FM | funktionsmaterialien

On the emissions of wood-log fueled fireplaces: correlation of continuous gas sensor data with particle spectra analysis

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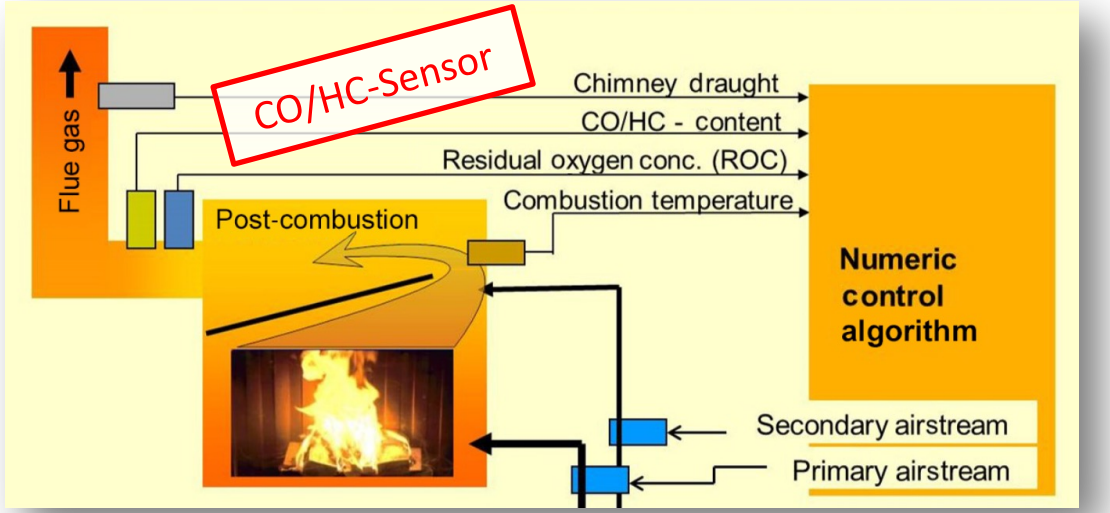
Motivation: Benefit of Sensor-Based Operation

[Kohler et al., J. Sens. Sens. Syst. 7, **2018**, 161-167]



- controlling primary and secondary air for wood-combustion automatically
- reduction of CO emissions up to 80 %
- use of catalyst and dust filter (electrostatic precipitator)
- costs: up to 4.000,- EUR

[German TV, **30.03.2023**, available @ SWR Mediathek]

11 million wood stoves in Germany
actual discussion: PM emissions

suitable sensor devices for monitoring / controlling are missing

our work / goal:
- robust / low-cost sensor device (CO/HC)
- PM detection also possible ?
- correlation PM - / gas-emissions ?

Real Gas Testing / Keylab “Clean Air”

- **single room fireplace** (LEDA Unica, DBFZ)
- **gas analysis** (FTIR Multigas, MKS)
  (FID / NDIR / param. O_2, Emerson)
- **particle analysis** (DMS 500, Cambustion)
- **residual oxygen concentration** (ETAS / LSU)
- **other devices** (Testo 340, Testo 380)
- **electrical metrology** (Keithley DMM)
- **in-house developed sensors**
  - Particulate Matter (PM)
  - CO/HC
  - H_2
  - others (O_2 / NO_x, NH_3)

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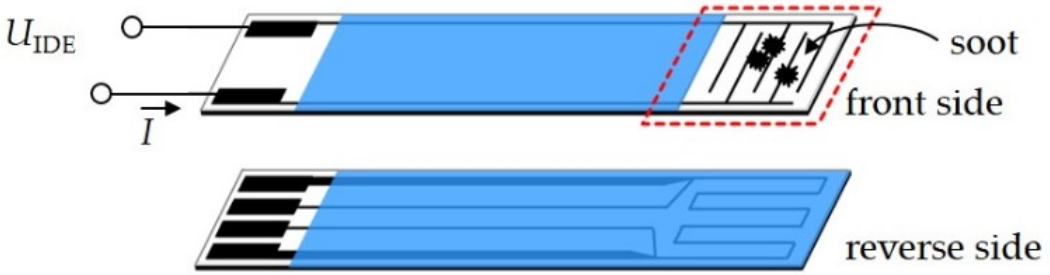
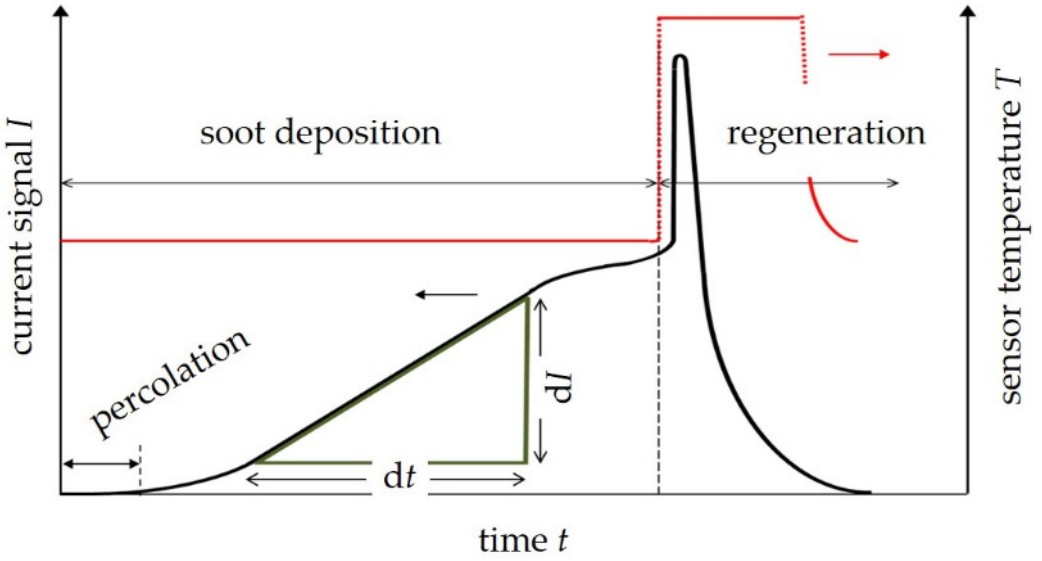
Shortly: Soot / Particle Sensing

former work (2010): automotive applications

- **resistive soot sensor**
- DPF failure detection
- challenges GPF
- In-operando filter diagnosis (RF-based)





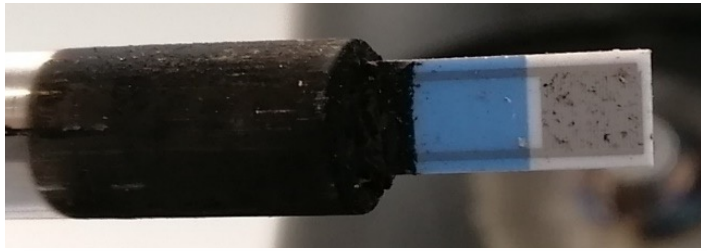
Detection of soot in "cycles":

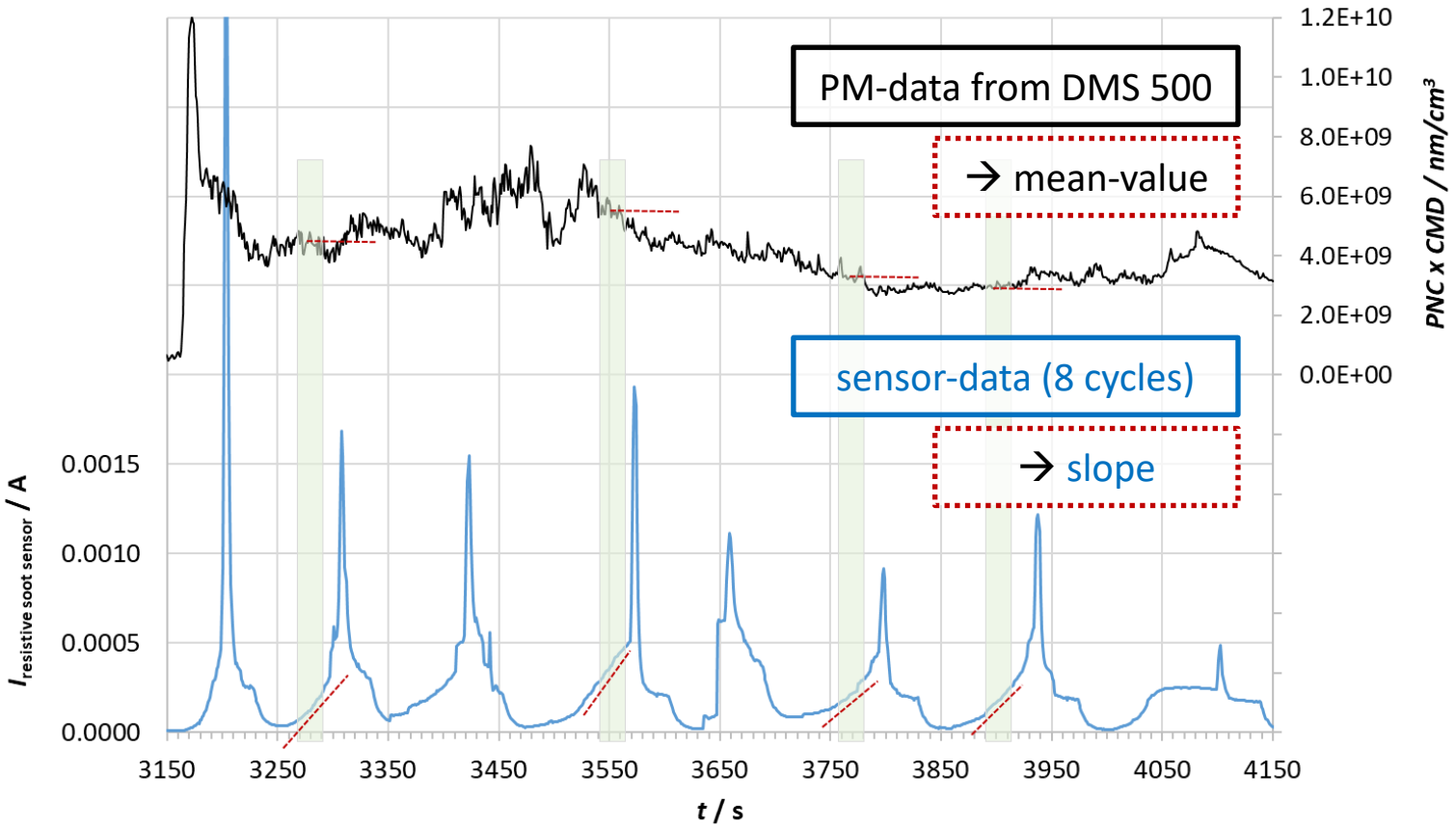
- **percolation time** (soot particles on surface / built conductive paths)
- **slope** (increase of current over time representing soot concentration)
- **regeneration** (to burn off soot layer and to start new measuring cycle)

