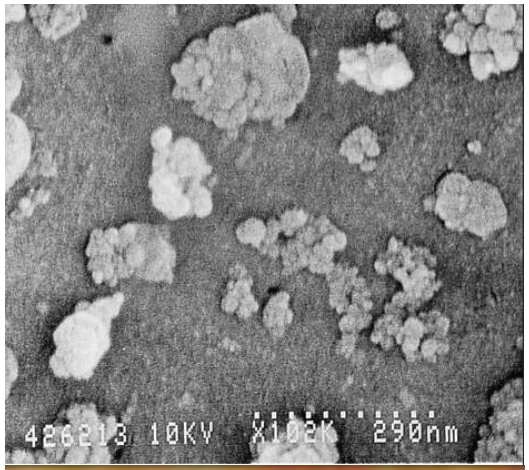

Introduction to biomass combustion and pollutant reduction in wood stoves and boilers

Prof. Dr. Thomas Nussbaumer

Verenum Research, Zürich
Lucerne University of Applied Sciences and Arts, Horw
Swiss Federal Office of Energy, Delegate in IEA Task 32

Switzerland

IEA Webinar 06 May 2021

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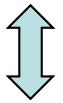
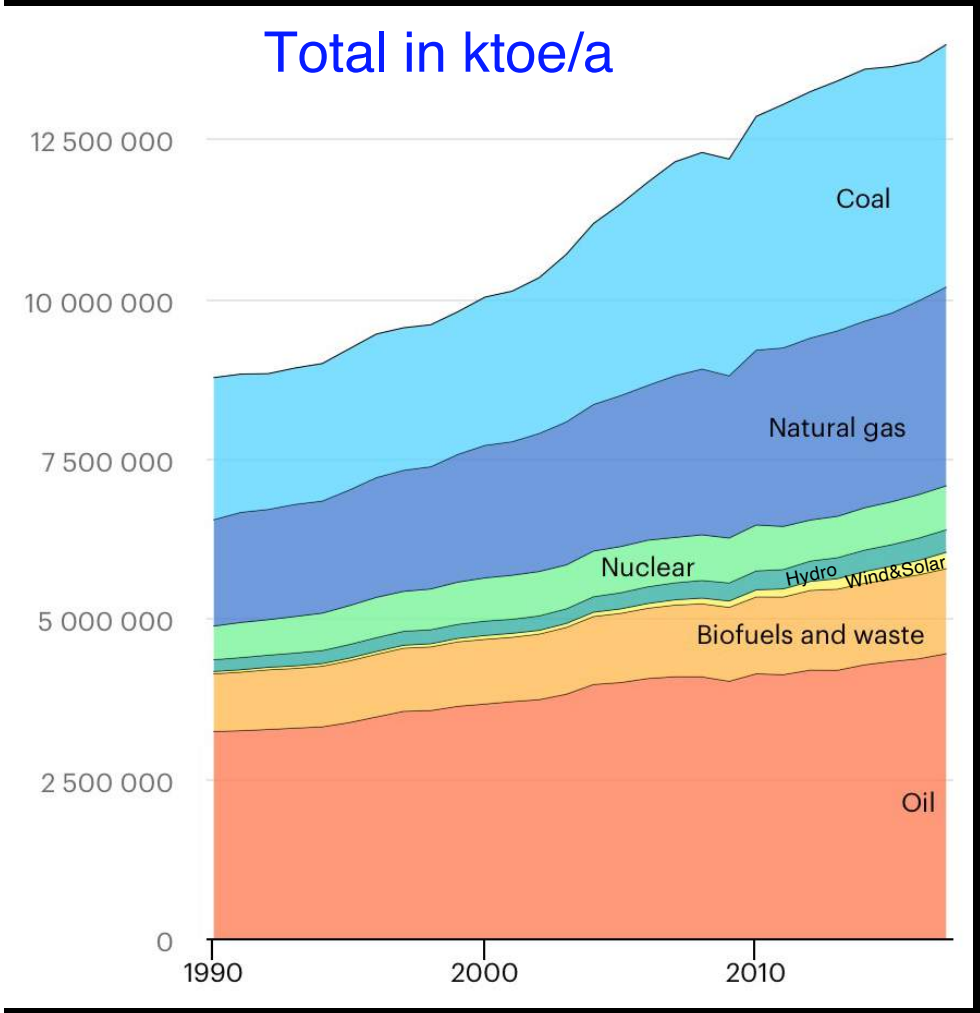
1. Intro: The role of bioenergy for

