Physical and Chemical on-line Characterization of Nanoparticles in Transient Burn Phases of Modern Wood Heat Appliances

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1 Introduction

The use of renewable biomass energy is one of the key strategies to reduce CO2 emissions and mitigate global warming. Wood combustion is an efficient, renewable, distributed and widely used source of energy for space hating. Rising energy prices will bring wood energy in focus for a save, locally available and CO2-neutral source of future energy. However, harmful effects on human health from nanoparticles generated by wood combustion are well recognized. Particularly small wood-fired appliances are of concern, since they contribute significantly to nanoparticle emissions in the airshed of urban and rural areas.

For this study the flue gas emissions of four different types of modern wood burners were investigated: an automatic pellet burner, a log wood stove, a log wood insert and a masonry stove. To characterize the emissions in transient phases of the combustion process, such as lighting or refuelling, a quadrupole based Aerosol Mass Spectrometer (AMS), a Fast Mobility Particle Sizer (FMPS), a Tapered Element Oscillating Microbalance (TEOM) and a Multi Angle Absorption Photometer (MAAP) were employed. The emissions were characterized for burn cycles according to the European type test procedure. For the measurements in the lighting stage the recommended procedures by the Swiss wood energy association (Holzenergie Schweiz) were applied.

2 Gravimetric dust measurements (TPE)

To identify different stages of each burn cycle, the flue gas parameters CO2, CO, O2 were measured. The gravimetrically measured Total Particle Emission (TPE) were colleted by constant volume sampling (CVS) of the entire flue gas flow in a dilution tunnel. This resulted in higher (Factor 1.5 - 2) emissions compared to in stack measurements according to EN type test procedures. Volume flow measurement in the dilution tunnel, together with CO2 measurements in the dilution tunnel and flue gas, made it possible to calculate the volume flow in stack by the dilution factor, and consequently to derive PM freight data for all wood burner investigated. This setup also allows calculating freight data of the different chemical components in the flue gas identified by AMS.

Among the different wood heat appliances, the masonry stove produces the least TPE emissions per mass wood fired. Also the lightingp stage with top down fire according to the recommendations of the Swiss wood energy association reduces TPE emissions by 50% compared to bottom up fire.

3 Physical characterization

TEOM measurements show that when lighting the log wood stove with kindling and bottom up fire, more than half of the total emissions of a burn cycle are emitted during the first 10 minutes. When lighting the stove with bottom up fire, particle emissions are constant during the whole burn cycle. Particle number concentration measured by FMPS is highest during transient phases. Especially small particles with < 40 nm mobility diameter are present in high concentrations, which could lead to underestimation of the health relevant emissions during transient phases if measured gravimetrically.

4 Chemical characterization

The results from the AMS show that during transient phases the main chemical constituents of nanoparticles are organic compounds. During the continuous burning stage, organic constituents are dominant for log wood appliances, but not for the pellet burner, where sulphates are dominant during continuous burning. Additionally, PAH’s are peaking at the same time as the organics, but do not always follow the same trend as the total organic fraction. Especially in phases of low air supply, caused by high burn rates, PAH’s are disproportionately high.

5 Outlook

The combination of the different measurement devices to characterize chemical and physical properties of nanoparticles from modern wood heat appliances with high time resolution allow identifying specific burn phases with high health-relevant emissions. These phases are analysed for the different appliances and prevented by improved hardware development and operator practice. More detailed analysis of the nanoparticle properties will be done by Paul Scherer Institute, Gasphase and Aerosol Chemistry Group.

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Centre of Appropriate Technology

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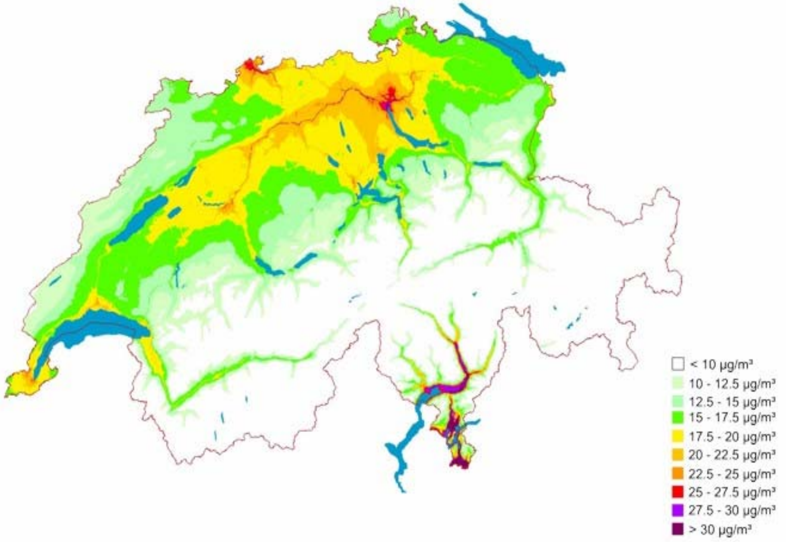
Motivation I

Wood burning and PM10 emissions

- **High contribution of PM10 from wood heat appliances in Switzerland (8%)**
- **Northern European countries have already higher PM10 emissions from wood burning than from transportation**
- **Increasing importance of wood energy with scarce of fossil energy**

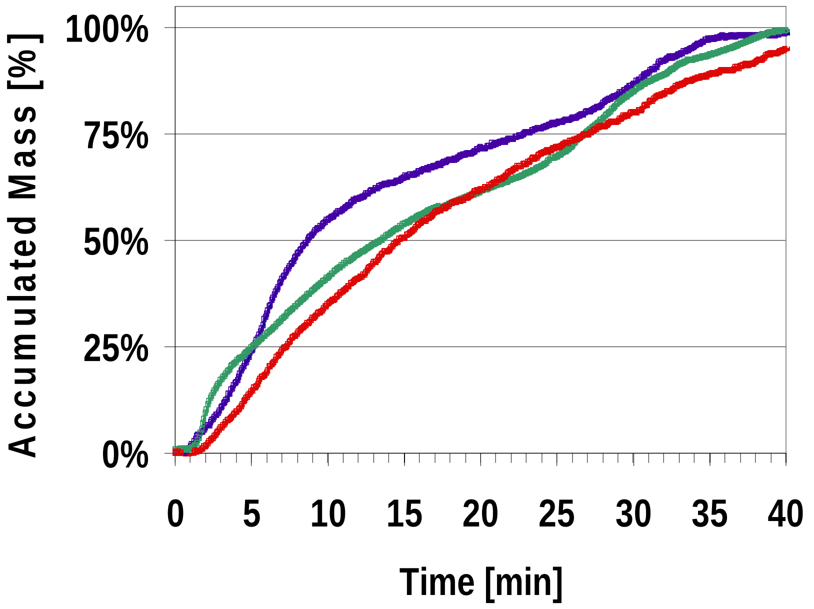


Average PM10-distribution Switzerland (BAFU 2000)

