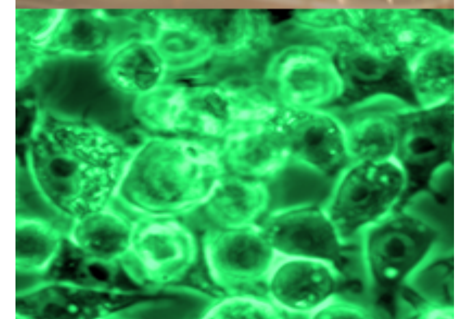
Particulate doses: 15, 50, 150 and 300 µg/ml

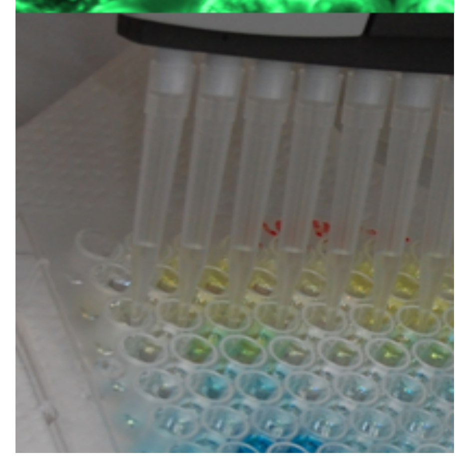
Exposure time: 24 hours

Detected endpoints:

- Cell death (acute and programmed)
- Inflammatory mediators (e.g.MIP-2, TNFα)
- DNA damage







Inhal Toxicol. 2012 May;24(6):343-55.

Efficiency of log wood combustion affects the toxicological and chemical properties of emission particles.

Tapanainen M, Jalava PI, Mäki-Paakkanen J, Hakulinen P, Lamberg H, Ruusunen J, Tissari J, **Jokiniemi J**, Hirvonen MR.

Combustion situations, bathes and sampling durations of four different log wood combustion appliances.

Appliance	Combustion situation	Batch	Sampling
Modern masonry heater	Improved batch combustion	1st batch 10x0.4 kg, others 4x1 kg	3rd and 4th batches, 50min
Conventional masonry heater 1	Conventional batch combustion	1st batch 7x0.43 kg, others 4x0.75 kg	2nd and 3rd batches, 40min
Conventional masonry heater 2	Conventional batch combustion	1st bach 3x1 kg, others 3x1.3 kg	Firing phase, beginning of the 2nd batch, 15min
Sauna stove	Inefficient batch combustion	1st batch 5x0.31 kg, 2nd batch 6x0.53 kg,	Ignition batch and 2nd batch, 20-35min

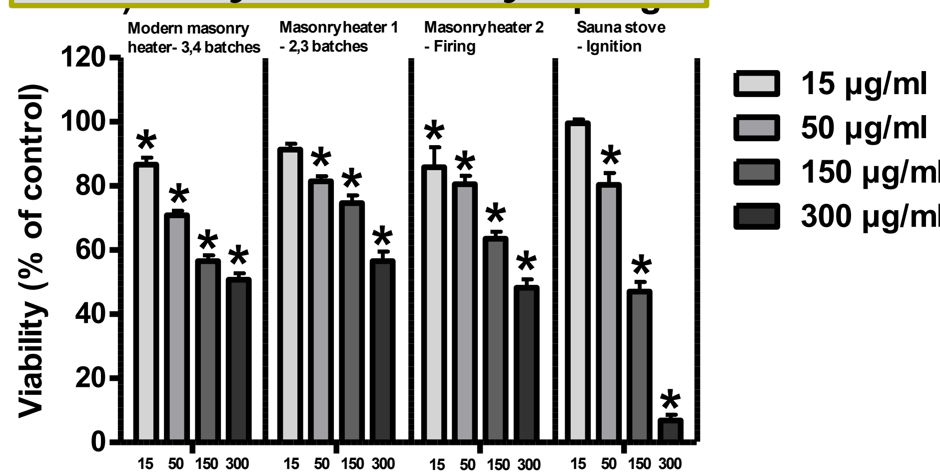
PM_1 emissions and their carbon content of four log wood combustion appliances.

mg/ MJ	Modern masonry heater 3,4 batches	Masonry heater 1 2,3 batches	Masonry heater 2 Firing	Sauna stove Ignition
PM_1	51±26	52±12	67±7	257±85
EC	24±7	28±4	49±10	130±23
OC	4±2	4±2	19±16	160±26

