

Toxicological characteristics of particulate emissions from biomass combustion

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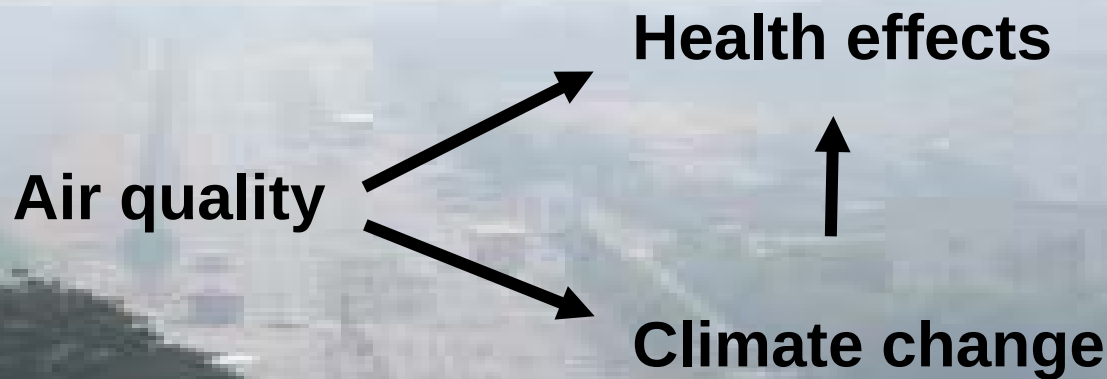
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**UNIVERSITY OF
EASTERN FINLAND**

Particulate air pollution is regarded as one the most important health concerns worldwide



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 which is mainly due to life years lost by cardiorespiratory patients (up to 10yrs)
- **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)

Adverse health effects associated with PM exposure

- Cardiac diseases
 - Arrhythmia, atherosclerosis, unstable plaques, blood pressure -> infarct, stroke
- Respiratory diseases
 - Asthma, COPD
- Lung cancer
- Chronic bronchitis

Most sensitive population groups are cardiorespiratory patients, small children and the elderly

Why worry about biomass combustion emission?

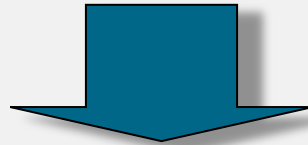
- The use of renewable energy in EU will be increased up to 20% of the total energy consumption by 2020 in order to slow down the climate change.
- This may lead to an increase in adverse effects on human health, because biomass combustion is one of the most important particulate sources.
- Currently only limited scientific data exist on the source-specific harmful characteristics of emissions, which are the actual cause of the health effects.

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- Thus, the increase in use of biomass based energy should be done without increasing fine particle emissions and their current extensive annual health impacts.



- In-depth toxicological and physicochemical characterisation of particles, connected to emission studies, is needed in assessing potential health risks of different combustion technologies and fuels as well as to develop clean combustion processes.

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
- specific 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

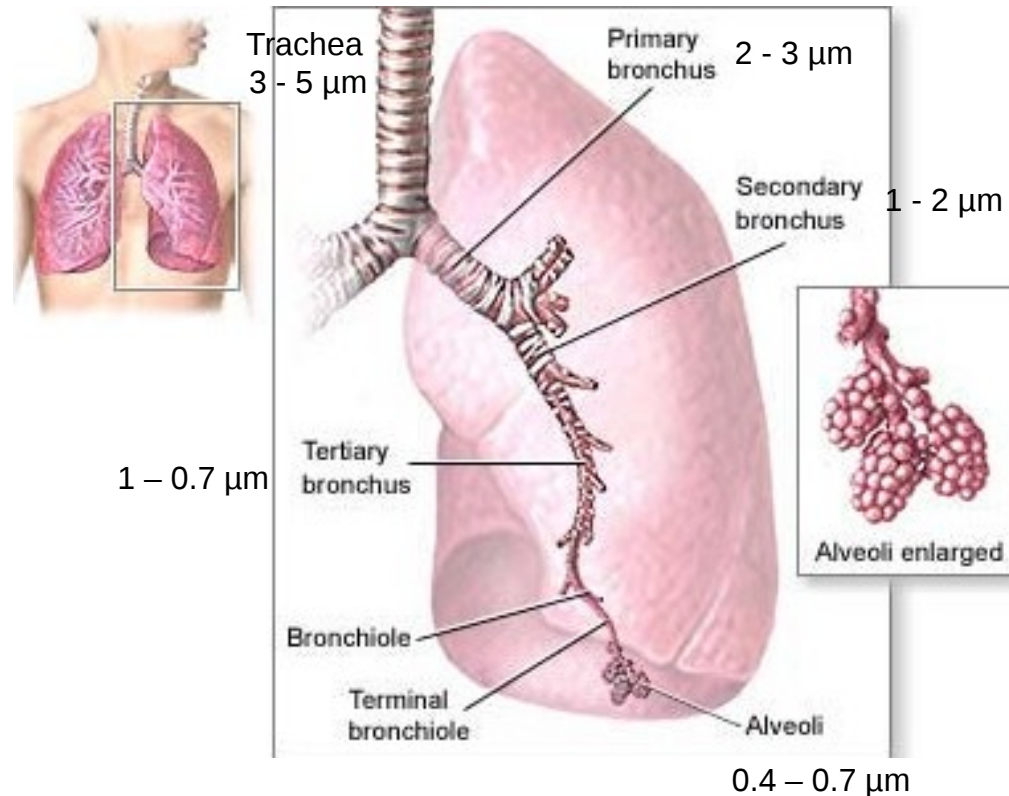
Why the fine particles are so dangerous?