Motivation II

Transient phases in wood combustion

- **Lighting and refueling phases**
- **Elevated particulate emissions**
- **Products of incomplete combustion**
- **Particle characterization**



Project

Mitigation of particulate emissions in transient phases

- **Stove, insert and masonry stove (log wood)**
- **Primary measures: material, air supply, operator practice**
- **Secondary measures: precipitators**

Stove and Masonry stove

Standard particle measurements

TPE and flue gas parameter measurements

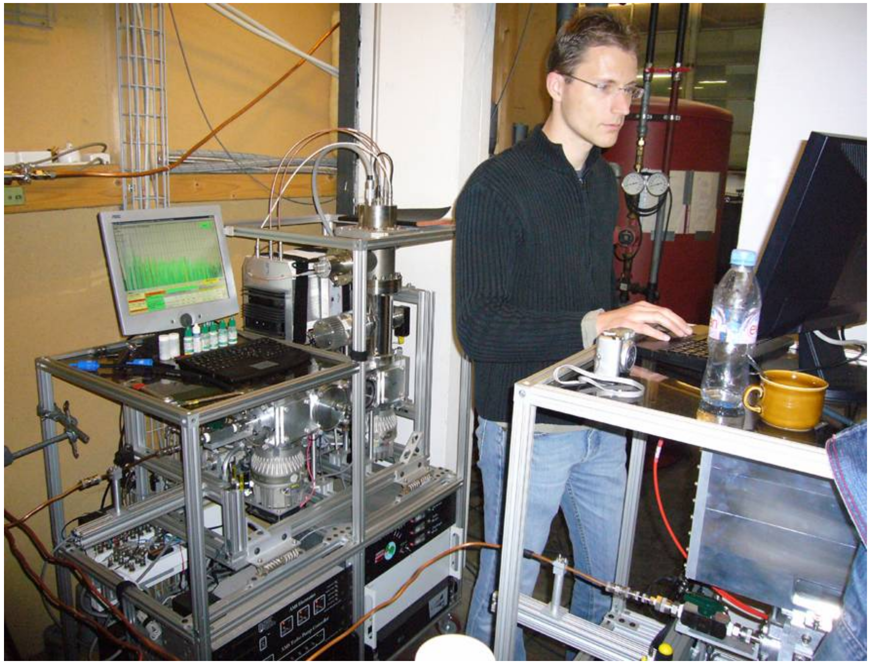
- **CO_2, CO, O_2**
- **TPE Sampling (Dilution tunnel for flue gas flow measurement)**
- **Emission factors**

Laboratory at the Centre of Appropriate Technology

Enhanced particle analysis

Physical and chemical on-line characterization

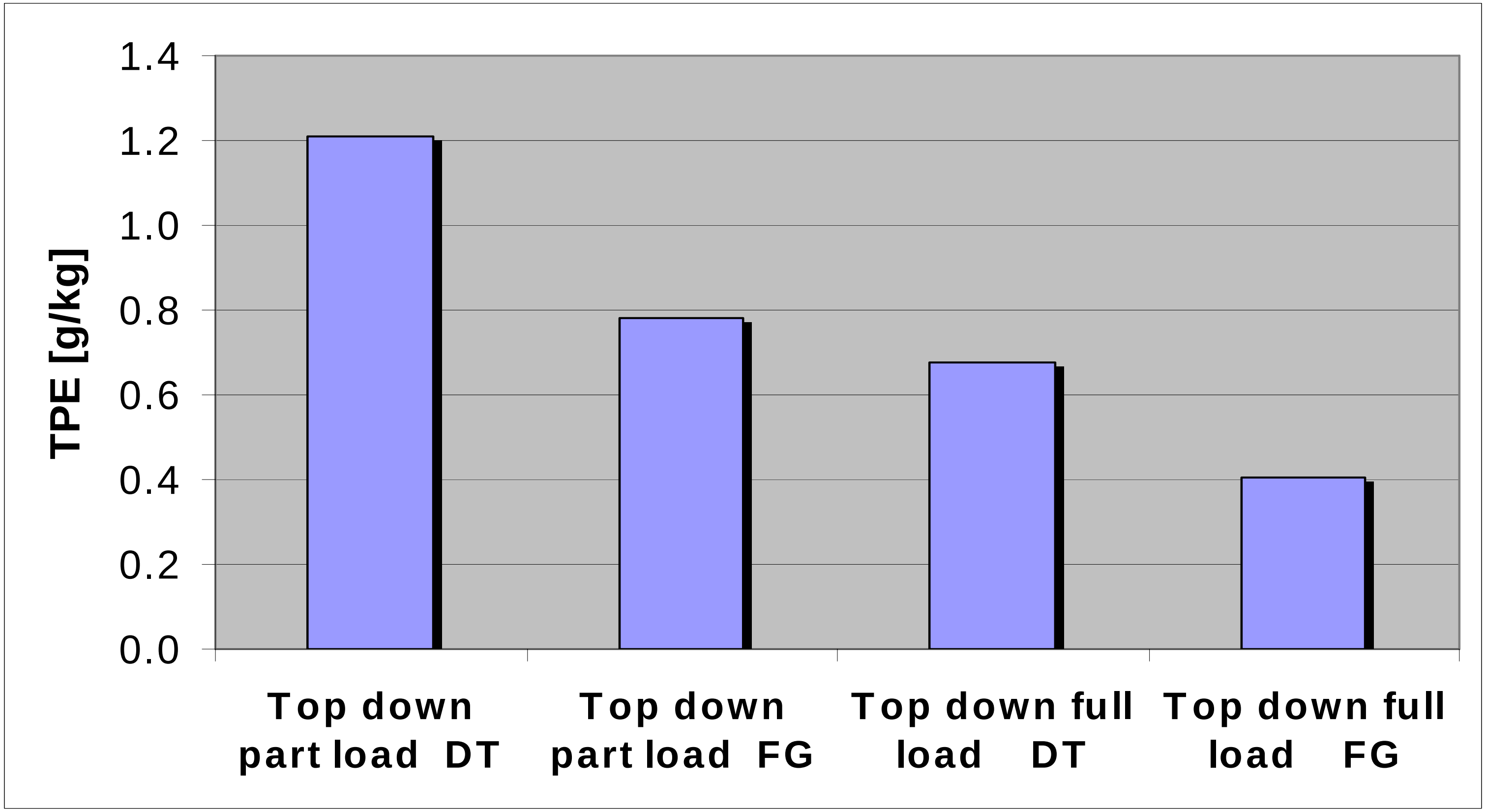
- **Chemical properties (AMS, MAAP, RDI)**
- **Physical properties (FMPS, APS, TEOM)**
- **Sampling (Dilution tunnel for flue gas flow measurement)**



