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Modelling and analysis of NO_x formation paths for pulverized biomass combustion

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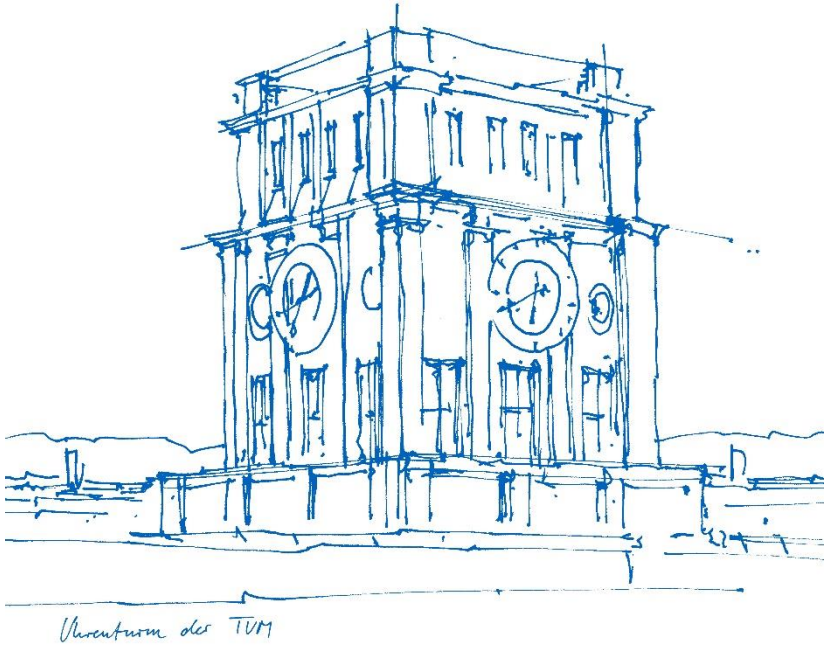


Federal Ministry of Food and Agriculture

FNR Fachagentur Nachwachsende Rohstoffe e.V.