Penetration deep in the airways

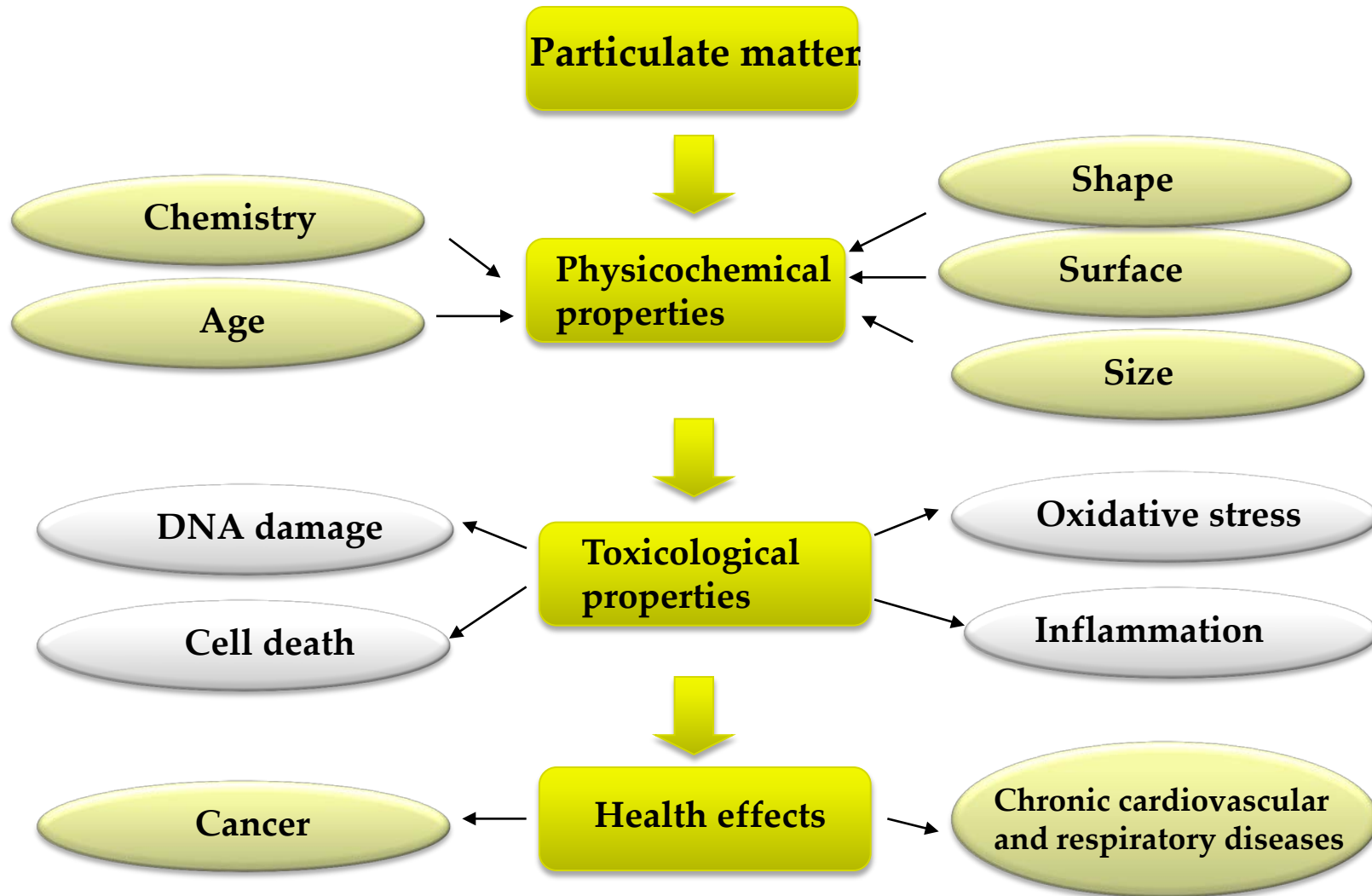
- PM less than 0.1 μm have the largest reactive surface
- Transition metals and their oxidized forms
- Reactive organic compounds (e.g. uncompleted combustion)
- Age of the particles (fresh PM more harmful than aged)
- Poor water solubility



