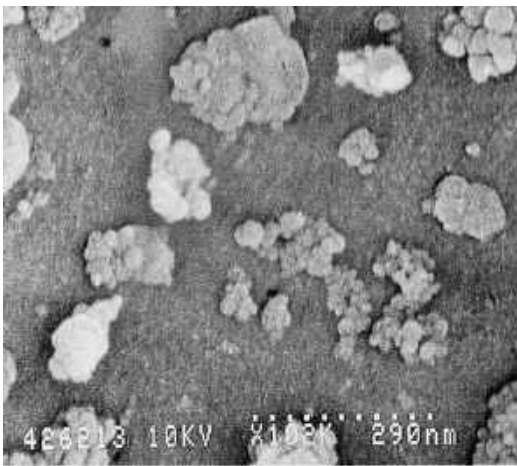




Introduction to biomass combustion and pollutant reduction in wood stoves and boilers

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Verenum Research, Zürich
Lucerne University of Applied Sciences and Arts, Horw
Swiss Federal Office of Energy, Delegate of in IEA BT32

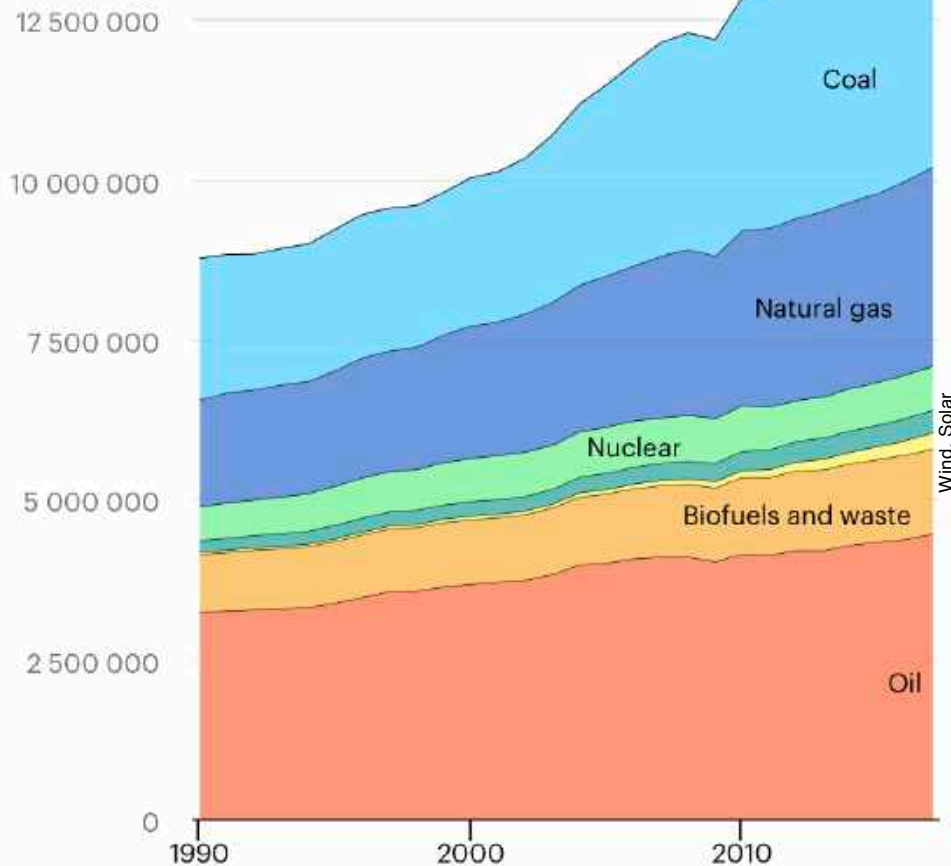
Switzerland

1. Intro: The role of bioenergy for CC and AP

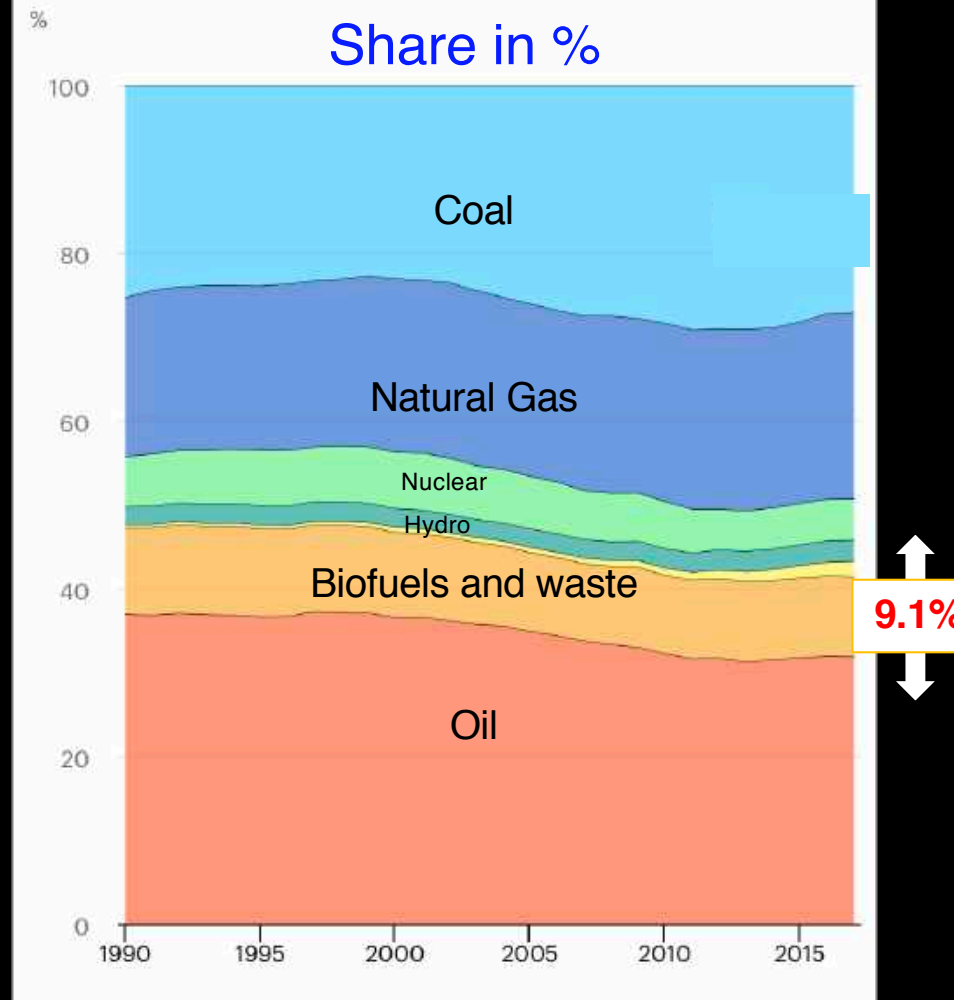
World energy supply 1990 to 2017

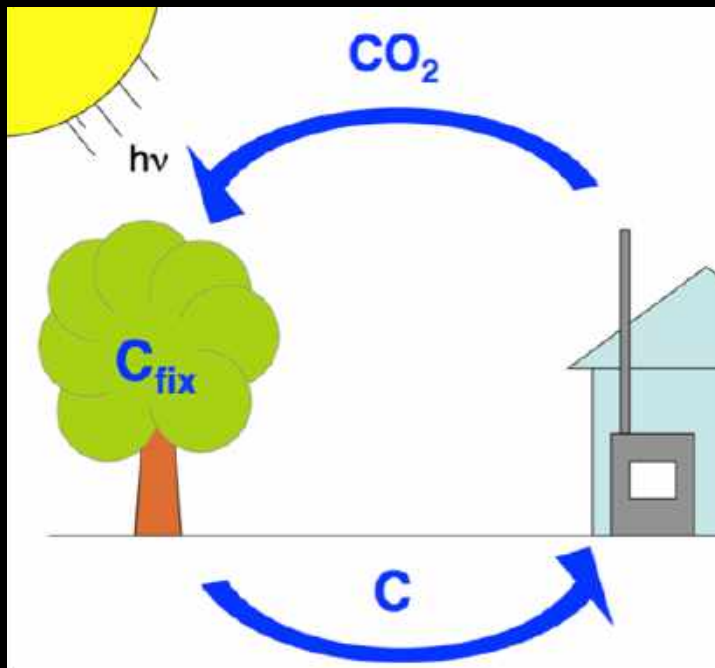
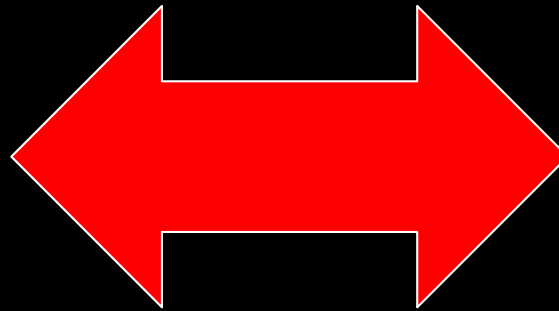
[International Energy Agency 2020]