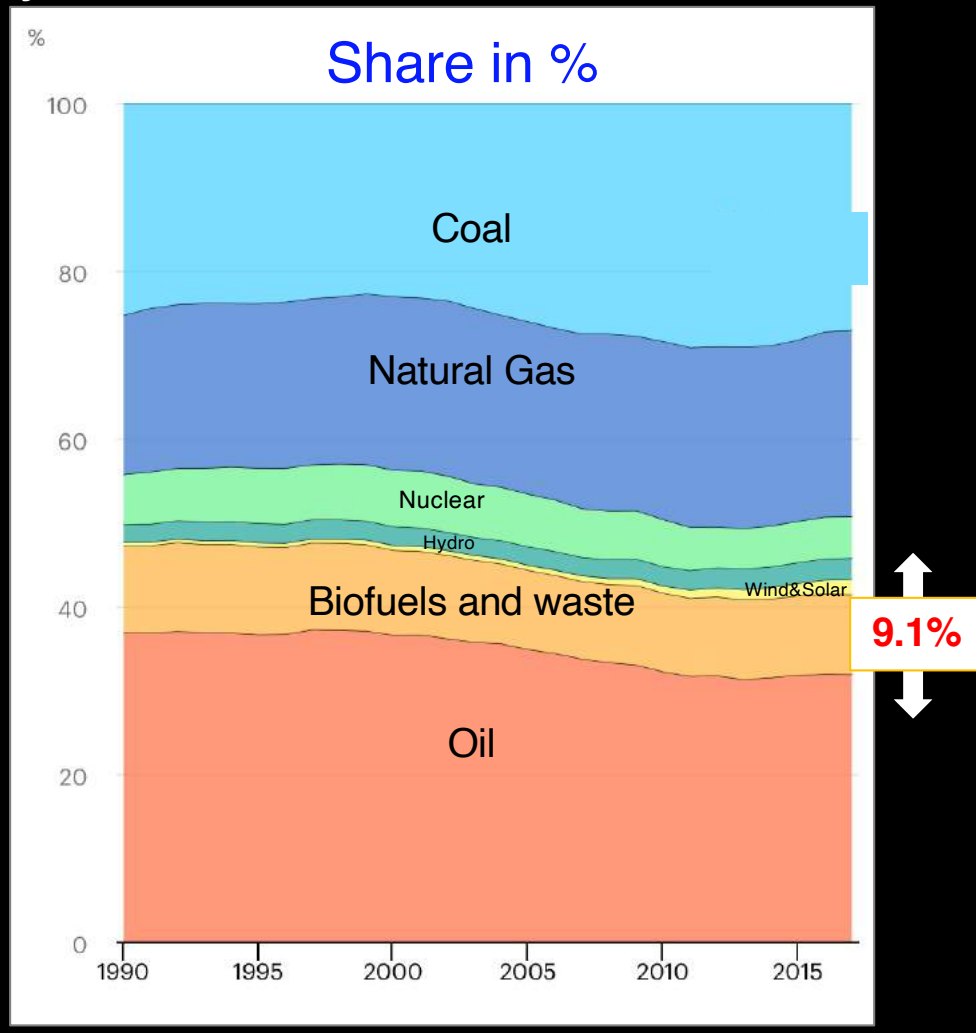
a) Energy Supply / Climate Change



b) Air Pollution

World energy supply 1990 to 2017

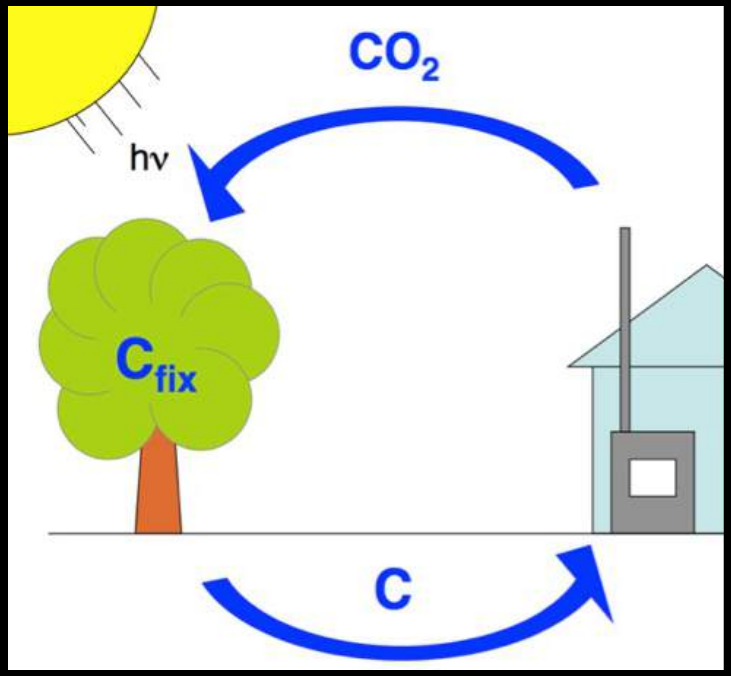




https://www.iea.org/data-and-statistics 20.1.20

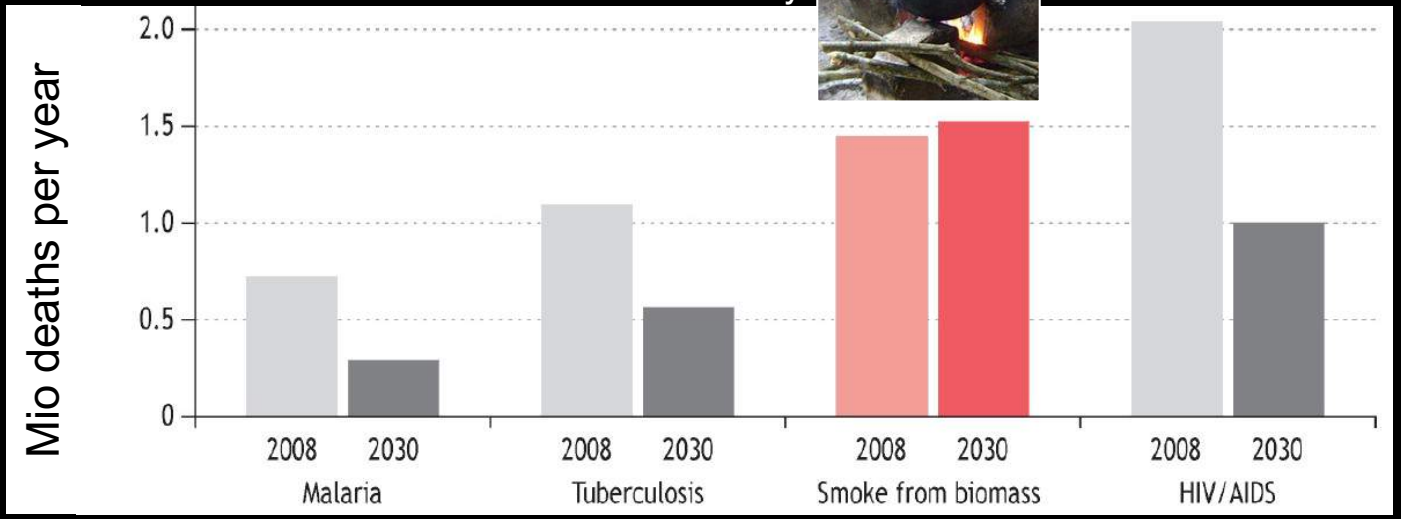
Facts or hypotheses

1. Solar energy has largest potential but causes need for energy storage
2. Wood from sustainable forestry is renewable and net CO_2 free (and easily storable) and can ideally complement solar energy as storable fuel



Target conflict

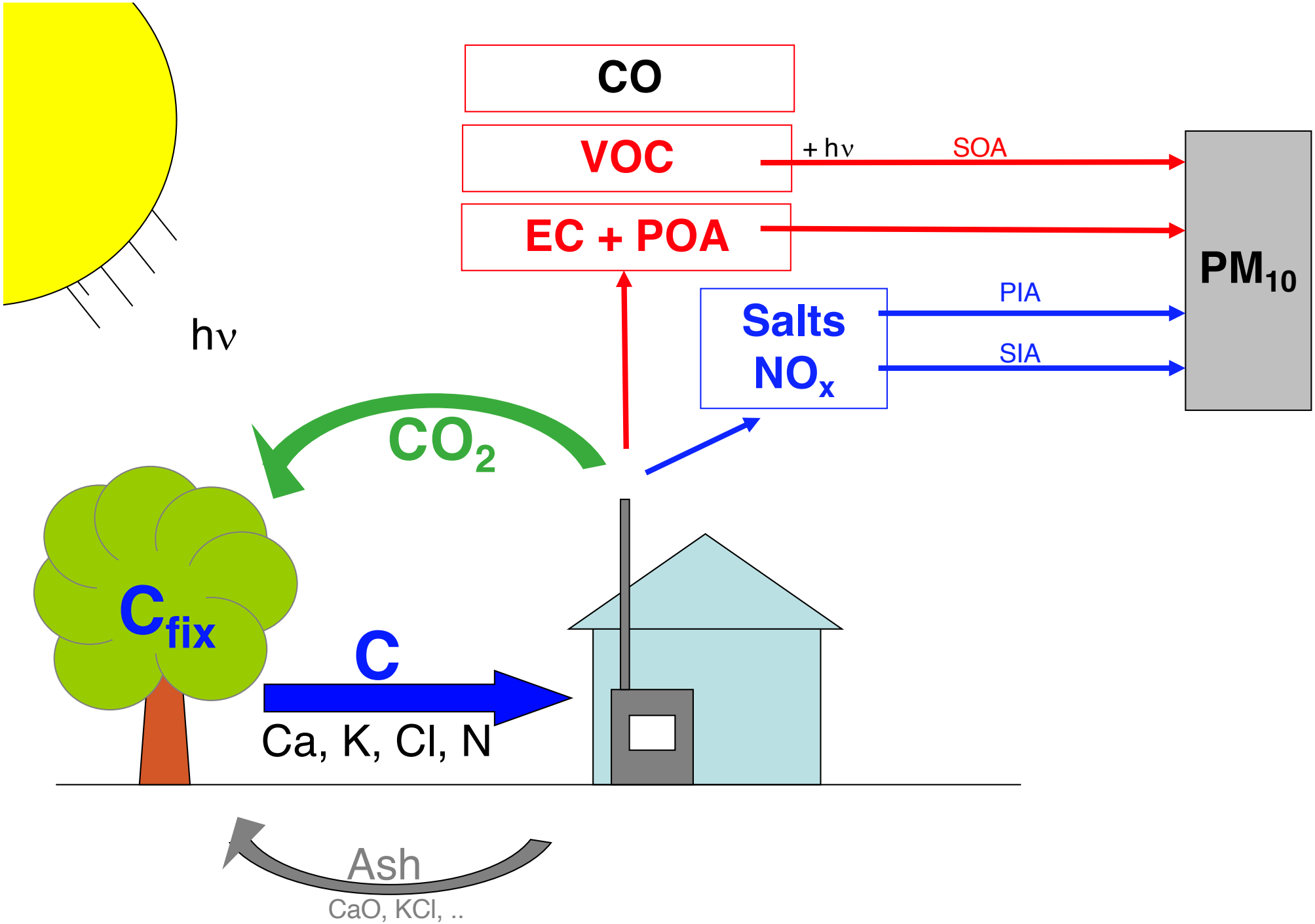
Global effect of smoke from biomass on mortality



[OECD/IEA: Energy Poverty, IEA, Paris 2010]