Activation of wide variety of mechanisms leading to adverse health effects



Mechanisms behind the health effects?



Multidisciplinary approach

- To define the Chemistry-Toxicology-Health connection, examining 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



Inhalation Toxicology 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



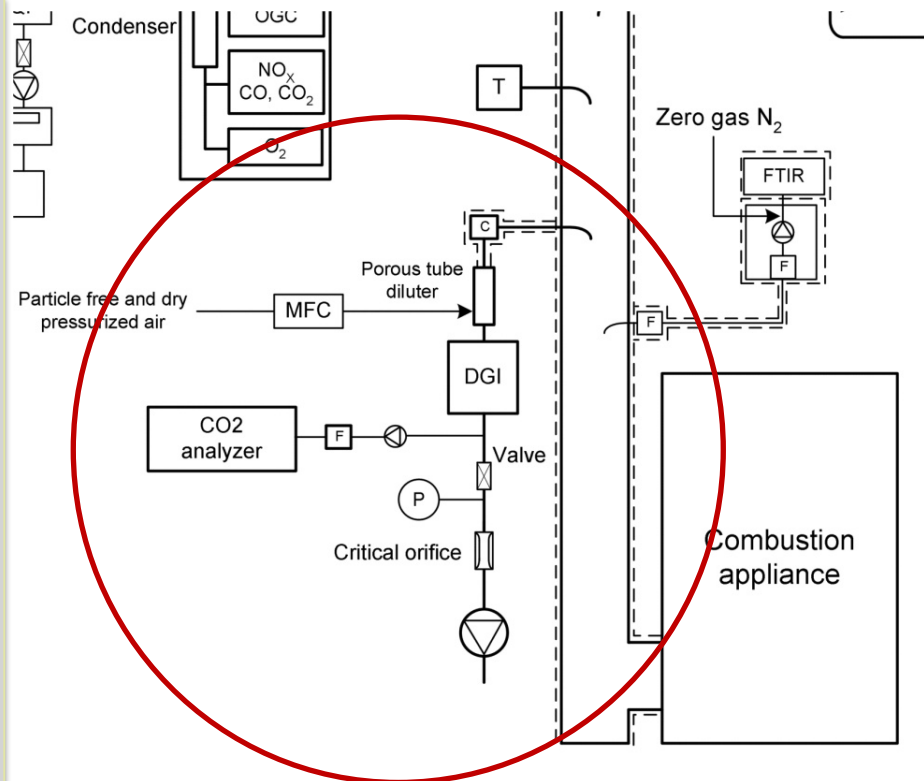
Objective

- To investigate chemical and consequent toxicological characteristics of PM(1) emitted from different phases of batch combustion in four heating appliances.

