Fachhochschule Nordwestschweiz
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FATCAT: a new characterization method for particulate emissions from wood burning appliances

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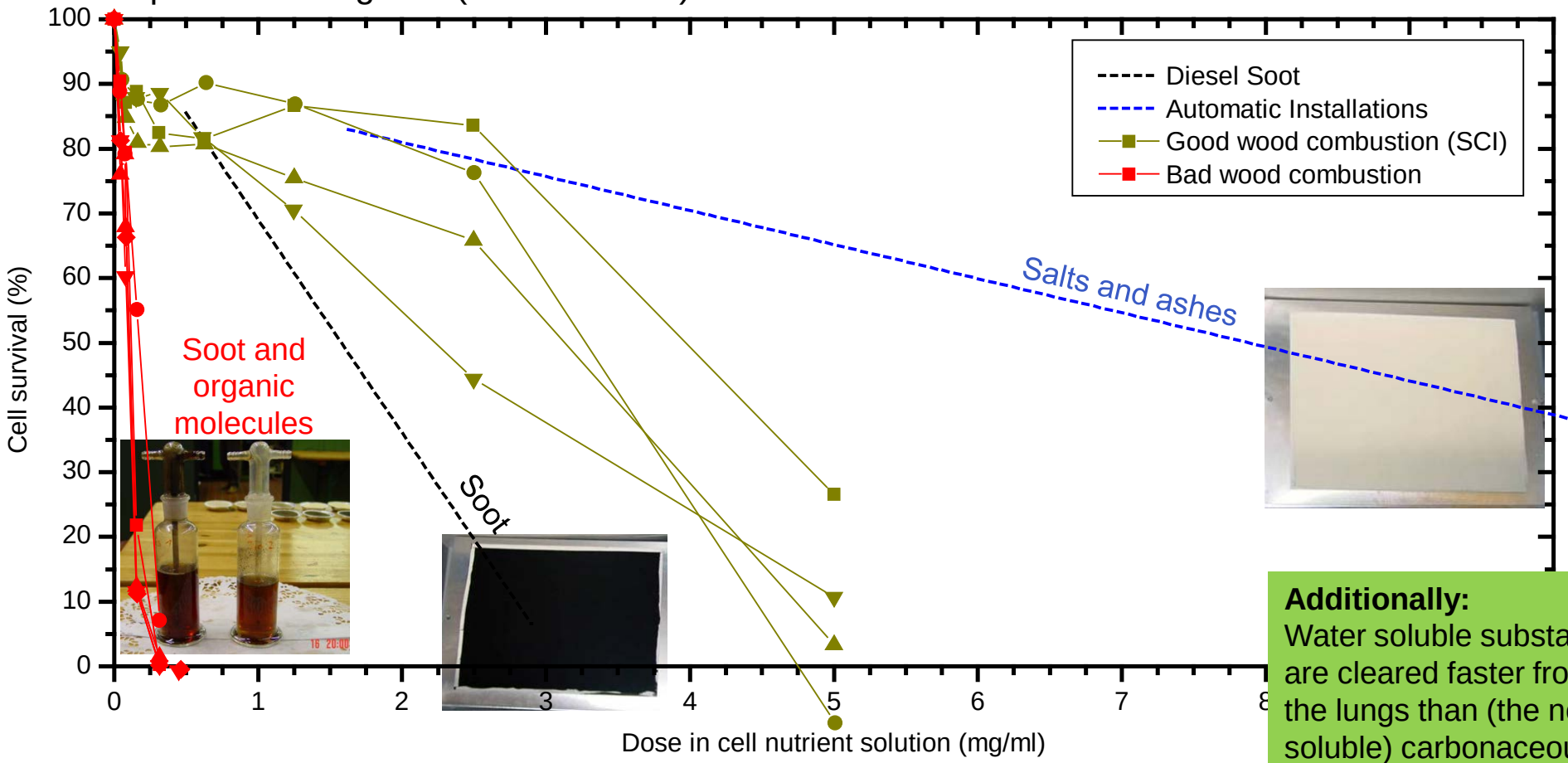
Toxicity of Particle Emissions (not are particles are created equal)

In Vitro exposure of lungcells (chin. hamster)



Source: N. Klippel & T. Nussbaumer, 9. Holzenergie-Symposium 2006

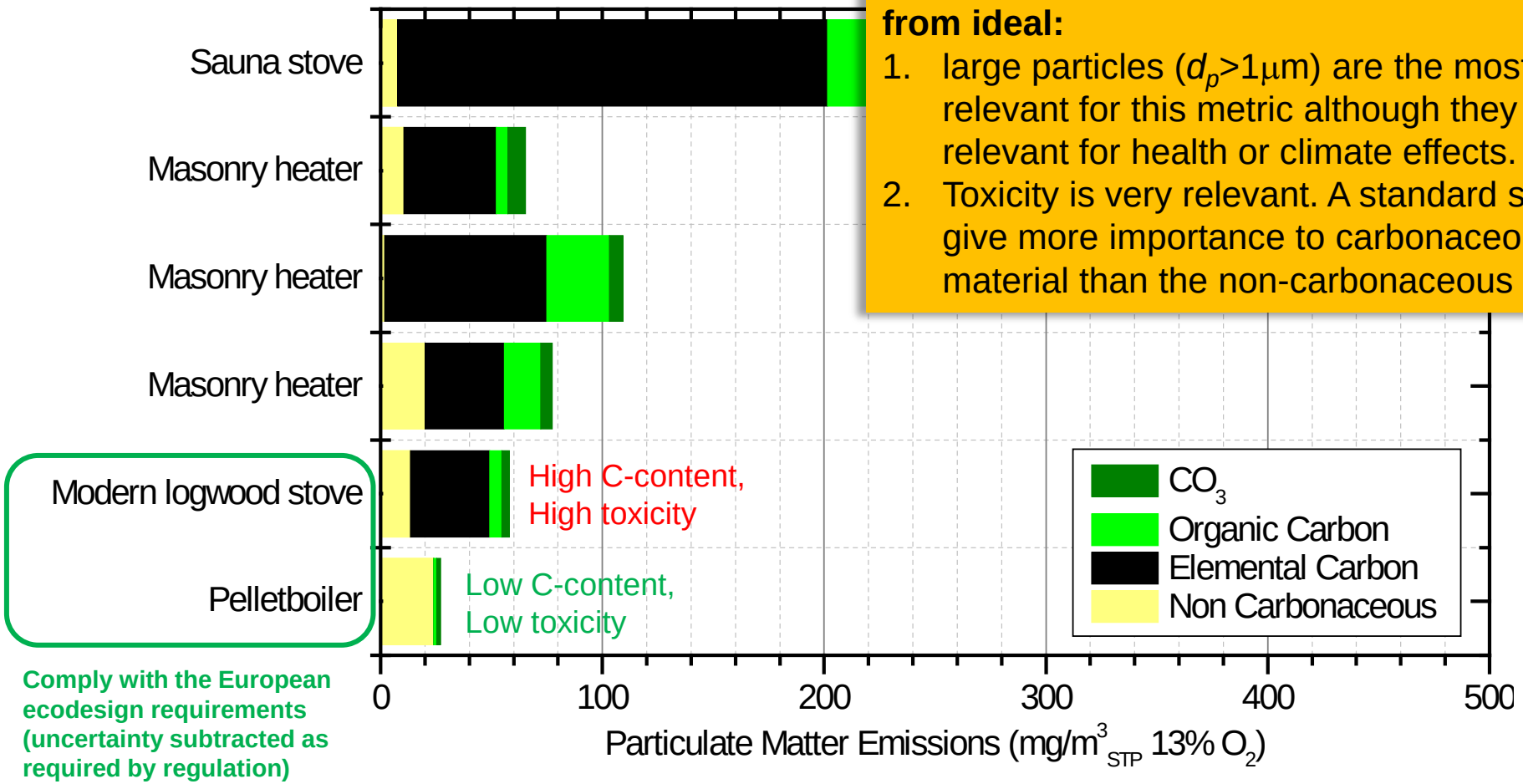
*More information regarding health impact: Sigsgaard, 2015. doi:10.1183/13993003.01865-2014

Additionally:
Water soluble substances are cleared faster from the lungs than (the non-soluble) carbonaceous fraction*.

