Bioenergy Research Group
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Primary & secondary particle & gas phase emissions from nine state-of-the-art wood combustion devices

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1 Introduction

Since there is a potential to increase the energy supply from wood combustion by more than 50 % in Switzerland to contribute to the Swiss energy strategy 2050, wood energy consumption is expected to significantly increase within the next years. [1].

However, wood combustion contributes to air pollution with adverse health effects [2]. Hence, there is a target conflict between air pollution and wood as a renewable energy source (**Fig.1**).

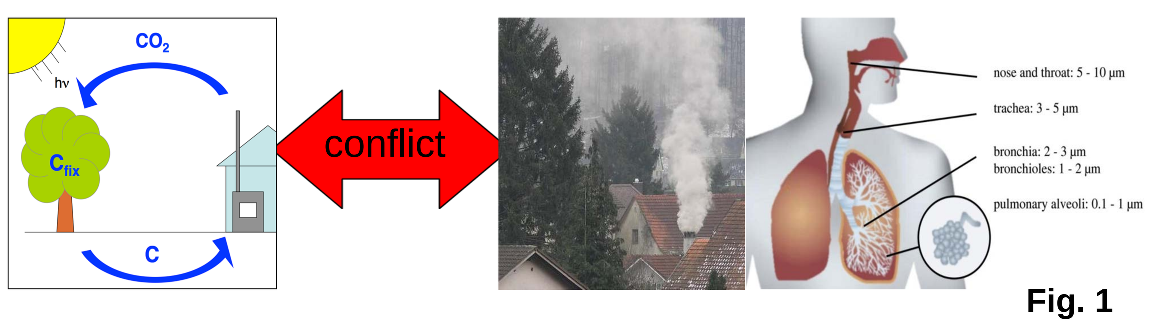

Fig. 1

Furthermore, PM in ambient air not only results from primary PM which is accounted for by emission limit values, but is also caused by secondary organic aerosol (SOA) formed from volatile organic compounds (VOC). [3].

2 Target

Within the framework of the **National Research Program "Energy Turnaround" (NRP 70)** the target of the **joint project between Lucerne UASA and LAC** is:

1. Deepen knowledge on primary and secondary pollutant formation and assess the impact of wood combustion on ambient air quality and human health.
2. Identification of best technologies and operation conditions.
3. Development of target-oriented air pollution strategies.
4. Definition of requirements for combustion design, control strategies and fuel properties.

The findings of this project should enable to overcome the barriers that hinder a stronger implementation of wood as a renewable energy resource.

3 Research Plan

To identify the influence of combustion technology, fuel type, operation type, combustion regime, and flue gas cleaning experiments with 9 different state-of-the art combustion devices (**Fig.2**) were carried out (see **Table 1**).

Table. 1 Measured gas- and particle phase species with corresponding measurement methods

Devices	Combustion	Nominal Heat Output	Combustion Phases
Wood stove A	one-stage, updraft (conventional wood stove)	6 kW	cold start warm start flaming burn out dry vs. wet wood normal load vs. overload
Wood stove B	two-stage, updraft with gravimetric fuel feeding	8 kW	
Wood stove C	two-stage updraft & downdraft (when hot)	4.6 kW	
Wood stove D	updraft, two-stage	4.6 kW	
Log wood boiler	two-stage, downdraft	30 kW	
Pellet stove	two-stage, updraft	6 kW (full load) 3 kW (part load)	cold start, full and part load, burn out normal vs. wheat pellets
Pellet boiler A	two-stage, updraft	15 kW	optimum, lack and high excess of O_2
Pellet boiler B	updraft, two-stage	30 kW	cold start, full and part load, burn out
Moving grate boiler	two-stage, updraft (prototype, down-scale from 450 kW)	150 kW (full load) 50 kW (part load)	full and part load going to standby from part load start up from standby to full load before vs. after electro filter

Fig. 2 Investigated combustion devices. Devices from left to right correspond to devices from top to down in Table 1