Cooperation with PSI – Laboratory for atmospheric chemistry and University of Applied Science Northwestern Switzerland –Institute of Aerosol and Sensor Technology

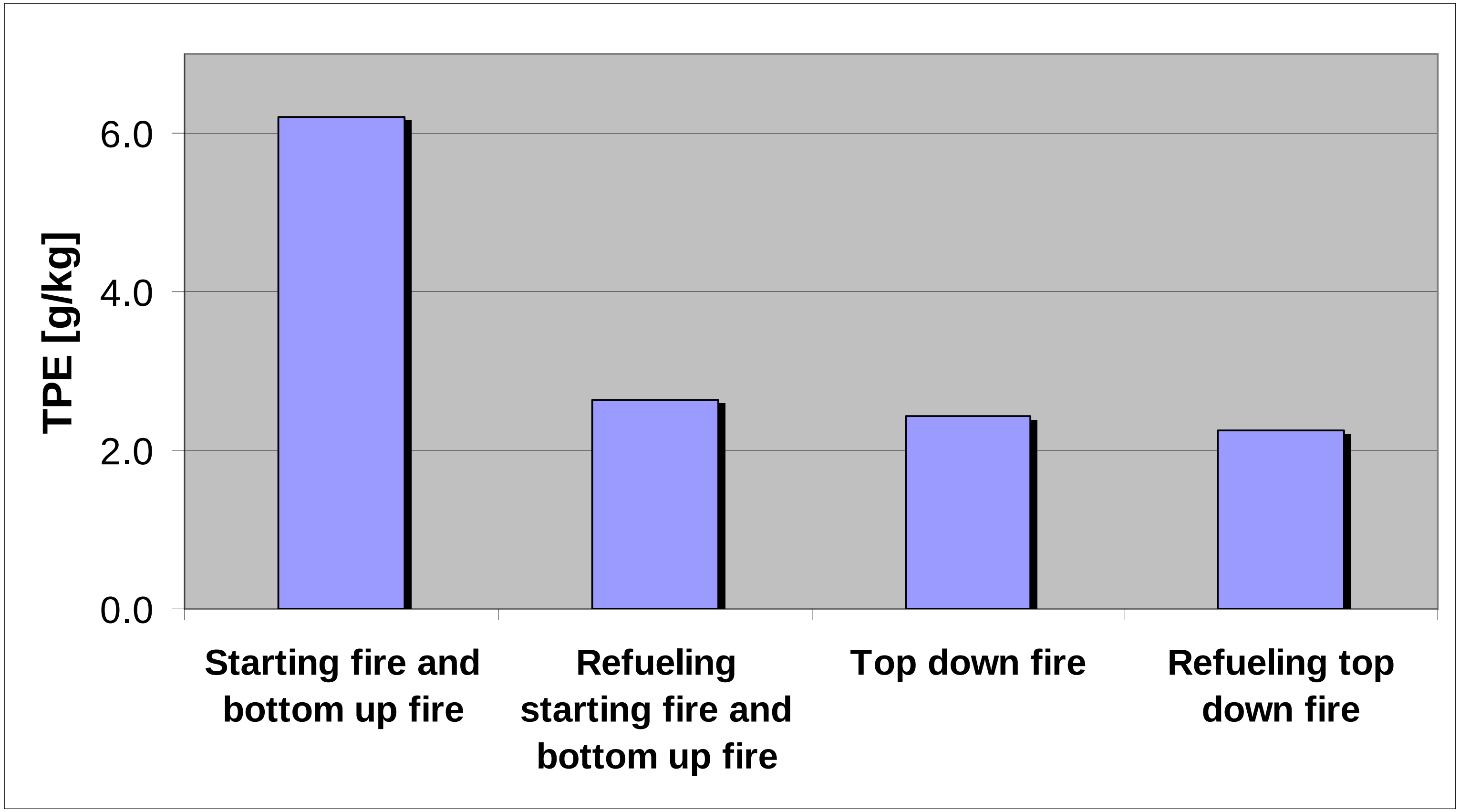
Results TPE I

Comparison TPE flue gas (FG) – dilution tunnel (DT)