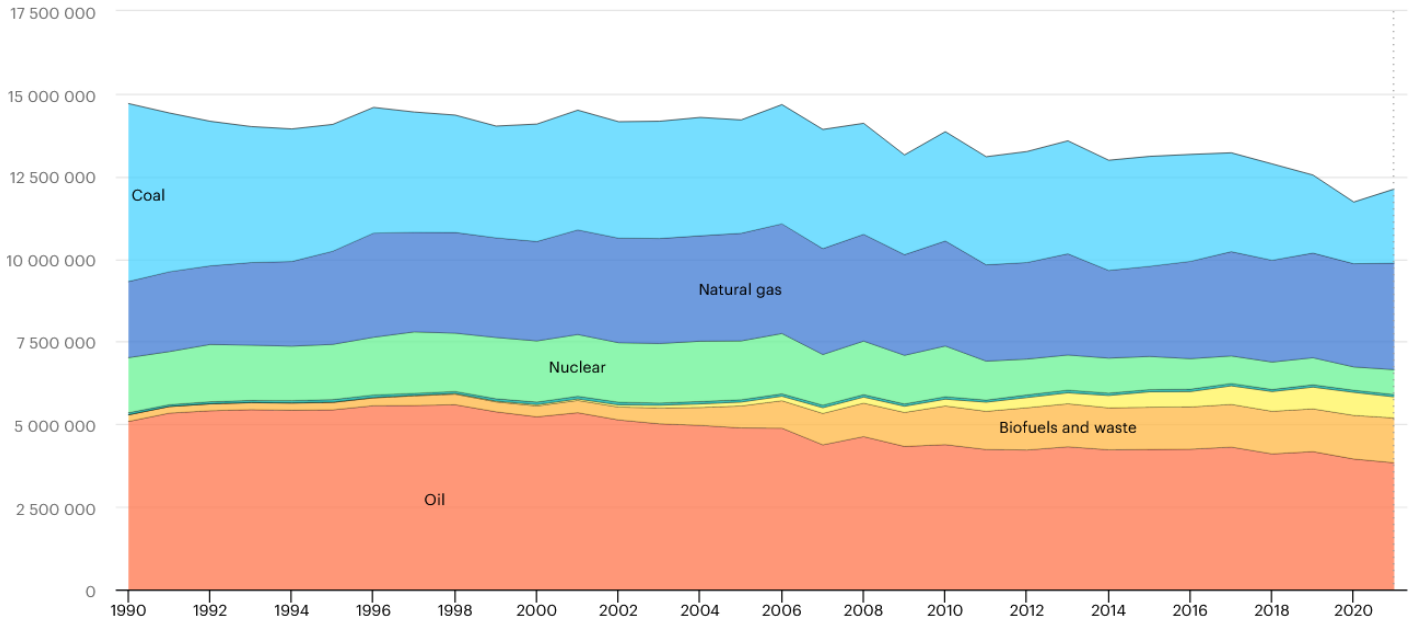
Agenda

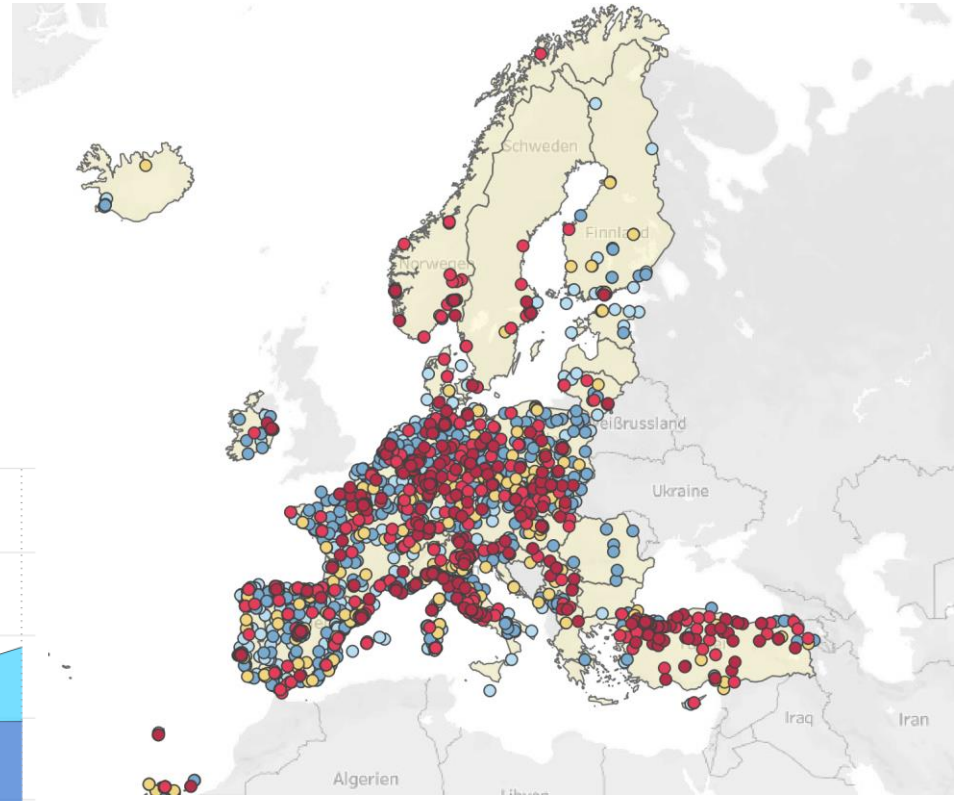
- Motivation
- OptiNOx
- CFD-Model
- Results
- Outlook

Motivation

Regulations (Annual mean value for NO_x):

- EU: < **40 µg/m³** for human health
  < **30 µg/m³** for vegetation
- WHO guideline: < **10 µg/m³**