Emissions Composition (Small Combustion Installations)

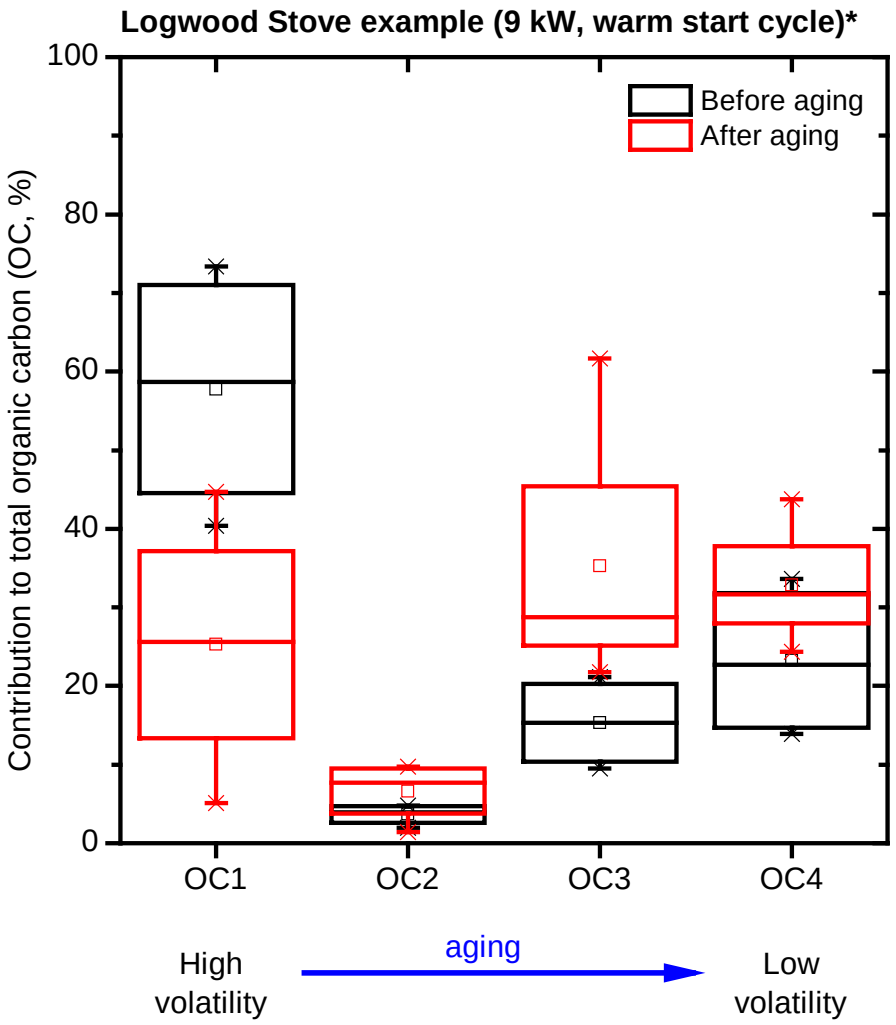
Current standards based on total PM are far from ideal:

1. large particles (d_p>1μm) are the most relevant for this metric although they are not relevant for health or climate effects.
2. Toxicity is very relevant. A standard should give more importance to carbonaceous material than the non-carbonaceous fraction.



Comply with the European ecodesign requirements (uncertainty subtracted as required by regulation)

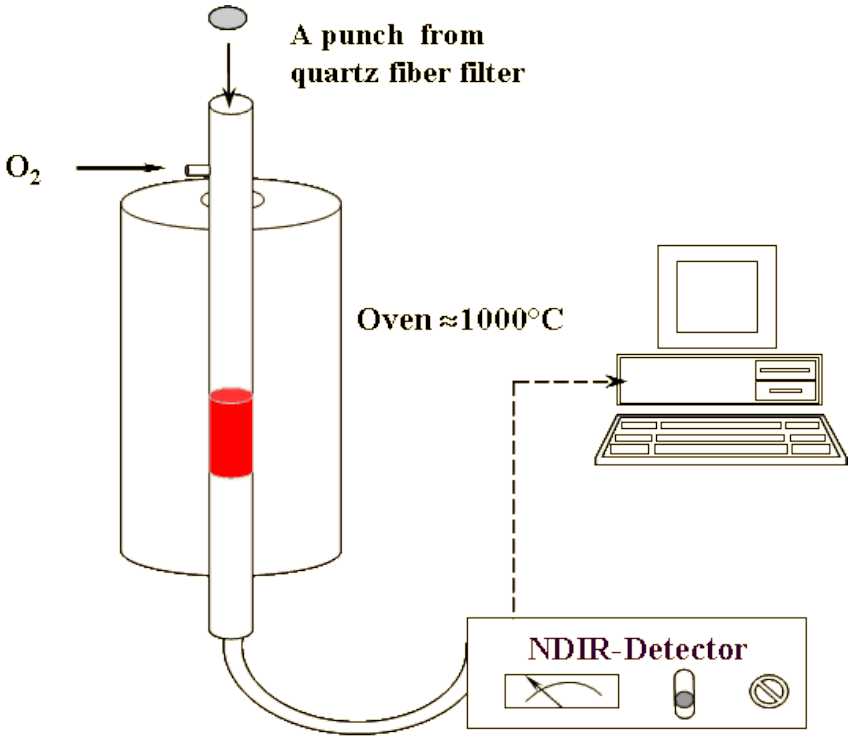
Source: Lamberg et al. / Atm. Env. 45 (2011) 7635-7643



* Keller and Burtscher, J. Aerosol Sci., under review.
** e.g., Lanz et al. ACP 7, p. 1503, 2007 and references therein

What does aging do?

- Aging produces secondary organic aerosol (SOA).
- SOA amounts ~2/3 of the organic aerosol mass in the atmosphere**.
- SOA can duplicate organic carbon emissions from wood burning*.
- Aging reduces volatility and makes sampling robust against differences in temperature or dilution level.
- Gravimetric sampling at 160°C (current standard) misses an important fraction of the organic carbon (including some primary organic carbon).

