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Bioenergy and Sustainable Technologies

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Numerical simulation of fuel nitrogen conversion and NO_x emissions in biomass boilers with advanced air staging technology

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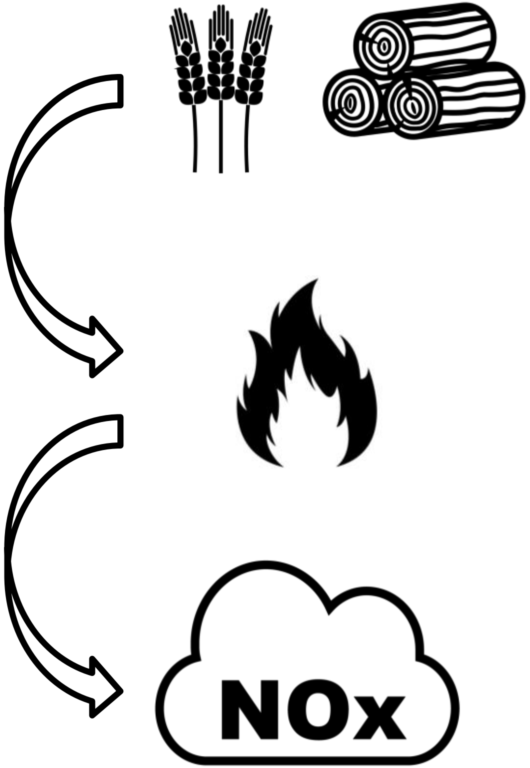
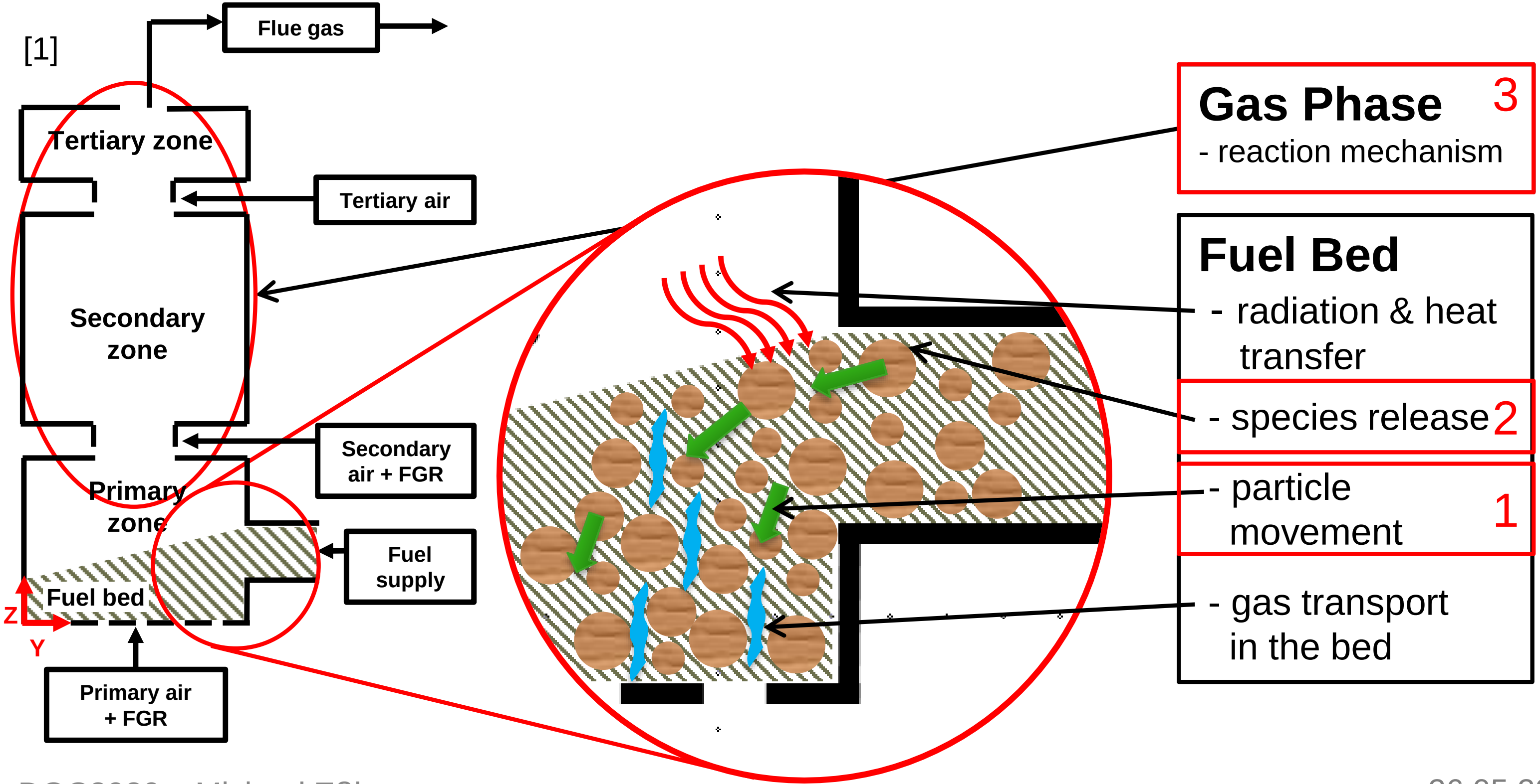
Introduction