4 Experimental Setup

Experiments were performed in the Lucerne UASA combustion laboratory (**Fig.3, Fig.4**). SOA formation was investigated (via exposure to UV light and OH radicals) with the Potential Aerosol Mass Chamber (**Fig. 11**) and an on-line characterization of the following species in the flue gas (**Table 2**) is carried out:

Table. 2 Online measured gas- and particle phase species with corresponding measurement methods

Particle phase					
Compounds	Total PM	# particles, size distribution	Organic matter, NH_4^+, NO_3^-, Cl^-, SO_4^{2-}	Black carbon (BC)	Reactive oxygen species (ROS) [4]
Measurement method/instrument	Gravimetric in hot flue gas	SMPS, PALAS Welas 2000	Aerosol Mass Spectrometry	Aeth-alometer	2'7'-dichlorofluorescin (DCFH) assay
Gas Phase					
Compounds	O_2	NO, CO	CH_4, VOC, NMVOC	VOC composition	
Measurement method/instrument	Paramagnetic	Non-Dispersive Infra-Red (NDIR)	Flame Ionization Detection (FID)	Proton Transfer Reaction Mass Spectrometry	

Fig. 3 Laboratory of the Bioenergy Research Group

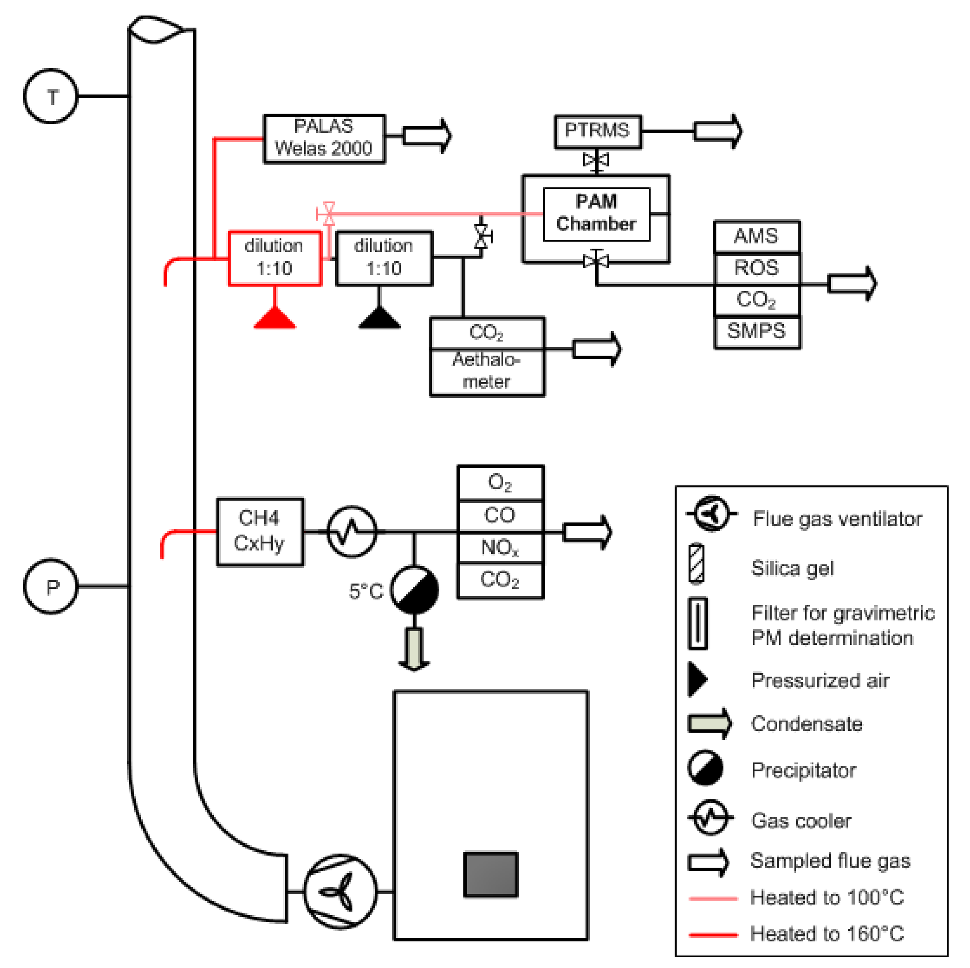

Fig. 4 Schematic of the experimental setup

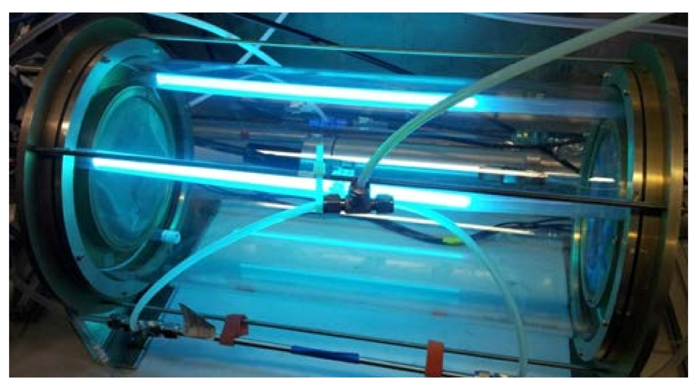

Fig. 5 Potential Aerosol Mass (PAM) chamber from LAC

5 Results

- Cold and warm start of devices with manual operation (log wood stoves and log wood boiler) exhibit the highest PM emissions (**Fig. 6**).