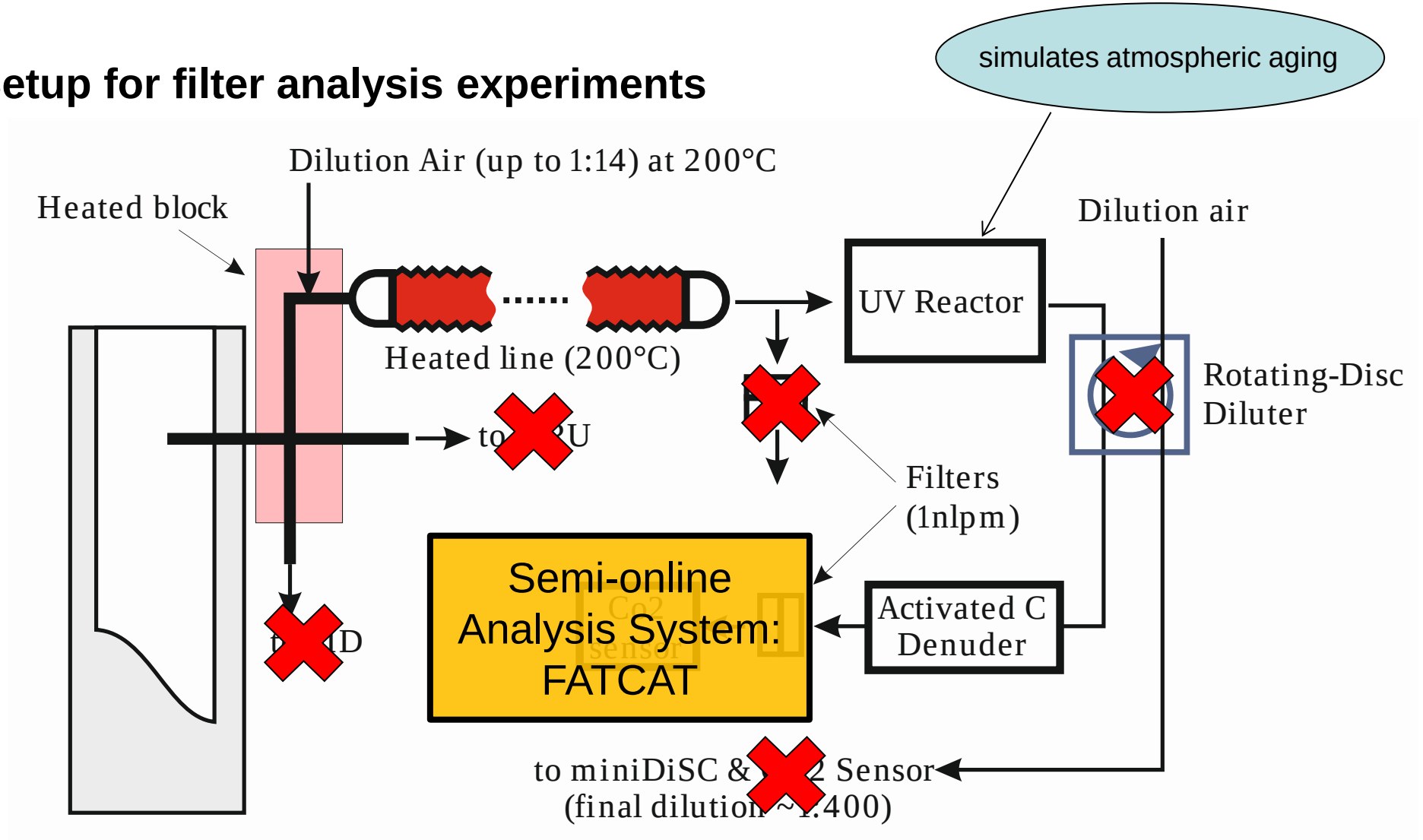


Total Carbon (TC) is the mass of all carbon atoms in a sample. This includes the mass of soot (elemental carbon, EC) as well as the mass of carbon atoms in organic molecules (organic carbon, OC). Usually measured by means of CO_2 determination. Carbonates are also detected by this technique. (graphic: TU-Wien)

The Metric: Why total carbon (TC)?

1. TC is directly related to the combustion quality. This is not the case for PME (TC fraction of PME is between 5% and 90% for “certifiable” appliances)
2. Total carbon is a better metric for health and climate impact than PME
3. Single value and less complicated than, e.g., OC/EC
4. Method already available as commercial devices and is also offered by independent laboratories
5. **Potential for automatic semi-online analysis system**