NO_x as NO_2 – Annual mean value

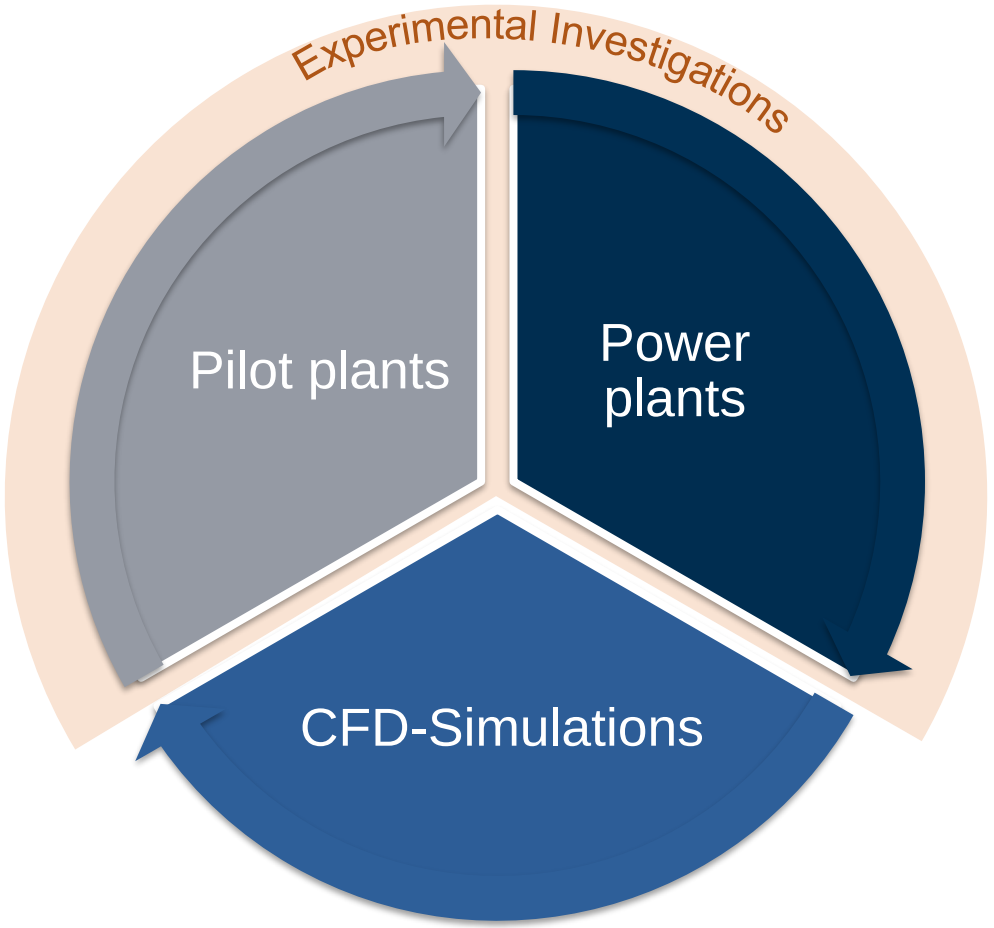
- > 50 µg/m³
- > 30 µg/m³ and ≤ 50 µg/m³
- > 20 µg/m³ and ≤ 30 µg/m³
- > 10 µg/m³ and ≤ 20 µg/m³
- ≤ 10 µg/m³

Sources: IEA Website, online, accessed 31.05.2023
EEA Website, online, accessed 31.05.2023

OptiNOx (Optimization of biomass furnaces with the aim of reducing NOx emissions)