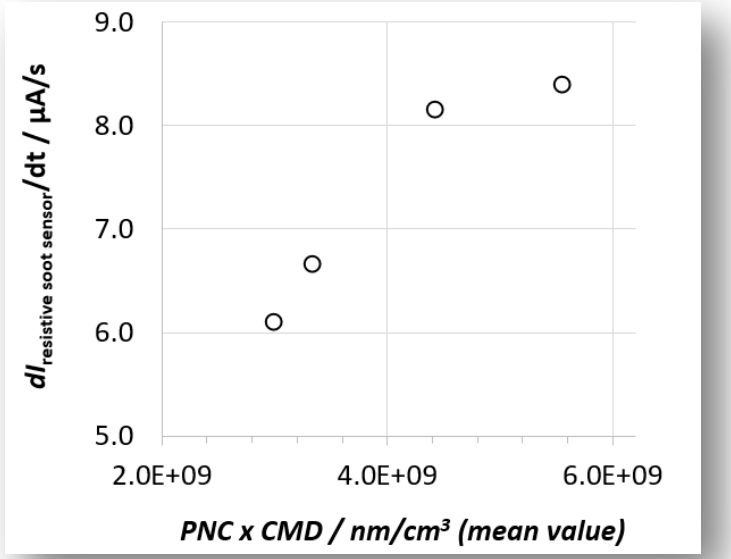
Source: [**Sensors 2018**, 18, 3531]

Shortly: Soot / Particle Sensing

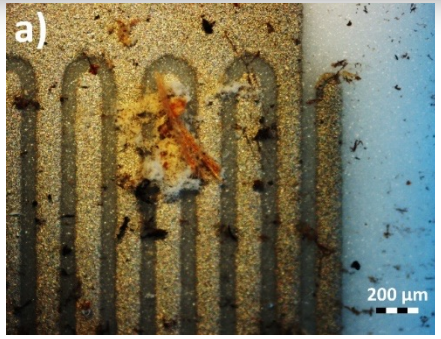
application in wood-burning







→ problem:
non-soot PM …



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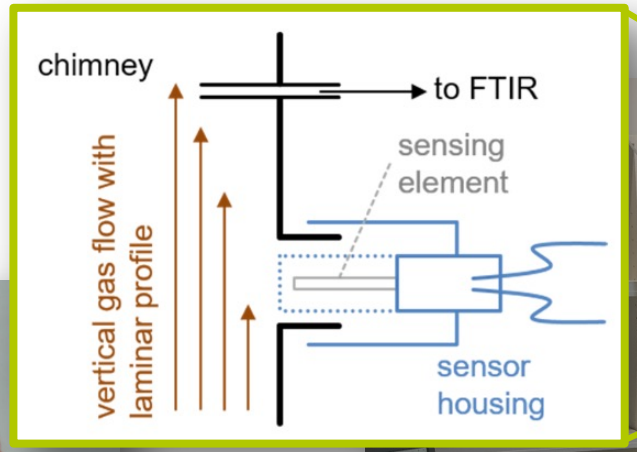
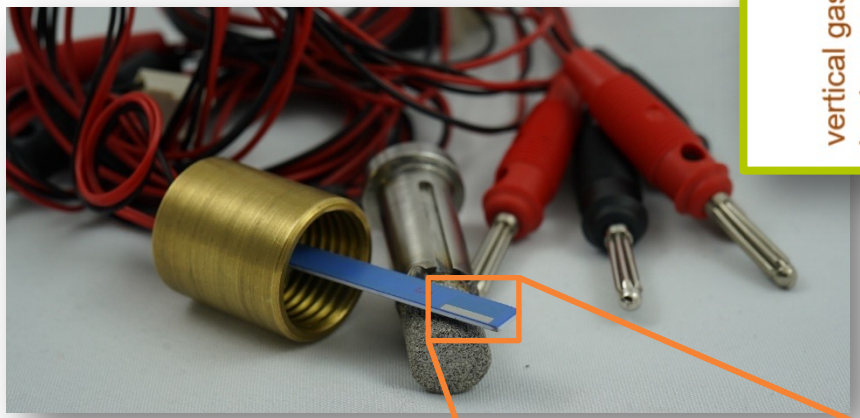
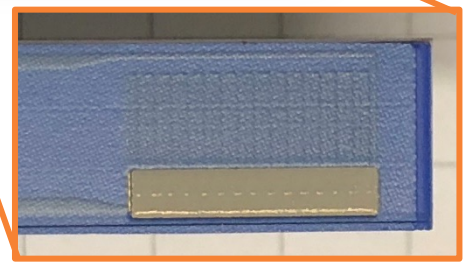
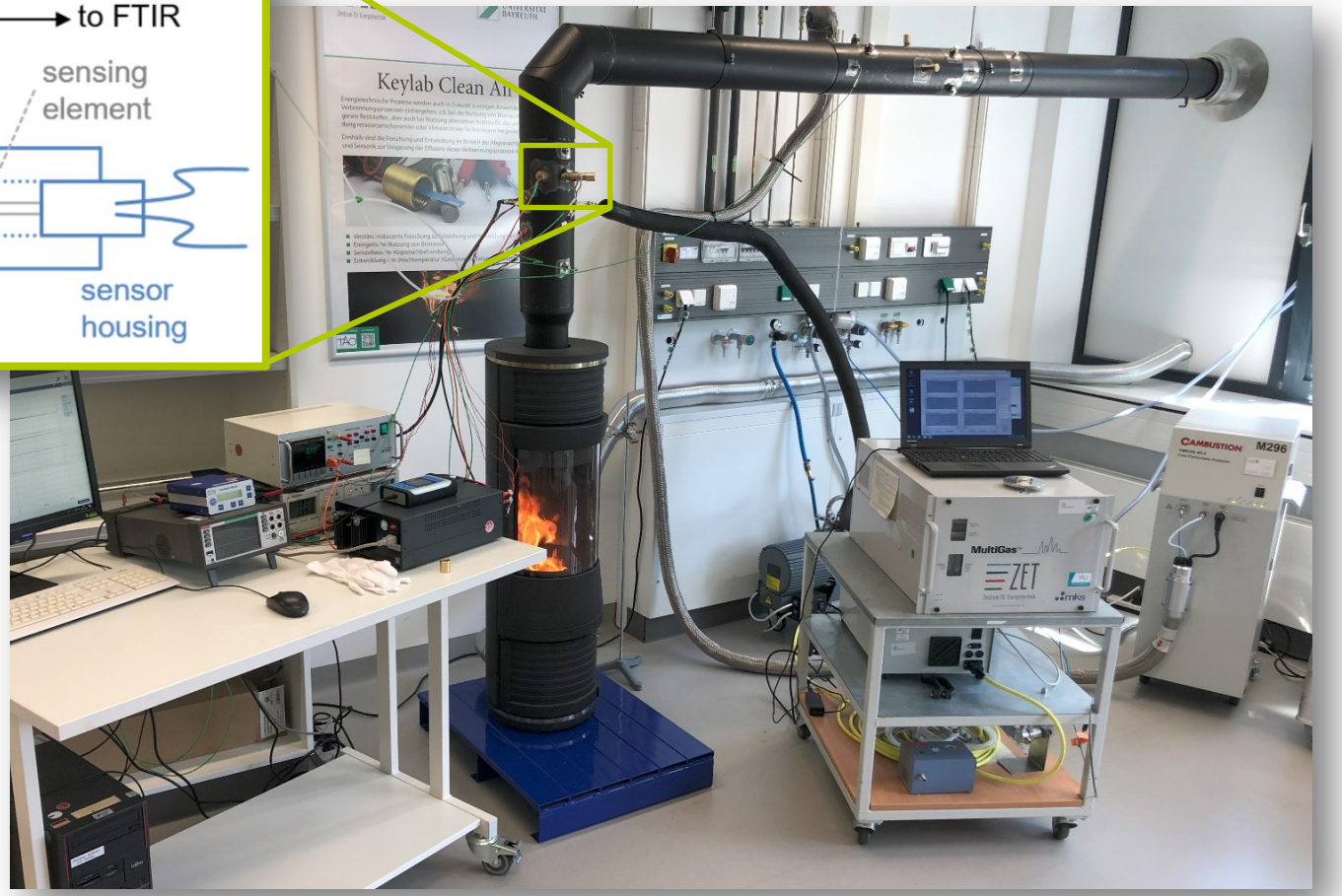
Real Gas Testing / Keylab “Clean Air”





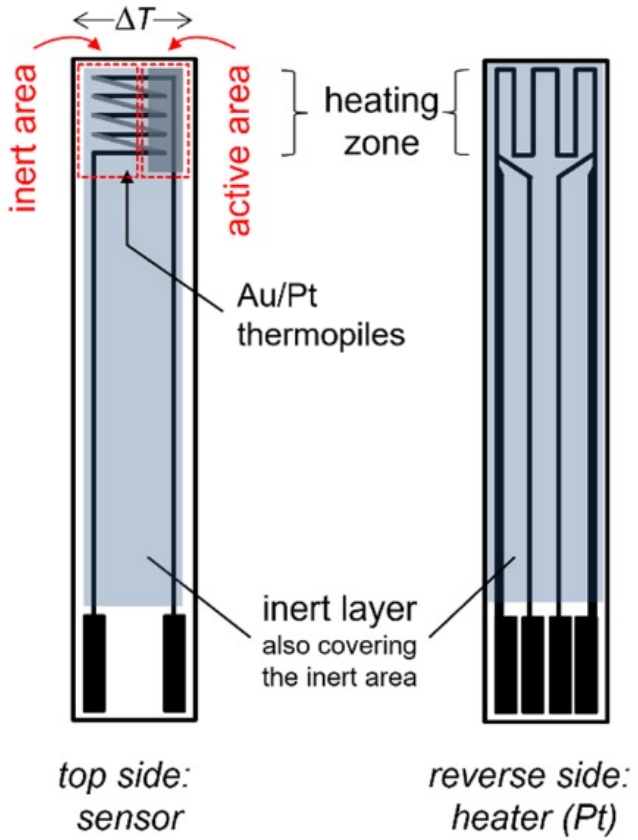




- **CO/HC**

CO/HC-Sensor

measurement principle / lab results



- linear sensor characteristic curve for each gas species, depending on
  - combustion enthalpy, diffusivity, reactivity
- sensor measures a SUM of reducing gases, each with different sensitivity

slope in sensor result (lab data) = **factor** to derive SUM of CO-equivalents in FTIR-data (real gas)