Total in ktoe/a

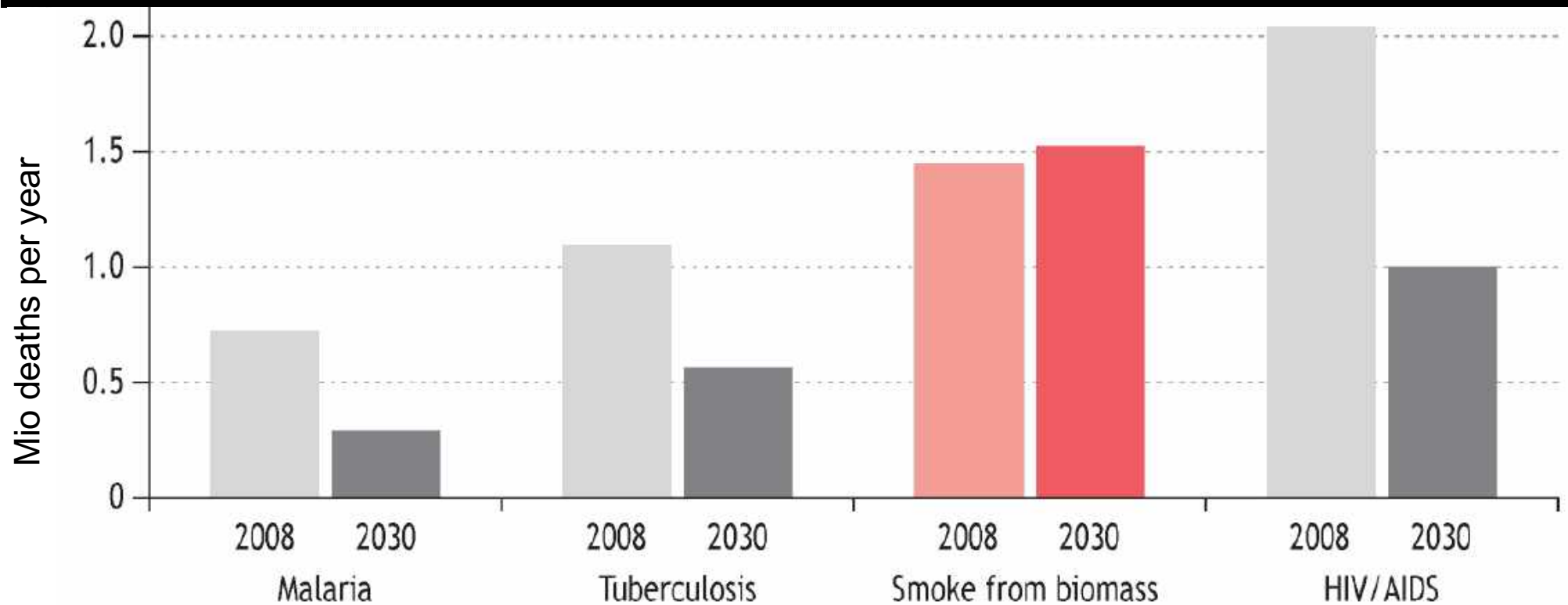


Share in %



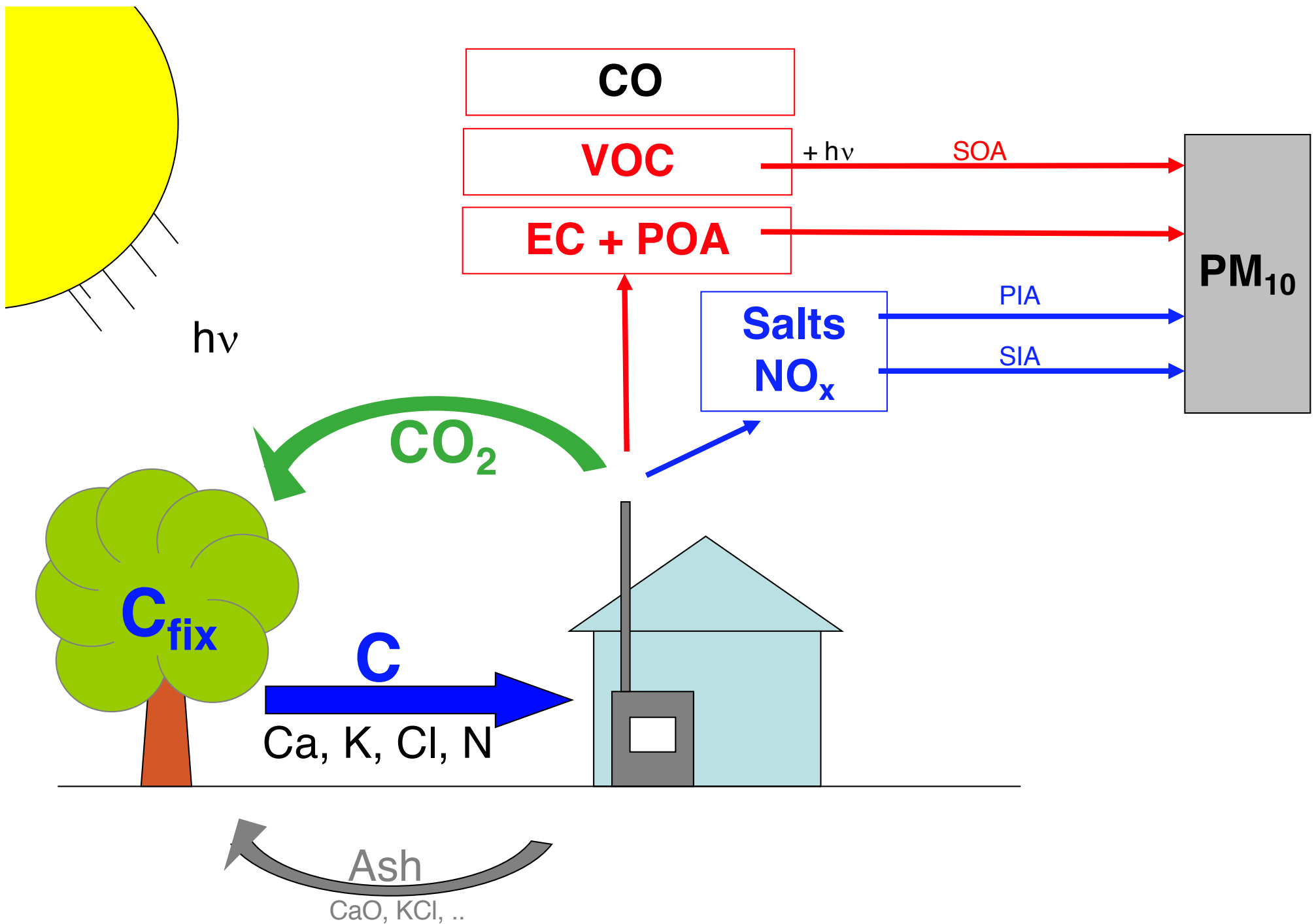


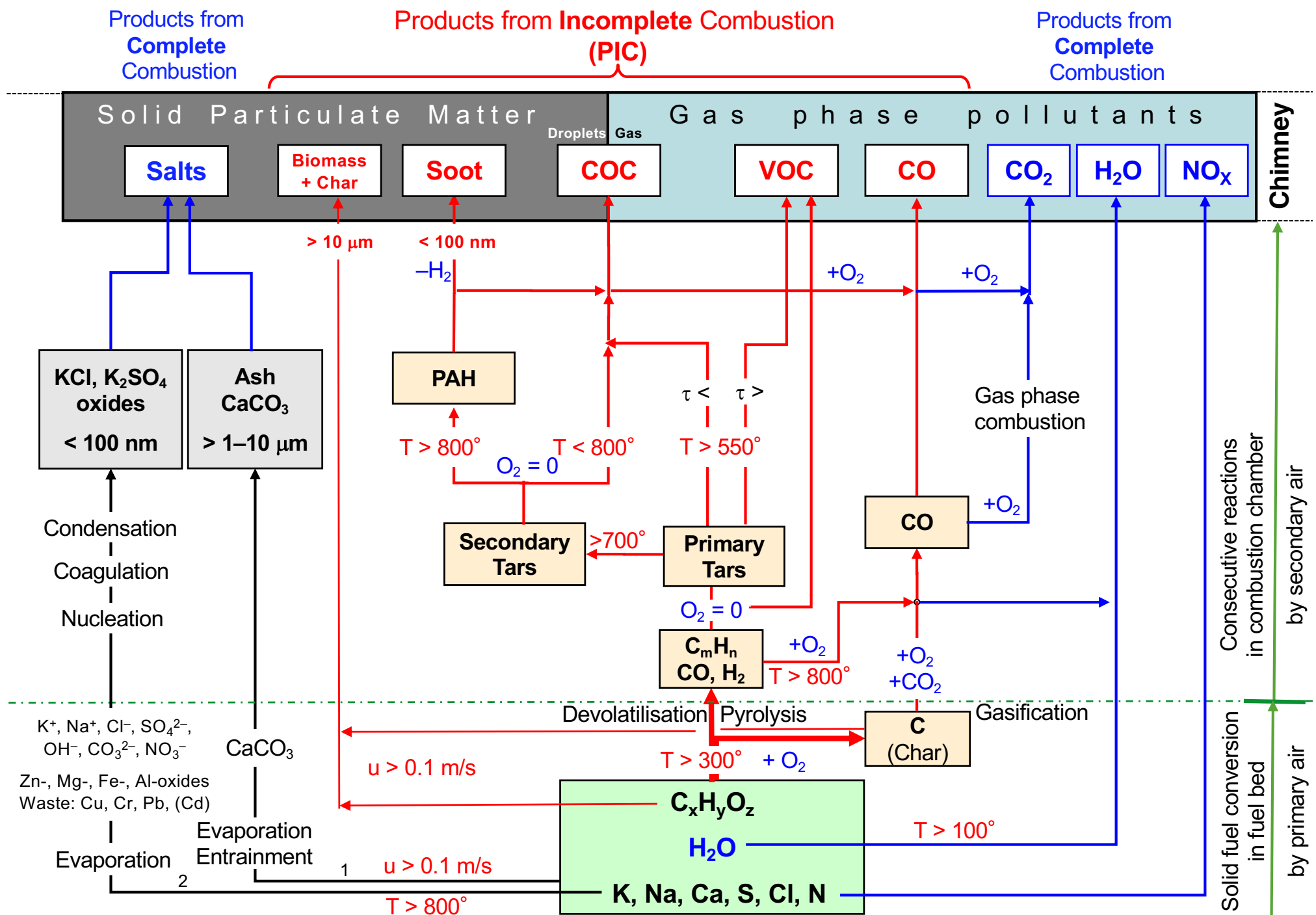
Global effect of smoke from biomass on mortality