- The combustion of cheap fuels with higher nitrogen contents and new legal regulations require a further reduction of NO_x and particulate emissions for biomass furnaces.
- For small scale furnaces secondary measures are currently too expensive.
- Therefore, new technologies which apply cheaper primary measures are under development → double air staging with flue gas recirculation (FGR)



Areas of modelling

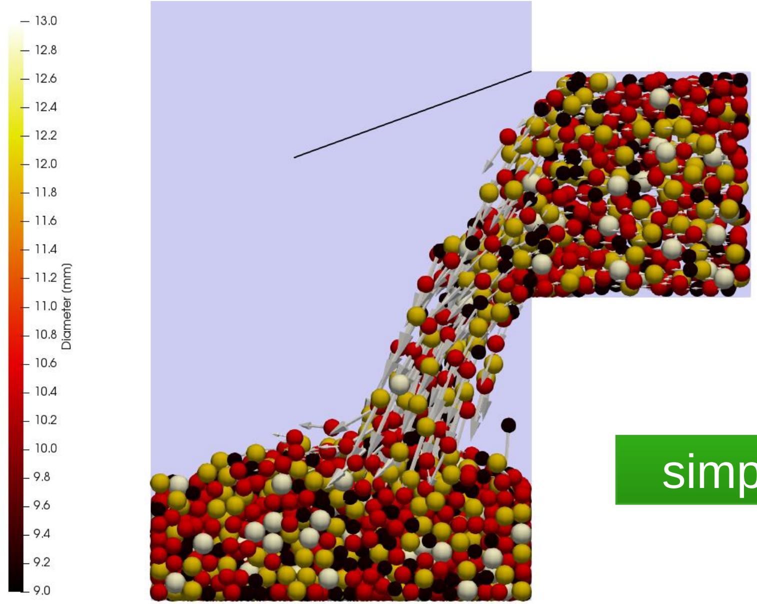
for low oxygen conditions in the fuel bed



[1] Archan, G., et.al., 2020. Detailed experimental investigation of the spatially distributed gas release and bed temperatures in fixed-bed biomass combustion with low oxygen concentration. Biomass and Bioenergy, 141, p.105725.

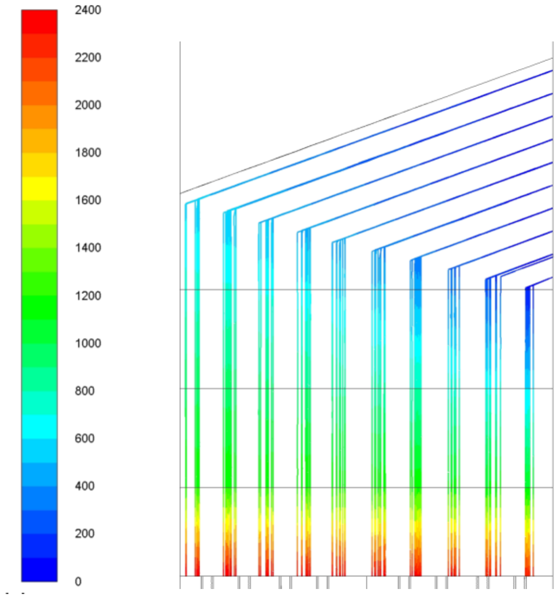
Modelling the fuel bed
particle movement