→ **comparison of sensor data and SUM of FTIR-data**

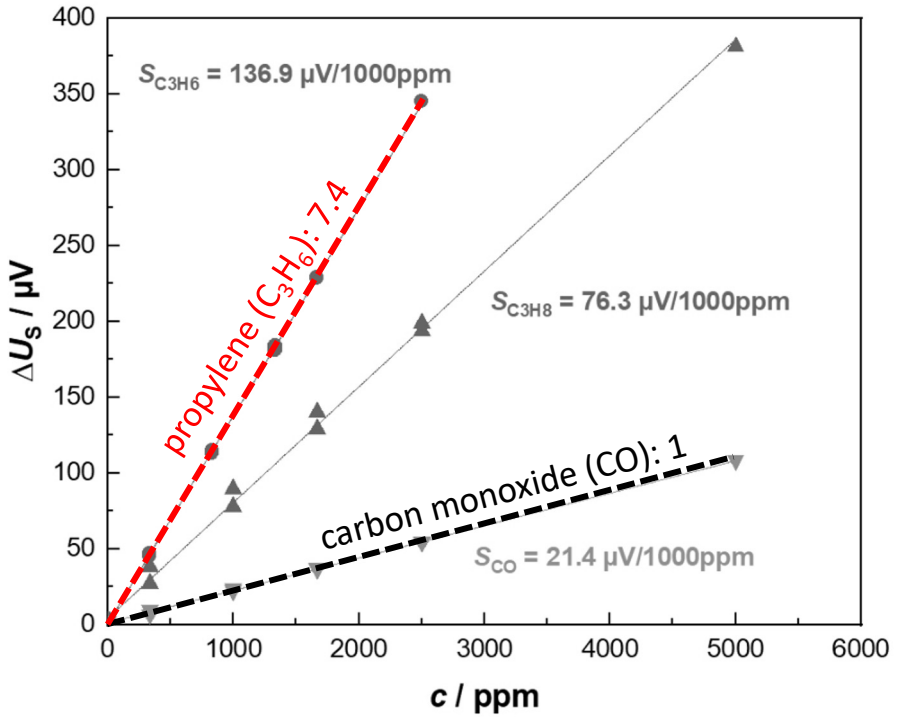
sensors MDPI

Article

Application of a Robust Thermoelectric Gas Sensor in Firewood Combustion Exhausts

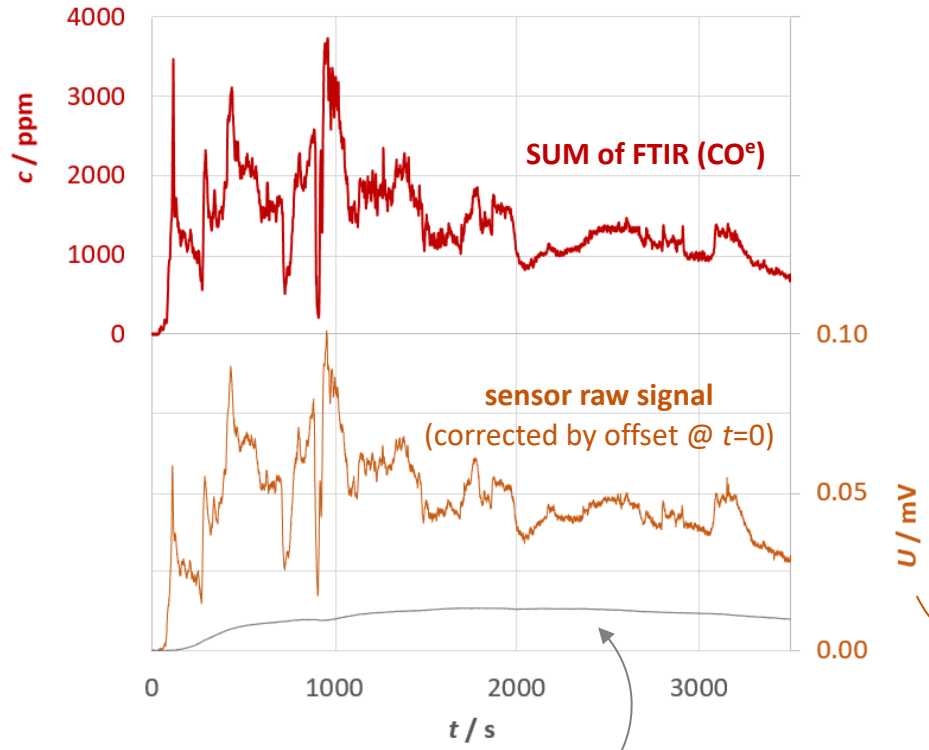
Gunter Hagen [1,*], Julia Herrmann [1], Xin Zhang [2], Heinz Kohler [2], Ingo Hartmann [3] and Ralf Moos [1]

Source: [**Sensors 2023**, 23, 2930]



CO/HC-Sensor

application in wood-burning

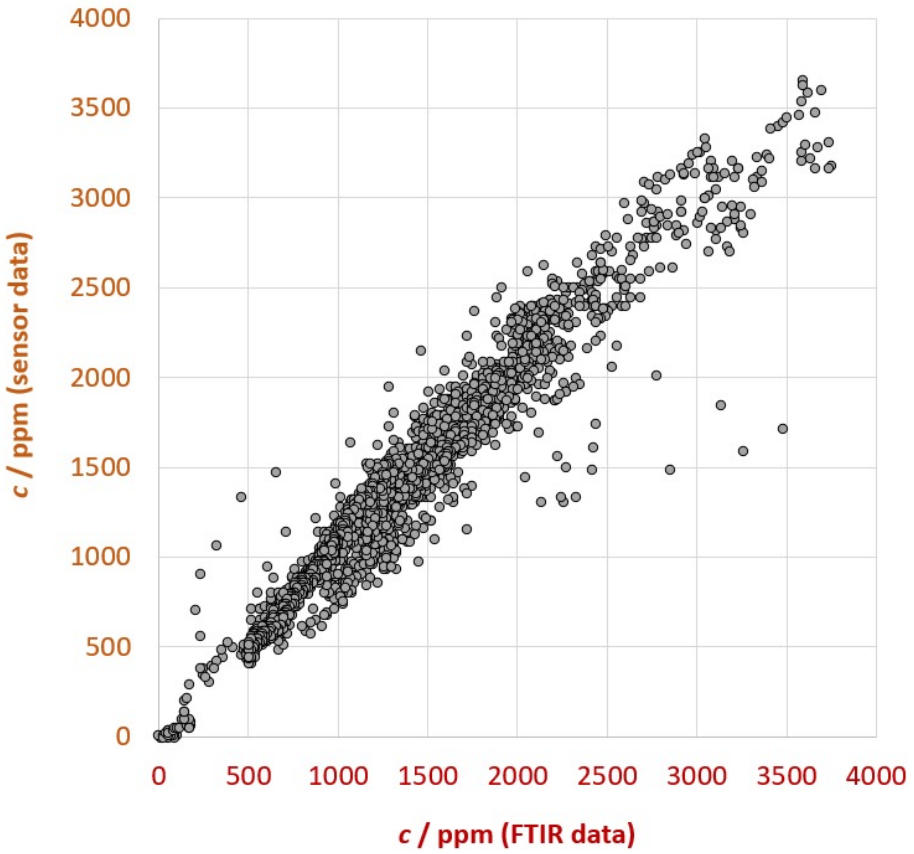


temperature correction
(depending on housing temperature)
linear factor: **0.00023 mV/°C**

Flue gas analysis of wood combustion

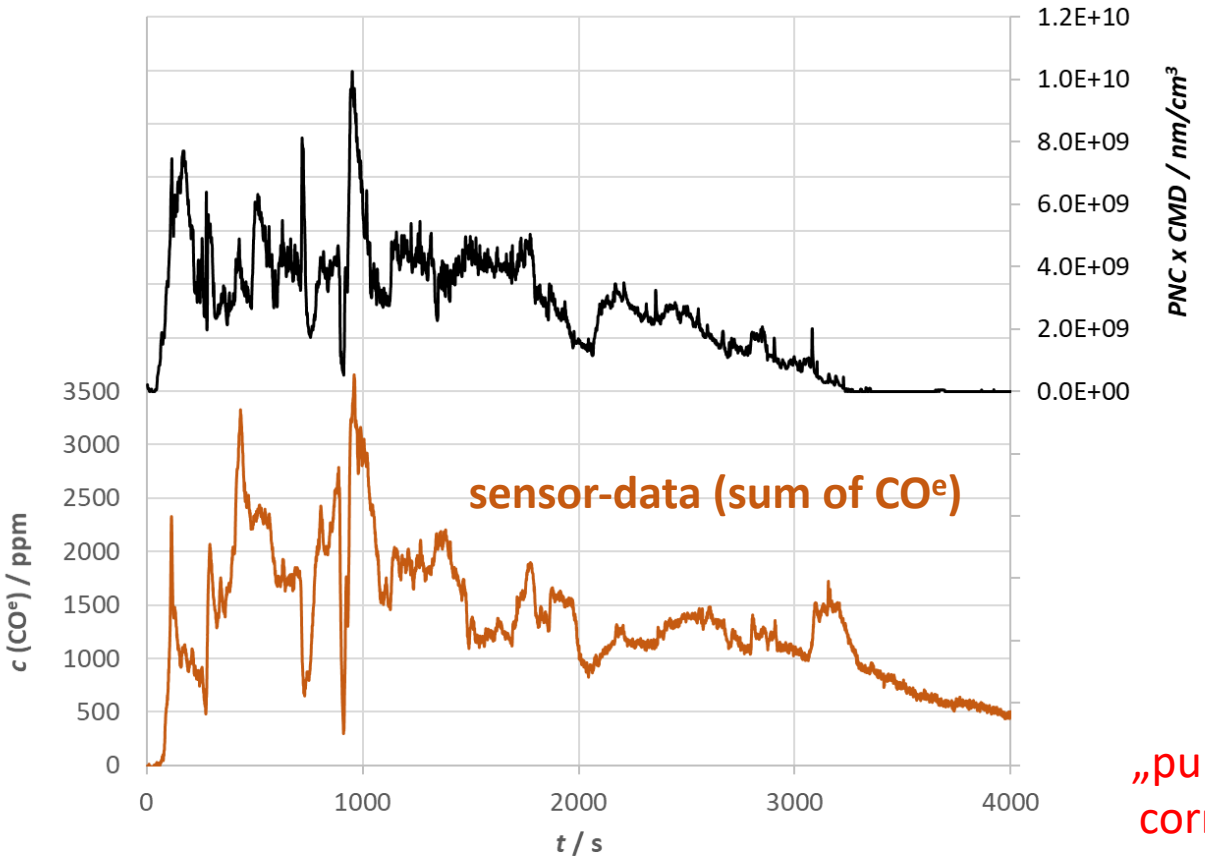
Gunter Hagen[1], Thomas Wöhrl[1], Andreas Müller[1], Julia Herrmann[1], Ingo Hartmann[2], Ralf Moos[1]
[1] Department of Functional Materials, Zentrum für Energietechnik (ZET), University of Bayreuth, 95440 Bayreuth, Germany
[2] Deutsches Biomasseforschungszentrum (DBFZ), 04347 Leipzig, Germany
gunter.hagen@uni-bayreuth.de