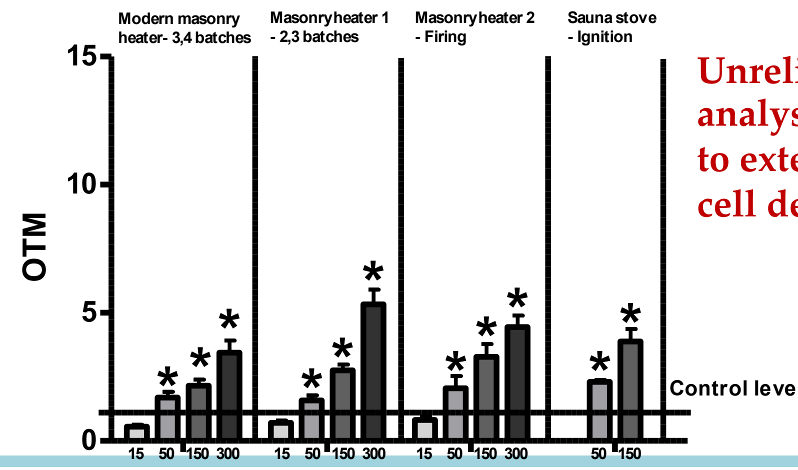
The inefficient batch combustion phase in the SS emitted particles with the strongest genotoxicity and cytotoxicity

Instead, the cytotoxic effects of more efficient combustion phases in the masonry heaters might be linked to water-soluble metal content of the PM samples.

Cytotoxicity



Genotoxicity



Unreliable analysis due to extensive cell death!

Conclusions

- All the wood combustion samples exerted high cytotoxicity, but only moderate inflammatory activity.
- The particles emitted from the inefficient phase of batch combustion in the sauna stove induced the most extensive cytotoxic and genotoxic responses.
- PAHs and other organic compounds in samples might have contributed to these effects. Instead, water-soluble metals seemed to participate in the cytotoxic responses triggered by the particles from more efficient batch combustion in the masonry heaters.
- Efficiency of batch combustion plays a significant role in the harmfulness of PM even under incomplete wood combustion processes.

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In vitro toxicological characterization of particulate emissions from residential biomass heating systems based on old and new technologies

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Toxicological properties of PM samples from seven different small-scale biomass heating systems

Collaboration: Professor Obernberger
Graz University of Technology and BIOENERGY 2020+ GmbH