Discrete Element Simulation (DEM)



simplify

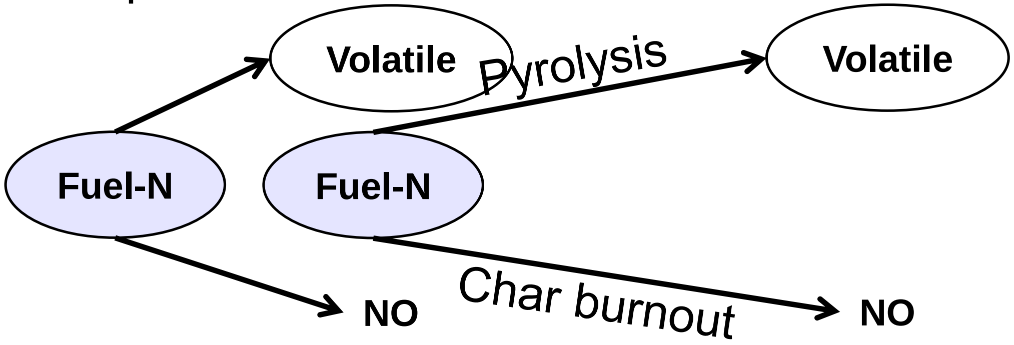
Residence time distribution [s]

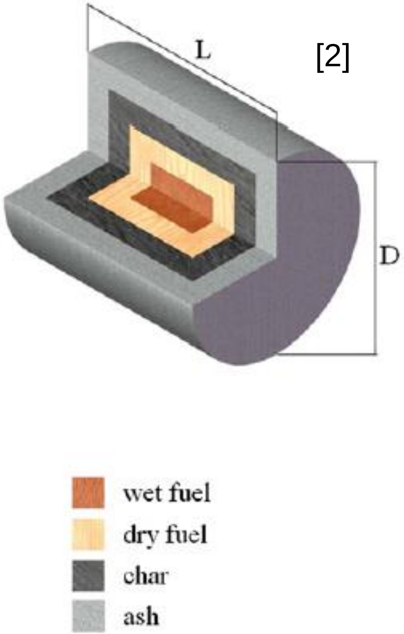


Modelling the fuel particles

species release

- The fuel is modelled via representative particles.
- The particles are tracked via a Lagrangian approach.
- The particle consist of four layers that describe the intra particle gradients and conversion processes, reactions and species release.
- NOx precursor release

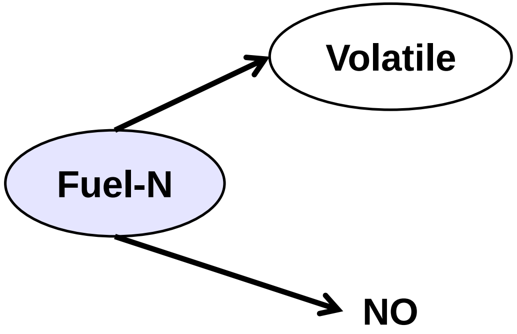




[2]