- Inappropriate fuels (wet wood or wheat pellets) or mal operation (lack of O_2 in the pellet boiler) results in much higher PM emissions (**Fig. 6**).
- Automated devices (pellet boiler and pellet stove, moving grate boiler) exhibit the lowest PM emissions which are dominated by inorganic particles which can be separated in ESPs (**Fig. 6**).
- In many combustion devices and conditions SOA significantly exceeds primary emissions (**Fig. 6**).
- A high correlation (R^2 = 0.74) is found between NMVOC and SOA as well as for CO and NMVOC (R^2 = 0.85). Consequently, if only simple measurement setups are available, NMVOC and CO could be used as indicators for SOA (**Fig. 7**).
- Differences between conventional and advanced wood stoves are mostly lower than the influence of the operation (**Fig. 8**).

→ Primary PM in the flue gas is not sufficient to estimate the contribution and impact of wood combustion to ambient PM.

→ Secondary aerosols should be considered in future emission regulations.

→ An increased use of biomass to contribute to the Swiss Energy Strategy 2050 is possible with even reduced impact on air quality, however, only if measures to reduce mal-operation of manual combustion devices are implemented and automated boilers with well operated flue gas cleaning are introduced.

For more information please also see Poster 73

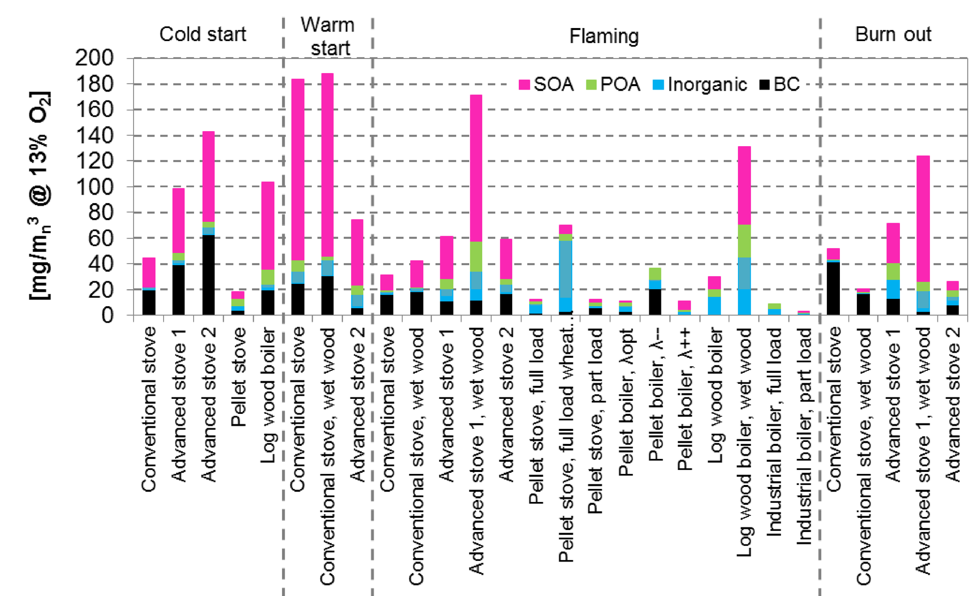

Fig. 6 Mean composition of PM.