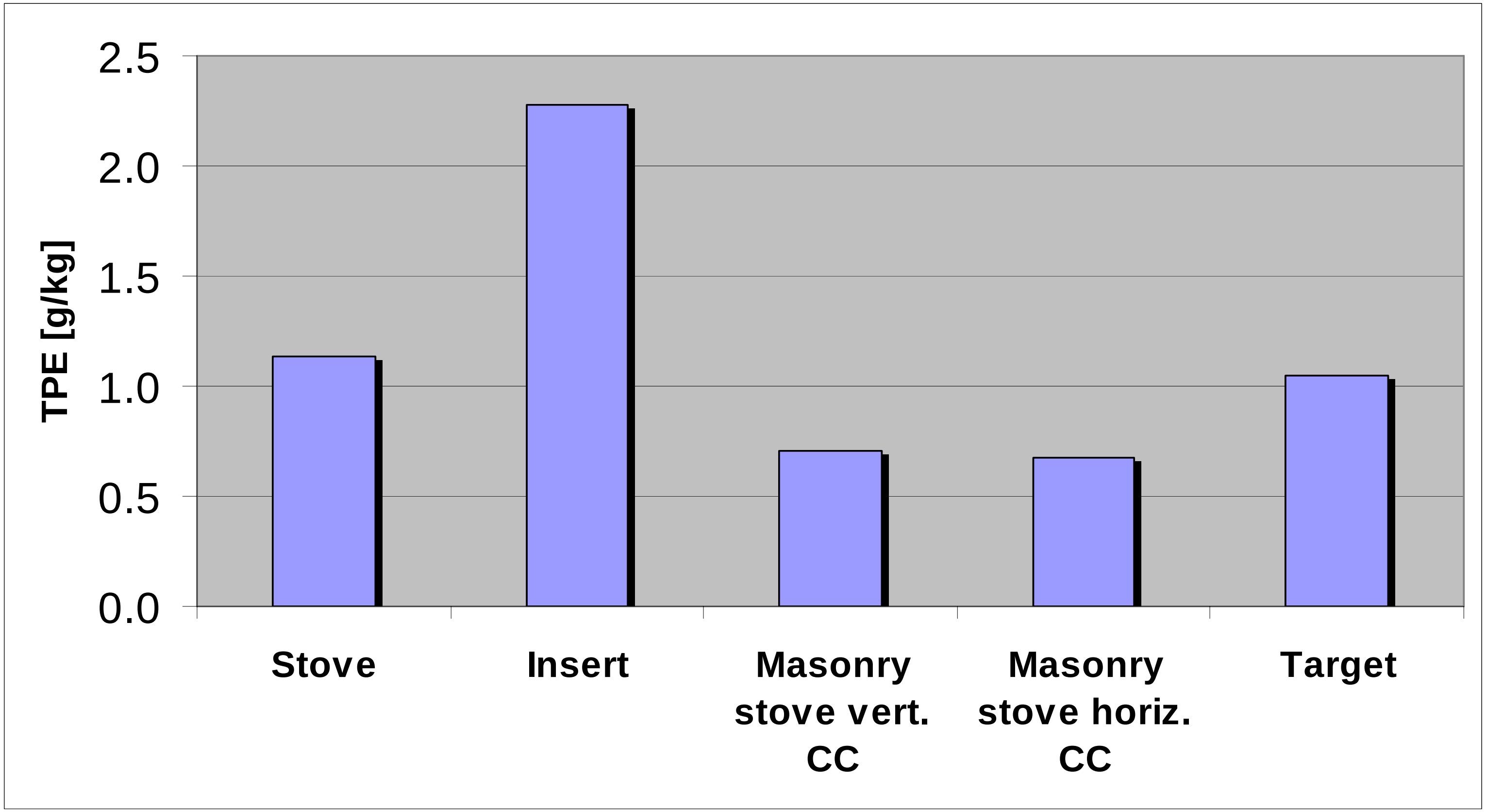
Results TPE II

Insert: Different procedures at lighting stage



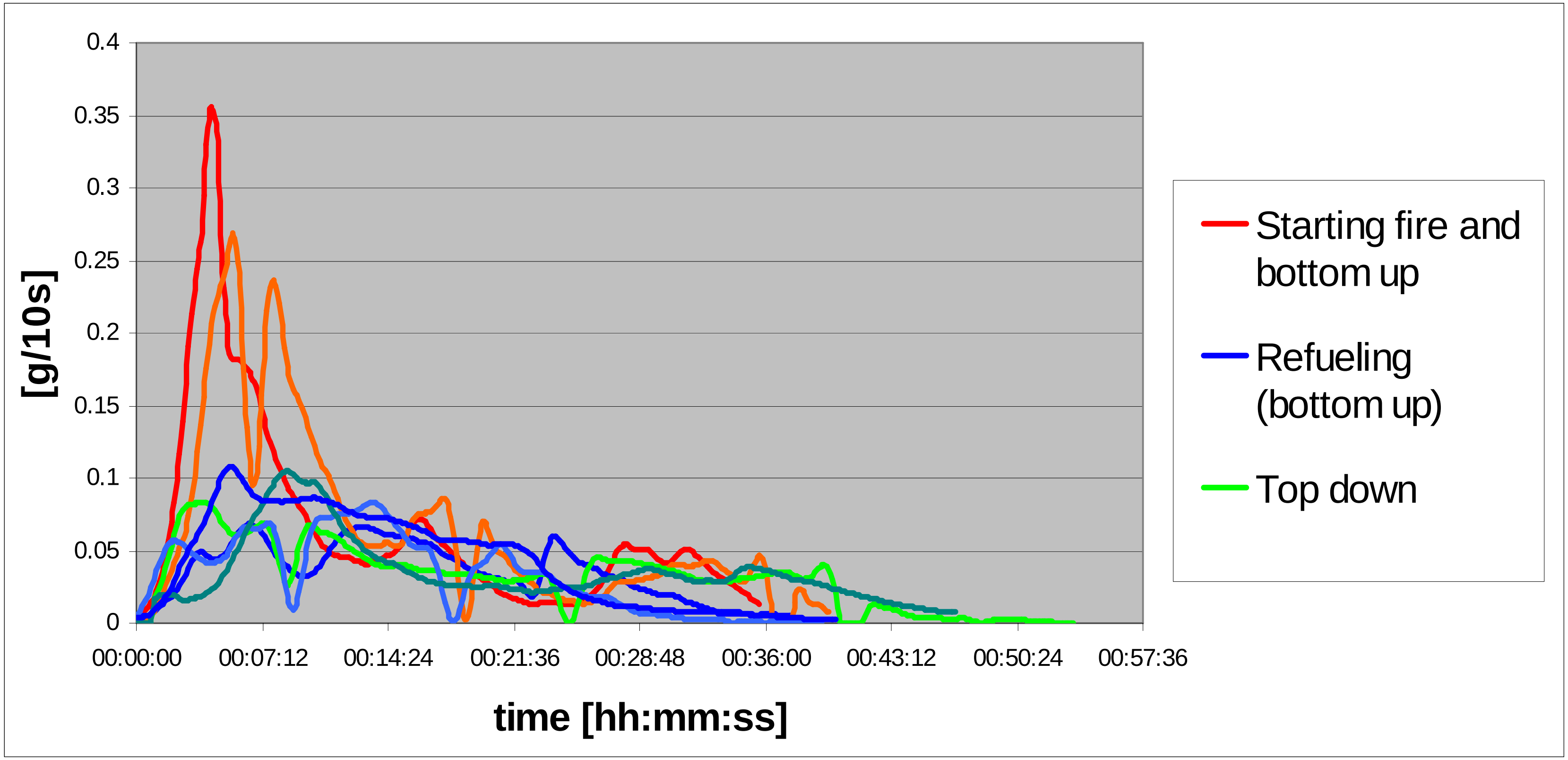
Results TPE III

Calculated TSP Emissions at same fuel load (15 kg)