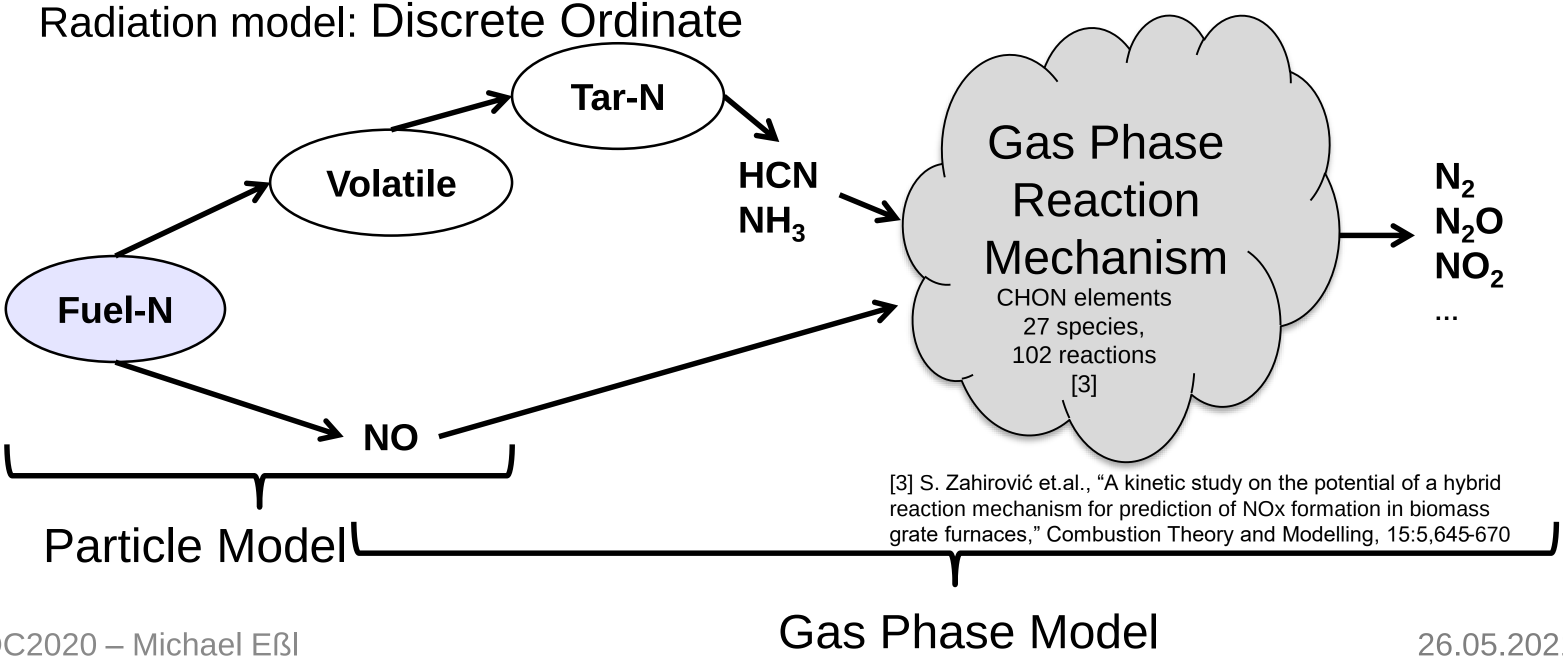
[2] Mehrabian, R., et.al., 2012. A CFD model for thermal conversion of thermally thick biomass particles. Fuel Processing Technology, 95, pp.96-108.

Modelling the fuel particles
species release



Modelling the gas phase
interaction with fuel bed and reaction mechanism

- Turb./Chem. Interaction: EDC (2005)
- Turbulence model: realizable k-ε
- Radiation model: Discrete Ordinate



[3] S. Zahirović et.al., "A kinetic study on the potential of a hybrid reaction mechanism for prediction of NOx formation in biomass grate furnaces," Combustion Theory and Modelling, 15:5,645-670