1. Intro

2. Pollutant formation with focus on PM and OC

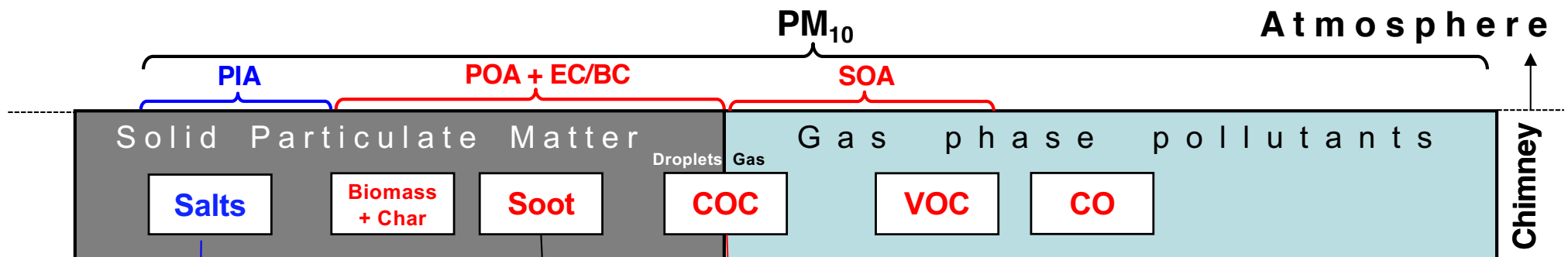
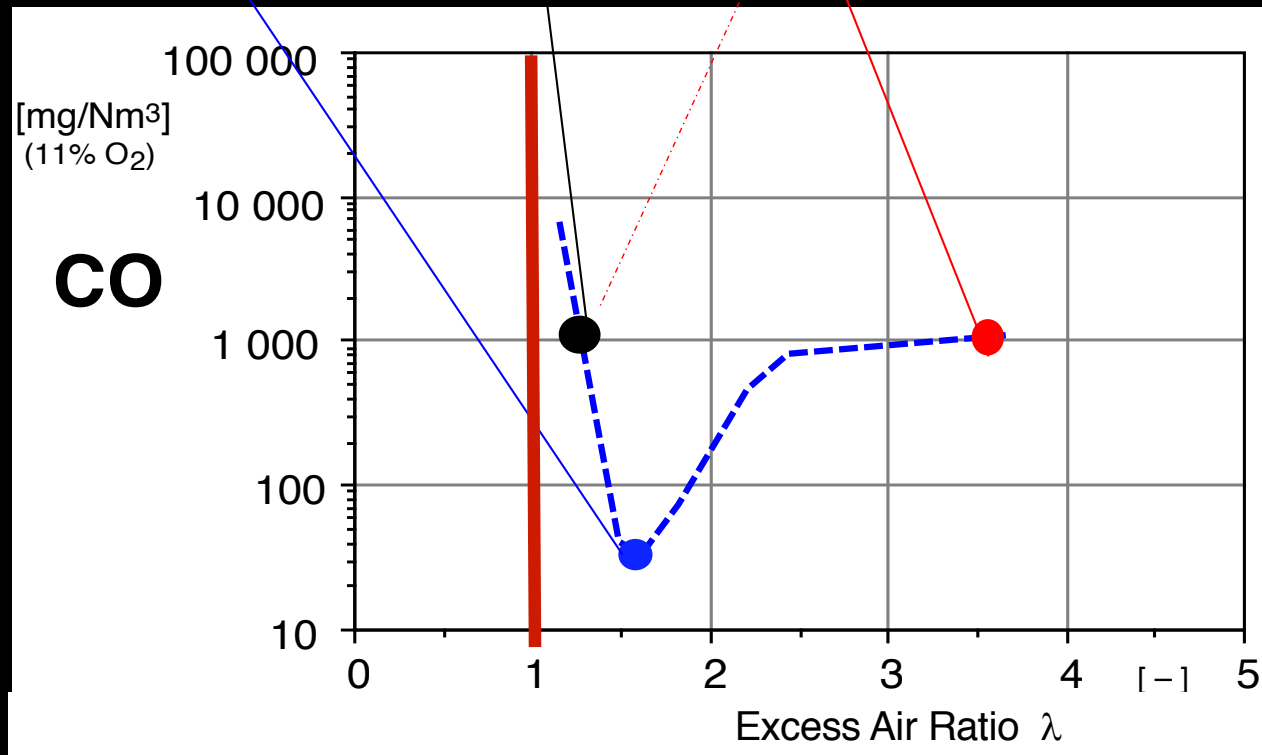




u Gas velocity, τ Residence time, </> short/long COC: Condensable Organic Compounds

1 Solid-particle-path, 2 Solid-vapour-particle-path VOC: Volatile Organic Compounds

T: [Evans and Milne, 1987], H₂: [Jess, 1996]



[Nussbaumer, T., Energy & Fuels, Vol. 17, No 6, 2003, 1510–1521, 17]

[Lauber, A.; Nussbaumer, T., 13th ETH-Conference on Combustion Generated Nanoparticles, June 22 – 24 2009, Zurich 2009]

Solid Particulate Matter

Salts

Biomass
+ Char

Soot

Droplets

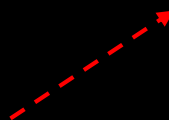
COC

Gas

Gas phase pollutants

VOC

CO



Solid Particulate Matter

Salts

Biomass
+ Char

Soot

Droplets

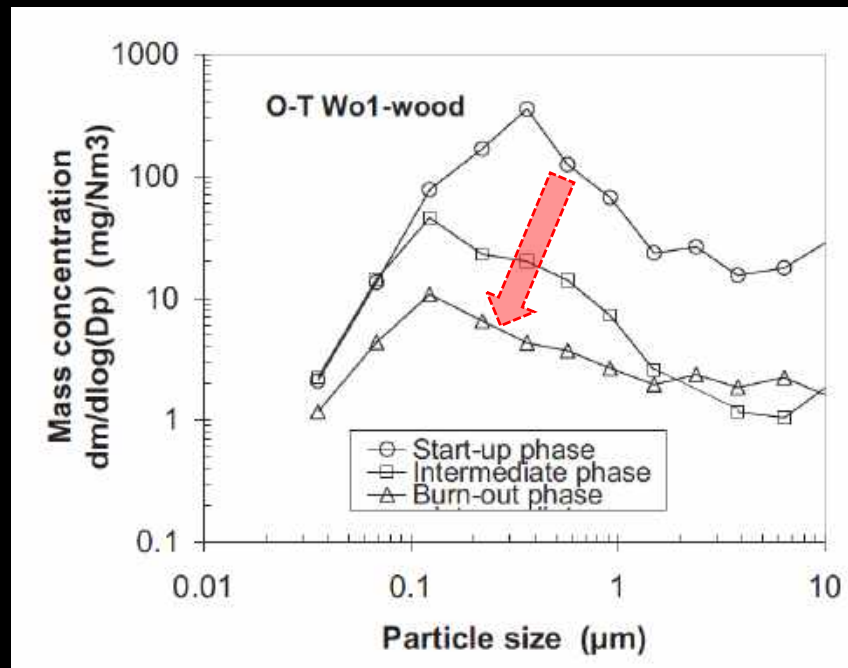
COC

Gas phase pollutants

VOC

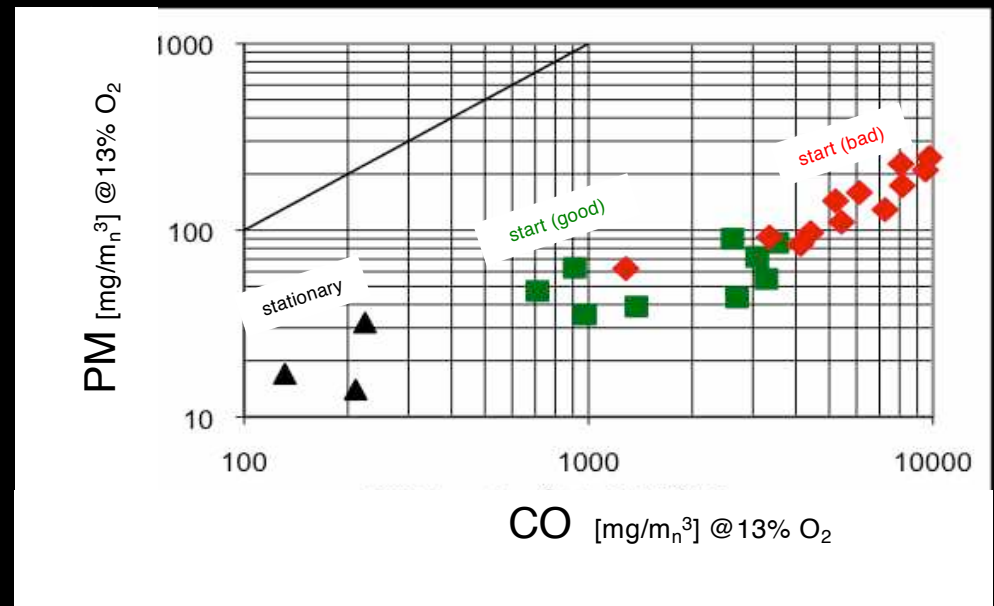
CO

Influence of combustion phase Start-up



[Bäfver, L. et al, Biomass and Bioenergy 35 (2011) 3648–3655]

Influence of operation (log wood boiler)



[Good, J., Obermayr, D., Nussbaumer, T., 11. Holzenergie-Symposium, ETH Zürich 2010]

Solid Particulate Matter

Salts

Biomass
+ Char

Soot

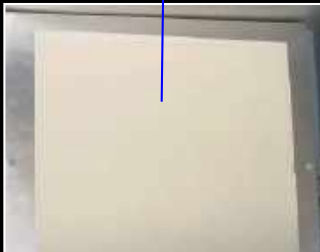
COC

Droplets Gas

Gas phase pollutants

VOC

CO



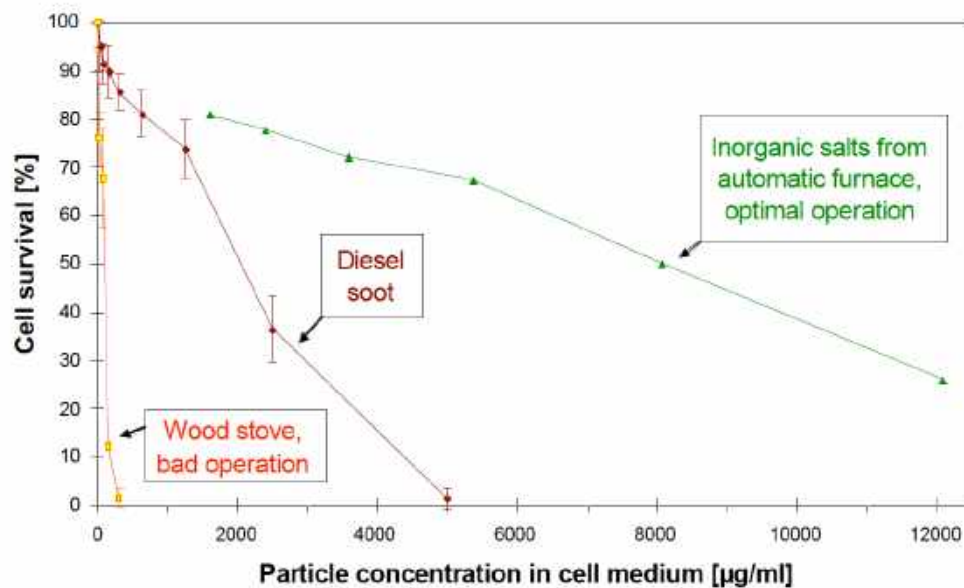
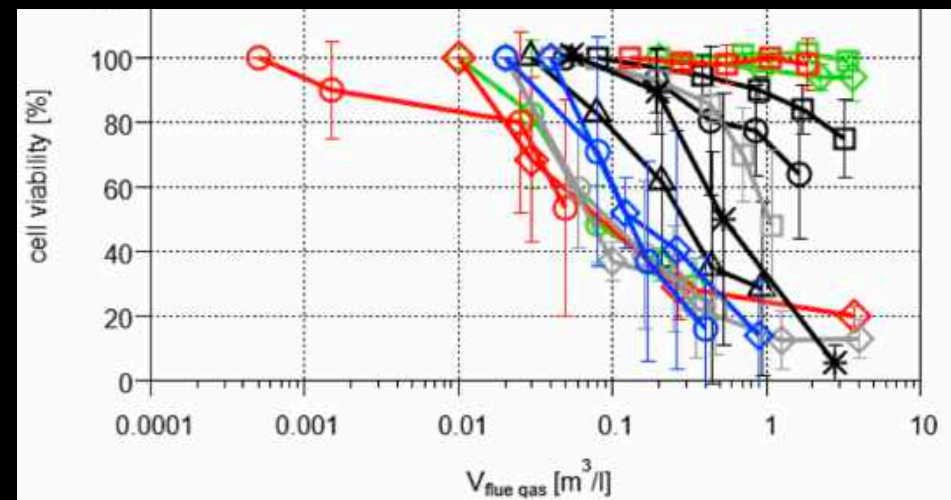
Toxicity

low

medium

high

Influence of operation and technology



[P. Zotter et al., Environ. Sci. Technol., 2019
Apr 2; 53(7): 3959-3968]