Source: [SMSI, Nuremberg **2023**]

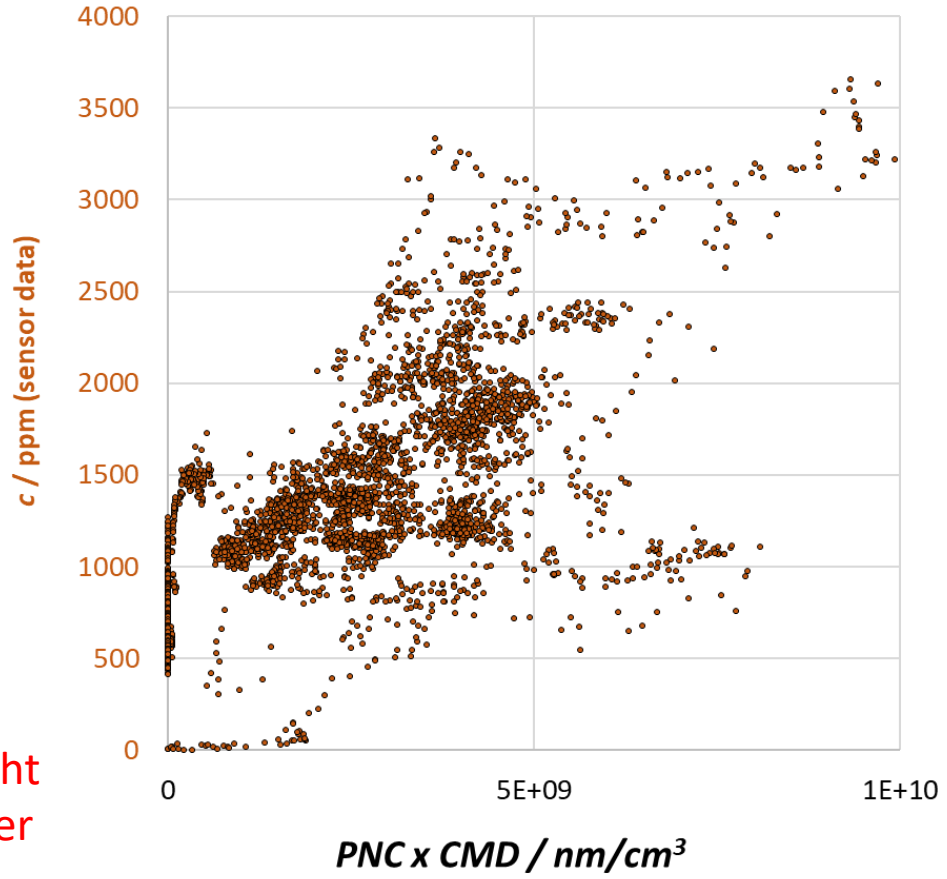


Correlation Gas Sensor Data – Particle Emissions

PNC x *CMD* (measured by DMS 500, CAMBUSTION)



„pure“ HC might correlate better with PM ?



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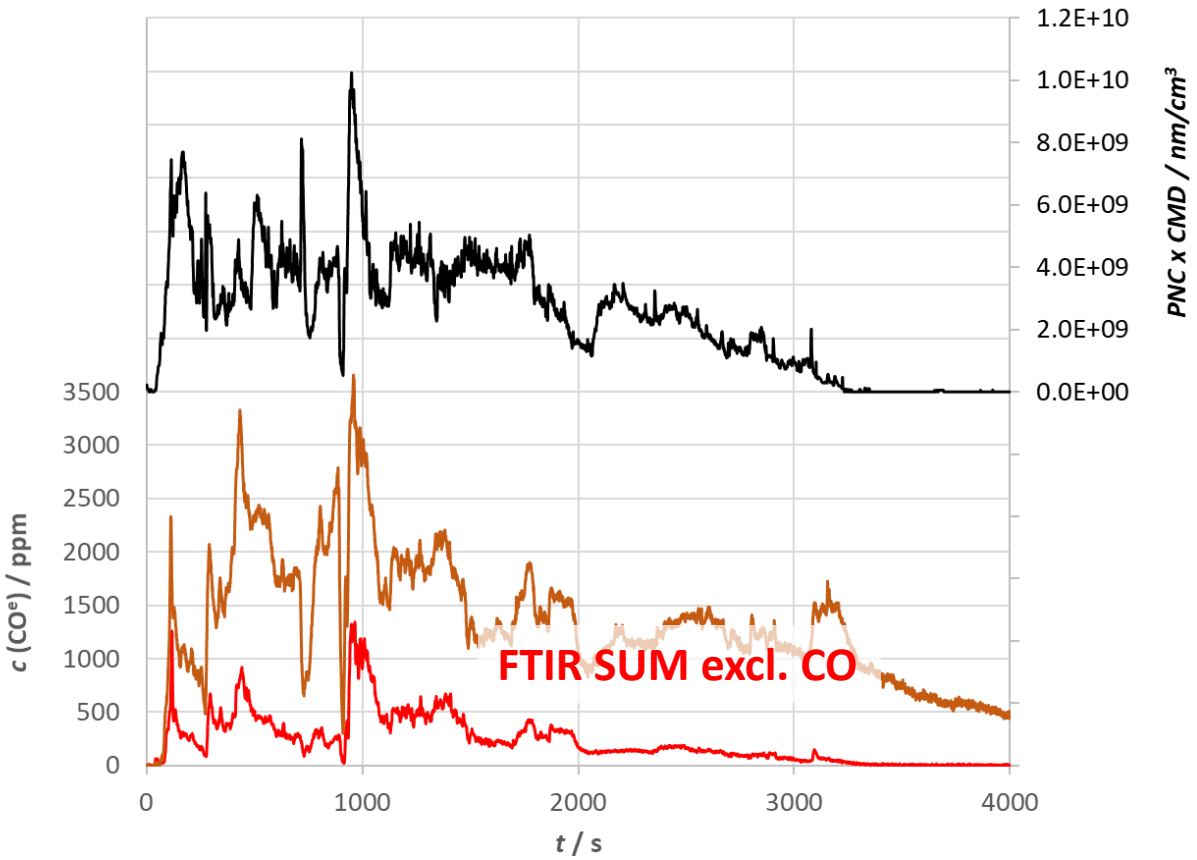