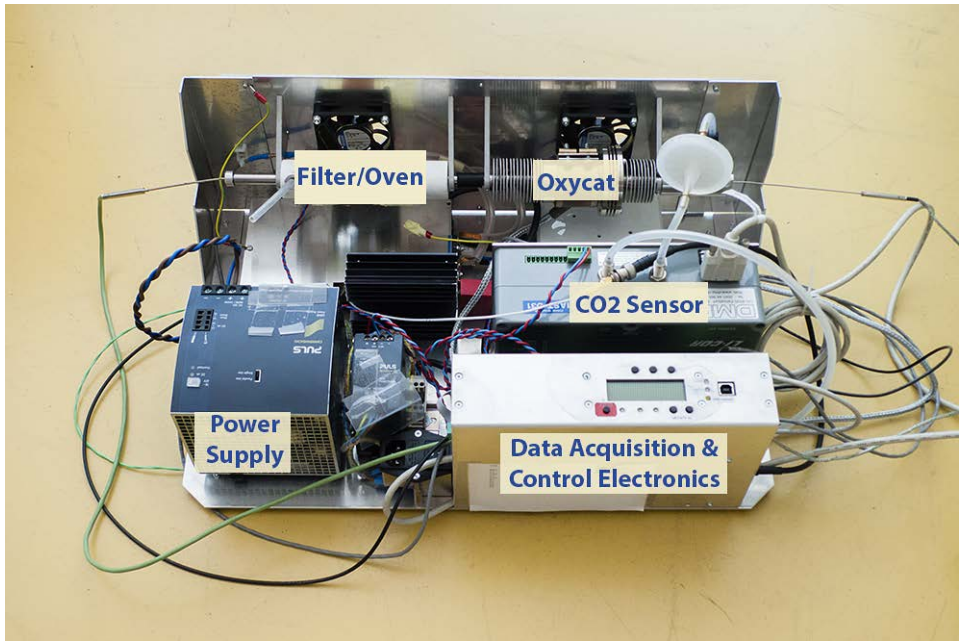
Setup for filter analysis experiments

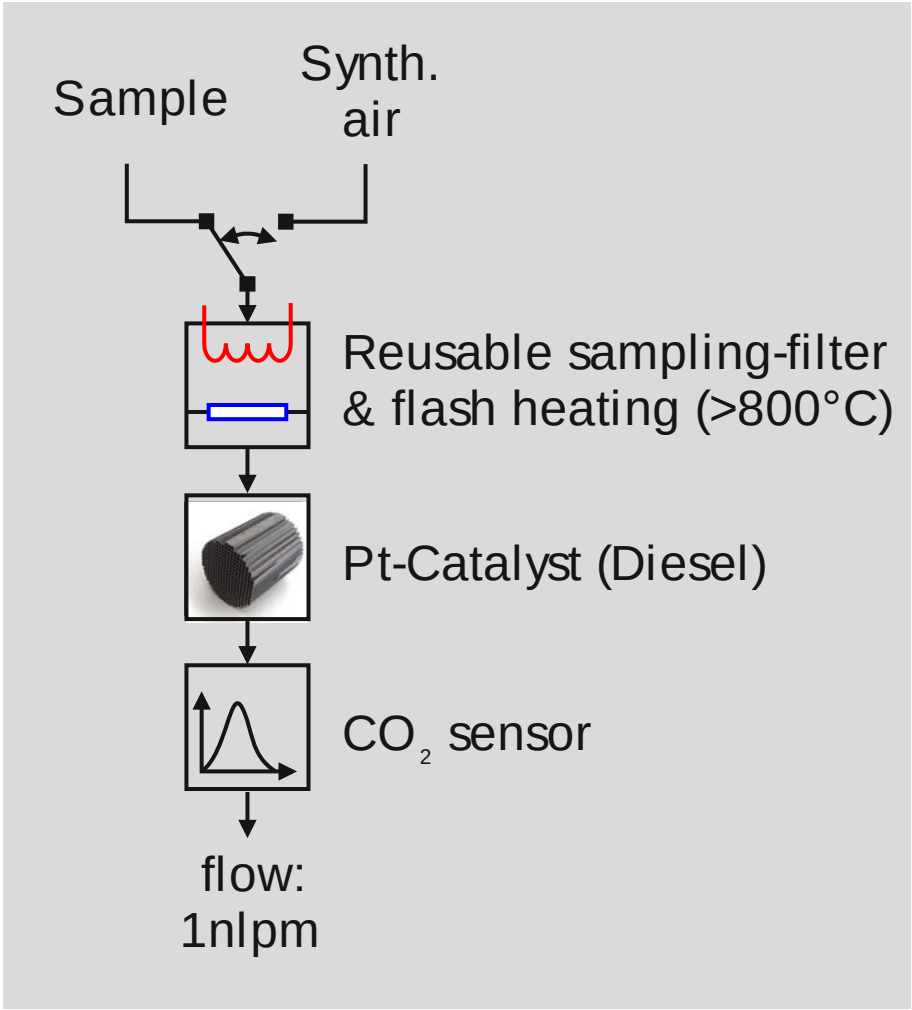


- On a first step, [particle bound] organic carbon (OC) and elemental carbon (EC) measurements by means of thermal-optical analysis (EUSAAR 2 protocol). Total Carbon, TC = OC + EC
- Analysis may be substituted by a relatively simpler thermal analysis for TC.

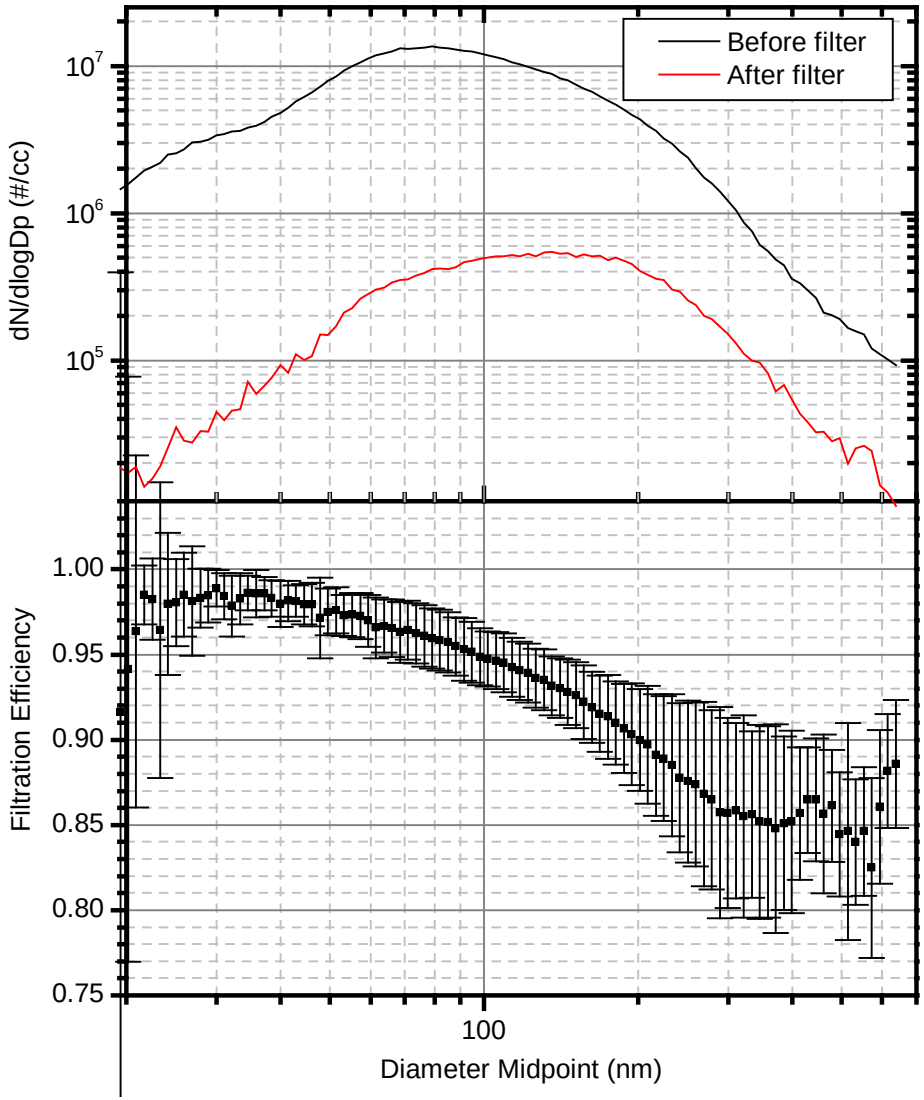
FAst Thermal CArbon Totalizator (FATCAT)

- Sampling: 30 minutes @ 1lpm (dilution ~1:5).
- Target mass: ~4-40μg.
- Analysis time: ~3.5 min (50s heating).
- Cool down time (to 30°C): 25 minutes (including analysis time).





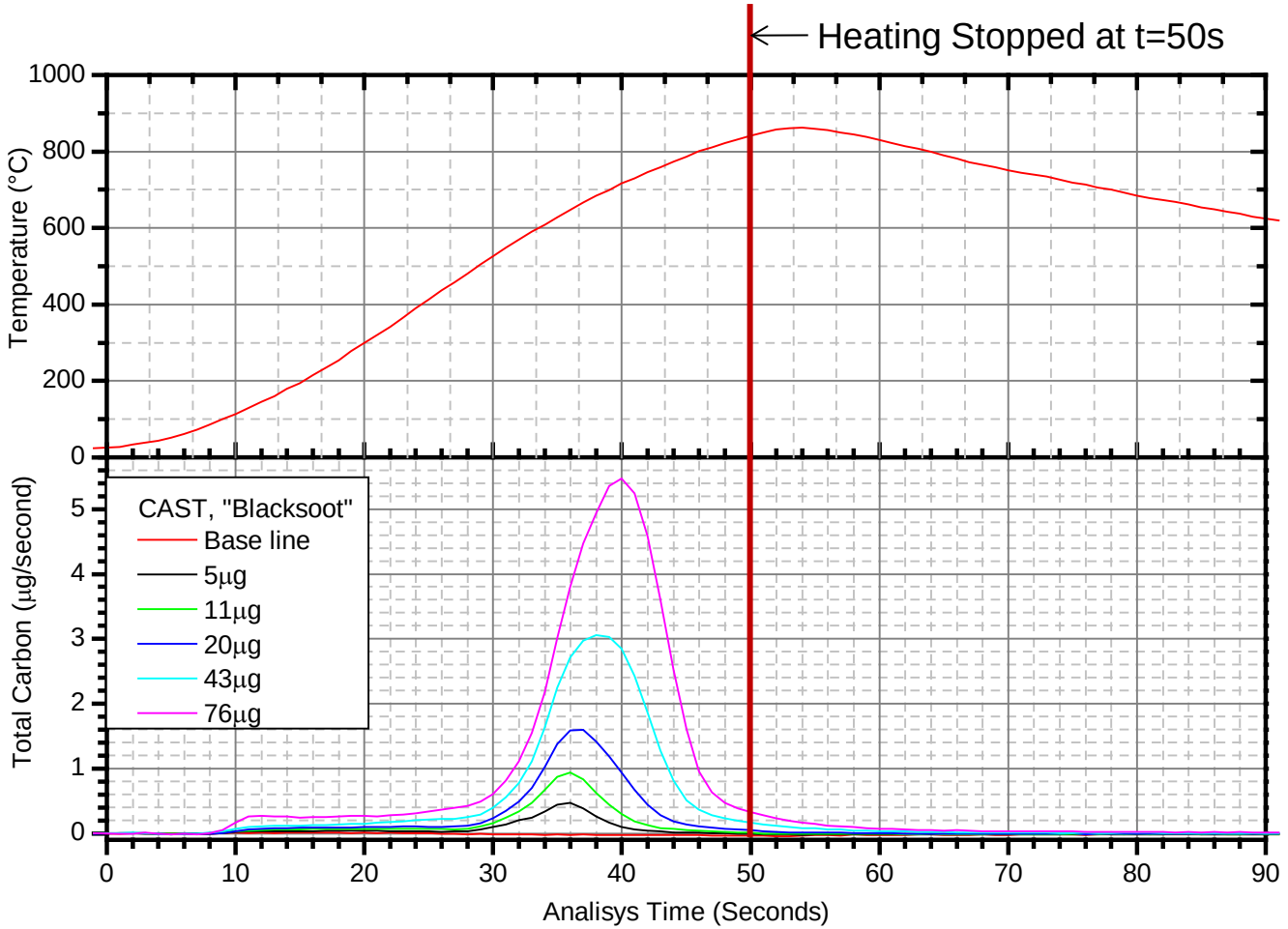
Filter with better efficiency (+ improved hardware) will be available in few weeks