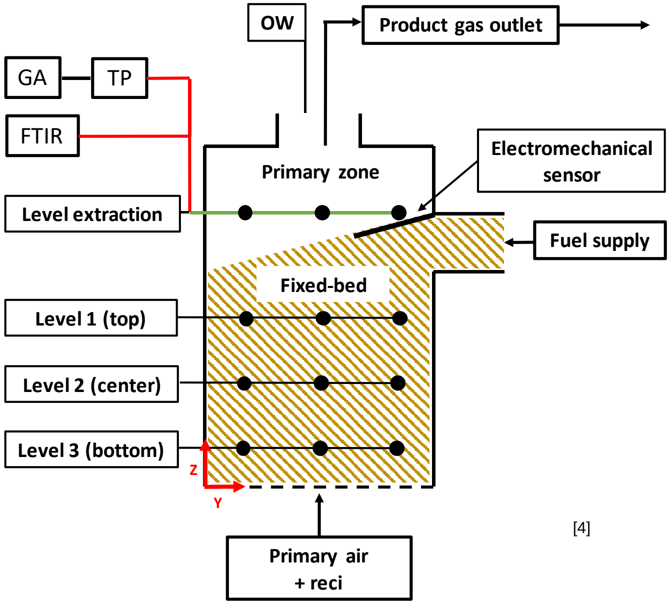
Simulation Setup

small scale application – 35kWth

Operating conditions

- Fuel: spruce wood chips
- Moisture: 8.0 and 30.7 m.%w.b.
- Fuel rate: 6.78 and 8.3 kg/h w.b.
- Fuel-N: < 0.1 m.%d.b.
- Primary air ratio: 0.2
- Secondary air ratio: 0.9
- Total air ratio: 1.4

Measurements



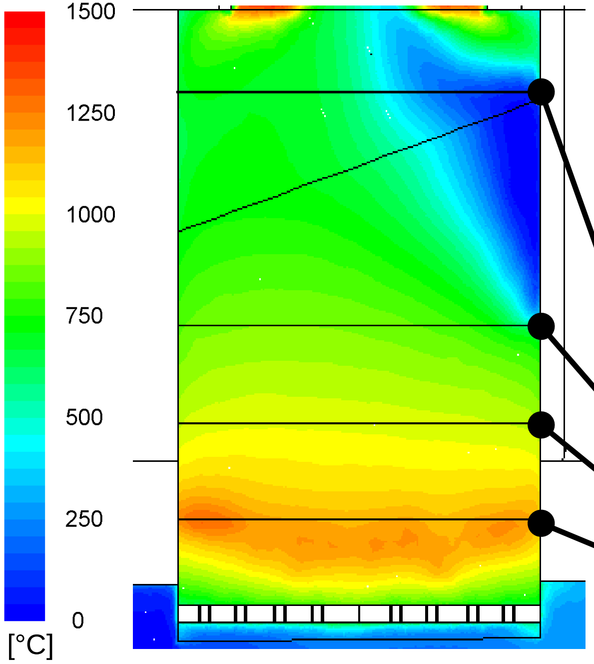
[4]

[4] Archan, G., et.al., 2020. Detailed experimental investigation of the spatially distributed gas release and bed temperatures in fixed-bed biomass combustion with low oxygen concentration. Biomass and Bioenergy, 141, p.105725.