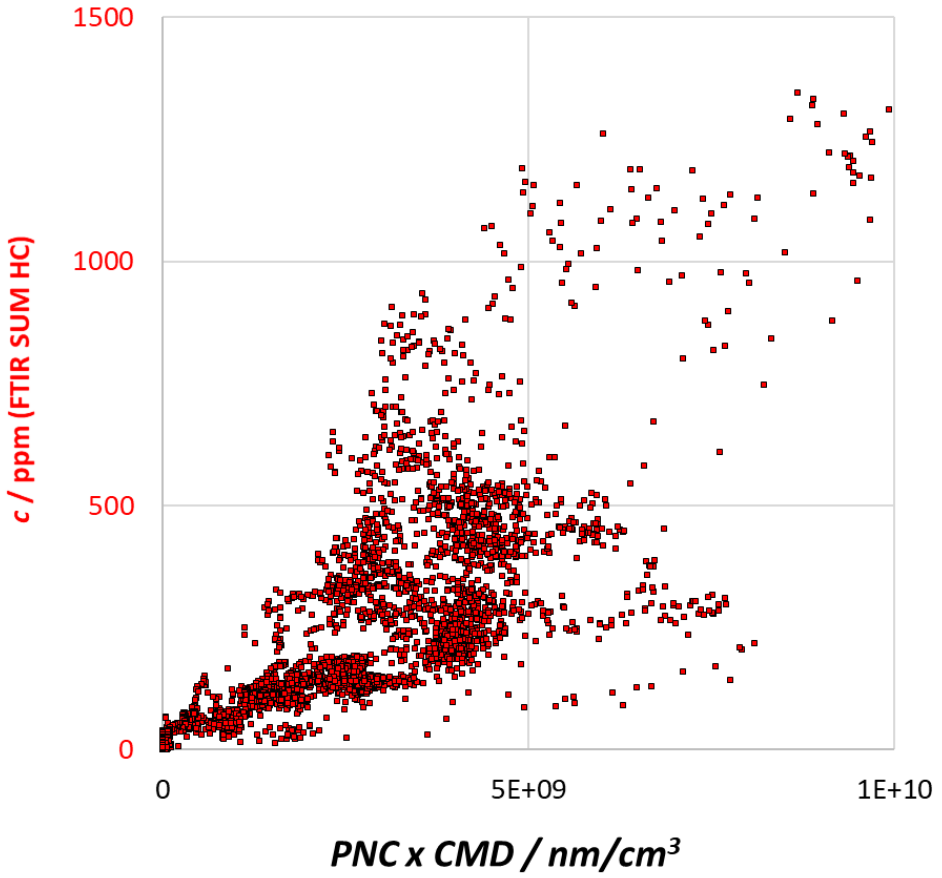

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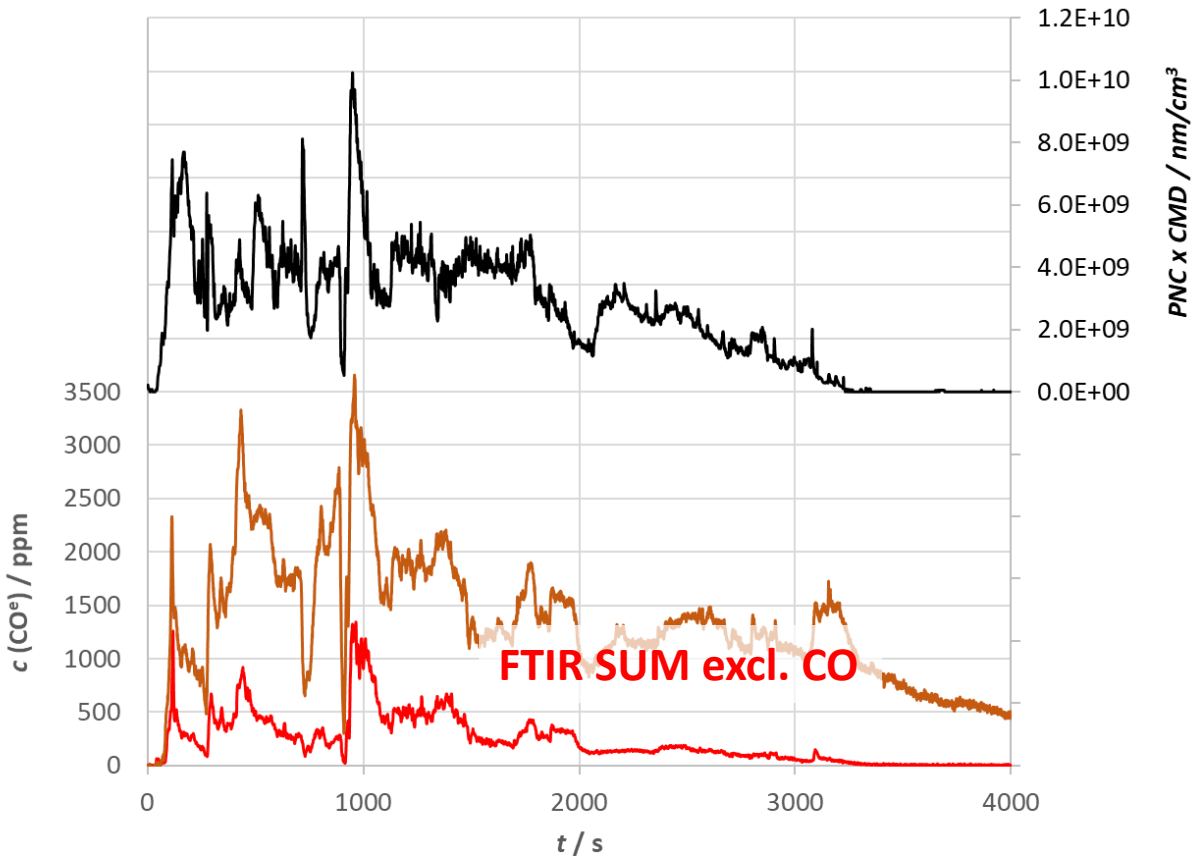


FTIR SUM excl. CO (= „pure“ HC)

(analytics data)

HOW TO MEASURE in-operando?

= gas sensor problem
(selectivity / cross-sensitivities of reducing species)

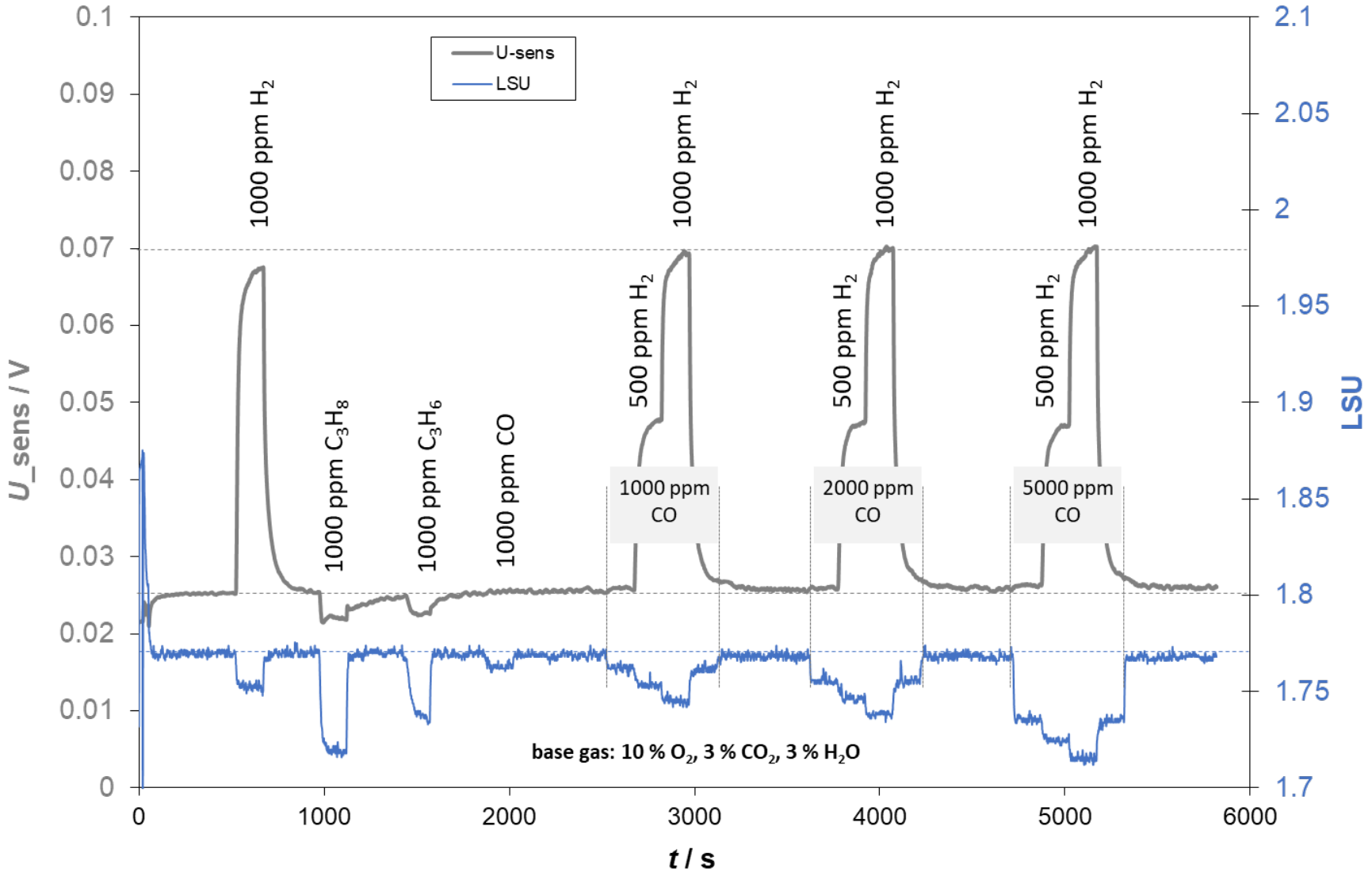
→ **IDEA**: H_2 correlates to CO during wood combustion

→ **availability of a H_2-sensor ?**

H_2-sensor

lab testing

unpublished results



H_2-sensor

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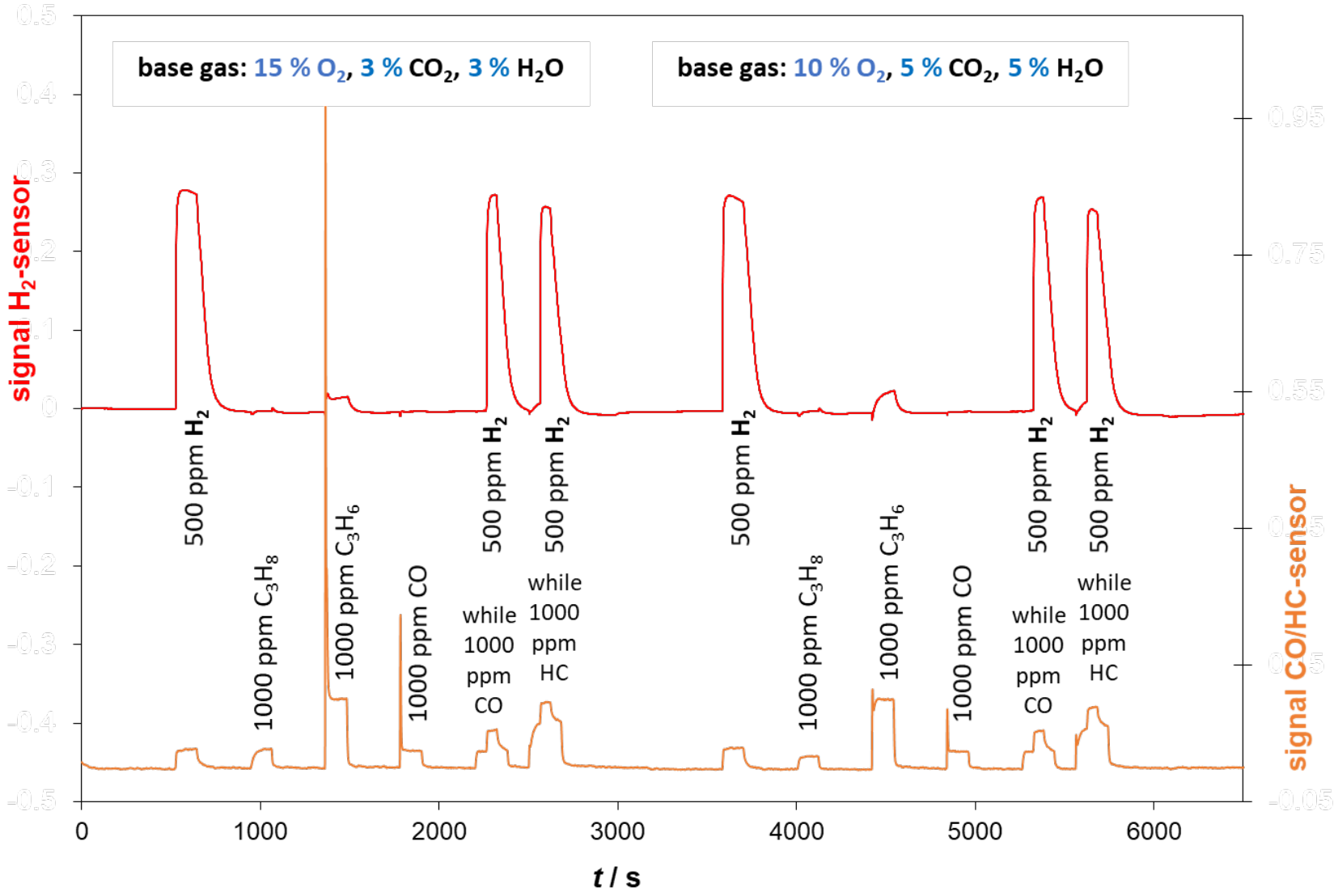