1. Intro

2. Pollutant formation with focus on Particulate Matter (PM) and Organic Compounds (OC)



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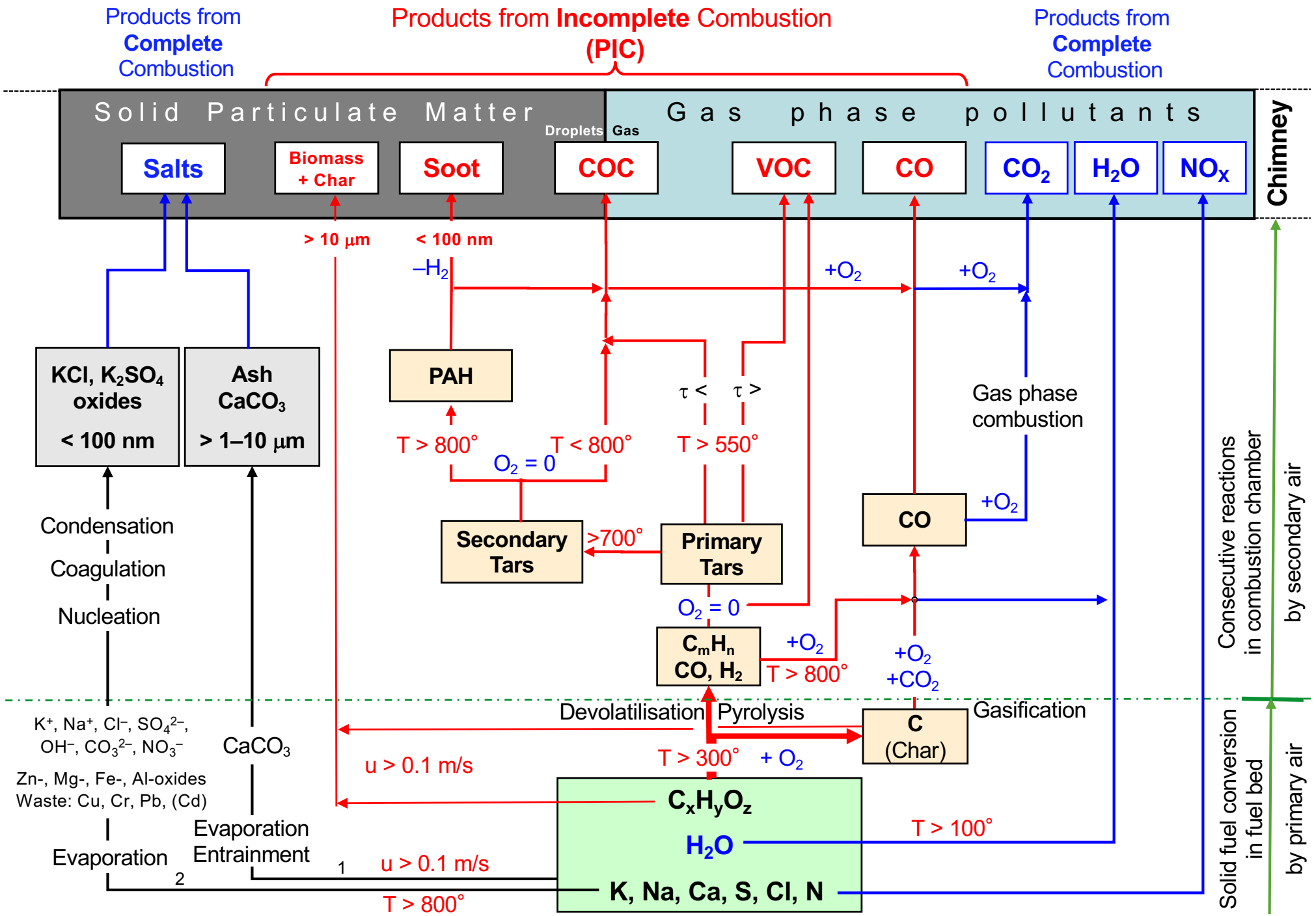
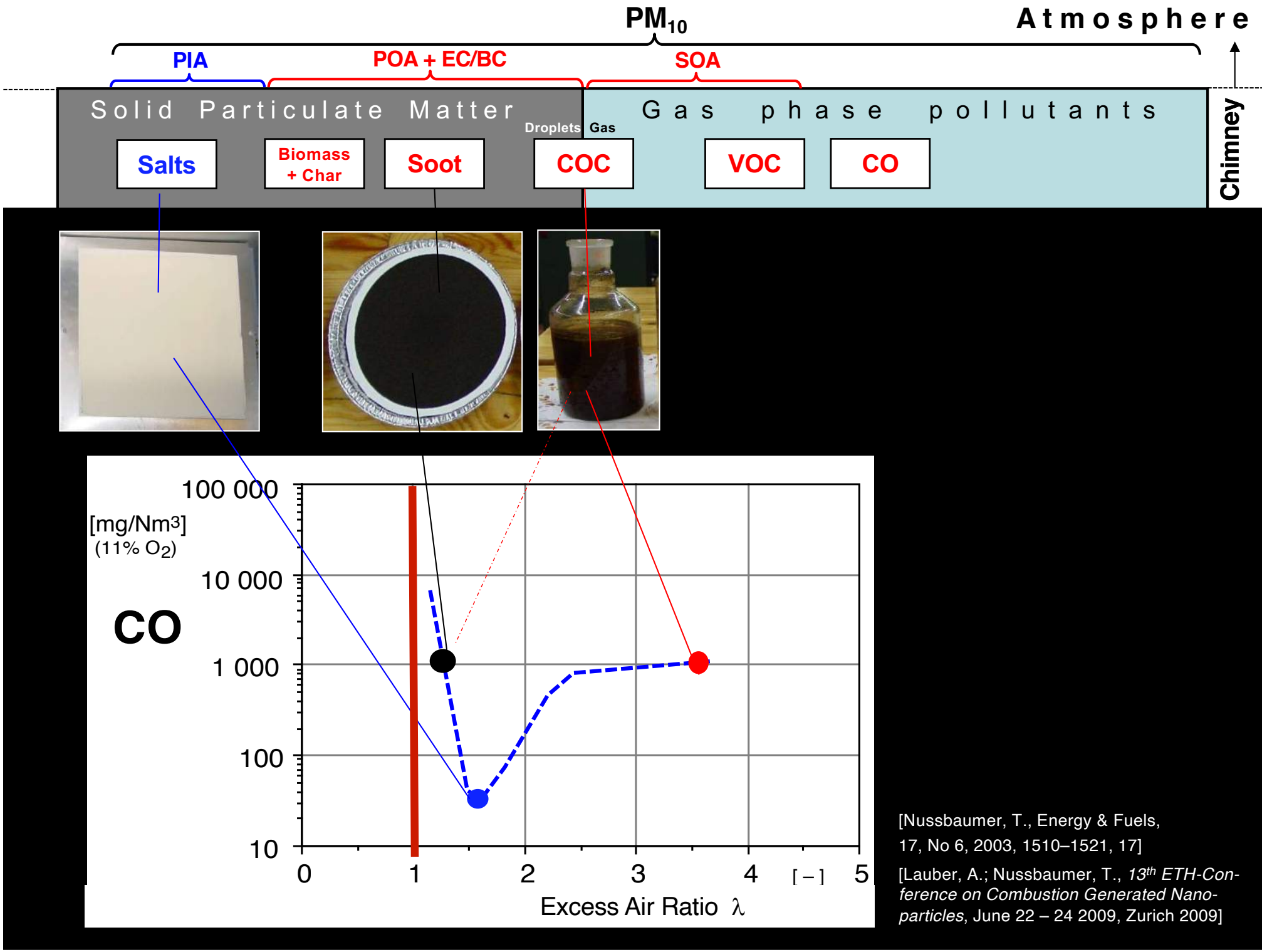


u Gas velocity, τ Residence time, </> short/long
1 Solid-particle-path, 2 Solid-vapour-particle-path

COC: Condensable Organic Compounds
VOC: Volatile Organic Compounds

T: [Evans and Milne, 1987], H_2: [Jess, 1996]



[Nussbaumer, T., Energy & Fuels, 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