[Klippel, N.; Nussbaumer, T., 15th Eur. Biomass Conf., Berlin 2007]

Solid Particulate Matter

Salts

Biomass
+ Char

Soot

Droplets

COC

Gas

Gas phase p

VOC

CO

+ suited for ESP

- critical for filter and catalysts
- not by removed by burning

- C causes fire risks
- COC clogging of filter back-corona in ESP
- soot re-entrainment in ESP
- C causes critical residues

+ suited for catalysts

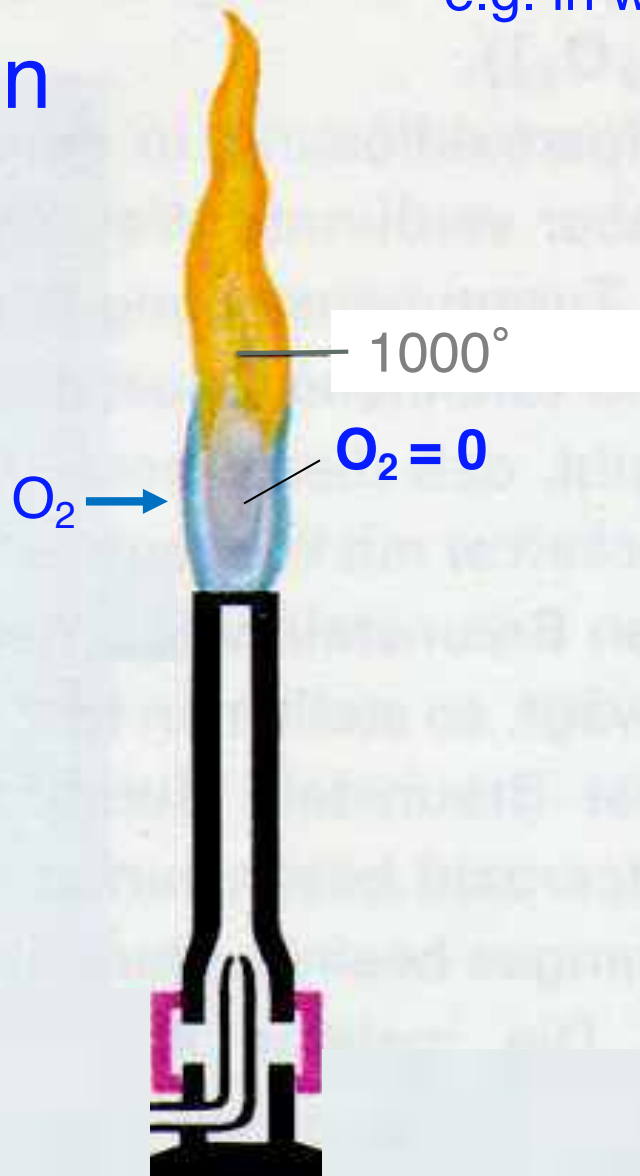
- unsuited for filtration

1. Intro
2. Pollutant formation
3. Measures for resid. wood combustion (RWC)
 - 3.1 Primary measures

Measure 1

e.g. in wood stoves

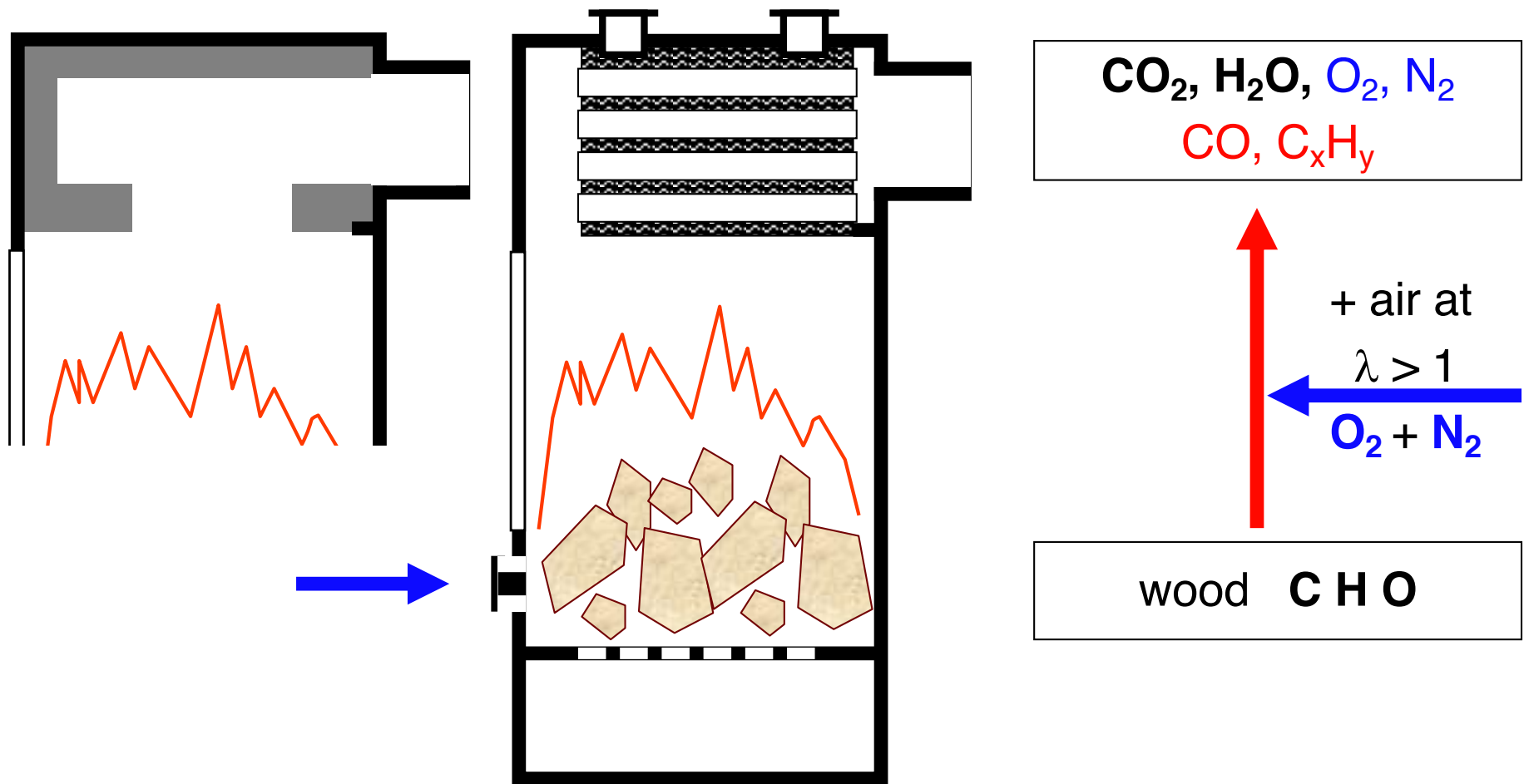
Diffusion flame



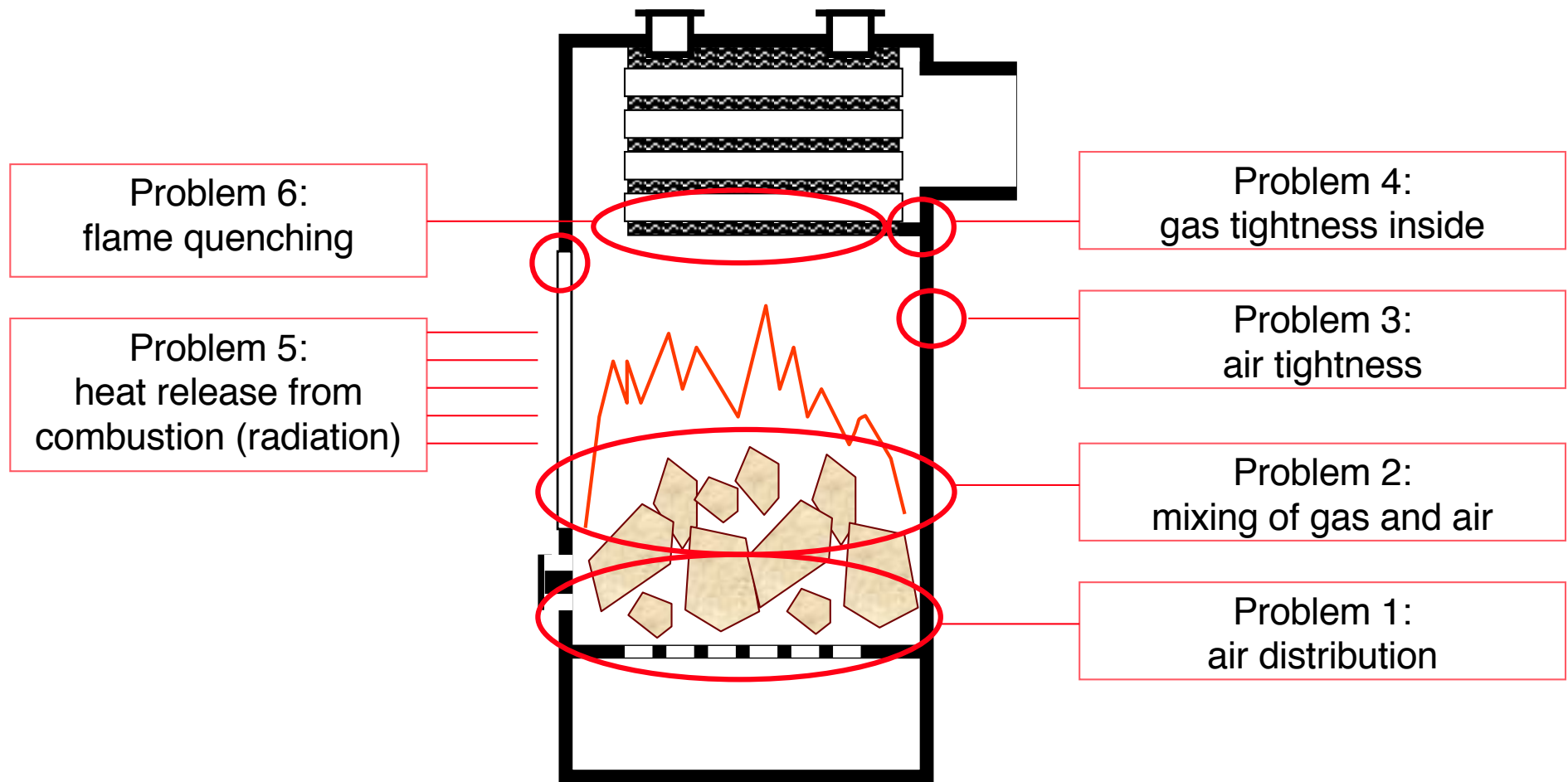
[H.R. Christen, Allgemeine Chemie, 1971]