Studied appliances

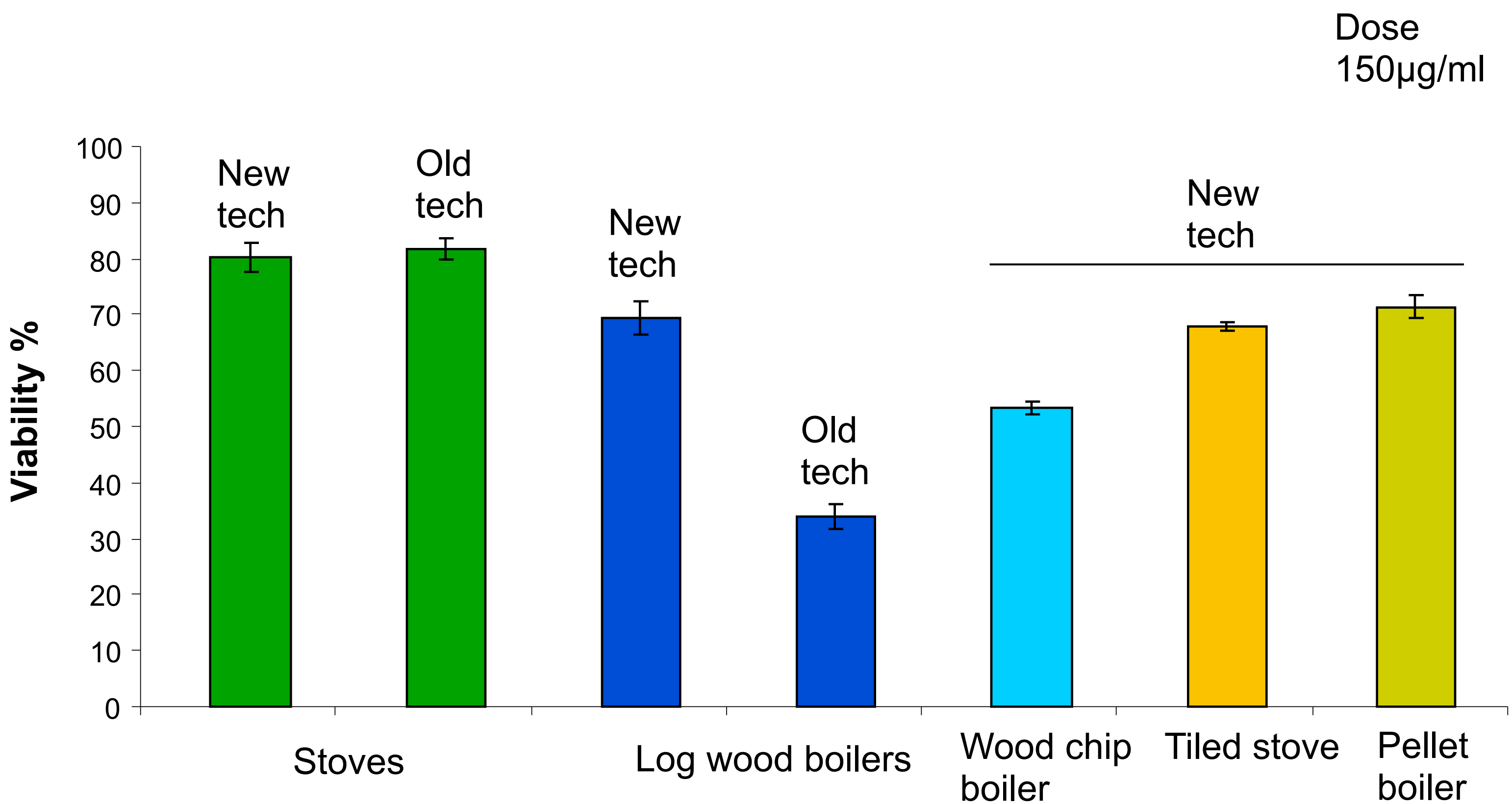
New technology

1. stove
2. log wood boiler
3. tiled stove
4. pellet boiler
5. wood chip boiler

Old technology

1. stove
2. log wood boiler

Cytotoxicity (MTT test)



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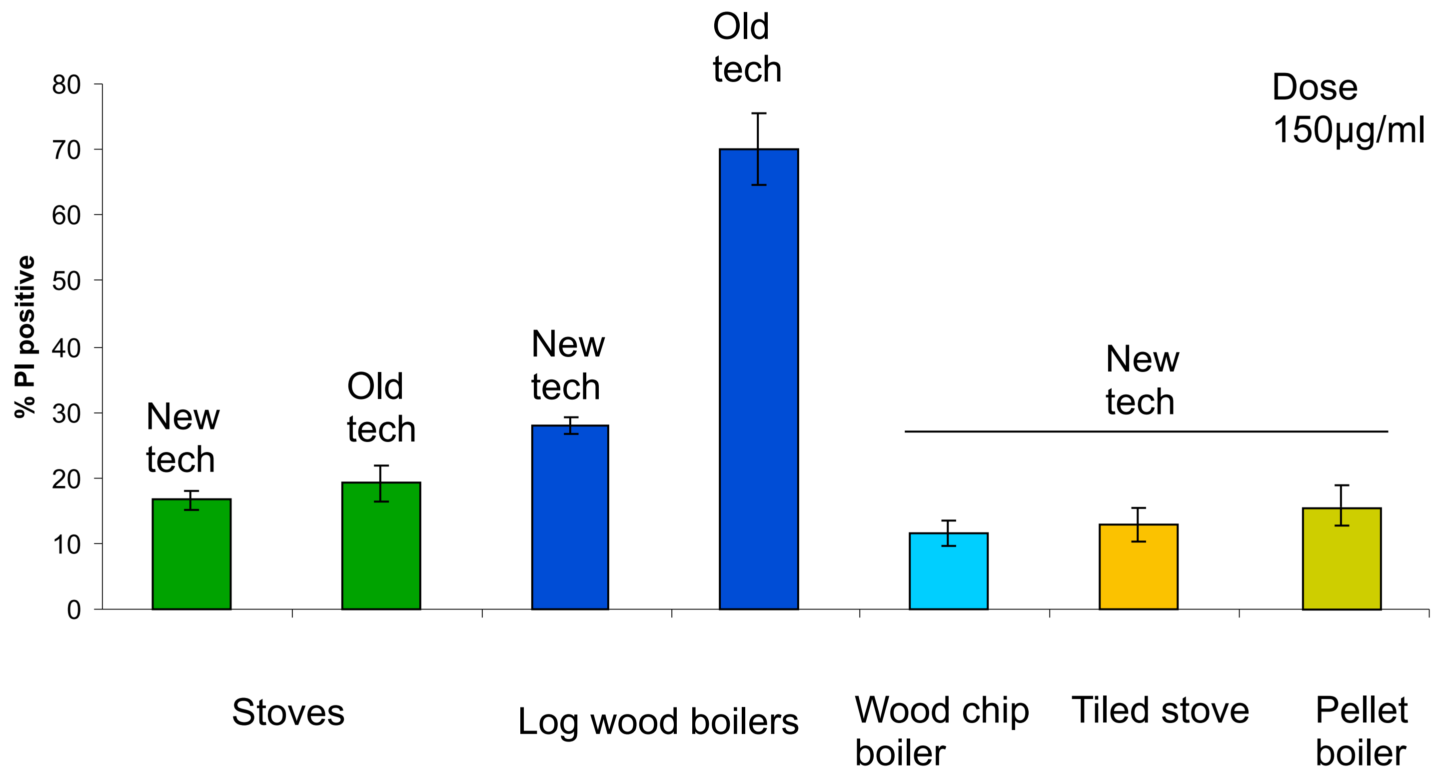
Cytotoxicity /Cell membrane permeability