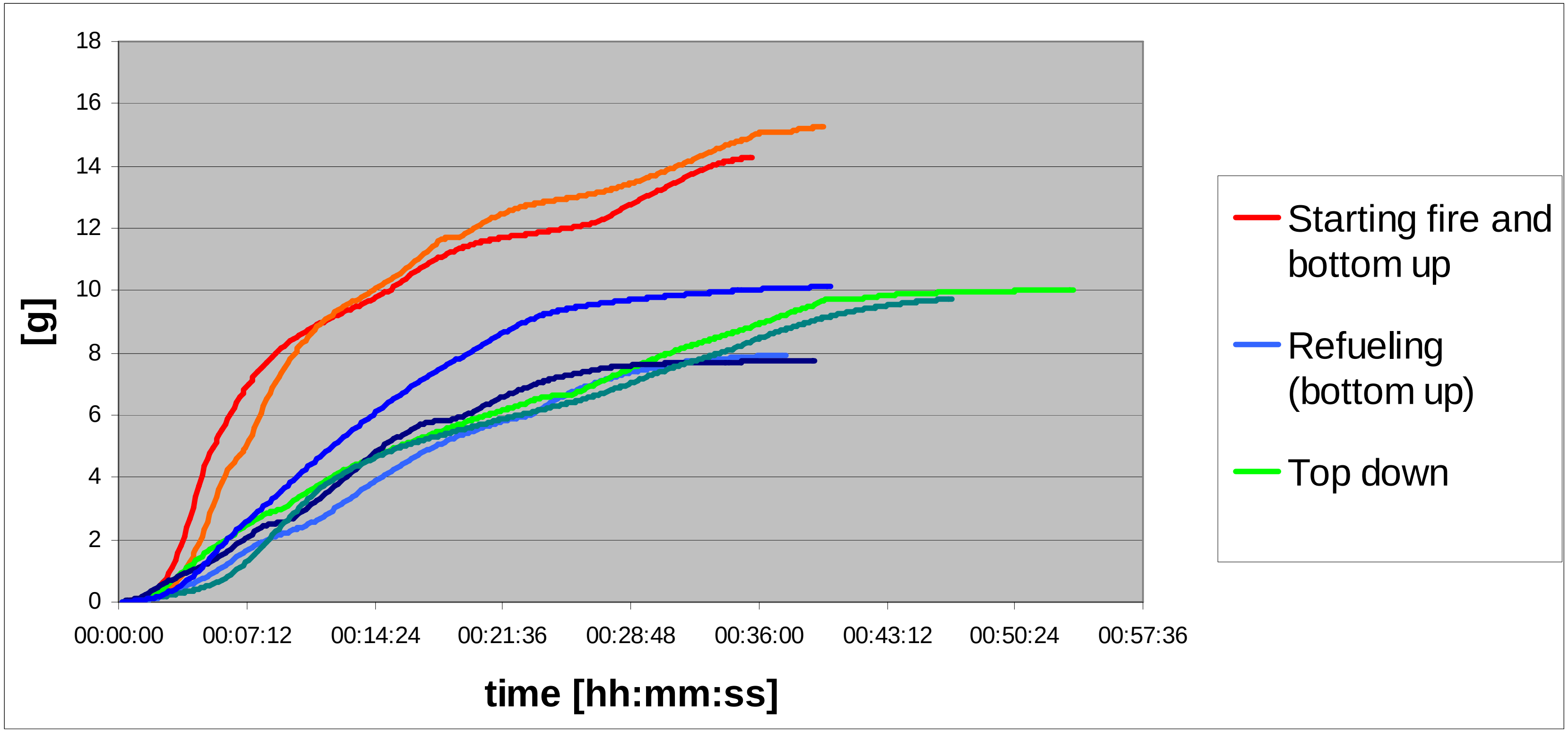
Results TEOM I

Stove: Particle freight for different burn cycles



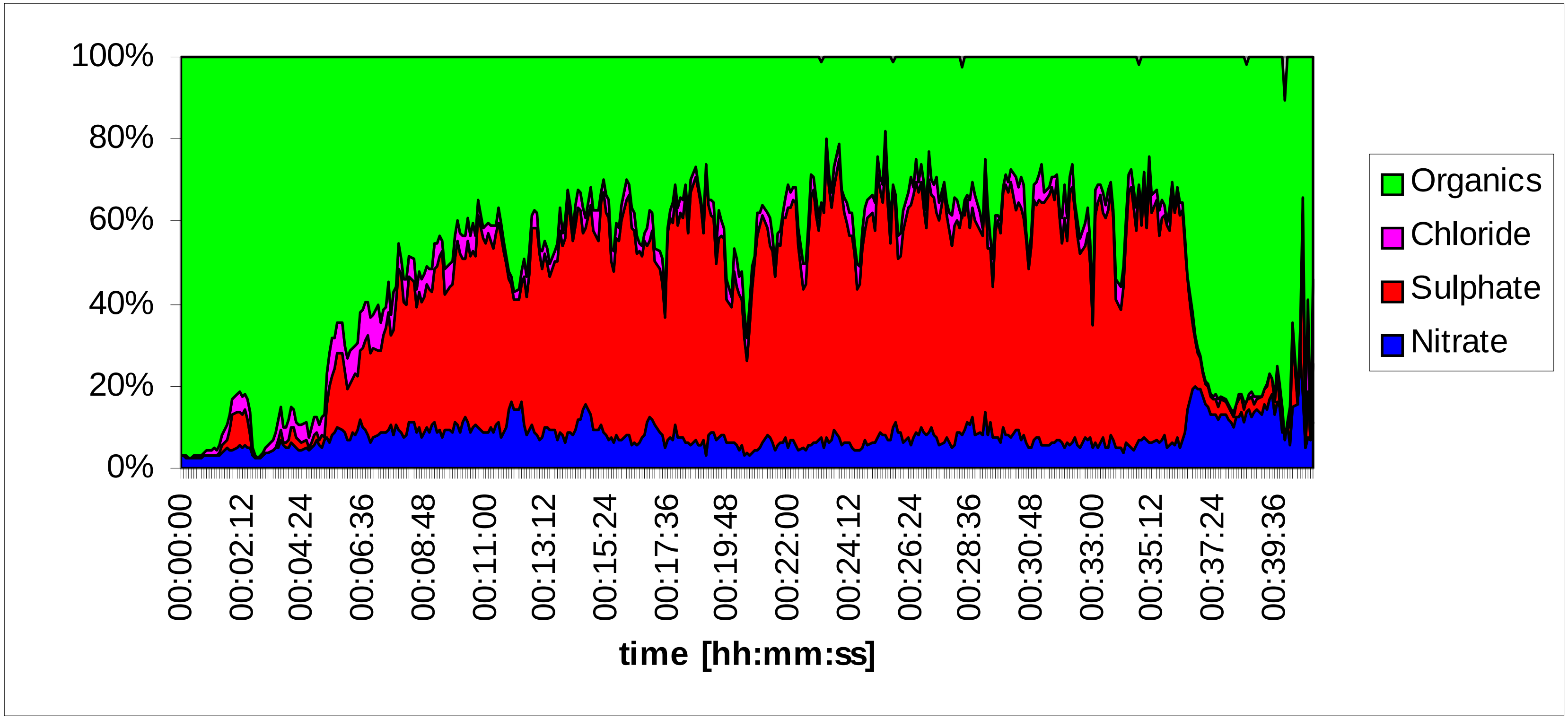
Results TEOM II

Stove: Accumulated particle freight for different burn cycles



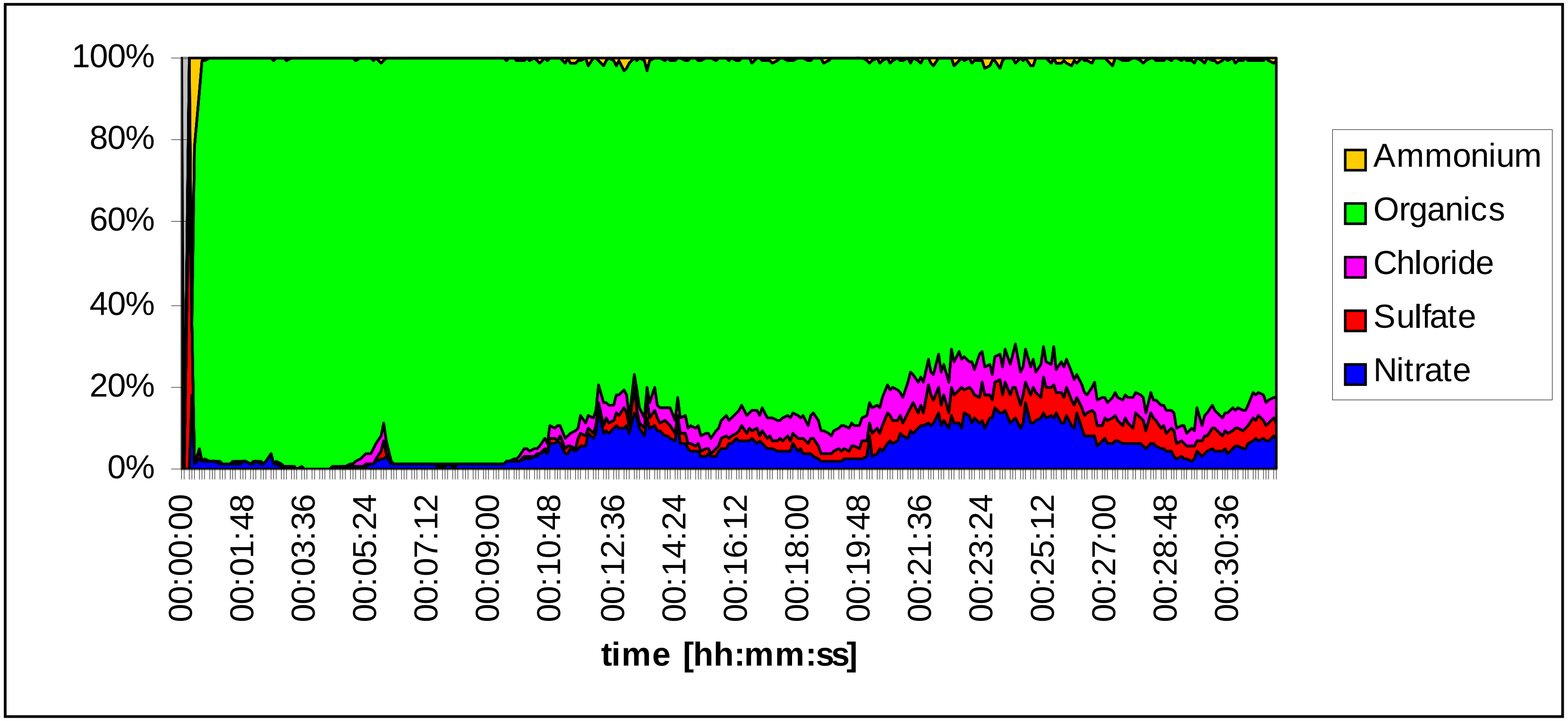
Results AMS Pellet burner