Preliminary studies

- characterization of the fuel

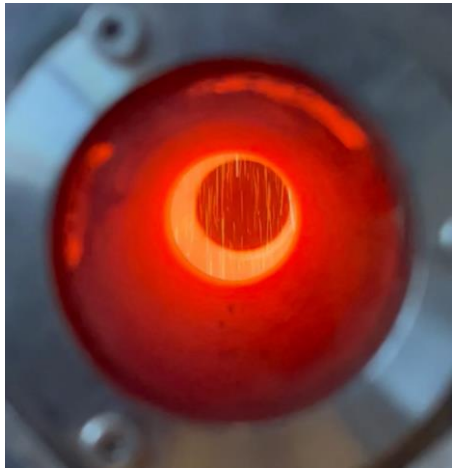


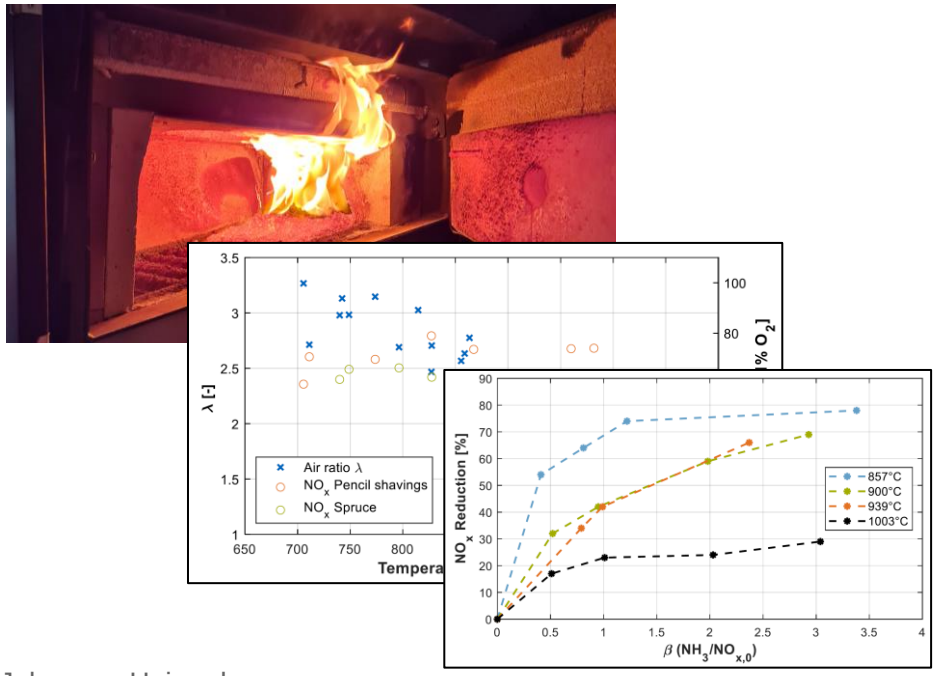
Technological evaluation and economic recommendation

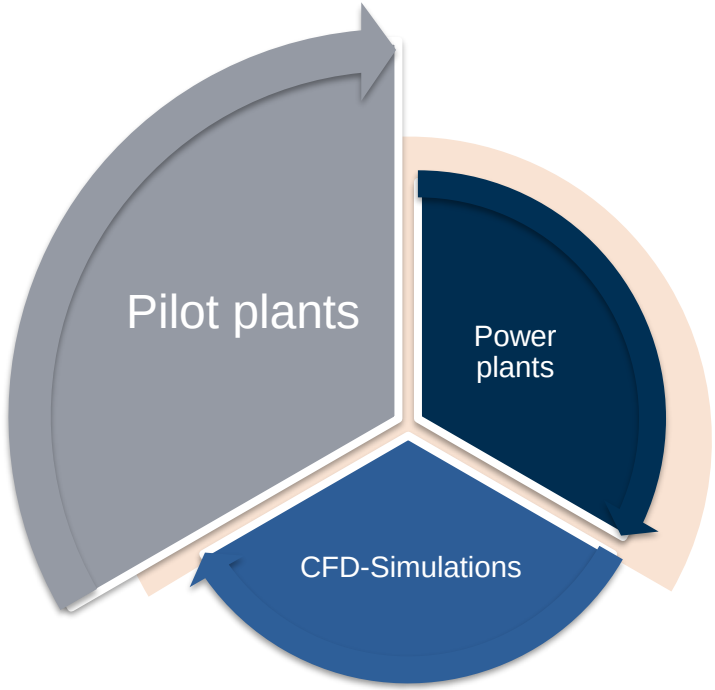
OptiNOx

Pilot plants:

- Combustion of fuel in different pilot-scale plants
- Measurement of NO_x precursor species (NH_3, HCN)
- Investigation of primary and secondary measures to reduce emissions



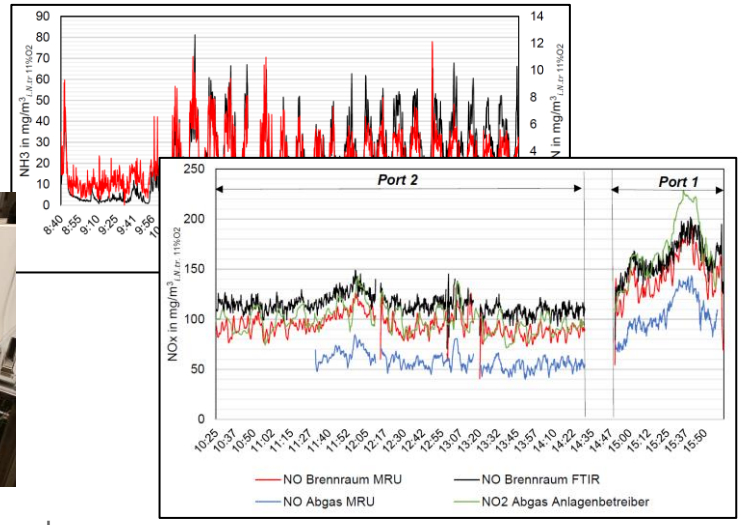


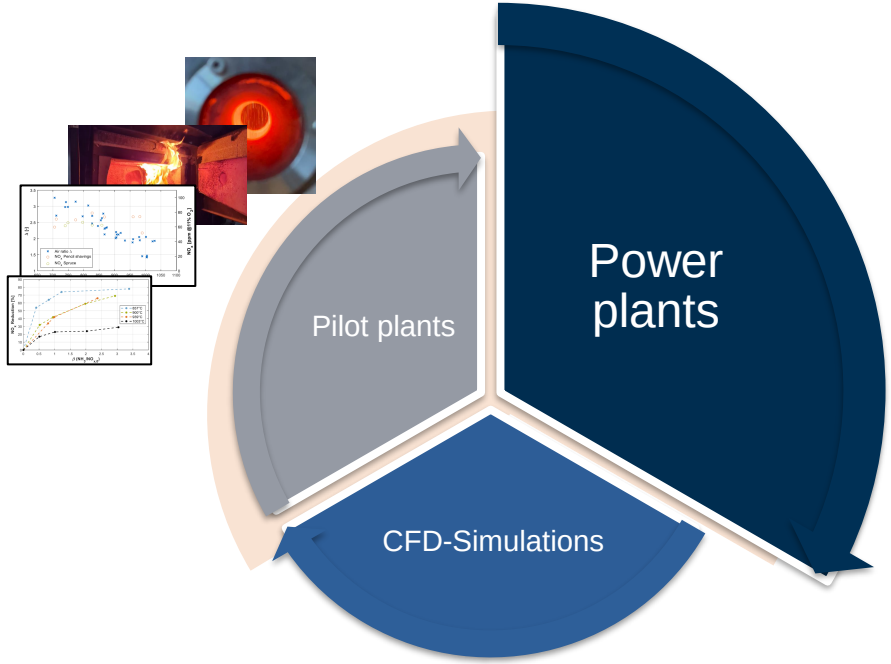


OptiNOx

Power Plants:

- Measurements of NO_x precursor species at different power plants
  - Skærbæk Power Plant (vibrating grate, 130 MW)
  - Avedøre Unit 2 (Straw Boiler) (vibrating grate, 105 MW)
  - Altenstadt HKW (fluidized bed, 49 MW)
  - Staedtler Residue Pencil Wood (injection furnace, 850 kW)

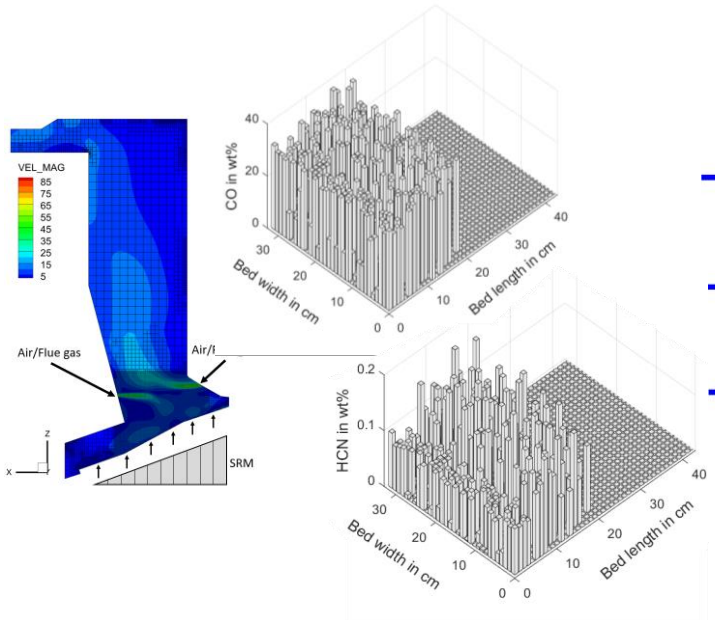