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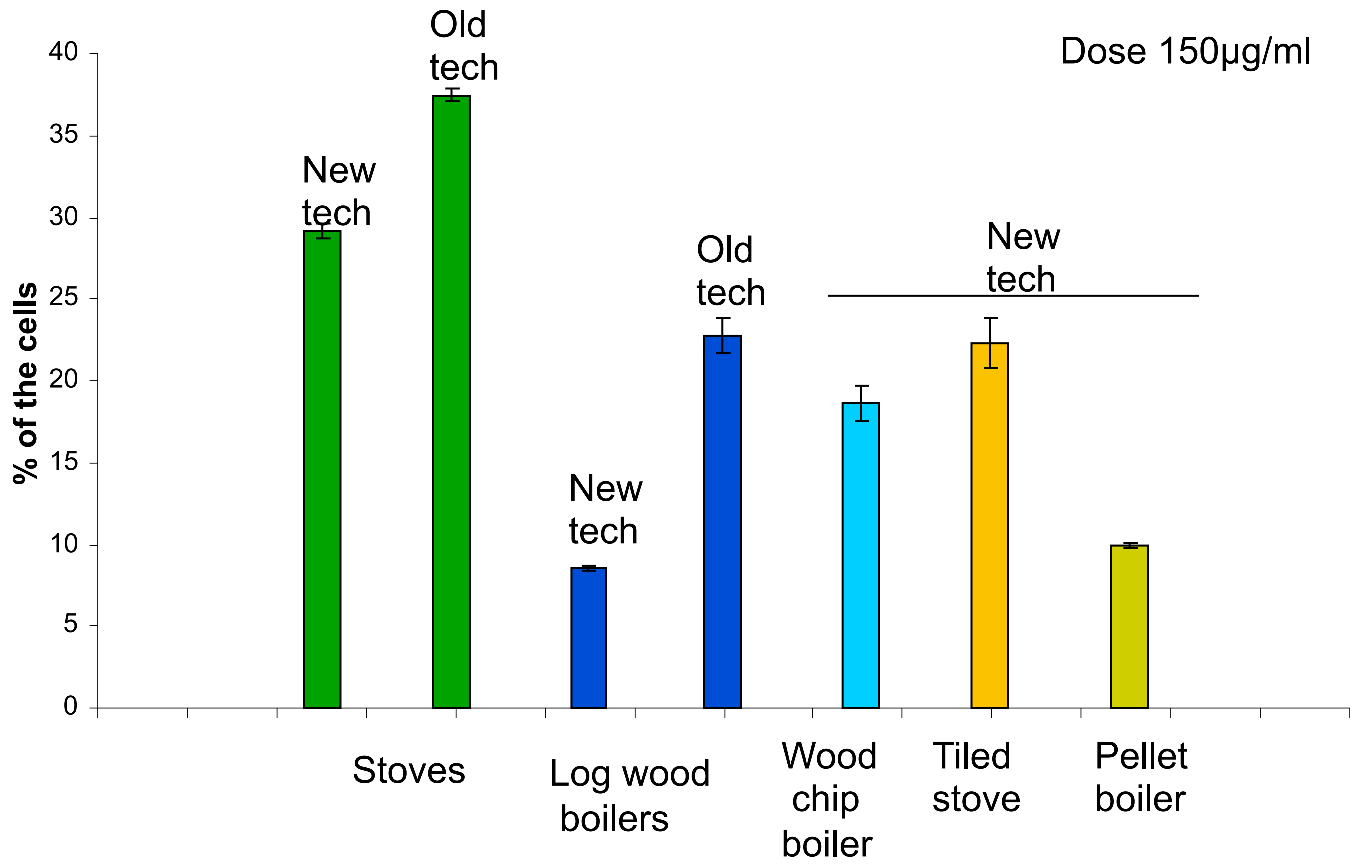
Programmed cell death