Chemical composition at lighting and stable burn phase



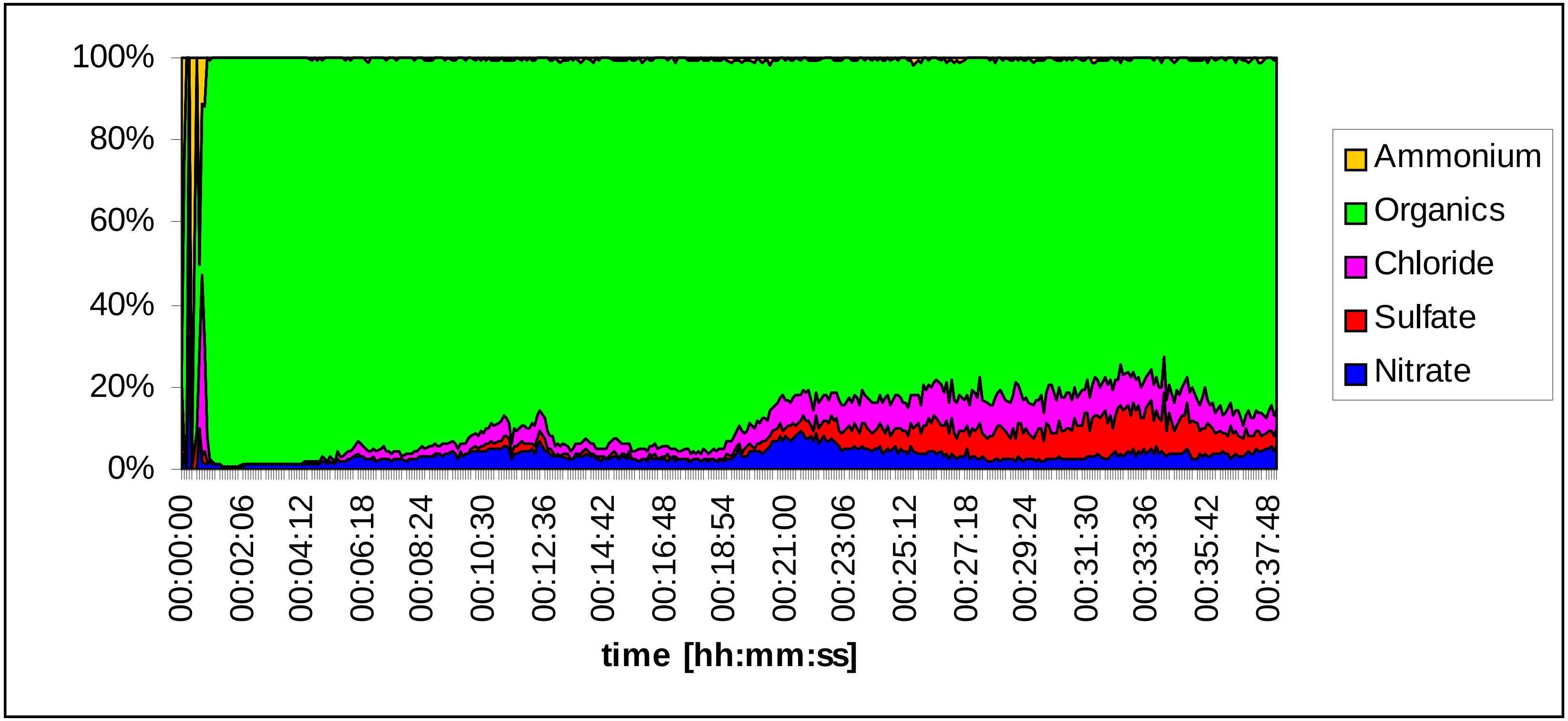
Results AMS Stove I

Chemical composition for burn cycle with starting fire



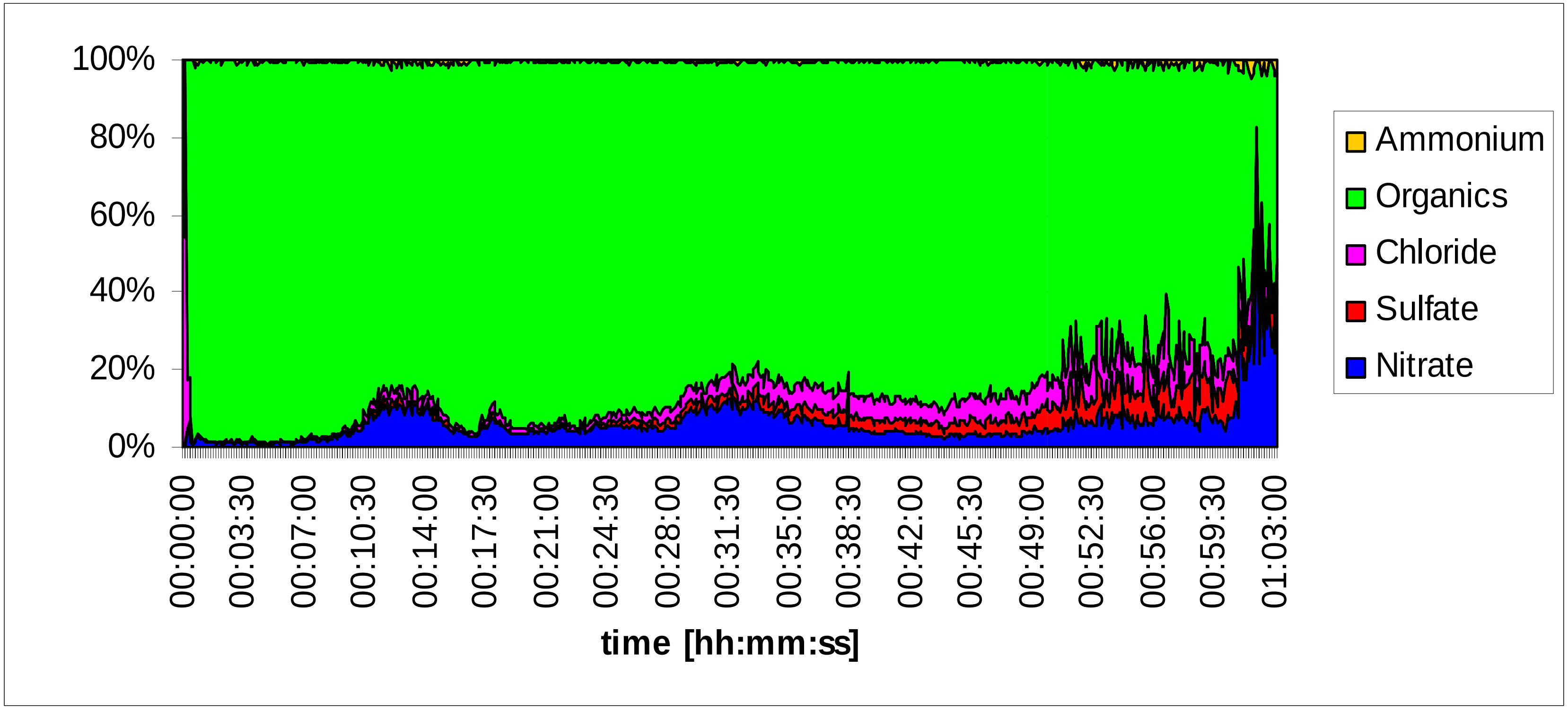
Results AMS Stove II

Chemical composition for burn cycle with bottom up fire

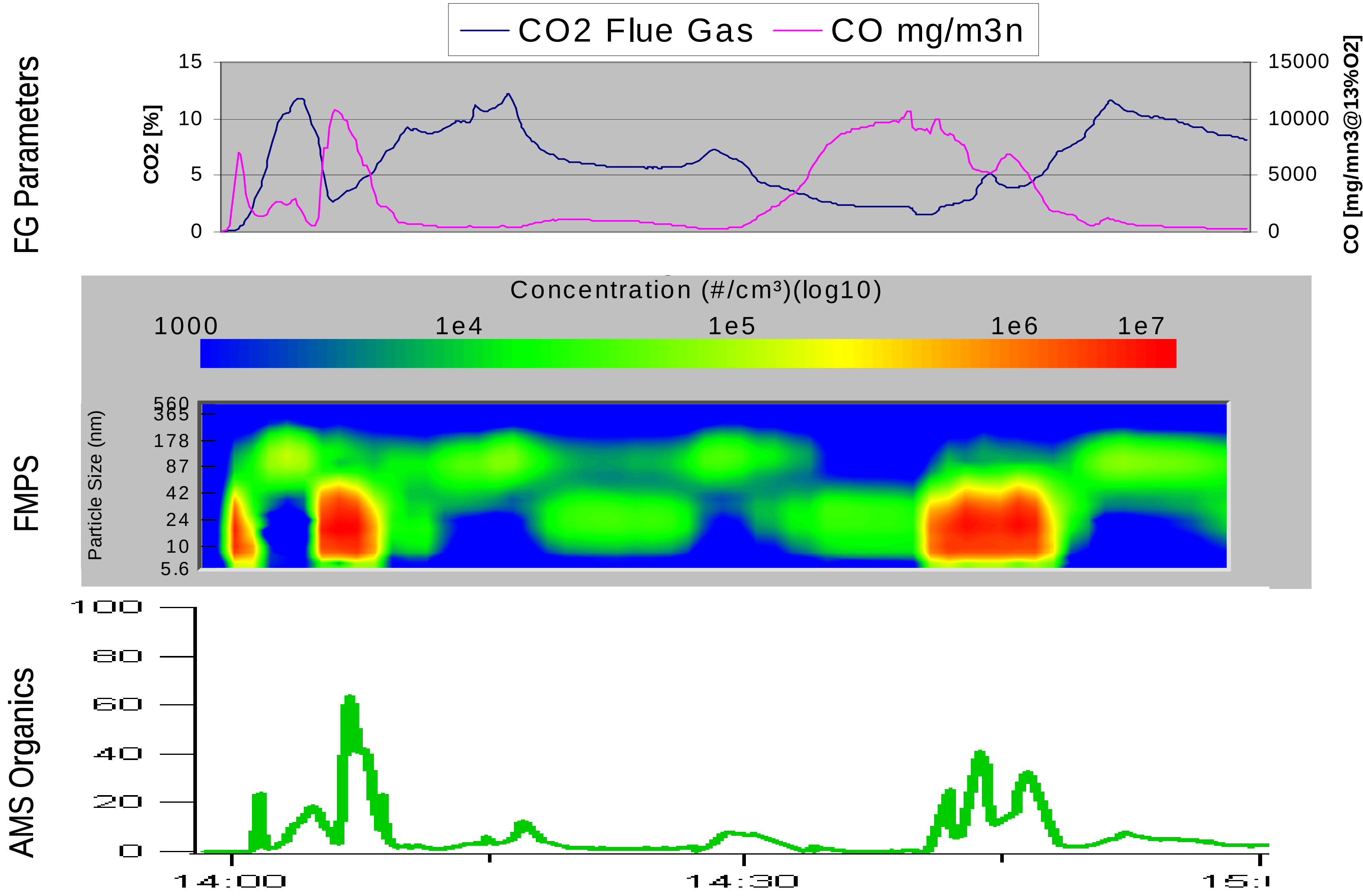