Simulation results - I

temperature distribution in the fuel bed

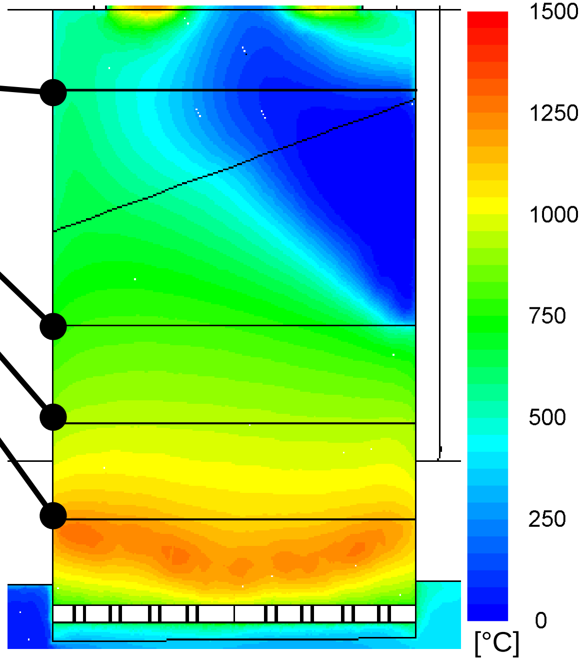
Fuel moisture content: 8 wt%



Sim.	Exp.	Dev.
453	553	-22%
807	738	+9%
972	950	+2%
1196	1079	+10%

Fuel moisture content: 30 wt%

Sim.	Exp.	Dev.
267	295	-10%
712	434	+39%
929	819	+12%
1137	1106	+3%

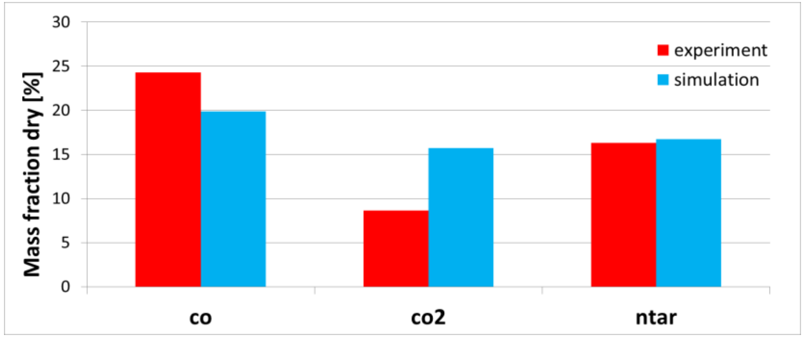


Exp. ➔ Thermo couples
Sim. ➔ Gas temperature

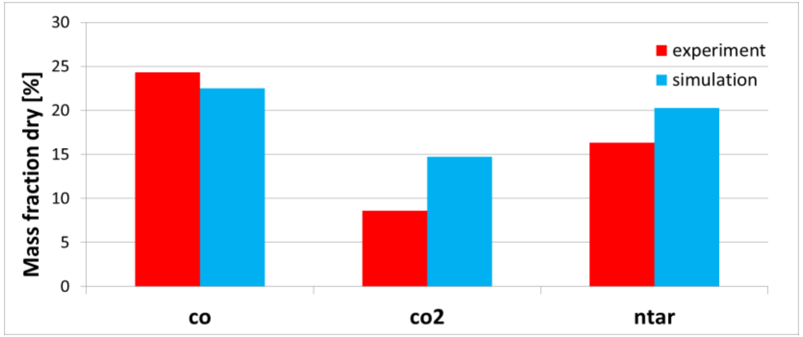
Simulation results - Ⅱ

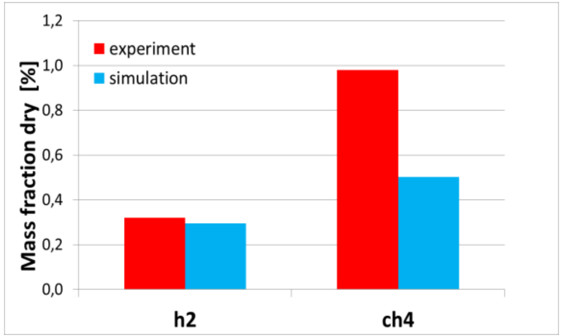
species release above the fuel bed – average at level extraction