Gas phase pollutants

Droplets

Gas

Salts

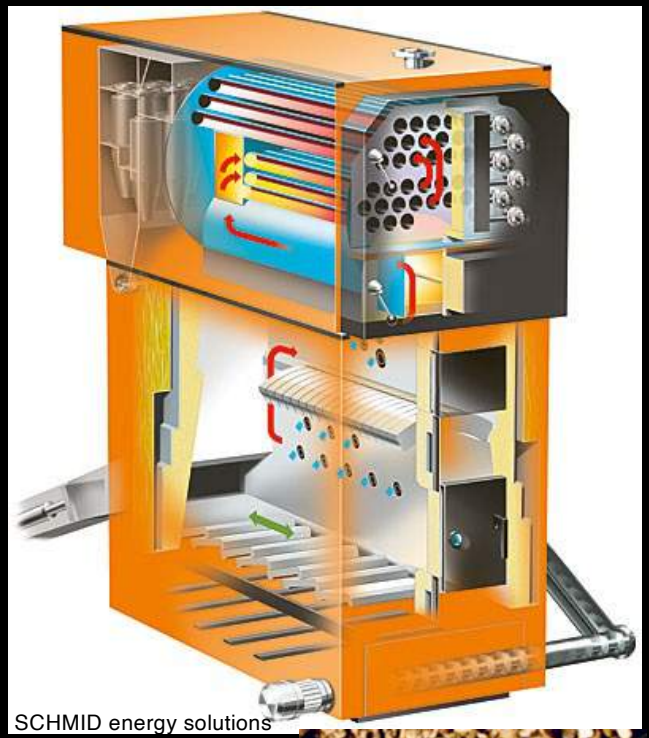
Biomass + Char

Soot

COC

VOC

CO



SCHMID energy solutions

Solid Particulate Matter

Droplets

Salts

Biomass + Char

Soot

COC

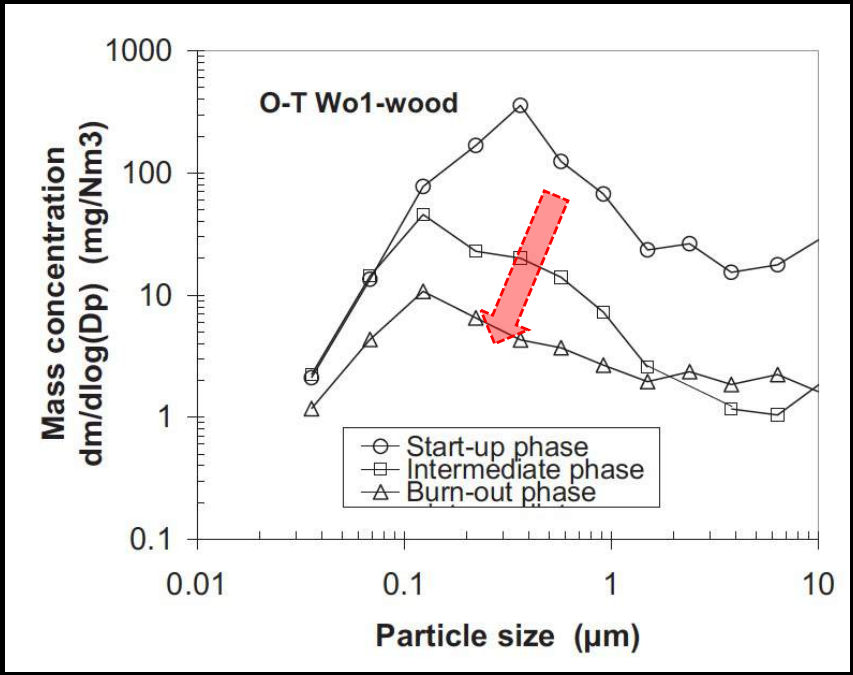
Gas

Gas phase pollutants

VOC

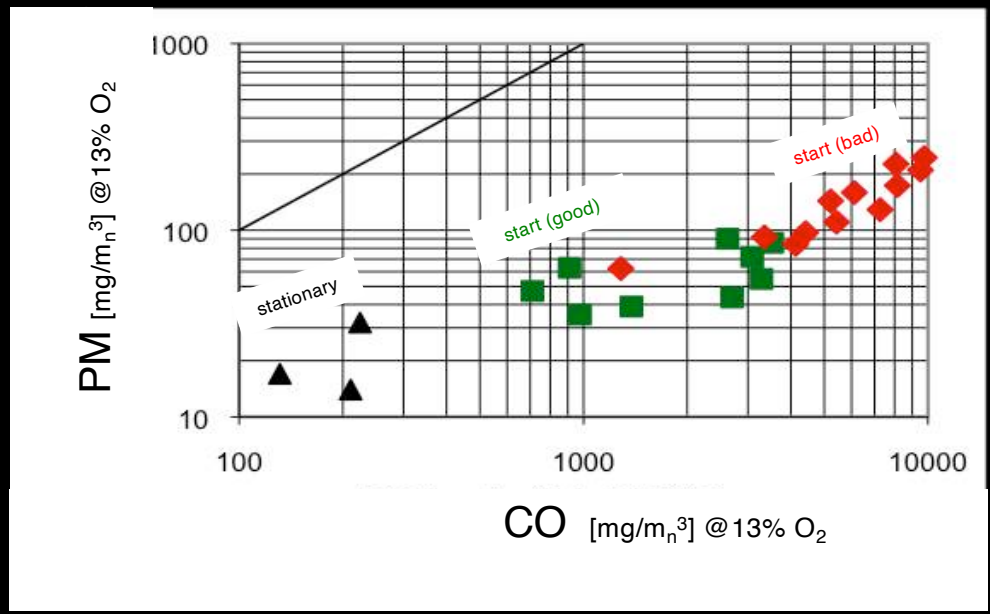
CO

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

Gas phase pollutants

Droplets

Gas

Salts

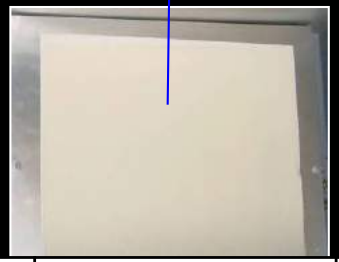
Biomass + Char

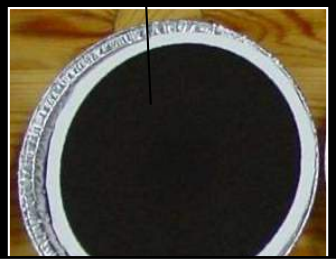
Soot

COC

VOC

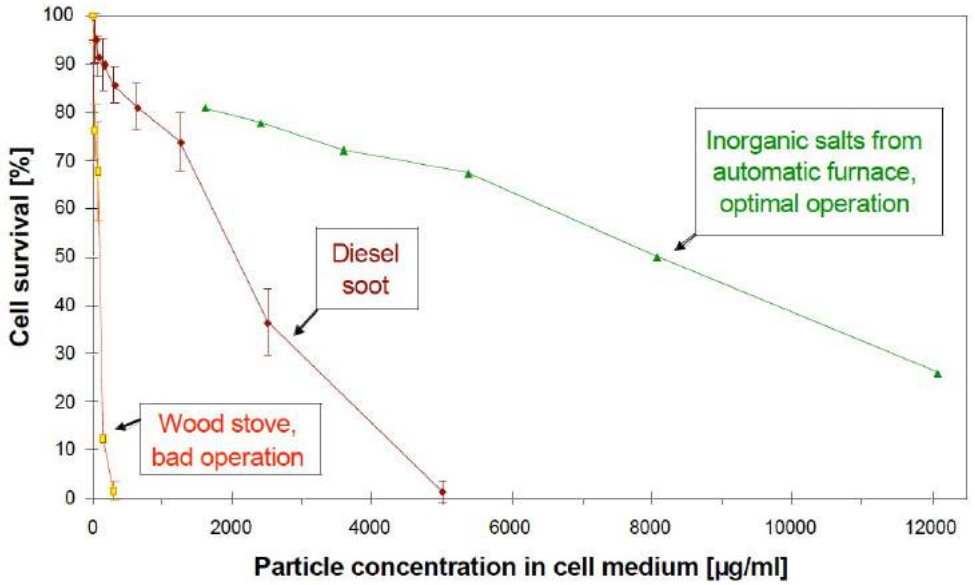
CO



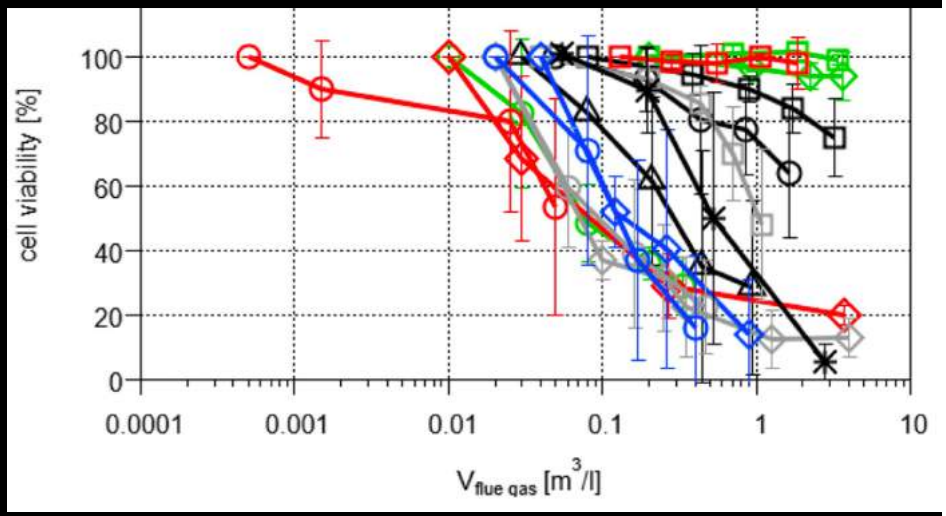


Toxicity	low	medium	**h i g h**

Influence of operation ... and technology



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



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

1. Intro

2. Pollutant formation

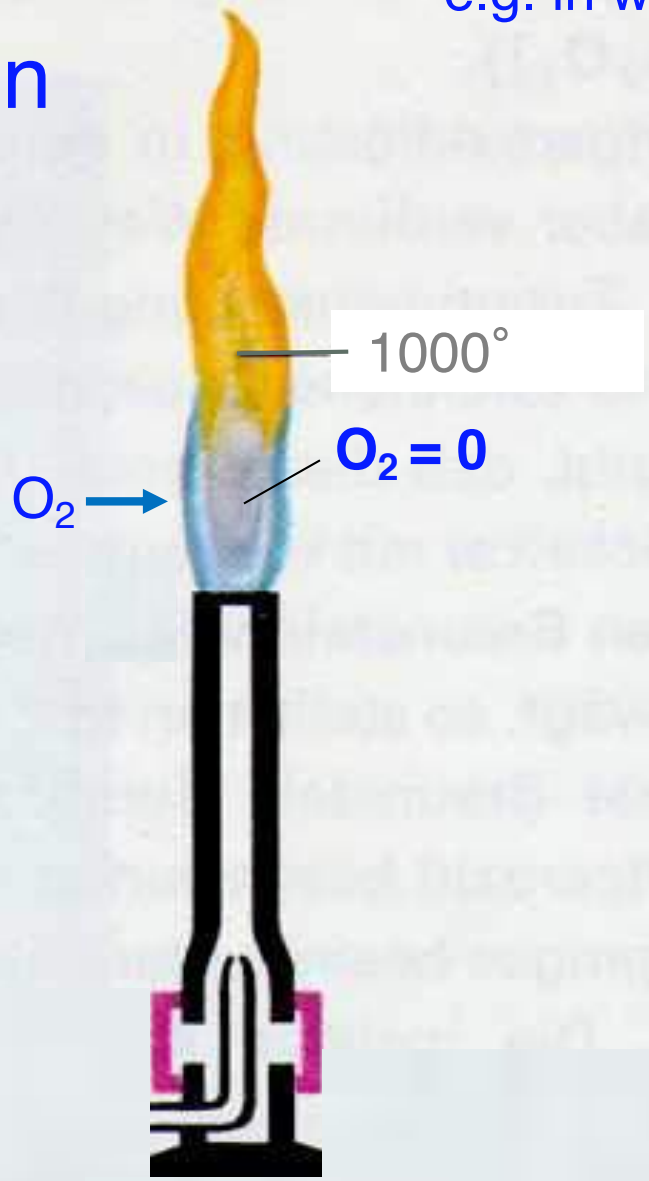
3. Measures for resid. wood combustion (RWC)

   3.1 Primary measures

Measure 1

e.g. in wood stoves

Diffusion flame



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

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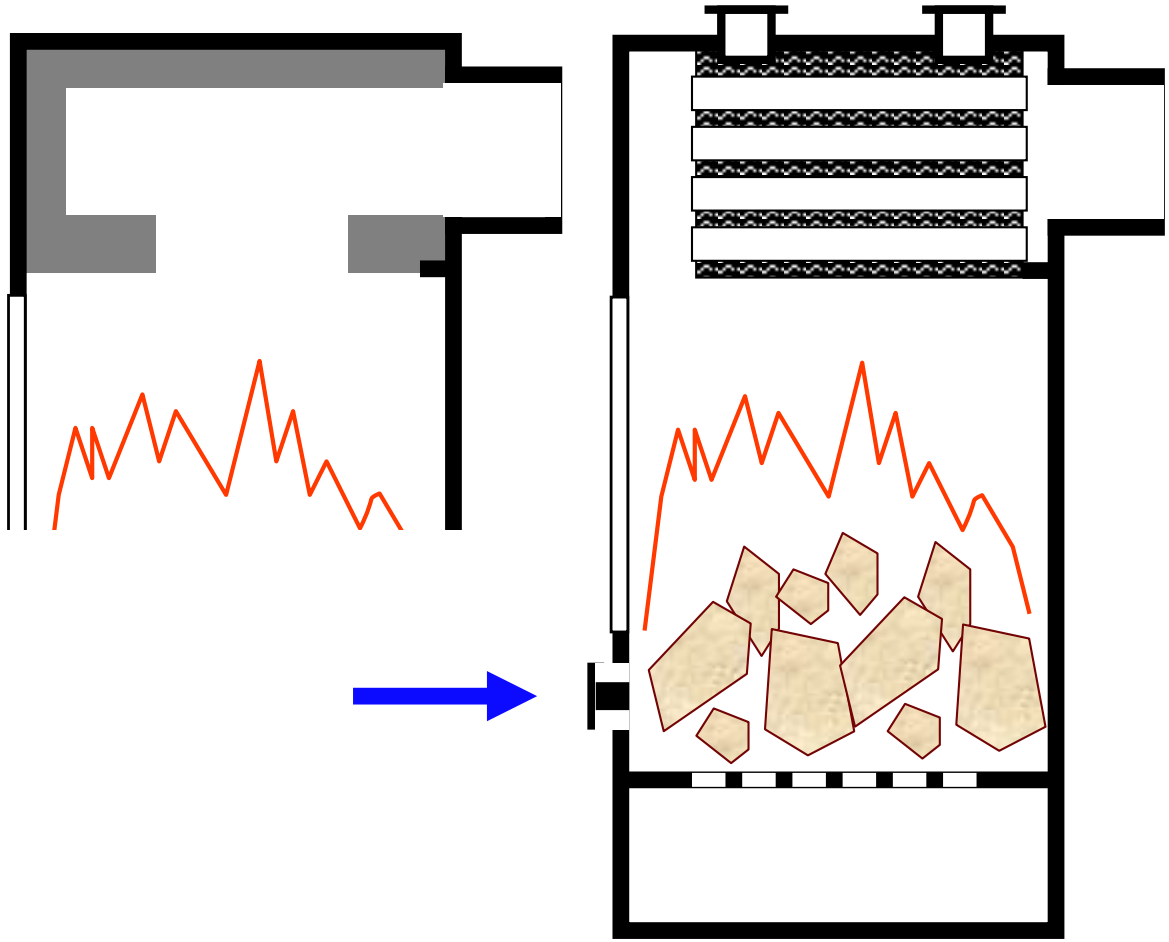
1-stage combustion