Sampling filter

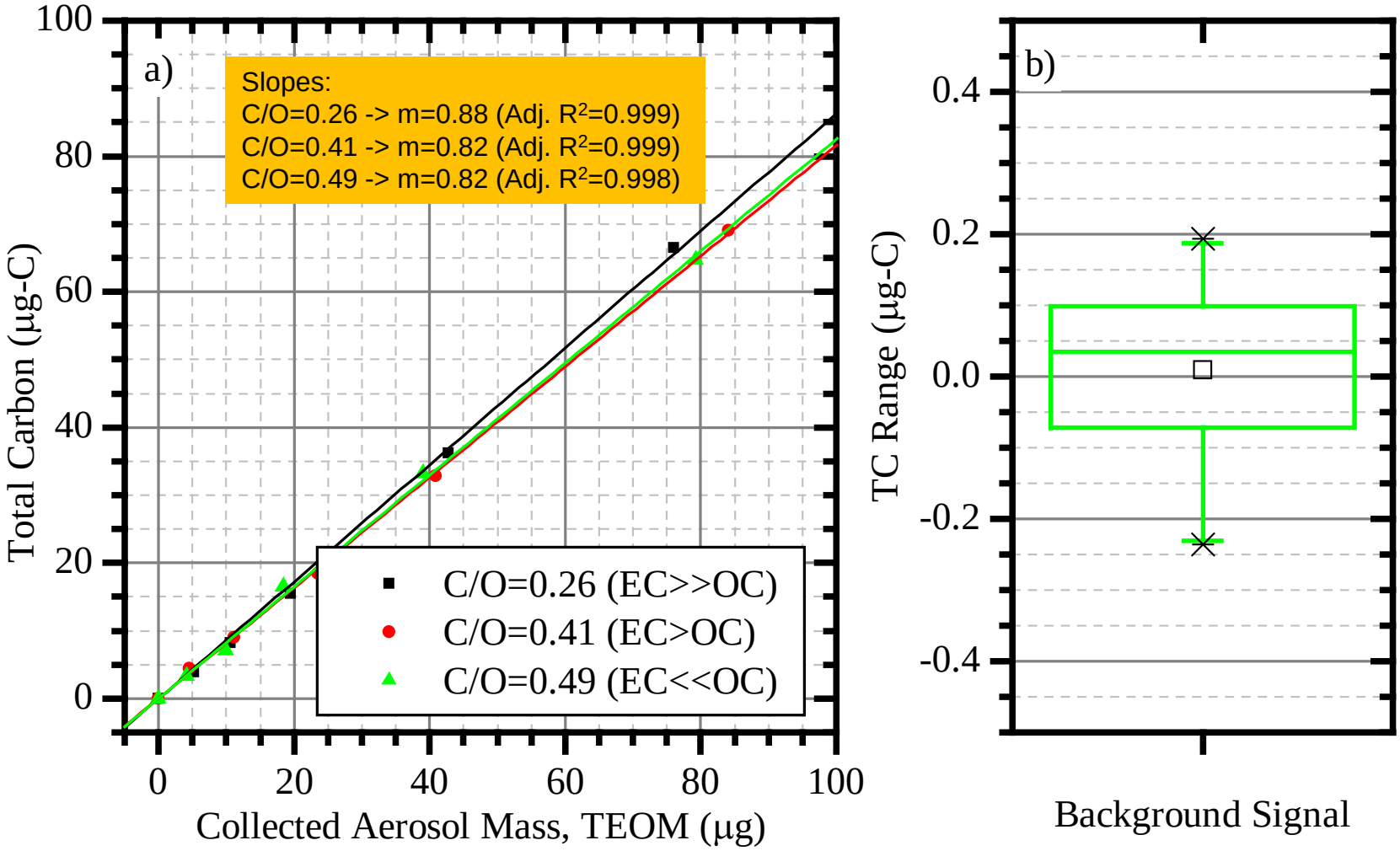
- Flash heating is possible due to direct heating of the filter (as opposed to using a conventional furnace).
- Design restrictions require a custom-made solution.
- Filtration efficiency: >95% for particle diameter d_p>100nm, but as low as 85% for certain sizes.
- Filter is reusable.

Soot sample measurements



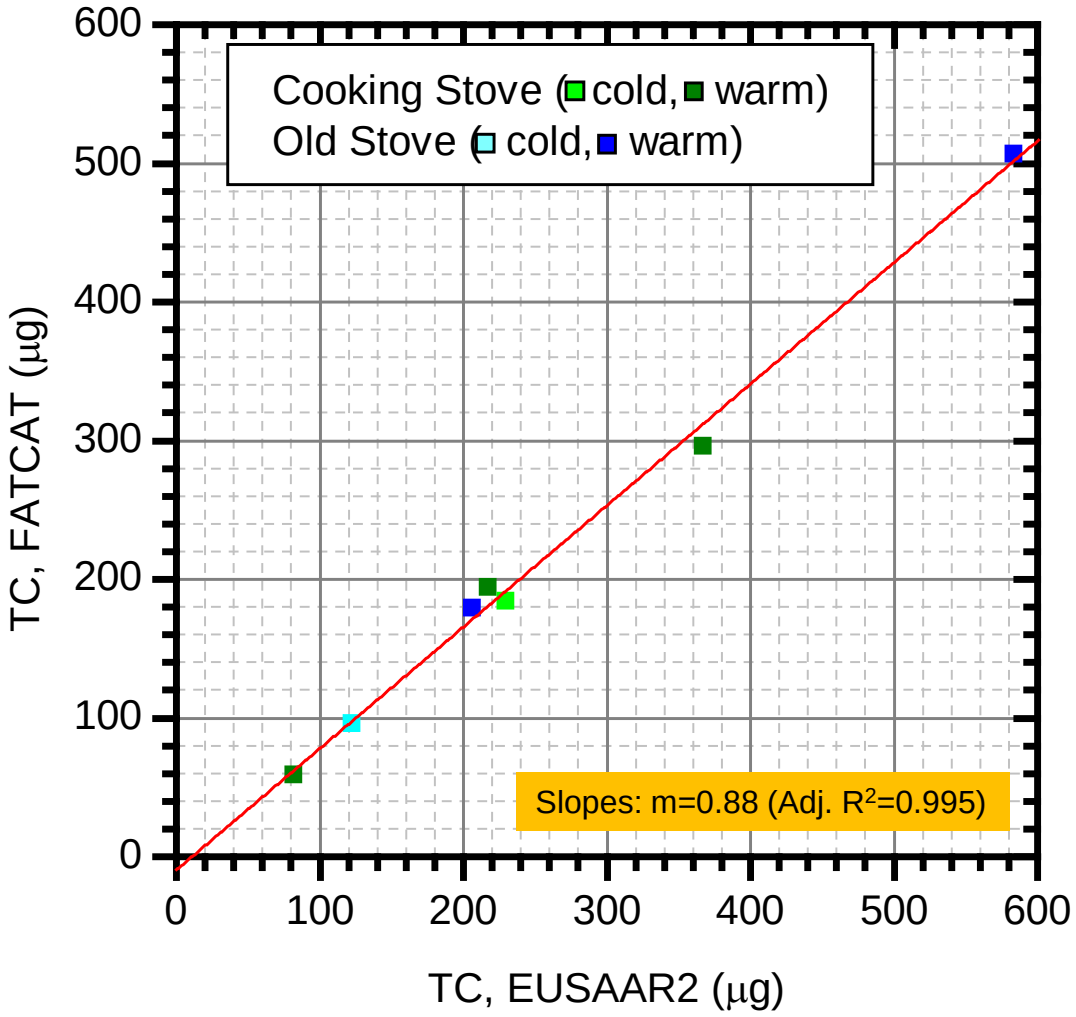
CAST: Combustion Aerosol Standard, Jing AG, is a propane-flame particle generator