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



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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

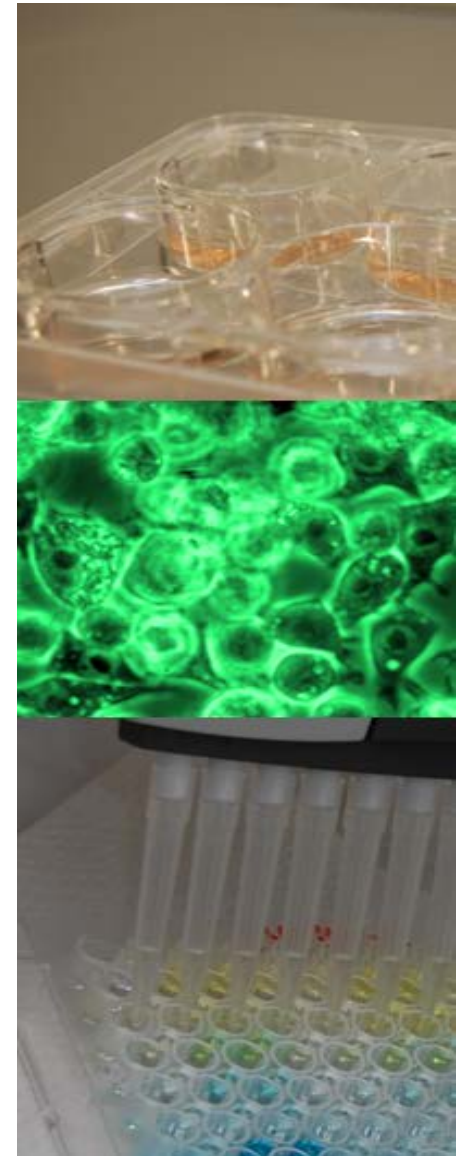
They are target cells in PM induced immunotoxicity

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



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

Collaboration: Professor Jorma Jokiniemi
University of Eastern Finland

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

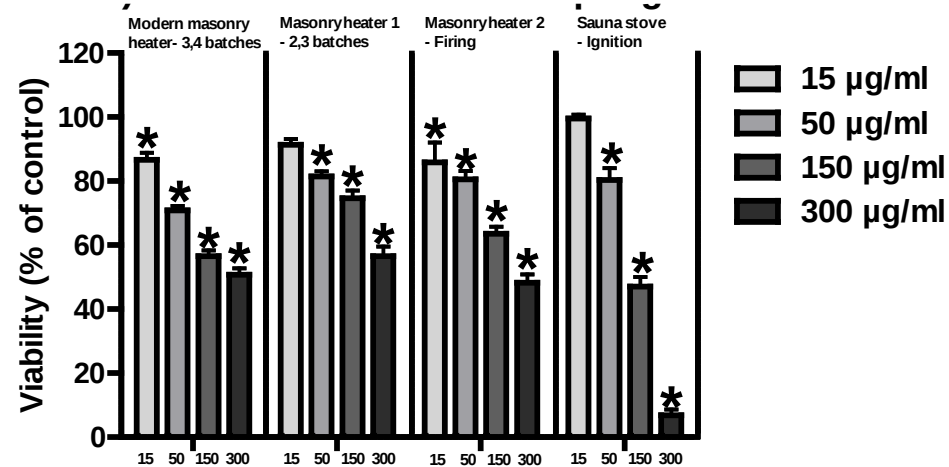
PM₁ emissions and their carbon content of four log wood combustion appliances.

mg/ MJ	Modern masonry heater 3,4 batches	Masonry heater 1 2,3 batches	Masonry heater 2 Firing	Sauna stove Ignition
PM₁	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

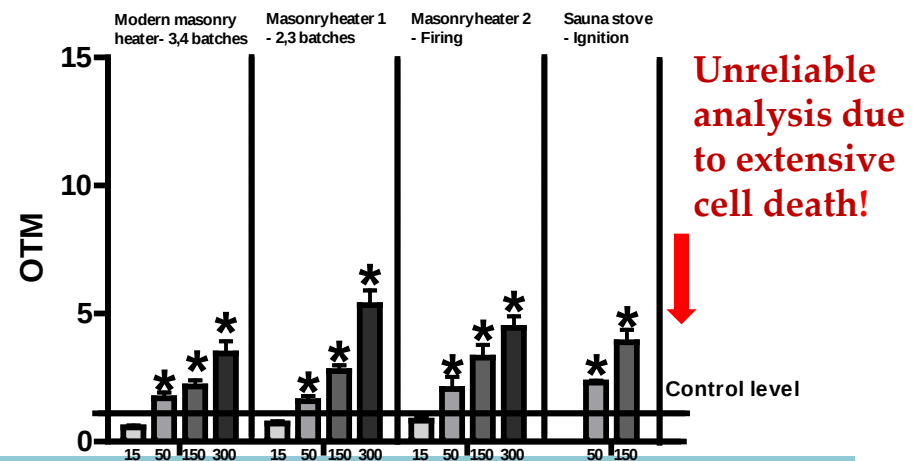
The inefficient batch combustion phase in the sauna stove emitted particles with the strongest genotoxicity and cytotoxicity