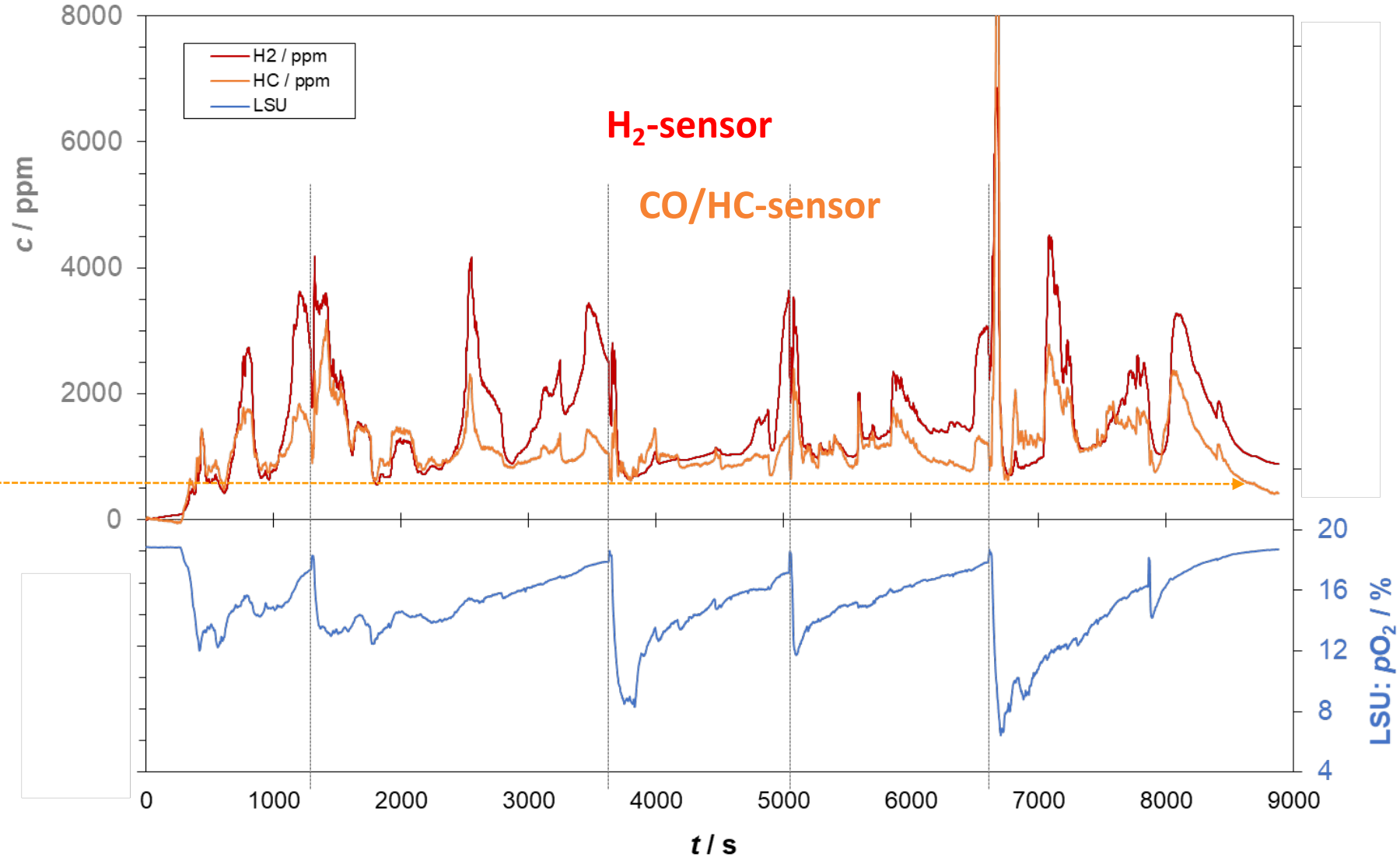
H_2-sensor

CO/HC-sensor

Real Gas Testing

biomass combustion

(single-room fireplace)



Real Gas Testing

biomass combustion

(single-room fireplace)

378 g (humidity 10,7 %) – wood 1

700 g (humidity 10,5 %) – wood 1

730 g (humidity LOW) – wood 2 (hardwood)

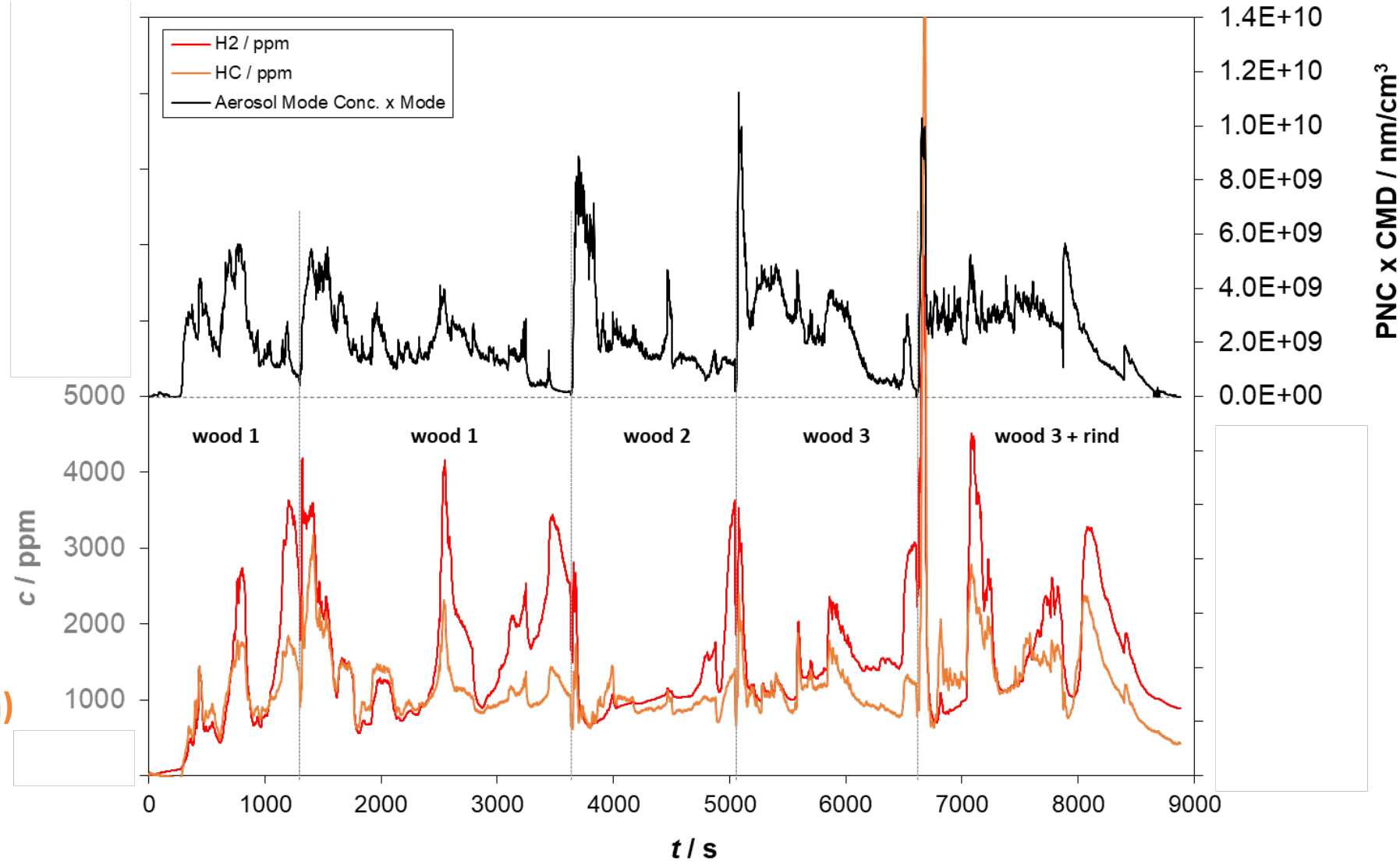
414 g (humidity 14 %) – wood 3)

660 g (humidity 12,6 %) – wood 3
+ 200 g rind)

Real Gas Testing

biomass combustion

(single-room fireplace)



H_2-sensor signal (in ppm)

CO/HC-sensor signal (in ppm)

Real Gas Testing

biomass combustion (single-room fireplace)

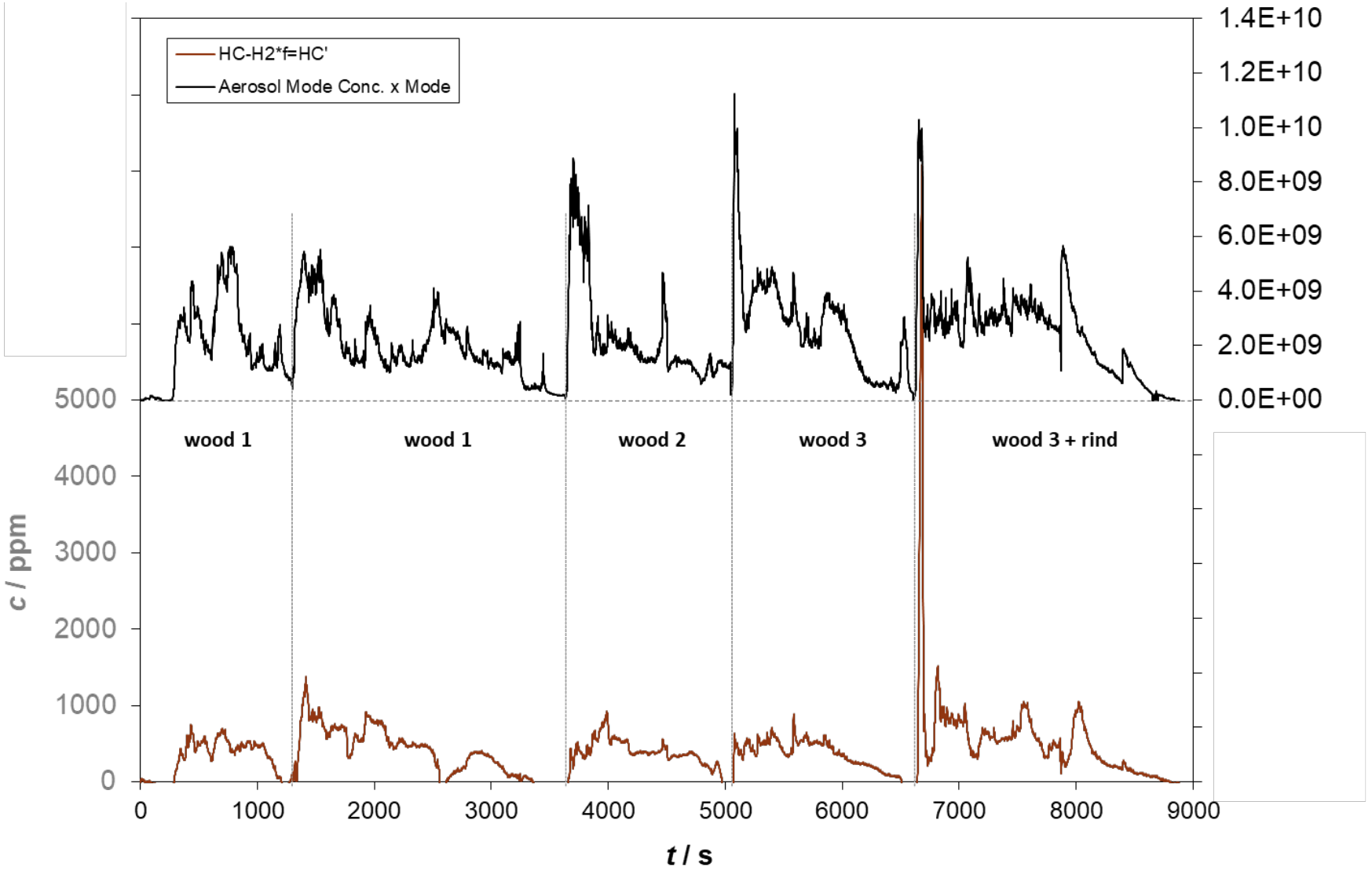
→ apply considerations…

H_2 (ppm) correlates to CO (ppm)