1-stage combustion

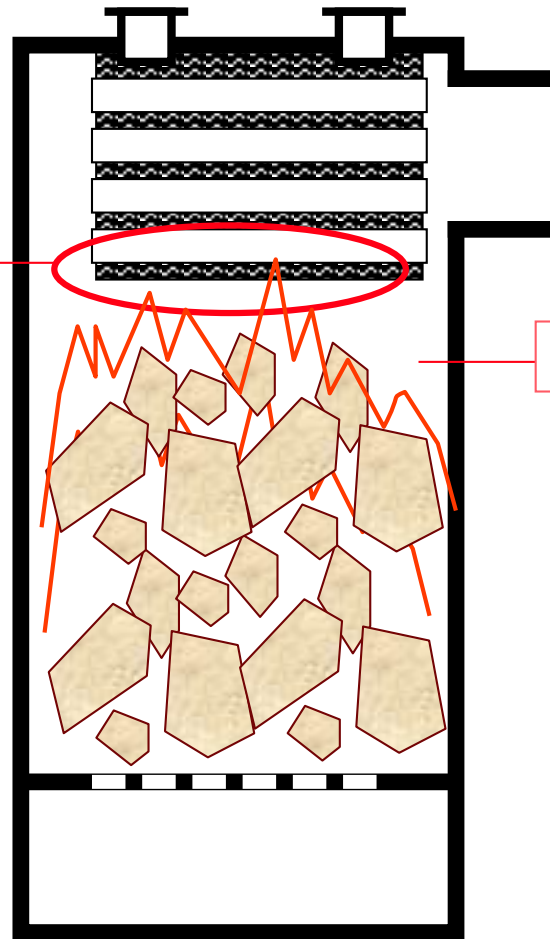


Limitations



Limitations

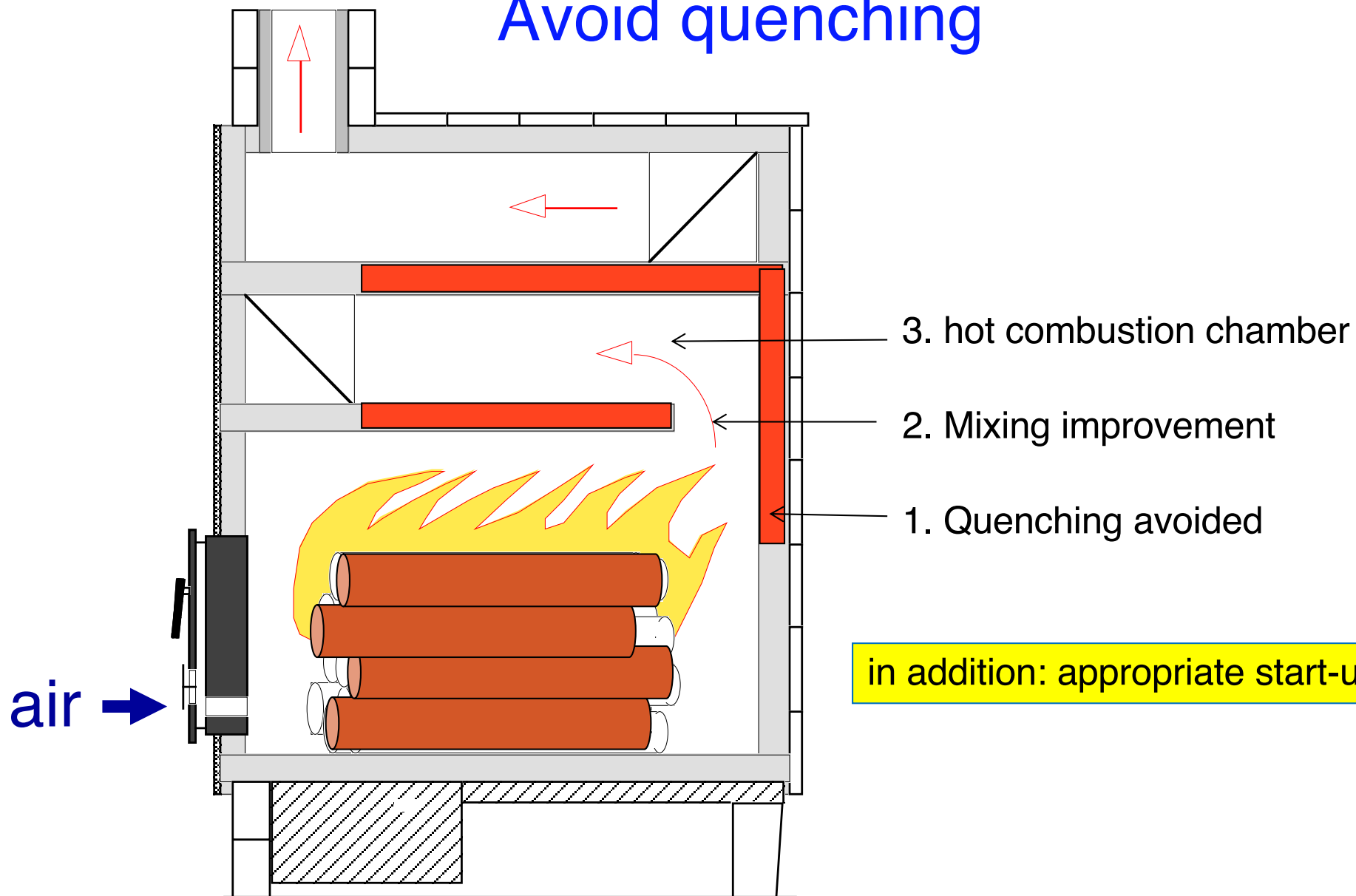
Problem 6:
flame quenching



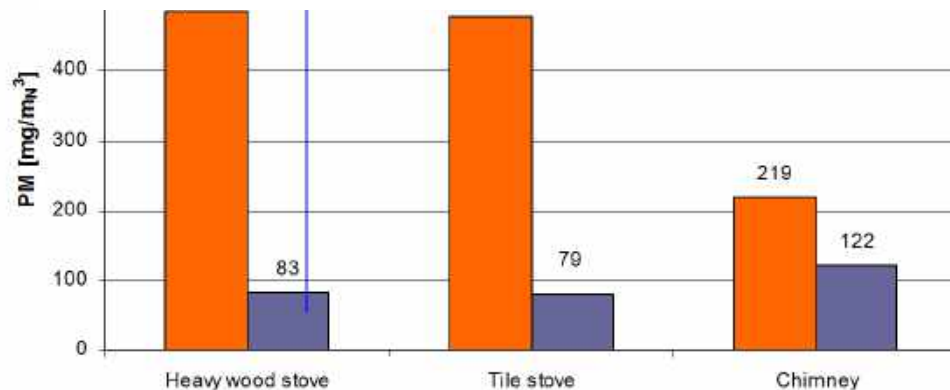
Overfilling can cause quenching



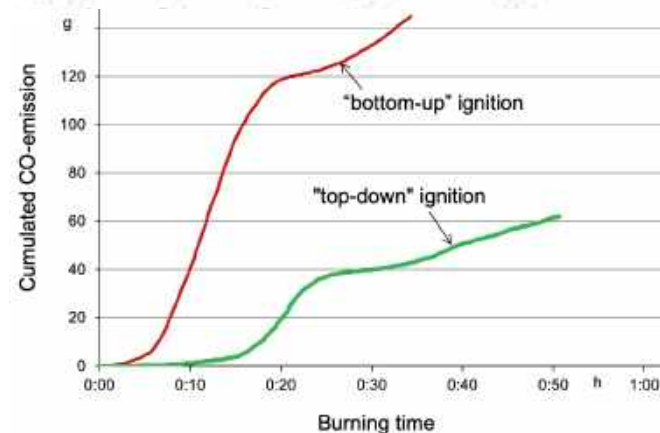
Avoid quenching



Appropriate start-up: technology dependent,
e.g. for updraft as a rule: ignition from the top



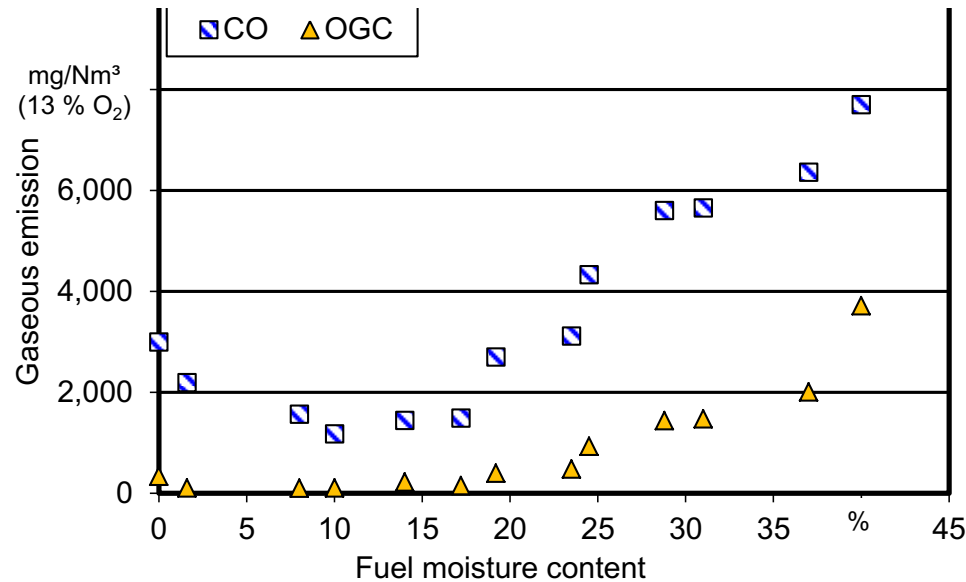
[T. Nussbaumer et al., EU Biomass Conference 2008]