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

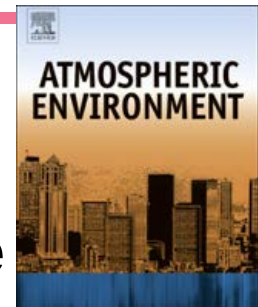


Conclusions (1)

- 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

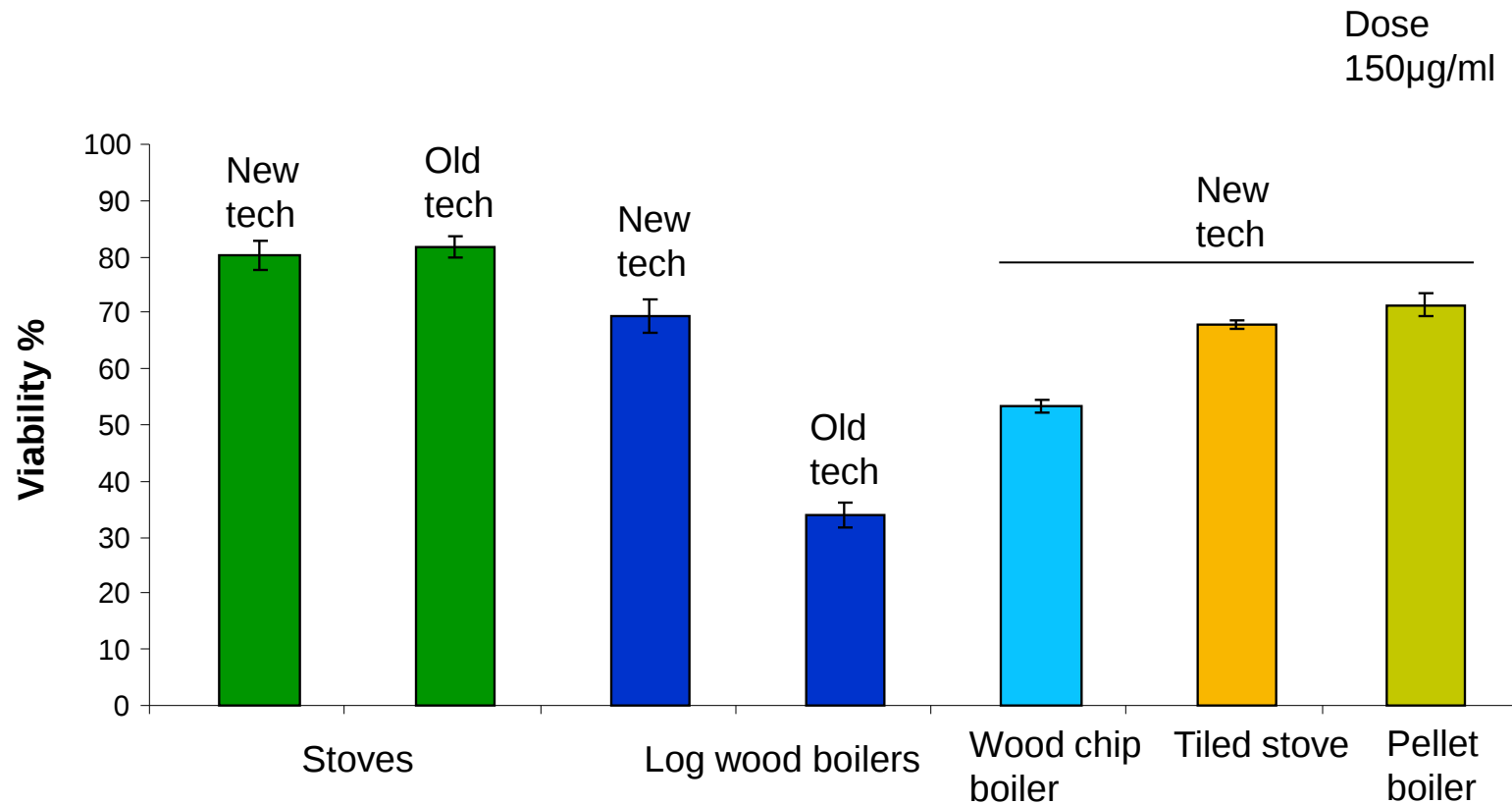