CAST soot samples

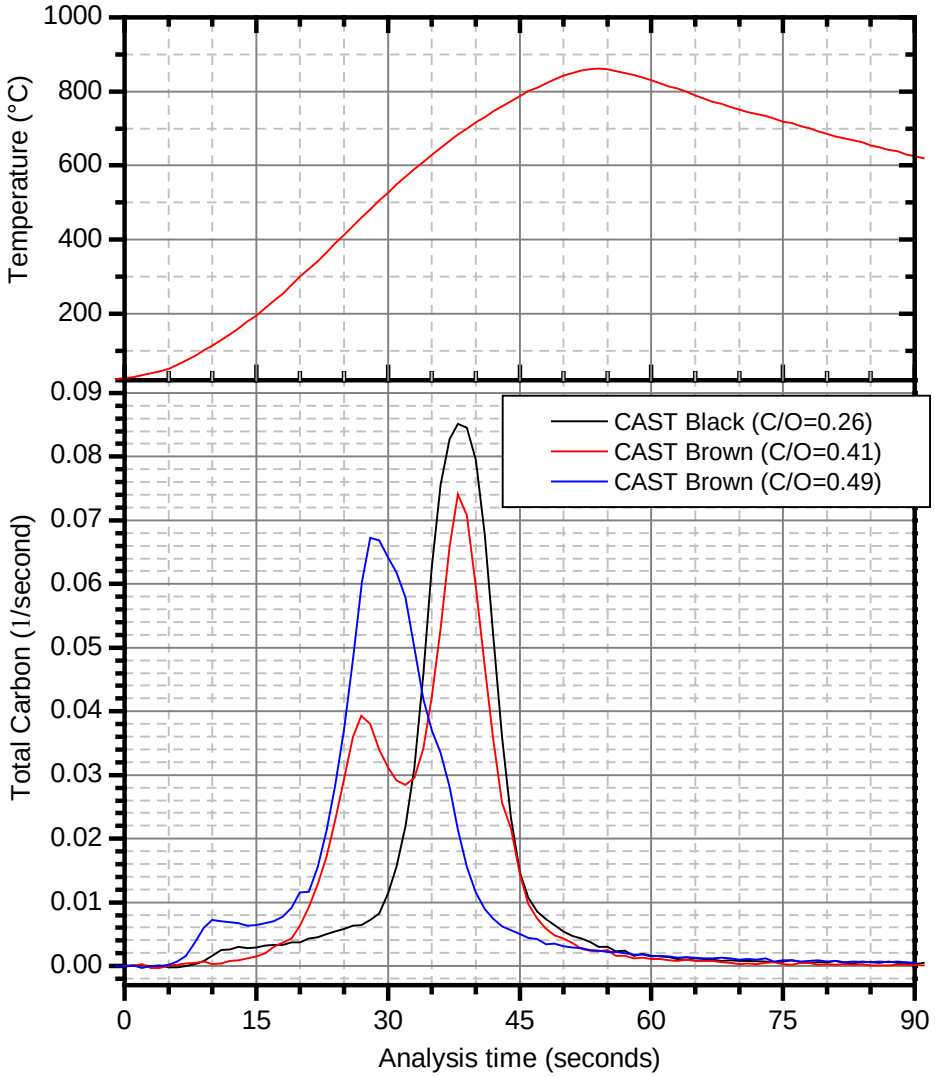


CAST: Combustion Aerosol Standard, Jing AG, is a propane-flame particle generator
TEOM: tapered element oscillating microbalance, Thermo Scientific

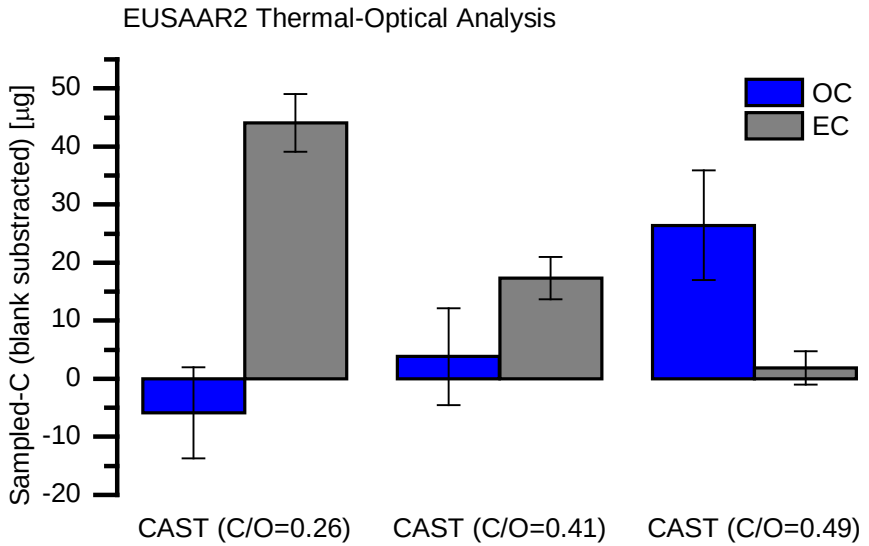
Wood burning example (test bench measurements)



Thermograms?



- Can we extract some information about the OC/EC split or the volatility of the sample from the individual peaks?
- Pyrolysis: promoted or reduced by flash heating?



To do….

- Improve filter efficiency (on its way)
- Transmission efficiency for complete setup (e.g., due to the use of a denuder)
- Further testing using wood burning appliances like, e.g., clean automatic boilers.
- Questions about real time data (*thermograms).*
- We have plans to adapt our device for ambient monitoring of total carbon as a stand-alone, continuous-operation instrument.