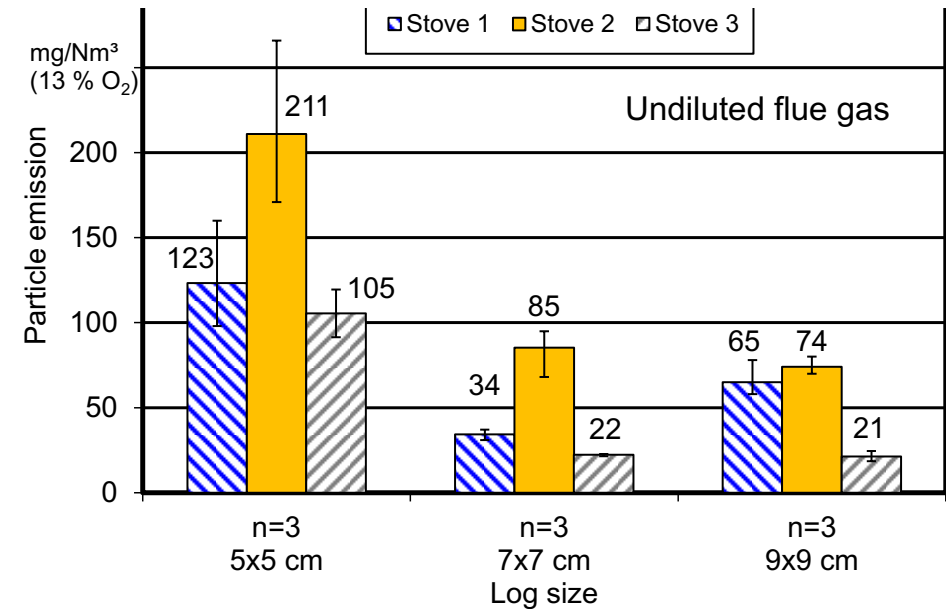
[H. Hartmann, 20th ETH-Conf. on Nanop., Zürich, 2016]

Appropriate fuel: technology dependent

Moisture content



Log size



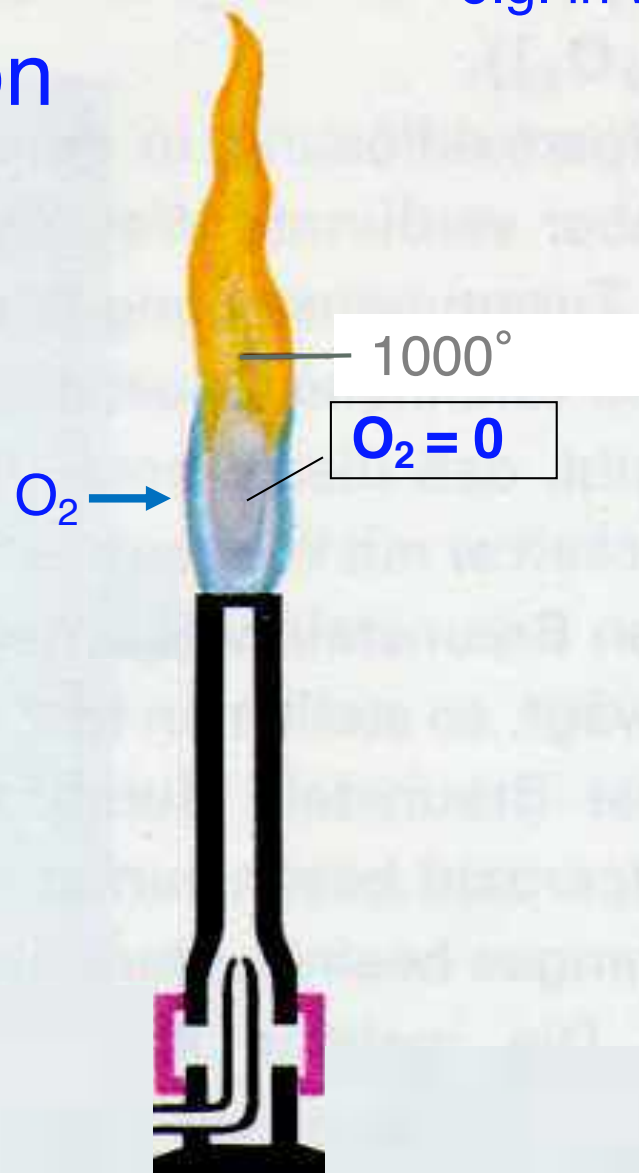
[H. Hartmann, 20th ETH-Conf. on Comb. Gen. Nanoparticles, Zürich, 2016 and TFZ-Bericht 36, www.tfz.bayern.de]

New results on user influence in:
Robert Mack et al. TFZ: presentation 3 in this session