New technology

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

Old technology

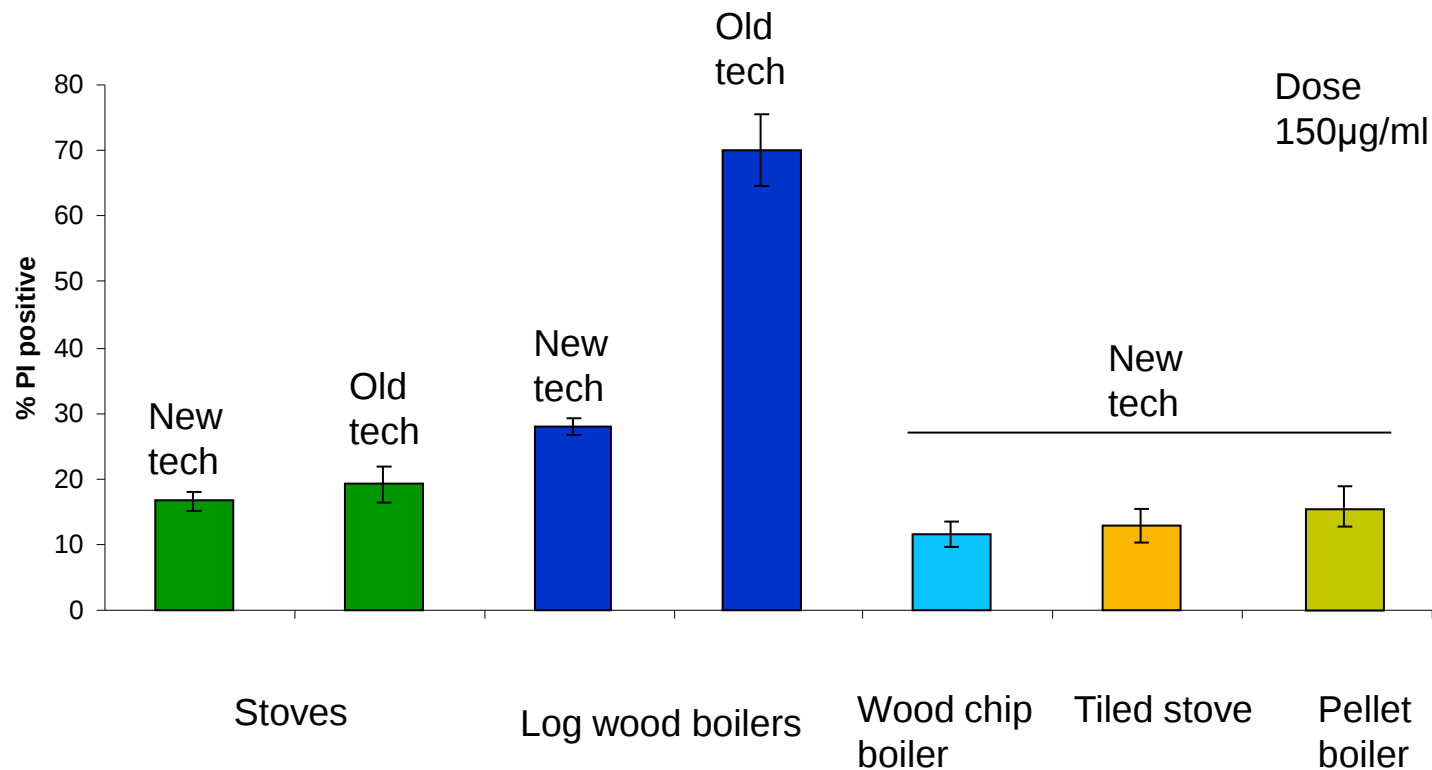
1. stove
2. log wood boiler

Cytotoxicity (MTT test)