Summary

- Total carbon (TC) analysis (combined with simulated atmospheric aging) should be considered as a candidate metric for biomass burning emissions. This is only possible if simple reliable instruments are available.
- Our solution, FATCAT, shows very good linearity during tests with standard combustion aerosol, as well as for tests using biomass burning appliances.
- The limit of detection is 3σ=0.4μg (noise-to-background). This is 10 to 100 times lower to the expected TC filter-load from a type approval tests performed on clean, certificated, biomass burning appliances.
- Filtration efficiency is as low as 85% for some sizes. A new improved prototype will be available in few weeks time.
- *Thermograms* show well separated peaks (fingerprints for different sources?). There may be more information in this real time data.

We are looking for partners for characterization, further development and/or commercialization. Both for emission measurements as well as for ambient monitoring.

Thanks to:

Markus Zürcher
Hug Engineering

Andreas Mayer
TTM

Daniel Egli and Peter Steigmeier
University of Applied Sciences Northwestern Switzerland

Thank you for your attention!

Backup Slides

Field measurement example (wood charcoal grill)

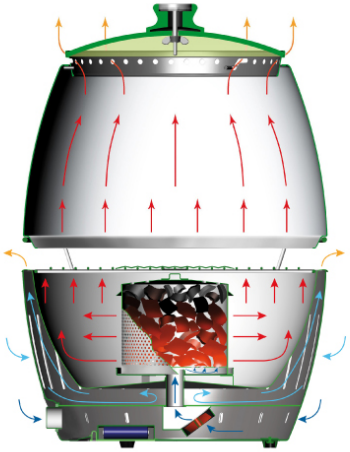
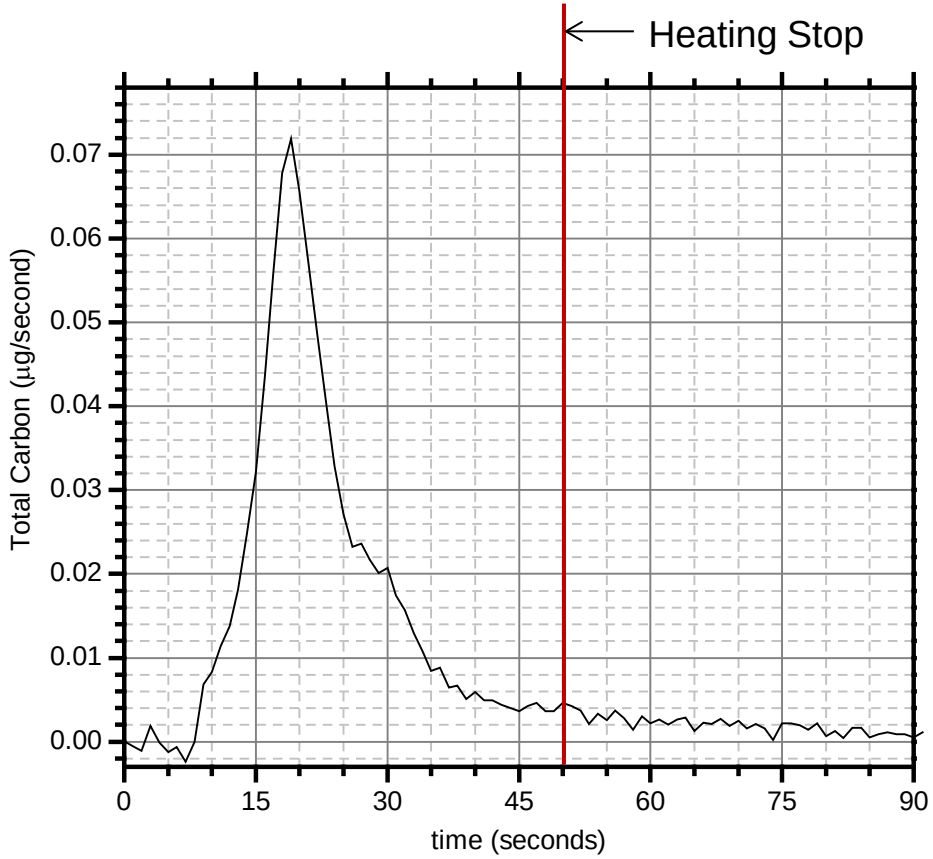