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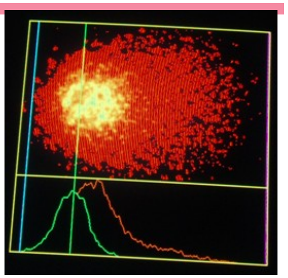
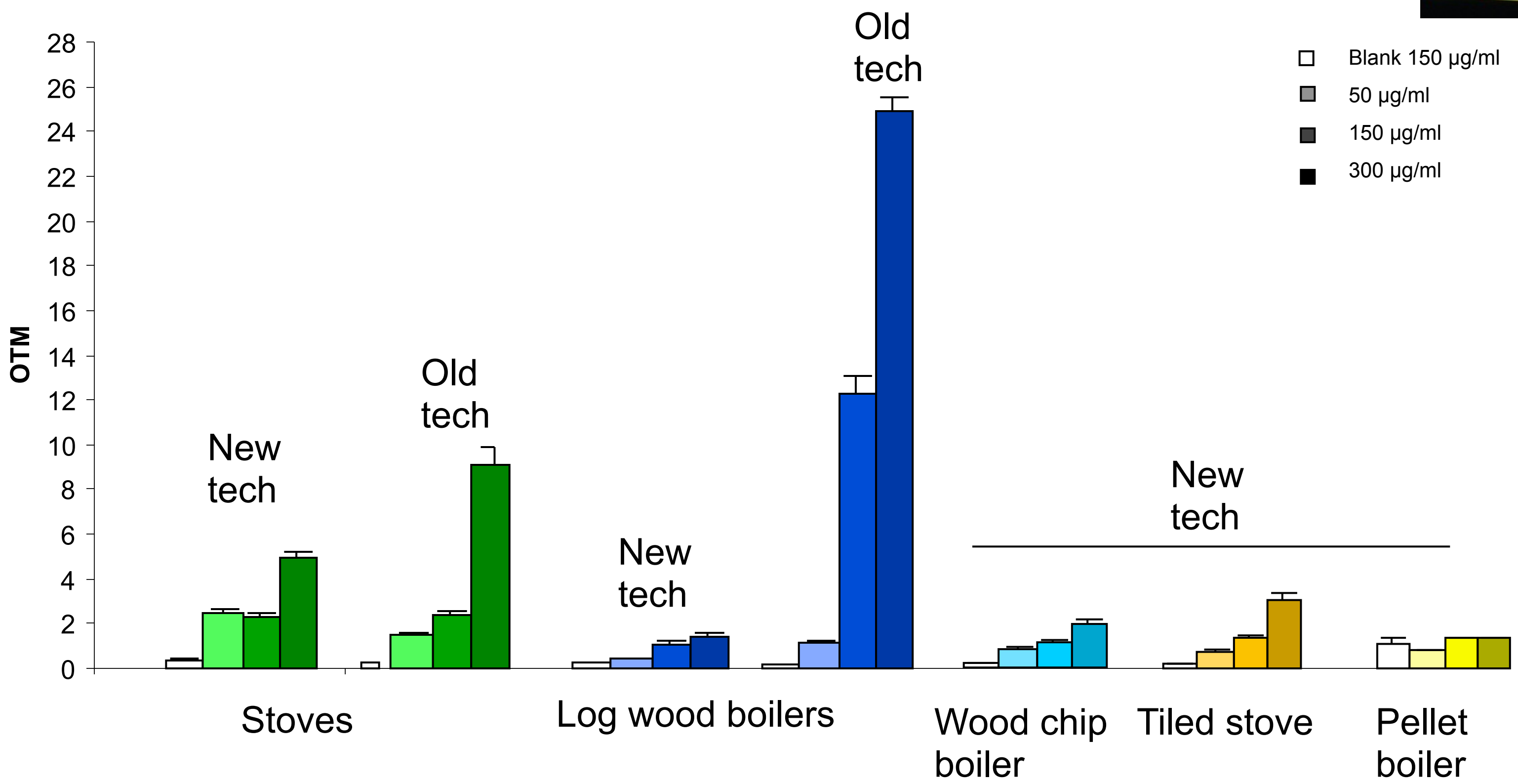
Genotoxicity /Comet assay