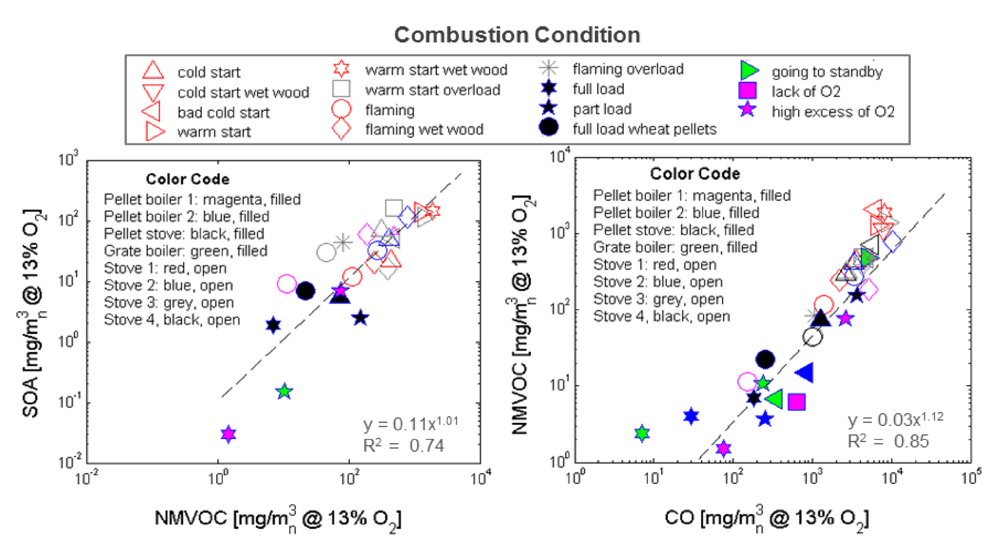

Fig. 7 Correlations of NMVOC vs. SOA and CO vs. NMVOC

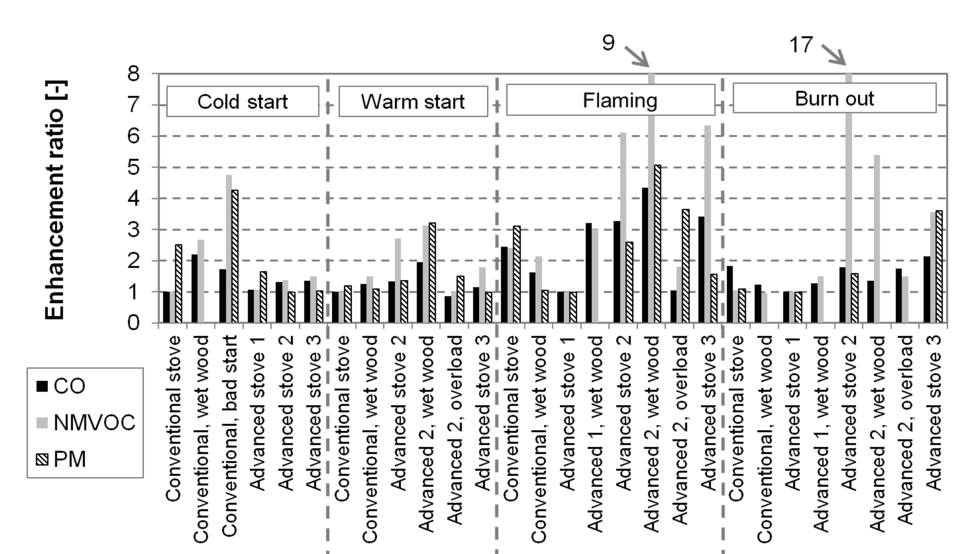

Fig. 8 Ratio of emissions between the different stoves and operation conditions

Literature

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