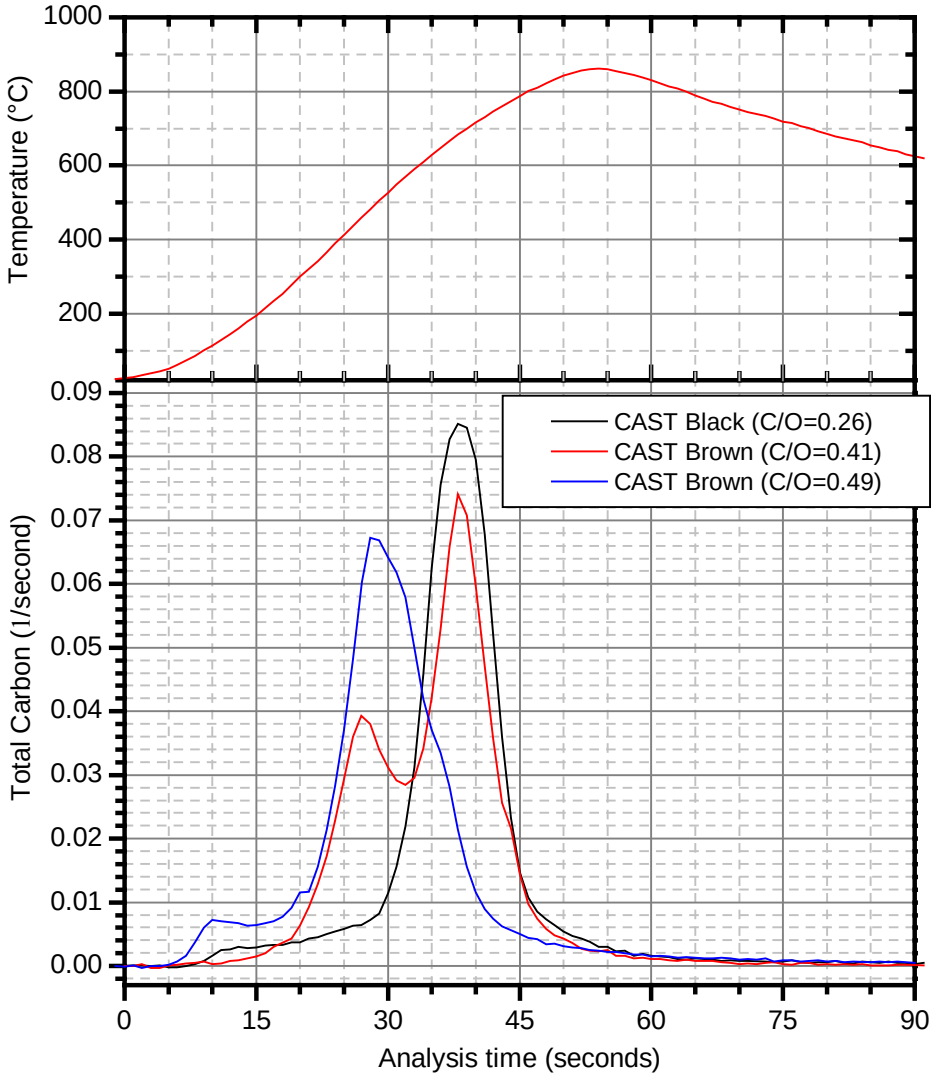
Image: lotusgrill.de

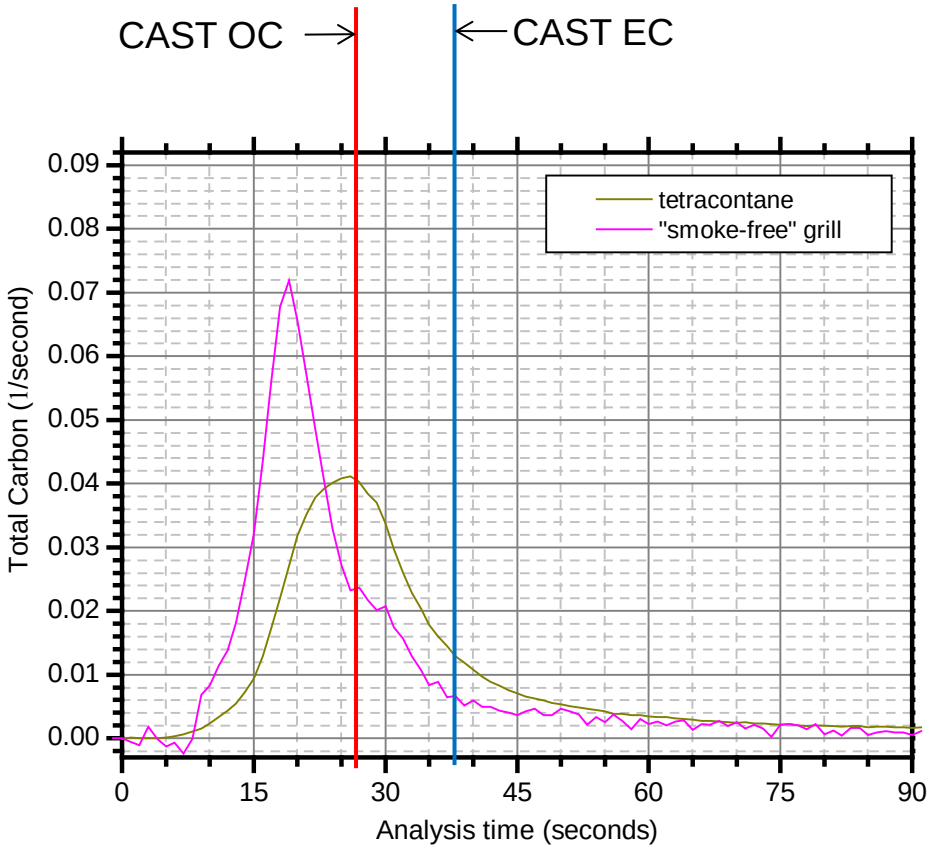
	Total Carbon	Total PM (TEOM)
	mg/m^3_{stp} @13% O_2	
Start (first 10 minutes)	16.4 (0.5)	
Full power (last 20 min.)	8.5 (0.4)	
Full power (full cycle)	3.3 (0.1)	21.0
Half power (first 40 min.)	6.1 (0.2)	



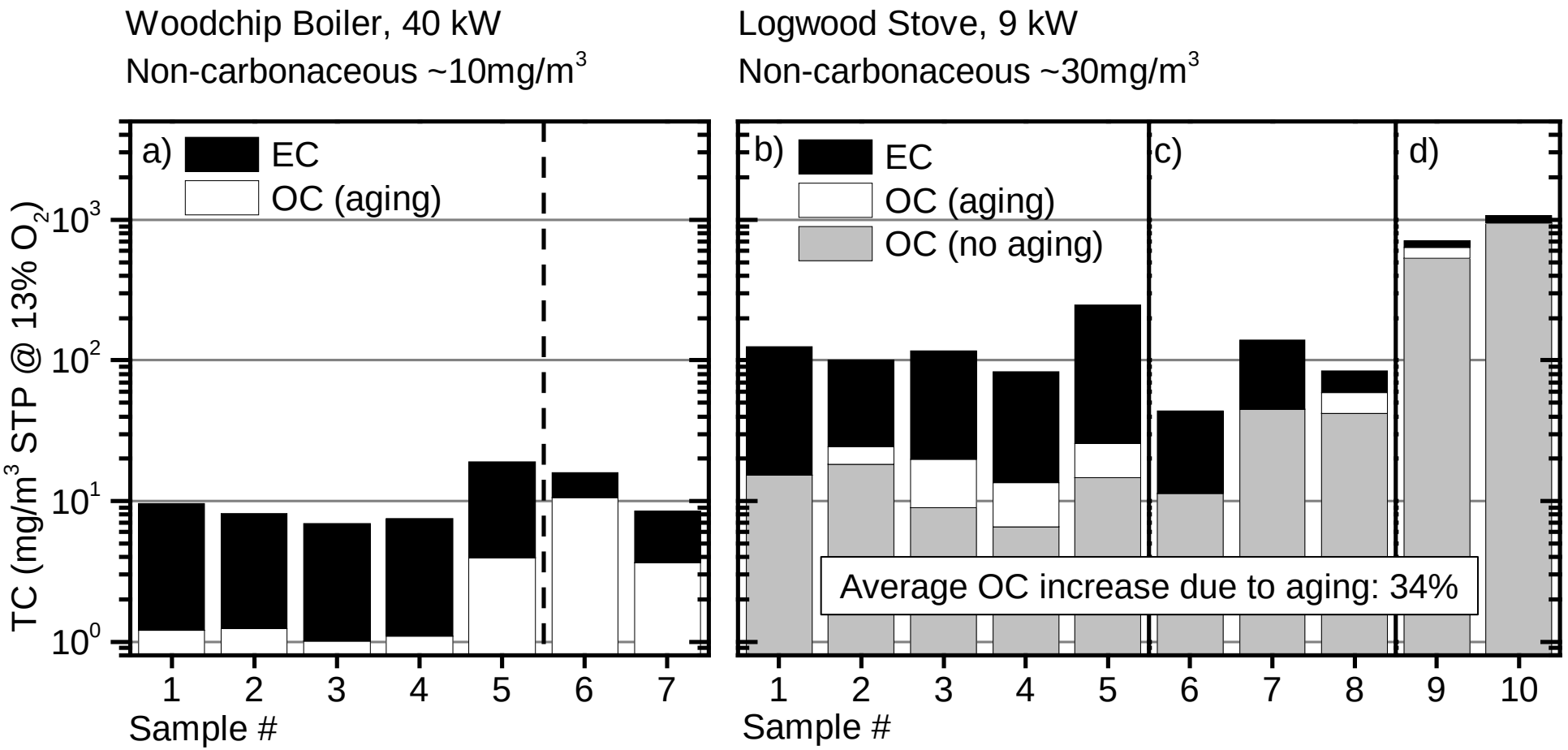
Thermograms? (2)

- It may prove difficult to set a proper split point between OC and EC
- Accumulation of non-carbonaceous material may have a catalytic effect on EC (i.e. filter history may cause EC combustion at lower temperature)





EUSAAR2 Measurements*



* Keller and Burtscher, J. Aerosol Sci., under review.

How does a better standard should look like

	Ecodesign	MSC + TC
Avoid large particles	**-**	**+**
Correlate with toxicity	**-**	**+***
Reflect combustion quality	**o**	**+**
Online or semi-online	**-(+)**	**+**
Suitable for test bench as well as field measurements	**o(+)**	**+**
Include primary as well as secondary emissions	**-**	**+**

Other requirements: low cost, low detection limit, reproducibility, ISO traceable, etc.

- Current method: Isokinetic sampling (160°C) and gravimetric analysis
- TC: total carbon analysis after conditioning in the micro smog chamber
- (+) some online mass measurements systems already available (Wöhler, Testo, …)