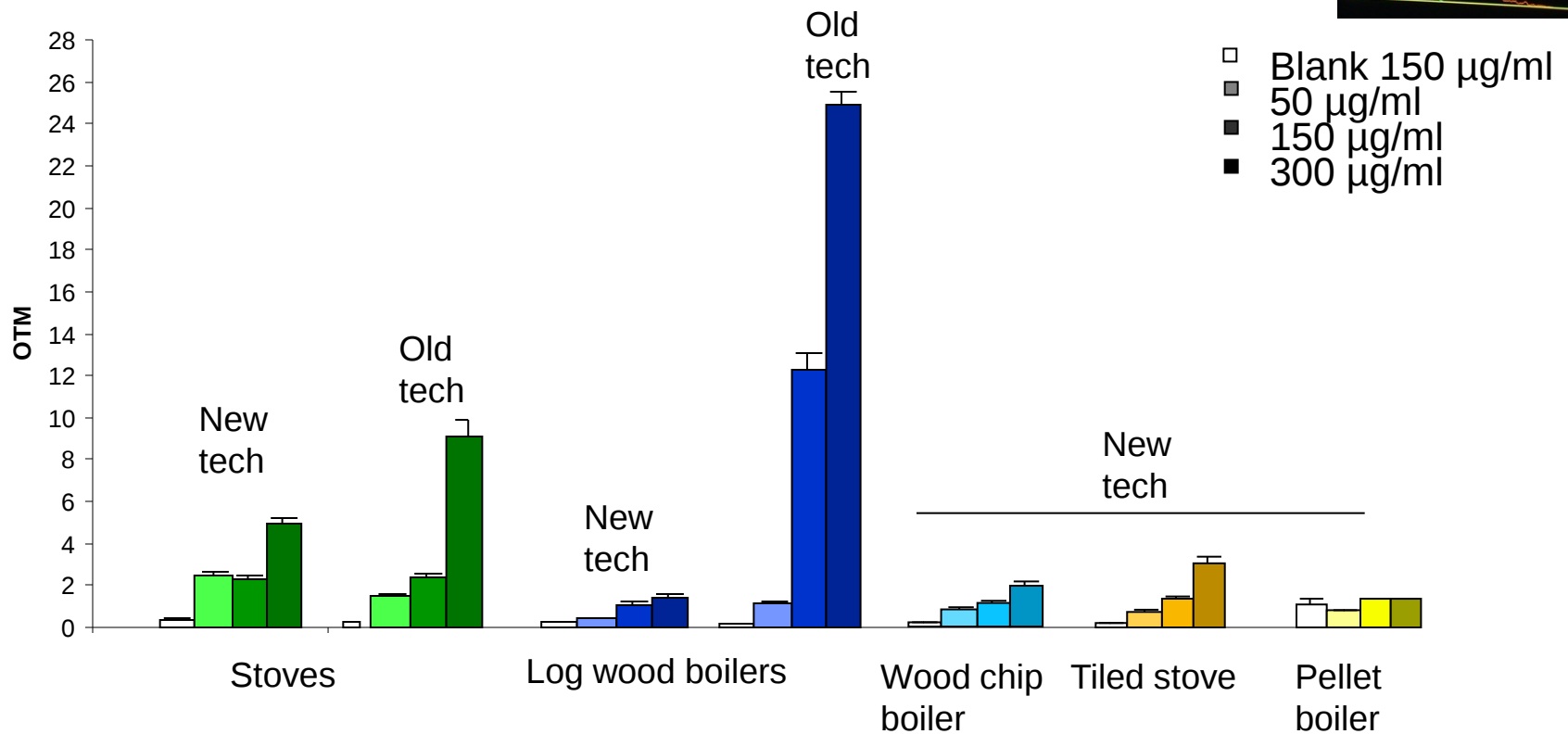
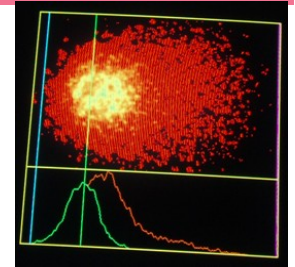
Jalava et al . 2012

Cytotoxicity /Cell membrane permeability



Jalava et al . 2012

Genotoxicity /Comet assay



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

Effect of chemical composition on toxicological responses

	MTT	TNF α	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

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
- slightly 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 (2)

- 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!