with $H_2 = 2 \times CO$

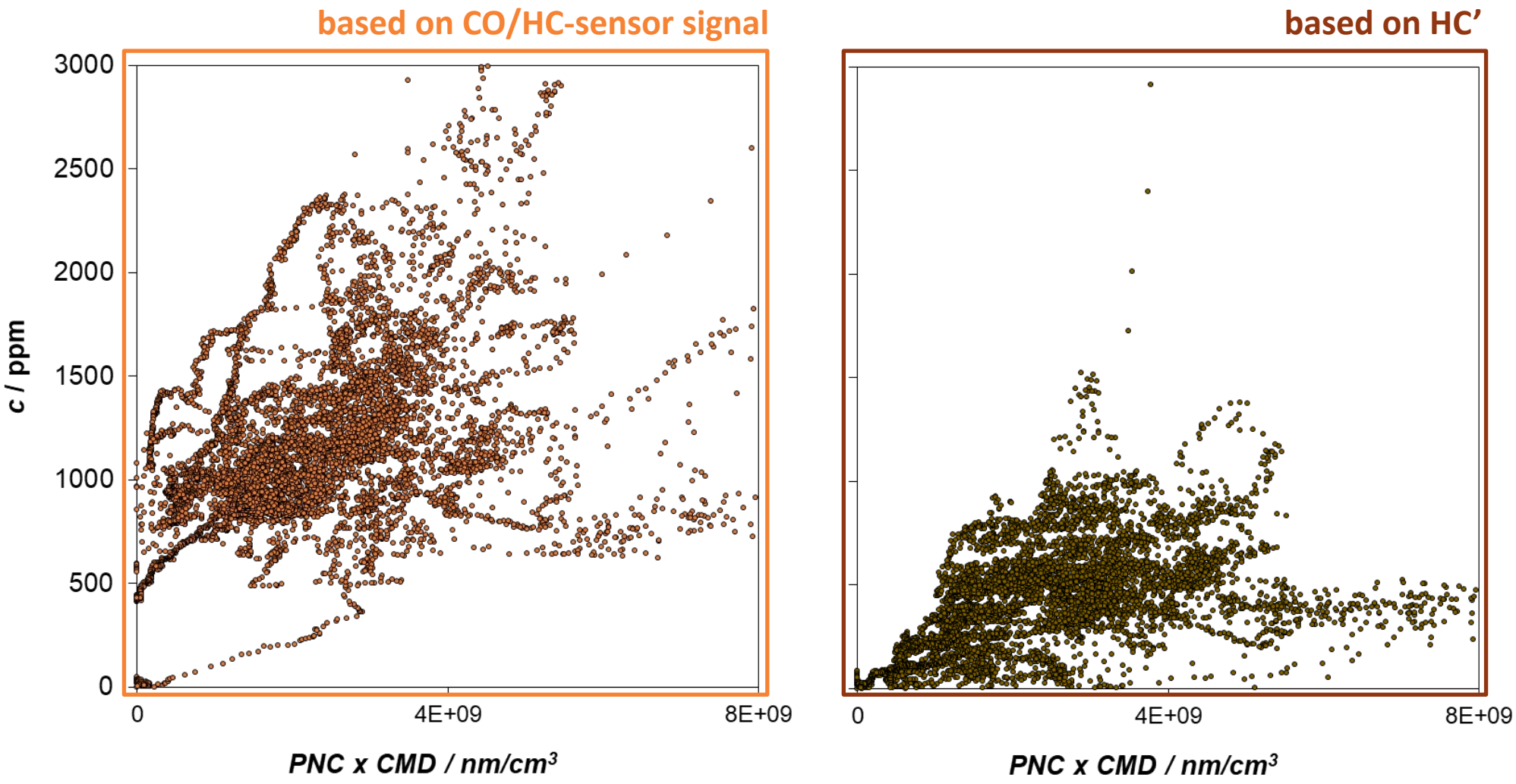
CO/HC / ppm – (1/2 x H_2 / ppm)

= HC ‘ / ppm



Real Gas Testing

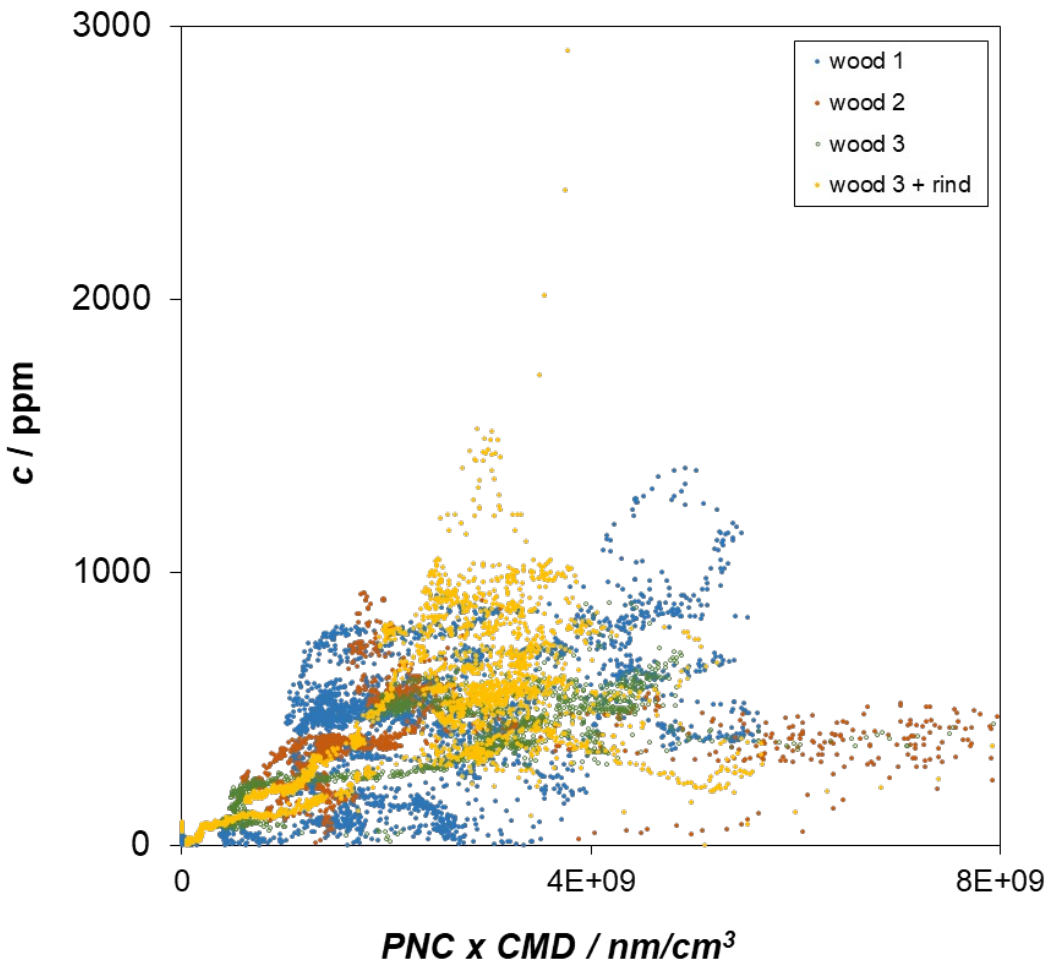
biomass combustion

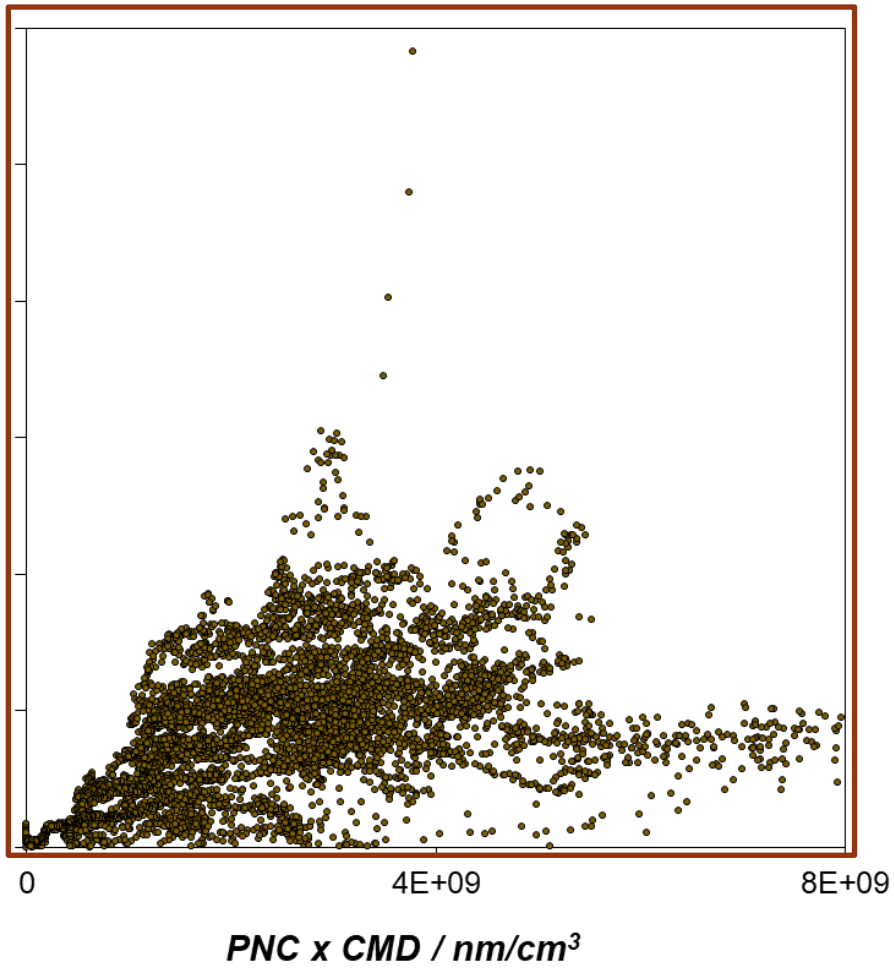


Real Gas Testing

biomass combustion

based on HC’