Measure 2

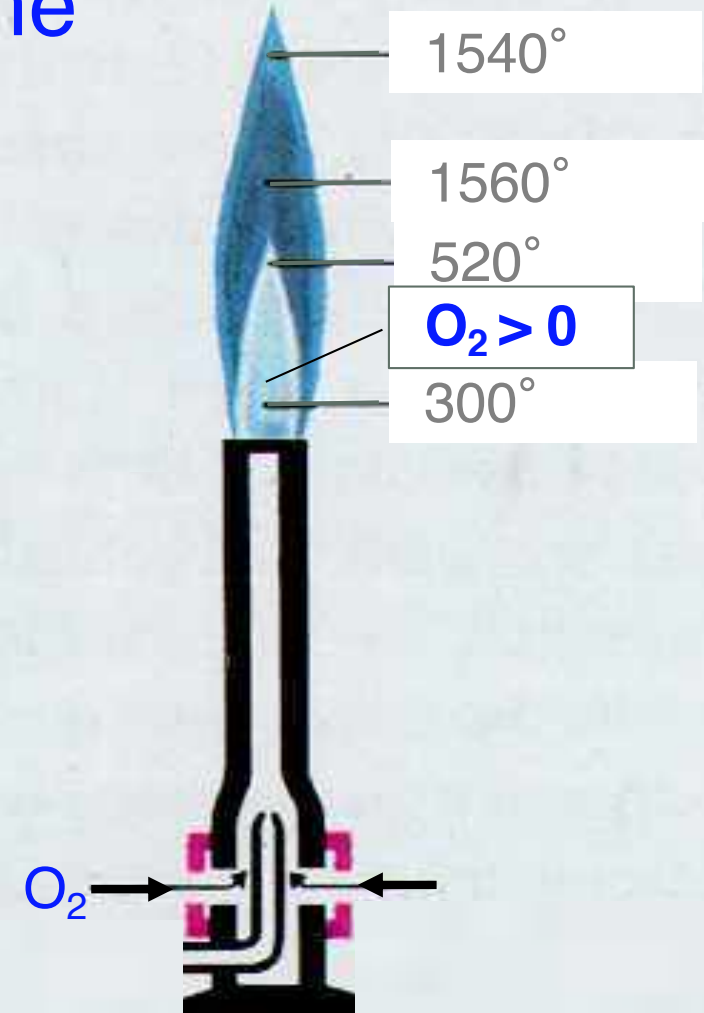
e.g. in wood boiler

Diffusion flame



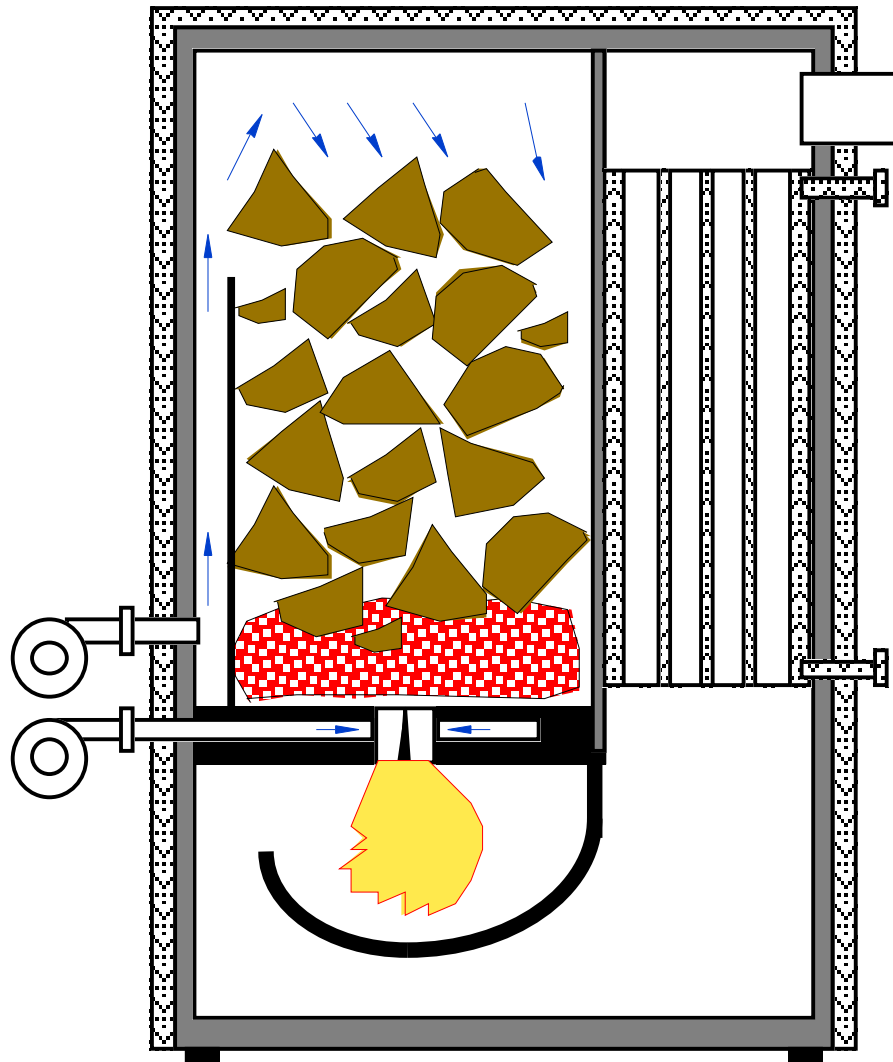
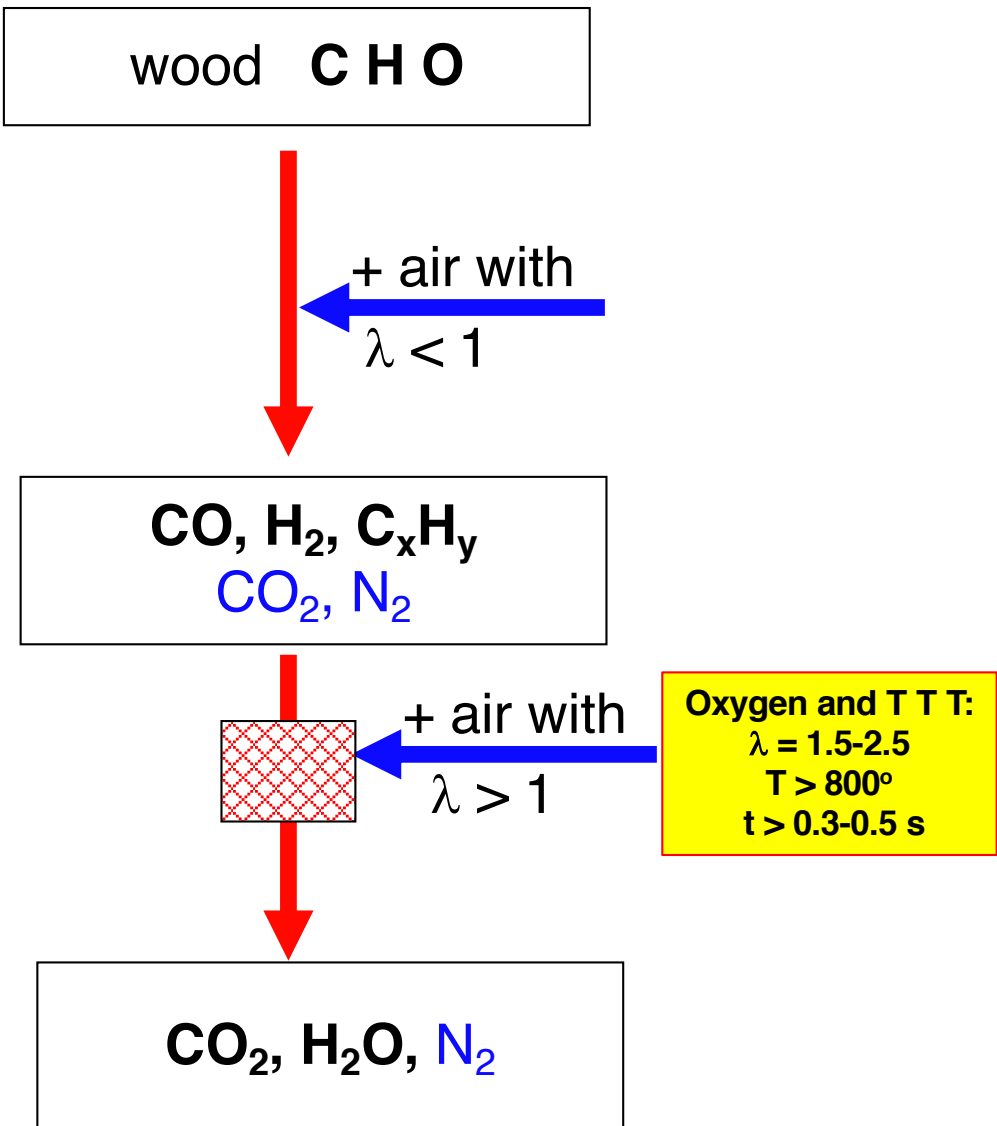
[H.R. Christen, Allgemeine Chemie, 1971]

Premixed flame



[H.R. Christen, Allgemeine Chemie, 1971]

2-stage combustion: principle in downdraft boiler



2-stage combustion: examples in stoves

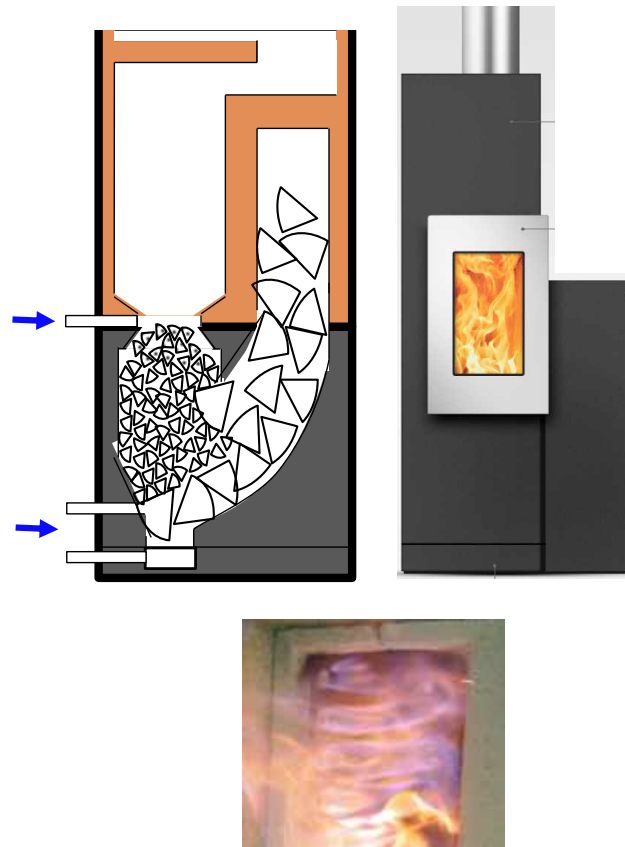
Bionic Fire



Specht TwinFire Xeoos <http://www.specht-ofen.de>

[W. Wiest., 13. Holzenergie-Symposium, Zürich 2014]

Tiba (Sirius)



Tiba AG & Hochschule Luzern 2012

[T. Nussbaumer & P. Odermatt, TGA 5 2013, 54–58]

Attika (Juna)



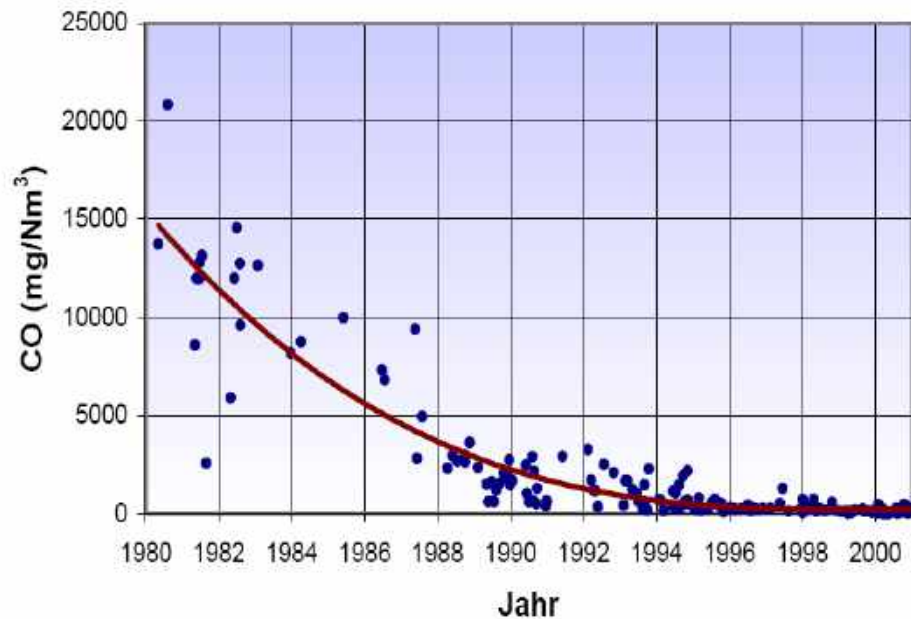
<https://attika.ch/>

Zotter et al. 2017, 21st ETH Conf.
on Comb. gen. Nanoparticles

Improvements since 1975/80

Boilers

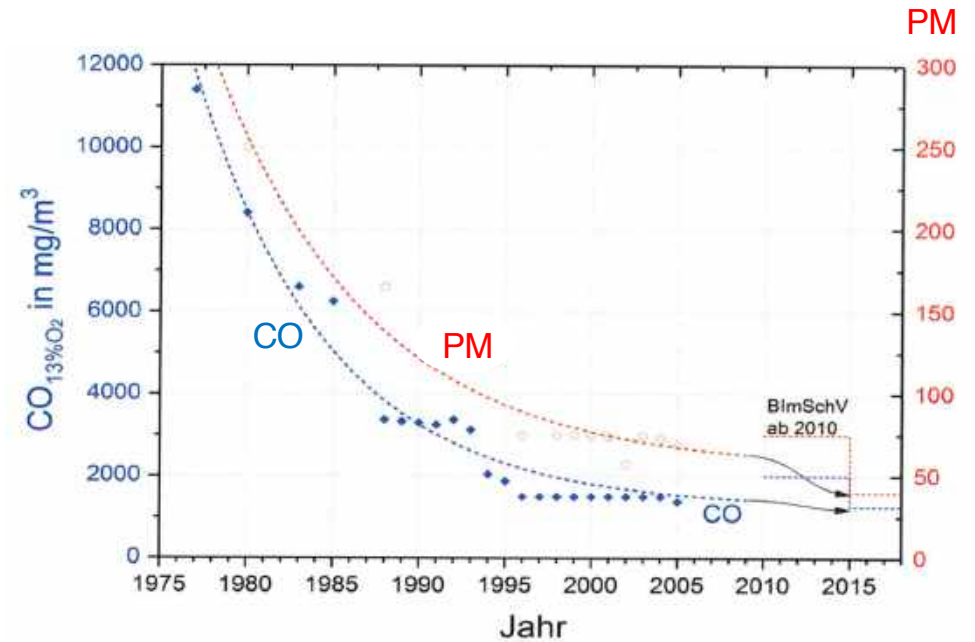
[BLT, AUT]



[L. Lasselsberger, BLT Wieselburg (A) 2016]]