CO_2, H_2O, O_2, N_2

CO, C_xH_y

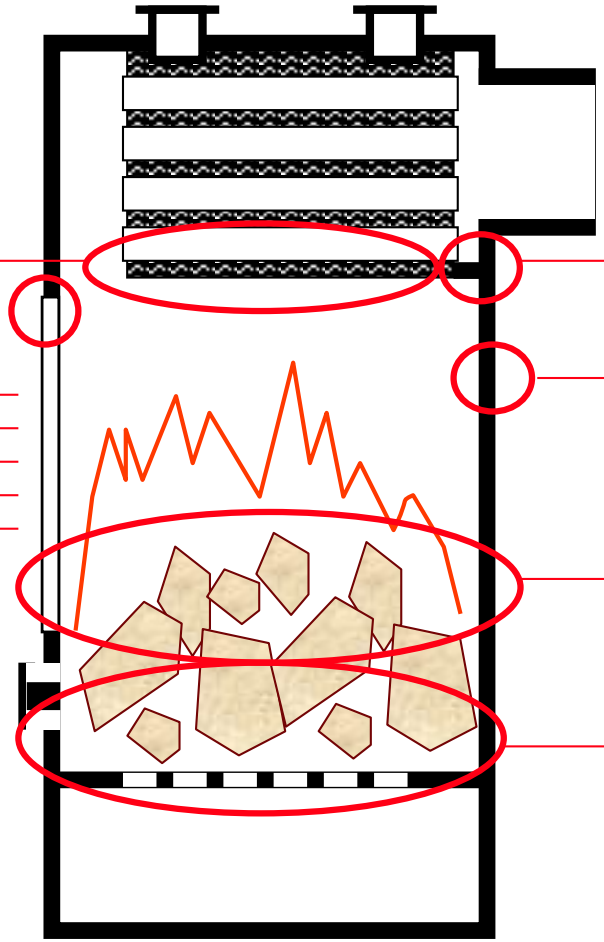
+ air at

$\lambda > 1$

$O_2 + N_2$

wood **C H O**

Limitations



Problem 6:
flame quenching

Problem 5:
heat release from
combustion (radiation)