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Effect of chemical composition on toxicological responses

	MTT	TNFα	MIP-2	PI	SubG1	G1	S/G2M
OC	-0.270	-0.013	0.445	0.451	0.456	-0.454	0.275
EC	0.440	0.492	**0.612***	0.382	**0.763****	-0.527	-0.332
Ca	-0.244	-0.433	**-0.705****	**-0.749****	**-0.793****	**0.833****	-0.262
Mg	-0.165	**-0.550***	**-0.783****	**-0.759****	**-0.724****	**0.772****	-0.220
Mn	-0.285	-0.510	**-0.766****	**-0.659***	**-0.798****	**-0.731****	0.065
K	0.051	-0.495	**-0.802****	**-0.670****	**-0.657***	**0.666****	-0.138
Na	-0.033	-0.332	**-0.653***	**-0.705****	**-0.776****	**0.824****	-0.301
Zn	-0.077	-0.515	**-0.789****	**-0.725****	**-0.641***	**0.969****	-0.194
S	-0.029	-0.455	**-0.758****	**-0.688****	**-0.622***	**0.662****	-0.152
Cl	-0.136	-0.493	**-0.711****	**-0.700****	**-0.587***	**0.695****	-0.163
Cd	-0.062	-0.251	**-0.556***	**-0.602***	-0.507	**0.629***	-0.389

Jalava et al . 2012

The PAH composition was in a key role in activated toxicological responses

Six criteria PAH (EC/ 2004)	MTT	TNF-α	MIP-2	PI	SubG1	G1	S/G2M
Benzo[a]anthracene	0.354	**0.587***	**0.697****	**0.697****	**0.648***	**-0.662****	0.116
Benzo[b]fluoranthene	0.323	**0.556***	**0.705****	**0.688****	**0.692****	**-0.692****	0.130
Benzo[k]fluoranthene	0.214	**0.762***	0.619	0.310	0.405	-0.357	-0.286
Benzo[a]pyrene	0.341	**0.569***	**0.714****	**0.679****	**0.666****	**-0.670****	0.103
Indeno[1.2.3-cd]pyrene	0.204	0.266	0.495	0.530	**0.543***	**-0.596***	0.358
Dibenzo[a.h]anthracene	0.049	0.119	0.399	0.448	0.434	**-0.594***	0.329

Jalava et al . 2012

Old technology log wood boiler

- rather high inflammatory response
- high cytotoxicity, especially with PI-method
- genotoxicity is dramatically increased.
- this appliance type may affect all the proposed disease mechanisms.

Old technology stove

- increased genotoxicity
- slighly increased Inflammatory responses

New technology stove

- same activated cellular mechanisms as by the PM emissions from old tech stove but response level is lower

Tiled stove, wood chip boiler and new technology log wood boiler

- at least some of the toxicological parameters are increased

Pellet boiler

- most of the toxicological parameters were only slightly increased, and the genotoxic response was negligible.

Conclusions

- Combustion technology largely affects the particulate emissions and their toxic potential this being reflected in substantially larger responses in devices with incomplete combustion.
- These differences become emphasized when the large emission factors from old technology appliances are taken into account.
- The present data also demonstrated clearly that toxicological methods can be applied in the development of new combustion technologies

Growing use of biomass energy should be done without increasing harmful health effects

Acknowledgements

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Thank you for your attention!

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