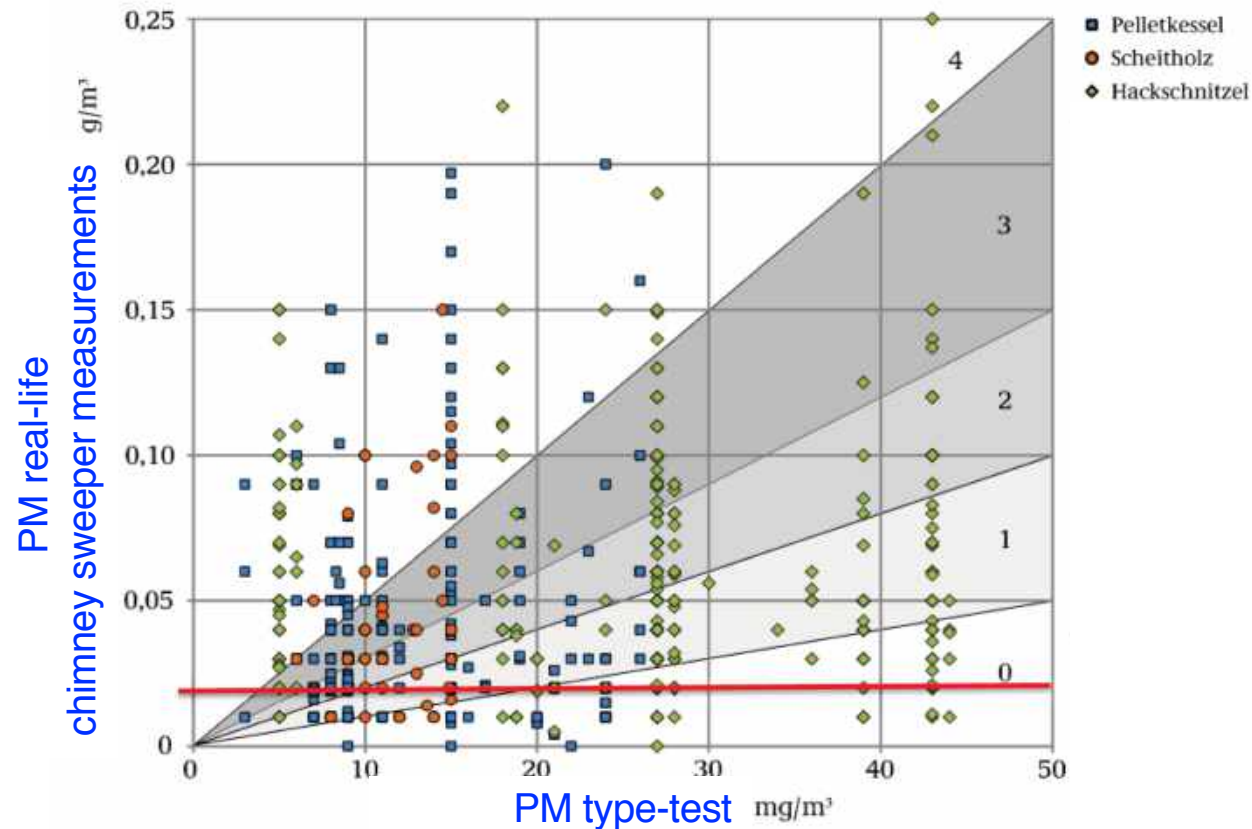
Stoves

[HKI, GER]



[V. Schmatloch, Kachelofen&Kamin, Januar 2018]

„Gap“ between type-test and reality



Conclusion: „no correlation“

approach

„Gap“ between type-test and reality



bioenergy2020+



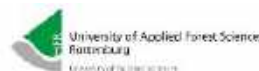
DANISH
TECHNOLOGICAL
INSTITUTE



FFG



NIBE



hwam
intelligent heat

Verenum

[C. Schmidl et al., «Be Real»
14. Holzenergie-Symposium, Zürich 2016]

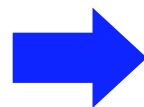
HOCHSCHULE
LUZERN

1. Intro

2. Pollutant formation

3. Measures

3.1



3.2 Secondary measures

Catalysts



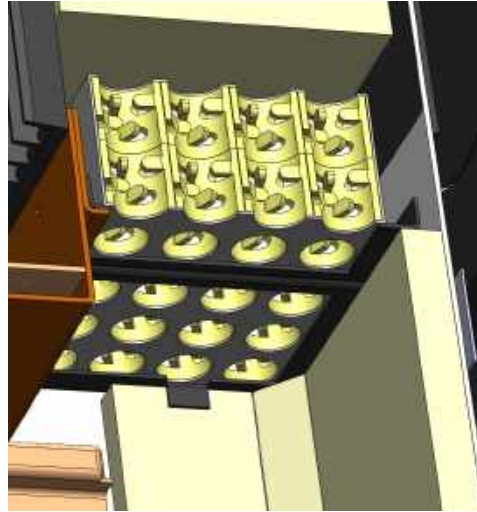
Reduction

CO > 70%
VOC > 40%

PM 30% - 40%

[G. Reichert et al., Bioenergy 2020+,
13. Holzenergie-Symp., Zürich 2014]

Inserts

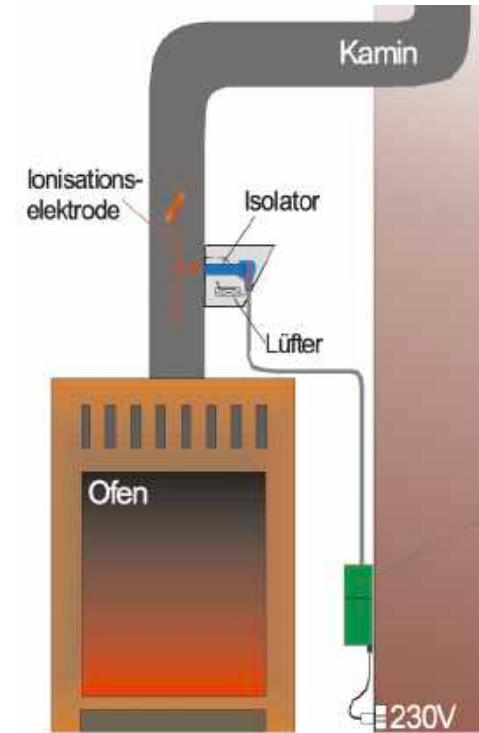


CO > 70%
VOC > 70%

oxidizable PM

[M. Aleysa, Fraunhofer IBP Stuttg.,
15. Holzenergie-Symp., 2018]

Electrostatic Precipitators (ESP)



[V. Schmatloch, EMPA
Dübendorf, 2004]

PM 60% - 80%



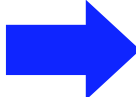
[Oekosolve
2019]

Catalysts	Inserts	Electrostatic Precipitators (ESP)
Pressure drop		Temperature control needed
Aging		Soot causes re-entrainment
Limited effect during cold start		Limited availability
Periodic cleaning needed		

1. Intro

2. Pollutant formation

3. Measures

 4. Consequences for low emissions

Requirements for low emissions

1. Appropriate **ignition and start-up**
2. Appropriate **fuel** (moisture, size, ash) and fuel amount
3. Technology with **2-stage combustion**, secondary air and hot comb. chamb.:
 $\lambda = 1.5-2.5$, $T > 800^\circ$, $t > 0.3-0.5$ s
Options:
 - forced draft with **ventilator**
 - inserts for mixing and/or catalytic effect
 - **combustion control**
4. Optional secondary measure: ESP with monitoring
5. For boilers: heat storage tank

Remaining challenges:

- cold start
- ambient conditions, mostly for natural draft
- operator influence

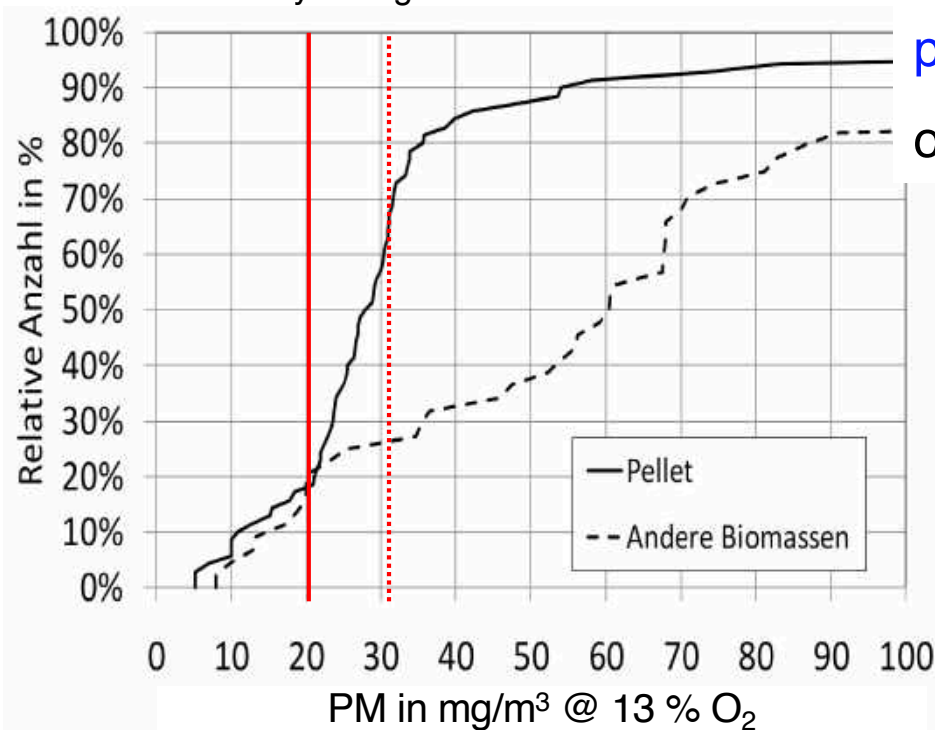
Requirements for low emissions
are valid for all combustion types
but:

- for **automatic** combustion safely applicable
(in small scale for wood pellets)

- for **manual devices** highly challenging
most importantly in real-life

PM emissions in small scale in **real-life** conditions

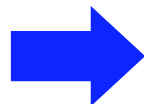
limit for boilers **20** mg/m³
with uncertainty **31** mg/m³:



pellet boilers: 64% meet emission limit

other boilers: 25% meet; **75% exceed**

1. Intro
2. Pollutant formation
3. Measures
4. Consequences

 5. Conclusions

1. RWC contributes to PM and OC and need to be reduced
2. Primary measures are:
 - combustion design
 - ideal start-up and fuel
 - ideal operation with appropriate air supply and high temperature
3. The technology has been improved by:
 - thermal insulation, air tightness, secondary air and hot combustion ch.
 - modern devices achieve low emissions on test-bench
4. Secondary measures can further reduce emissions,
but cannot replace primary measures
5. Main reason for high impact of RWC is the
«gap» between test-bench results and non-ideal operation in real life
6. Control systems and monitoring can assist to improve real-life operation
7. Information und inspections remain necessary



Acknowledgements

Swiss Federal Office of Energie

Swiss Federal Office for the Environment

Swiss National Research Foundation

Innosuisse and SCCER Biosweet

IEA Bioenergy Task 32

Info

www.verenum.ch

www.hslu.ch

www.holzenergie-symposium.ch