Problem 4:
gas tightness inside

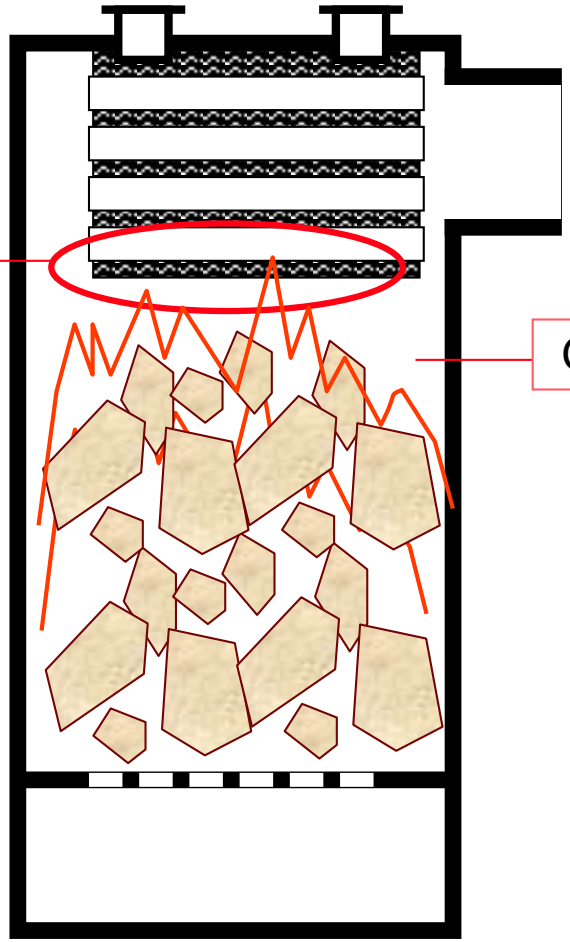
Problem 3:
air tightness

Problem 2:
mixing of gas and air

Problem 1:
air distribution

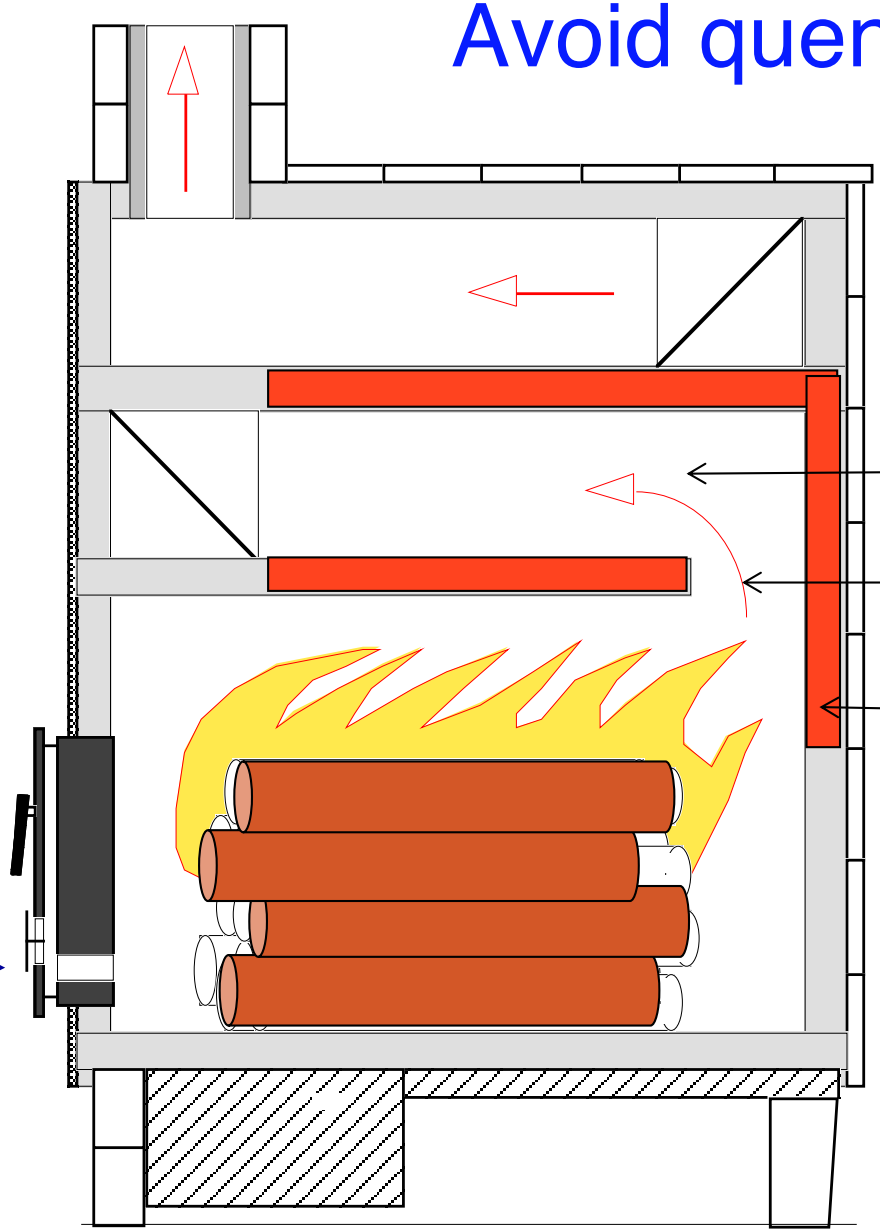
Limitations

Problem 6:
flame quenching



Overfilling can cause quenching

Avoid quenching



3. hot combustion chamber

2. Mixing improvement

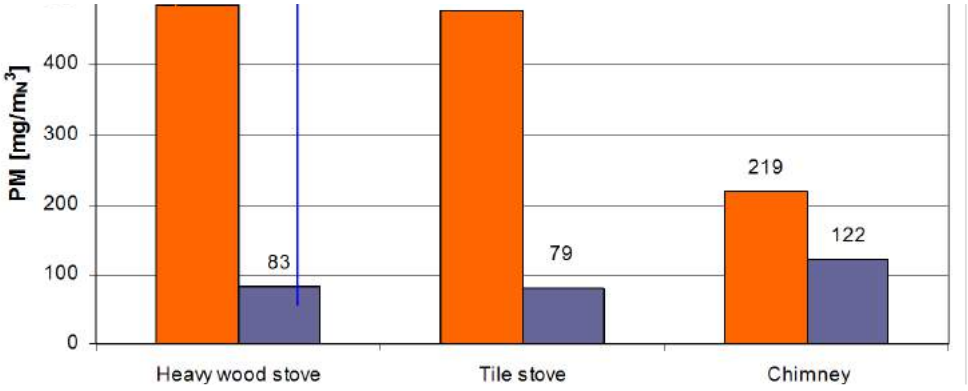
1. Quenching avoided

air →

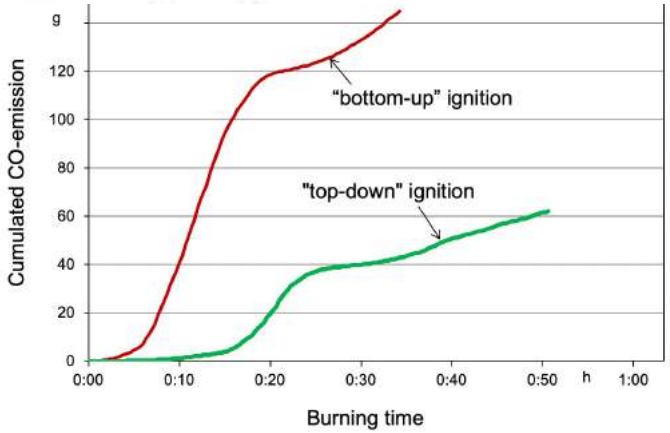
and (additionally and mandatory):

appropriate start-up ..

.. 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]

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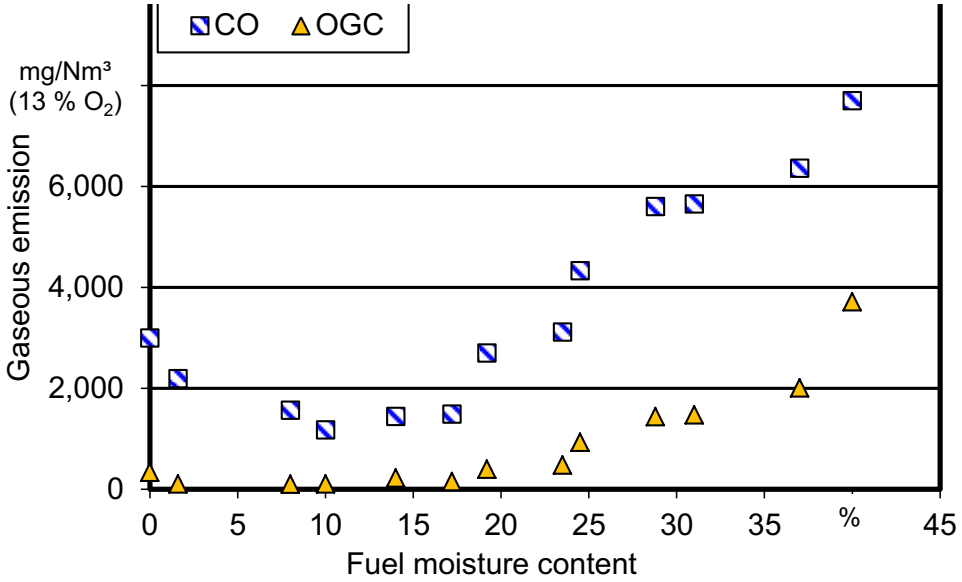
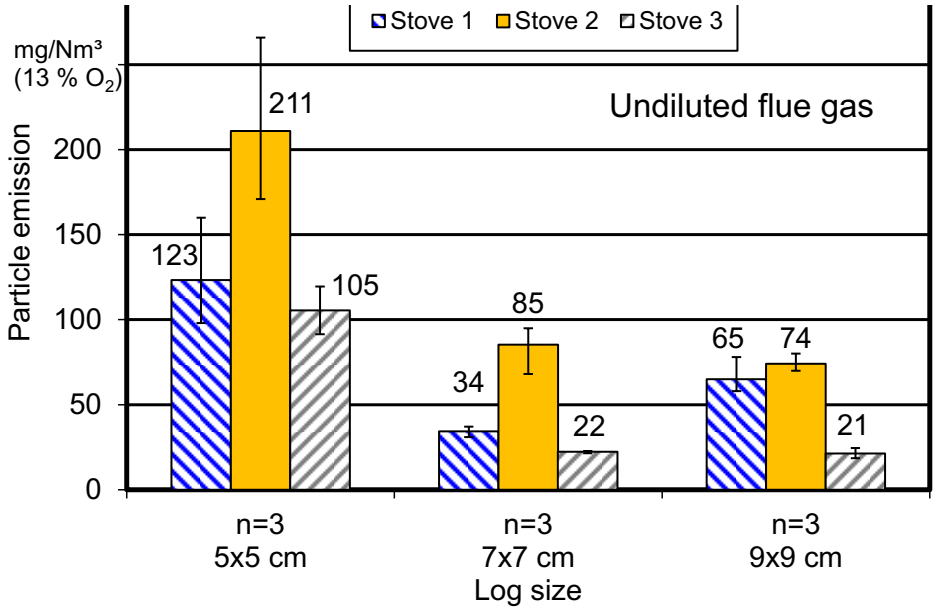
Appropriate fuel: technology dependent

Moisture content



Log size



[H. Hartmann, 20th ETH-Conf. on Comb. Gen. Nanoparticles, Zürich, 2016
and TFZ-Bericht 36, www.tfz.bayern.de] and additional info by
[R. Mack et al. Central European Biomass Conference, Graz 2020]

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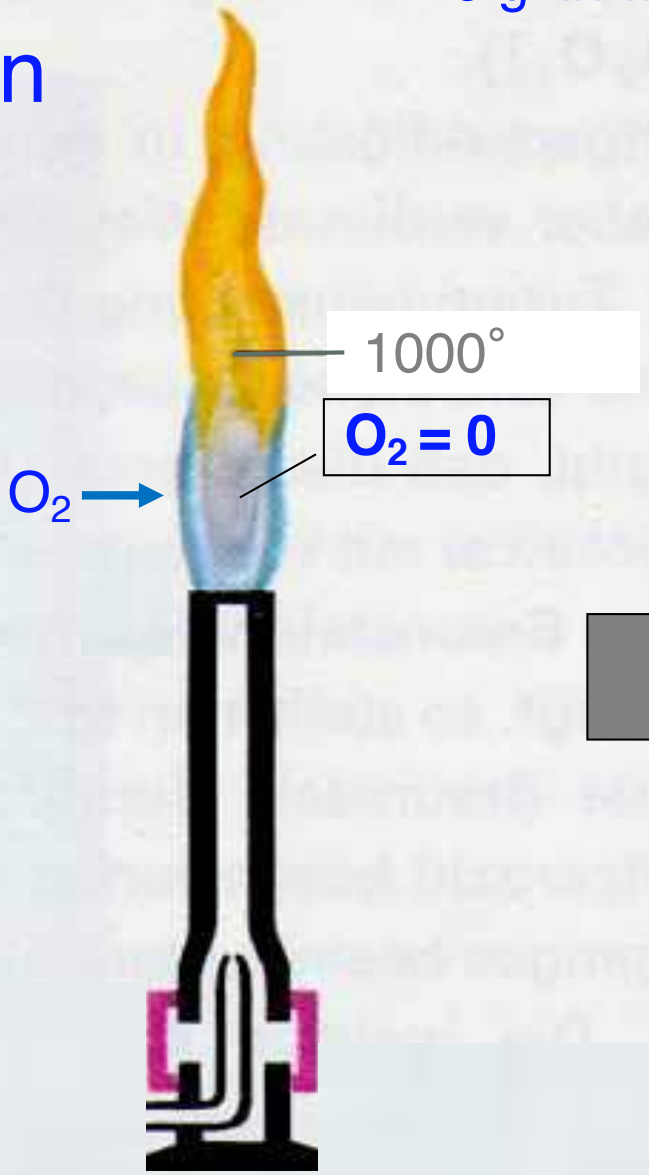
Measure 2