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biomass combustion

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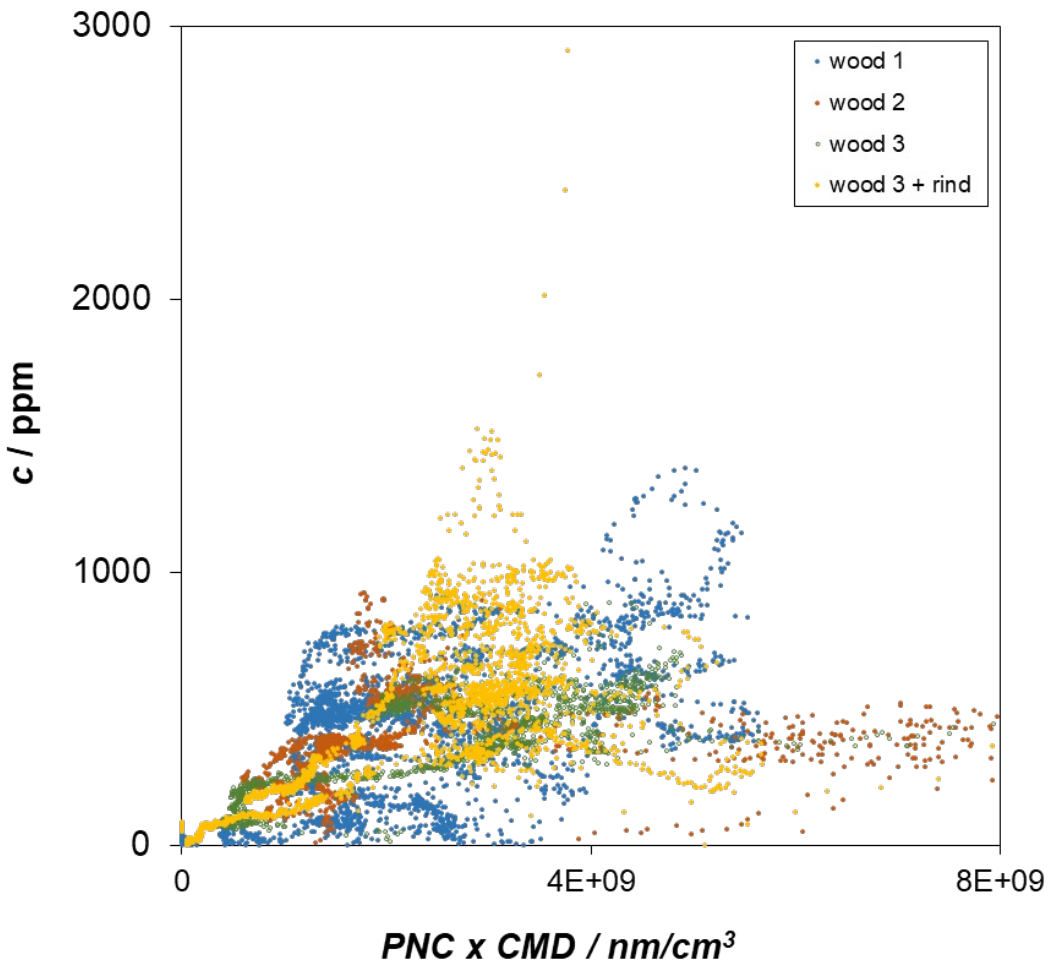
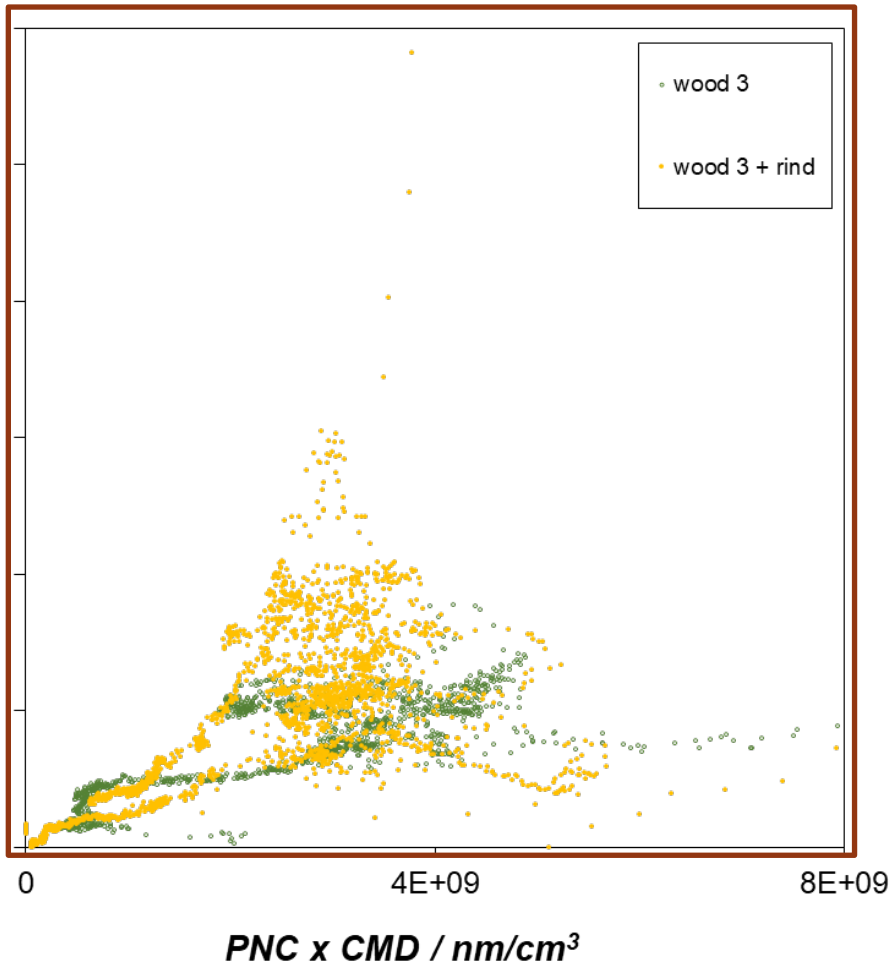
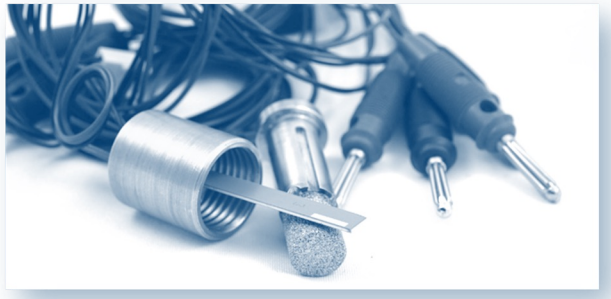
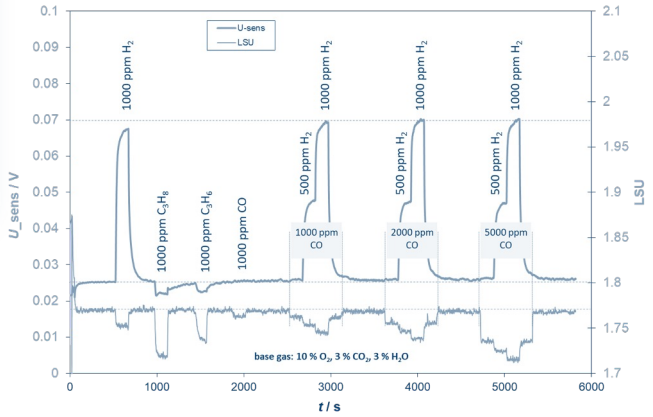


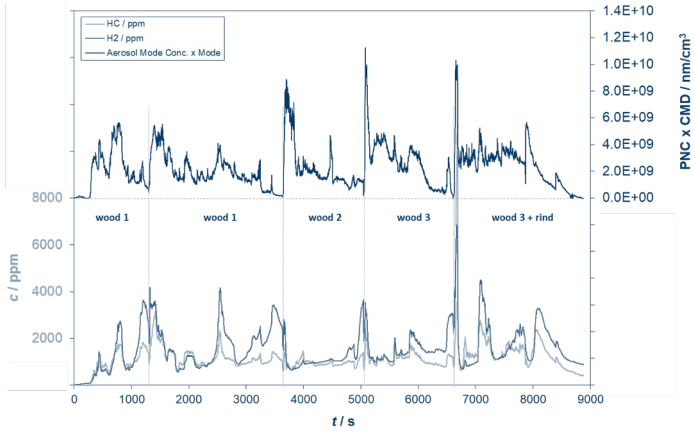


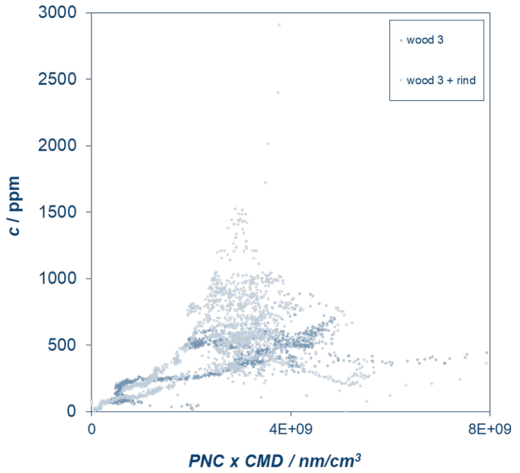
Summary and Outlook

correlation of gas and particle data?









- robust gas sensing device (CO/HC) for application in the flue gas
- correlation of continuous gas data with PM emissions
- improvement by excluding “CO”

→ several other secondary signals available
  - ROC, *T,* (…)

→ further refinement

→ in-operando measurement for controlled operation to reduce emissions