Results AMS Masonry stove

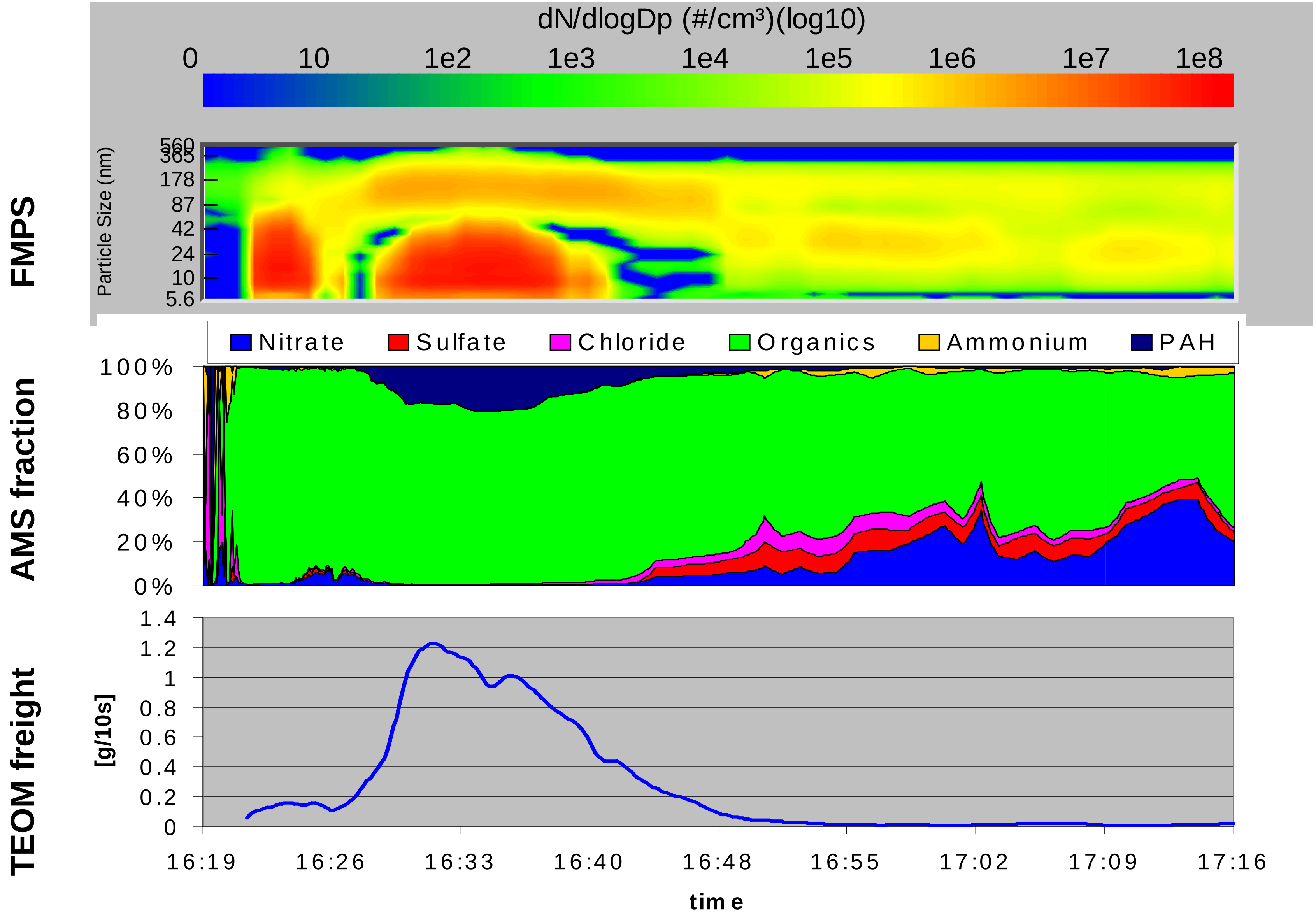
Chemical composition for burn cycle with bottom up fire



Characterizing PM Emissions I (Stove)



Characterizing PM Emissions II (Masonry st.)



Outlook

Headwear

- Improvement of modern wood heat appliances in transient phases
- Controlled combustion (no lack of air)

Environment

- Fingerprints of wood-burning emissions
- Precursor analysis for smog chamber experiments (secondary aerosols)

Legislation

- Field inspection

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Project Partners

Research

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