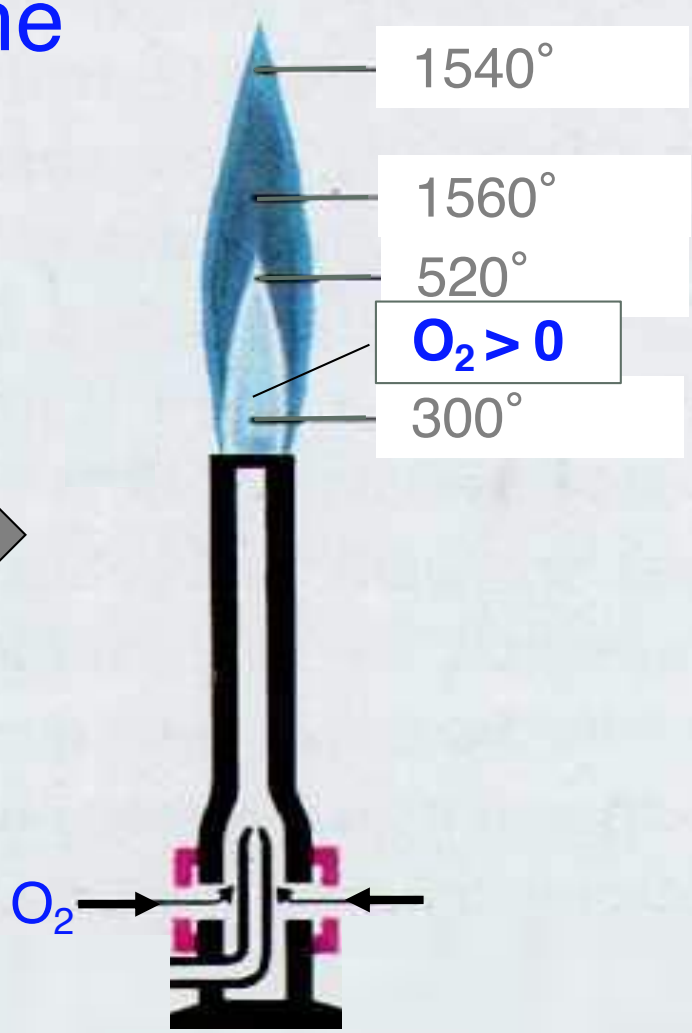
e.g. in wood boiler

Diffusion flame



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

Premixed flame



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

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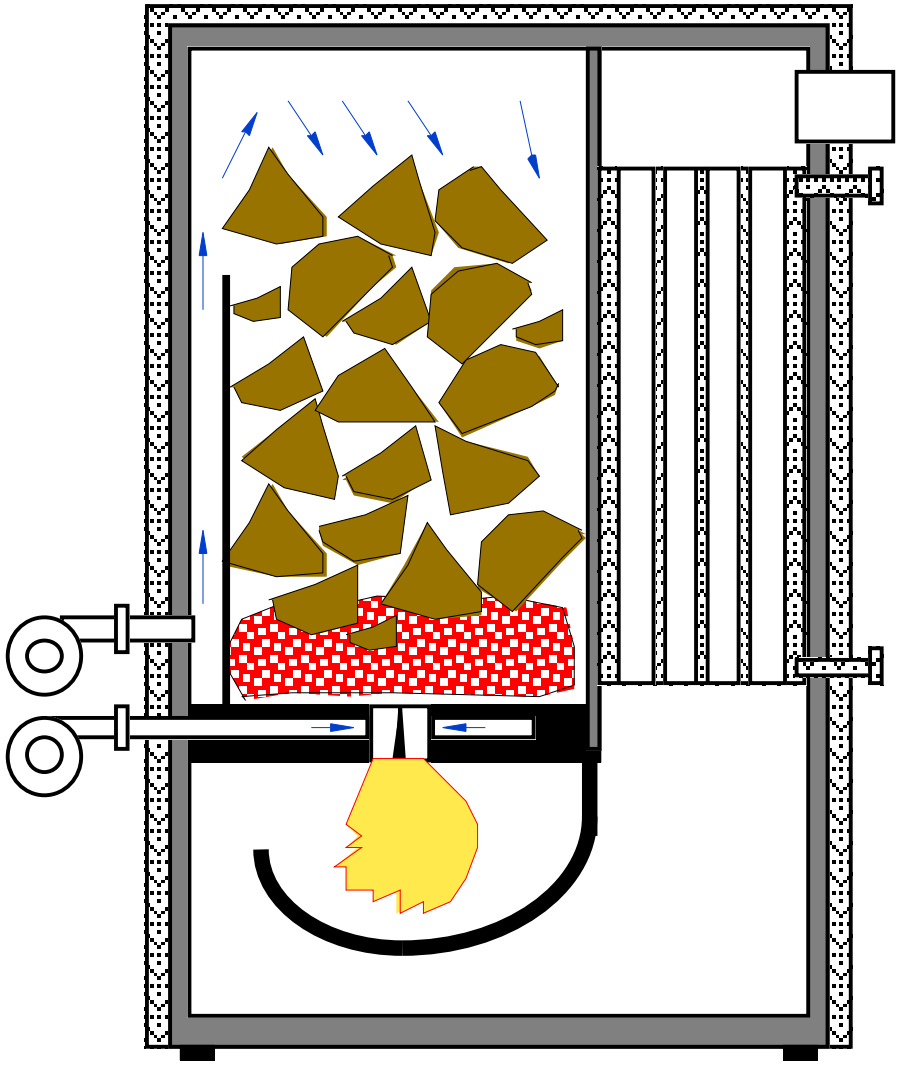
2-stage combustion: principle in downdraft boiler



wood **C H O**

+ air with

$\lambda < 1$

CO, H_2, C_xH_y

CO_2, N_2

+ air with

$\lambda > 1$

Oxygen and T T T:
λ = 1.5-2.5
T > 800°
t > 0.3-0.5 s

CO_2, H_2O, N_2

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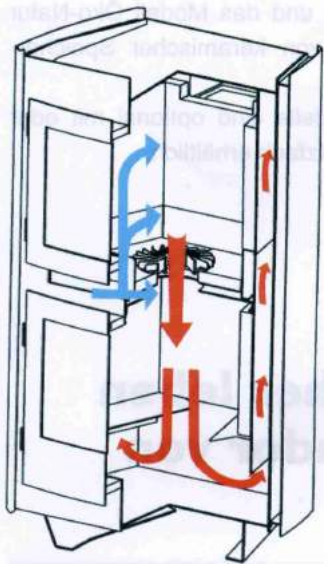
[Nussbaumer, Energy & Fuels, Vol. 17, No 6, 2003, 1510–1521, 17]

2-stage combustion: examples in stoves

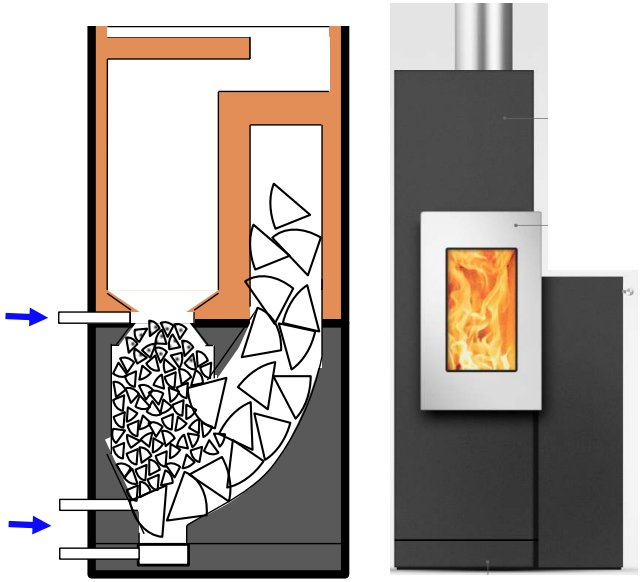
Bionic Fire



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

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

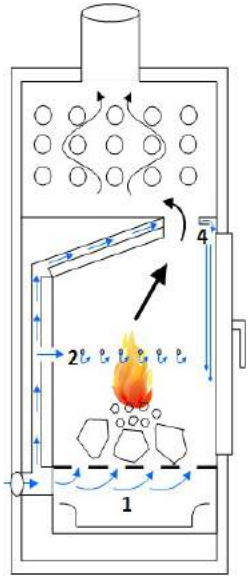
Tiba (Sirius)



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]

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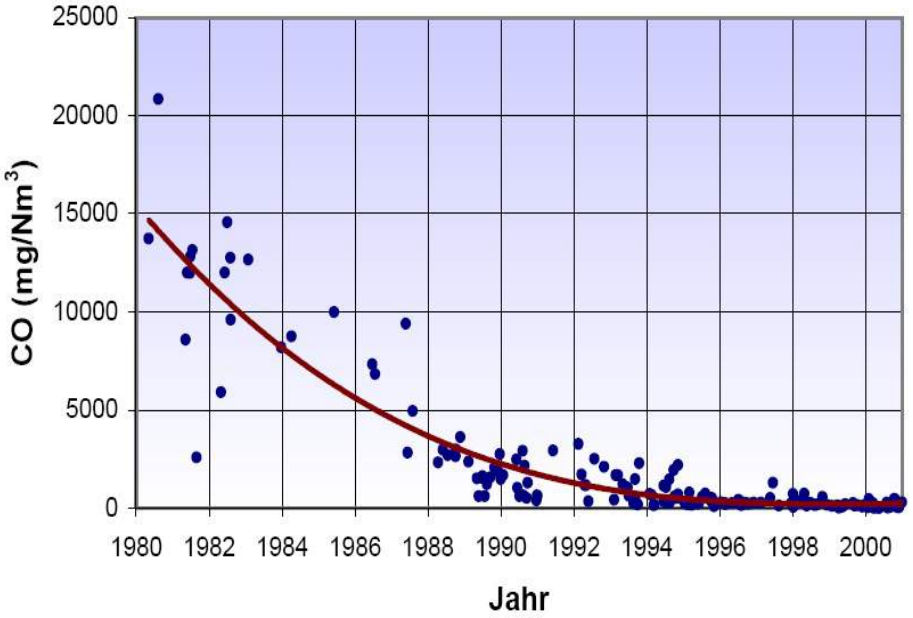
Improvements since 1975/80

Boilers

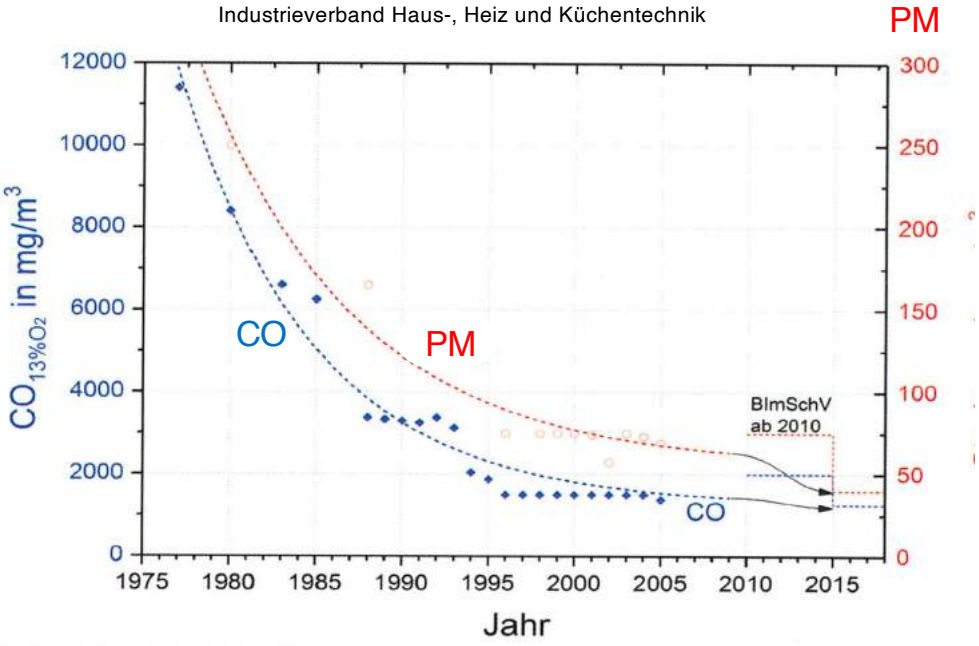
[BEST (formerly BLT), AUT]