Fuel moisture content: 8 wt%

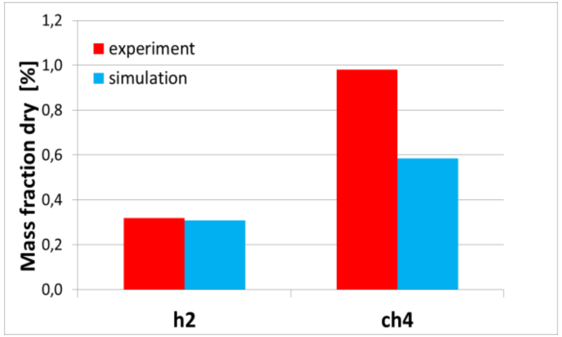


Fuel moisture content: 30 wt%





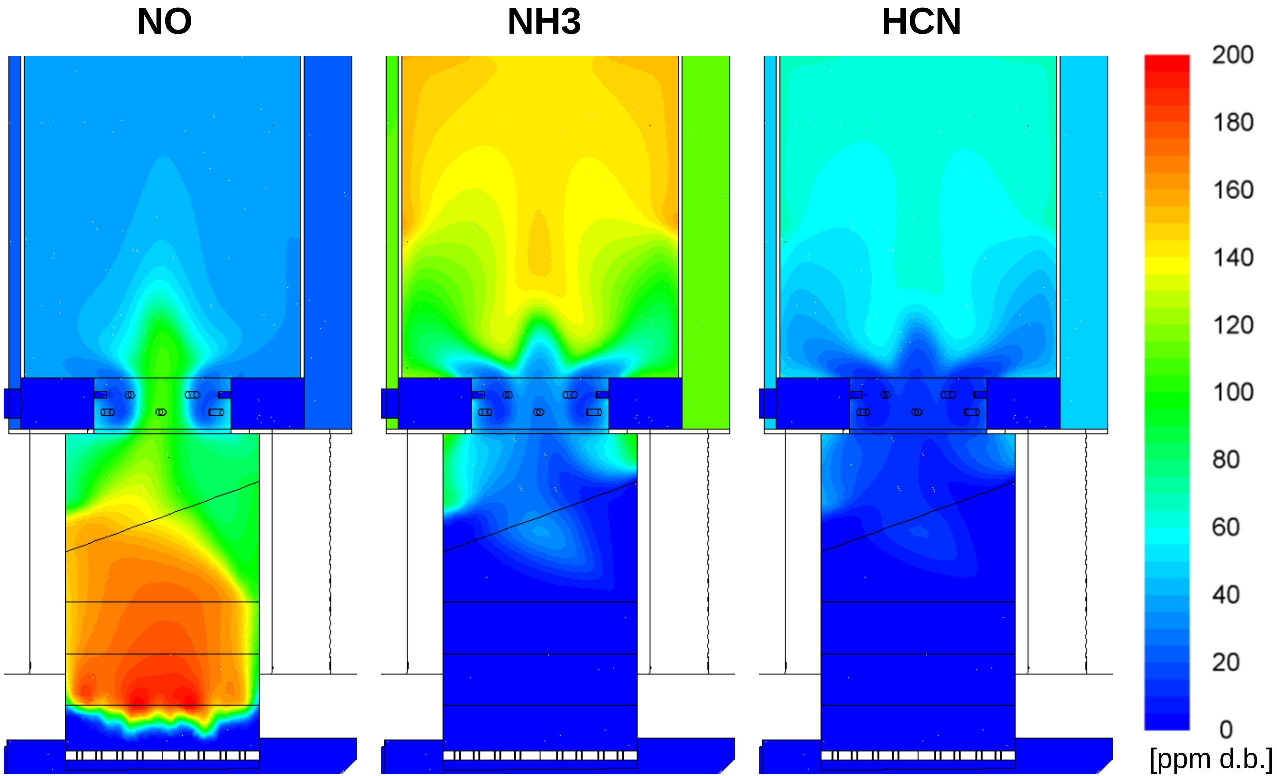
- The concentrations vary widely over the cross section and the simulation can also represent that.
- Reasonable agreement for averaged value
- Underprediction of CO, CH_4
- Overprediction of CO_2



Simulation results - Ⅲ

N-precursor release - fuel moisture content: 8 wt%

- Release and transport of:
  - NO from char burnout
  - NH_3, HCN from Tar-cracking in PCZ and SCZ
- No gas phase reactions active to reduce NO_x.



Summary

- The presented work marks the first step towards a better understanding of the mechanisms of the newly developed technology.
- The applied models for the heat transfer in the fuel bed still lack to predict the measured temperature distribution in the bed with acceptable accuracy.
- However the simulations can represent the measured species concentration above the fuel bed with acceptable accuracy for wood chips at different moisture contents.

Outlook

- In order to get a more realistic prediction of the fuel bed movement further simulations with multiphase or DEM models should be performed. A direct coupling of these models with the current particle model will be pursued.
- The streak formation in the fuel bed should be taken into account to get a better representation of the gas flow and reaction kinetic inside the bed.
- The radiation and heat transfer models also need further improvement to better predict the temperature distribution inside the fuel bed.
- Furthermore also the conversion of NO_x species in the gas phase as well as inside the fuel bed.