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

Stoves

[HKI, GER]



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

Approach: "Technical Guidelines for design of low emission stoves, presentation 2 by Morten Warming (DTI, DK)

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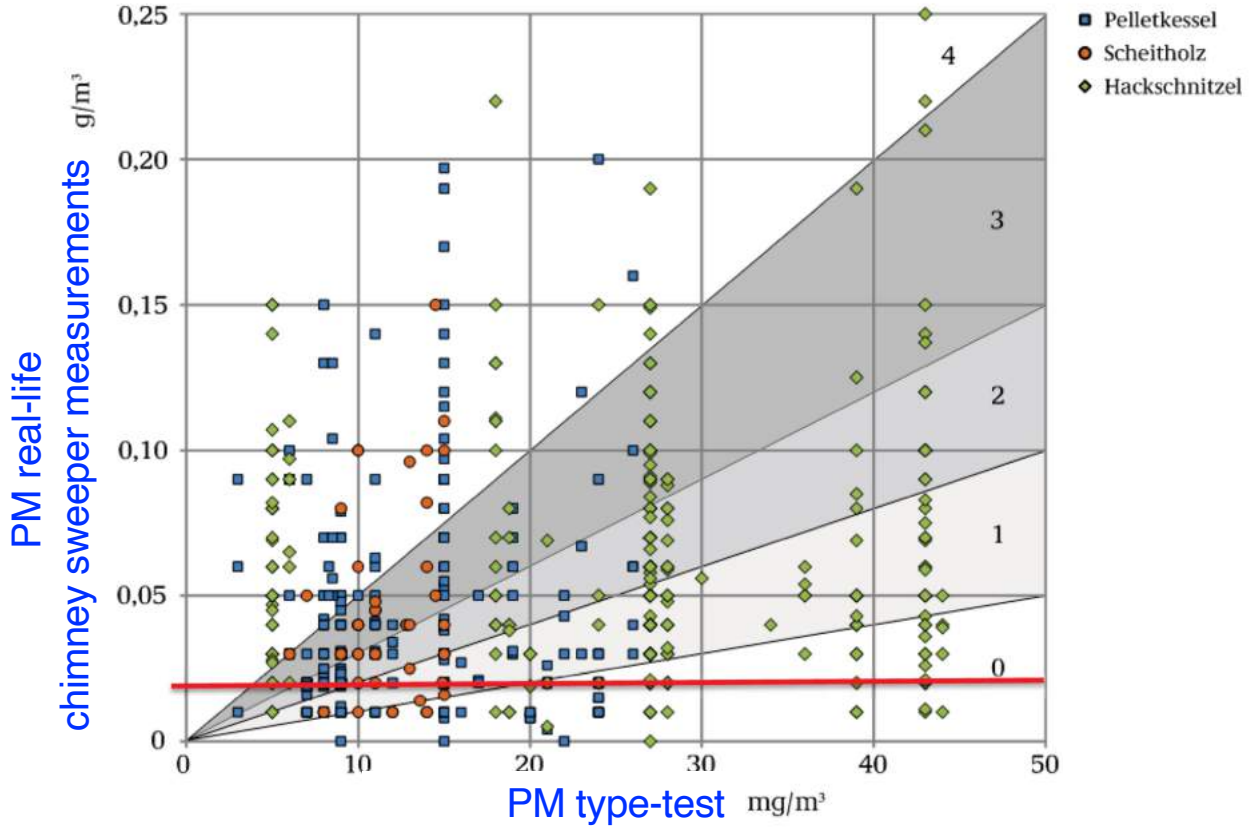
„Gap“
between type-test and reality



Conclusion: „no correlation“

[German Biomass Research Center –
Deutsches Biomasseforschungszentrum, DBFZ, Leipzig 2014]

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„Gap“
between type-test and reality

Approach: "Real life" test methods:
presentation 3 by Gabriel Reichert (BEST, AUT)

1. Intro

2. Pollutant formation

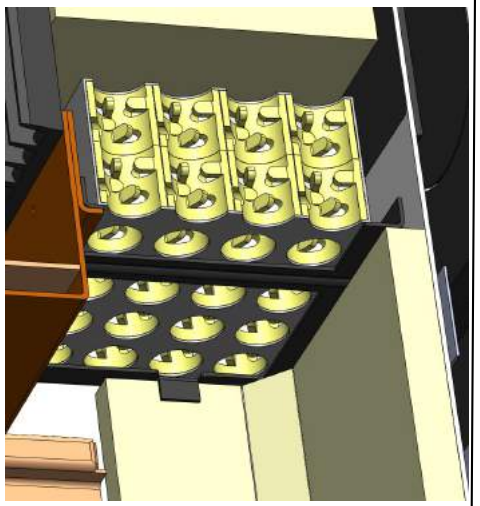
3. Measures

   3.1 Primary measures

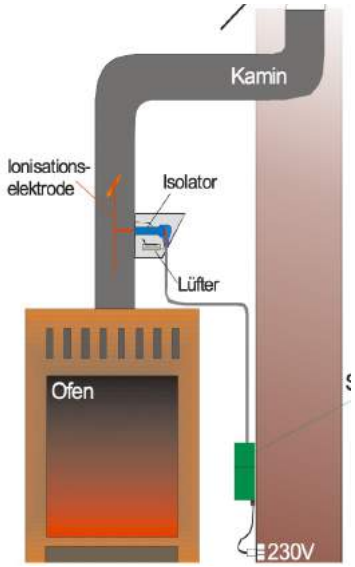
   3.2 Secondary measures

Catalysts

Inserts



Electrostatic Precipitators (ESP)



Reduction		
CO	> 70%	
VOC	> 40%	
PM	**30% - 40%**	

[G. Reichert et al., BEST, 13. Holzenergie-Symp., Zürich 2014]

CO	> 70%
VOC	> 70%
oxidizable PM	

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

PM	**60% - 80%**

[V. Schmatloch, EMPA Dübendorf, 2004]

[D. Jud, Oekosolve, CEBC Graz 2020]

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

Secondary measures
can complement (but not replace) primary measures
since they are limited in case of incomplete combustion

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.:

   Target for T T T: λ = 1.5-2.5, T > 800°, 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

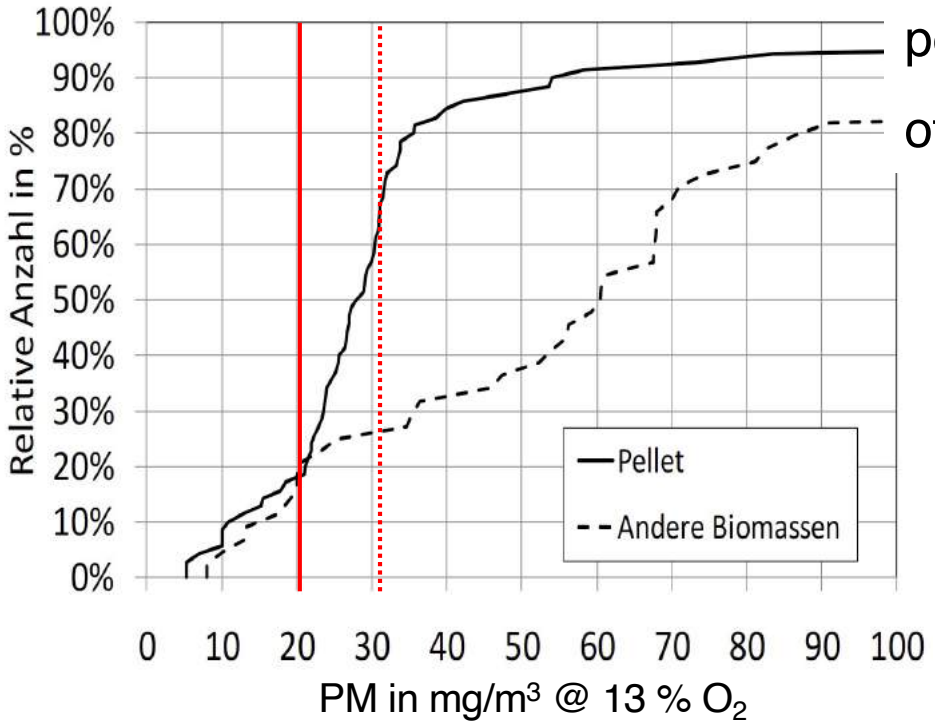
but:

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

- for **manual devices** highly challenging
  most important 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

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[A. Kather, N. Woltersdorf: Feinstaubemissionen aus biomasse-befeuerten Kleinfeuerungsanlagen, IET, TUHH, Hamburg 2013]

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

1. RWC contributes to PM and OC hence their emissions need to be reduced
2. Primary measures are:
   - combustion design
   - ideal start-up and appropriate 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 Energy
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IEA Bioenergy Task 32

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