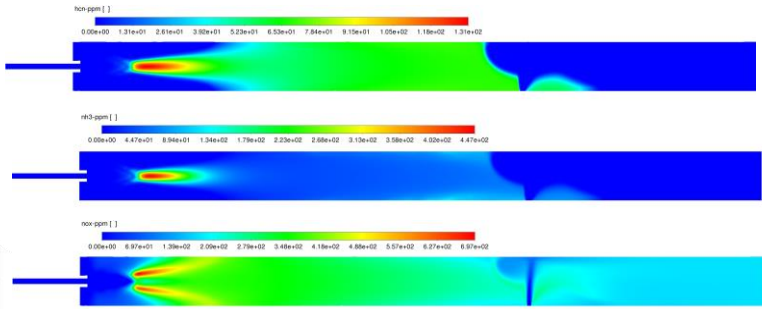


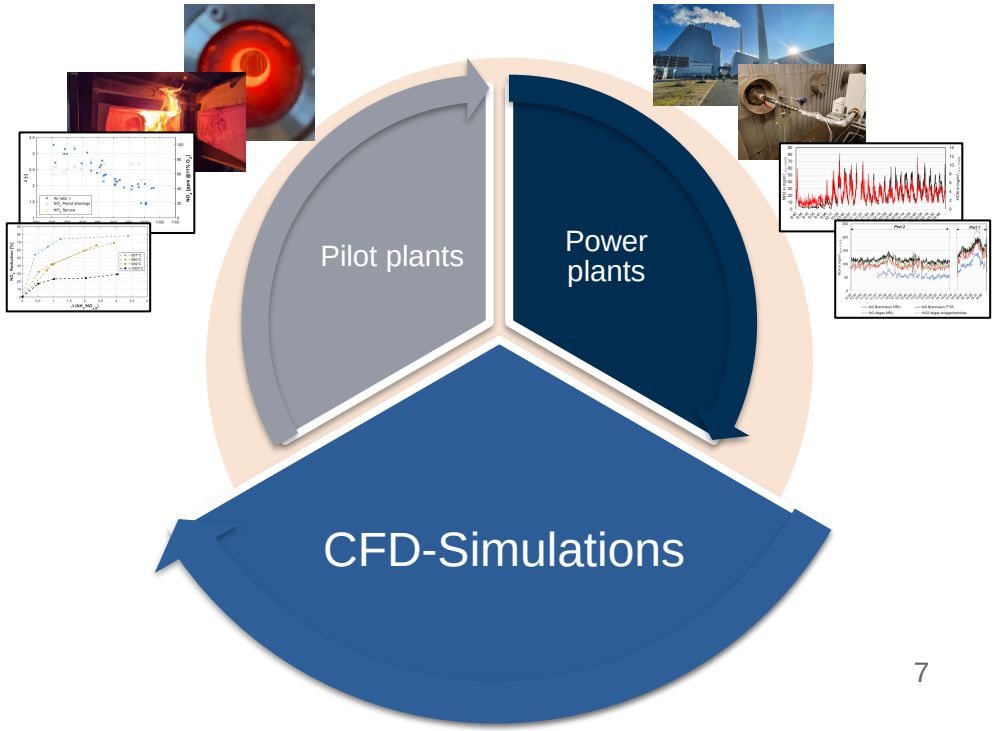
OptiNOx

CFD-Simulations:

- Development of NO_x and burnout models
- Simulation of pilot plants and real power plants
  → Validation with the gained experimental data
- **Optimization of the power plants**

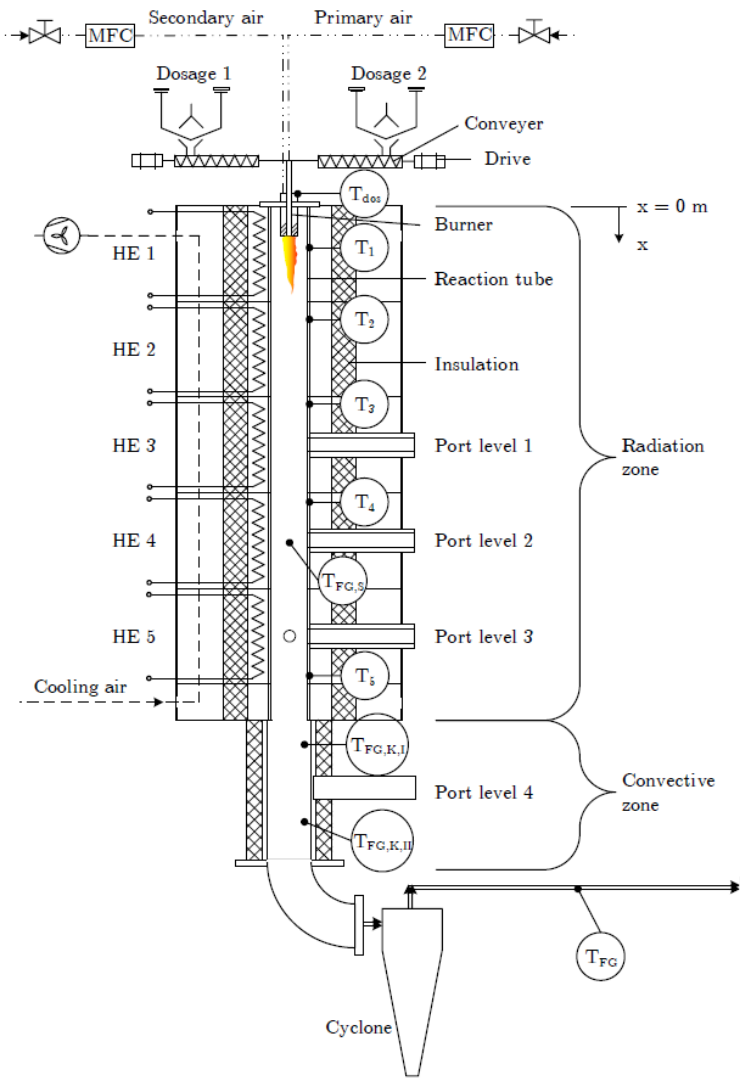






Model

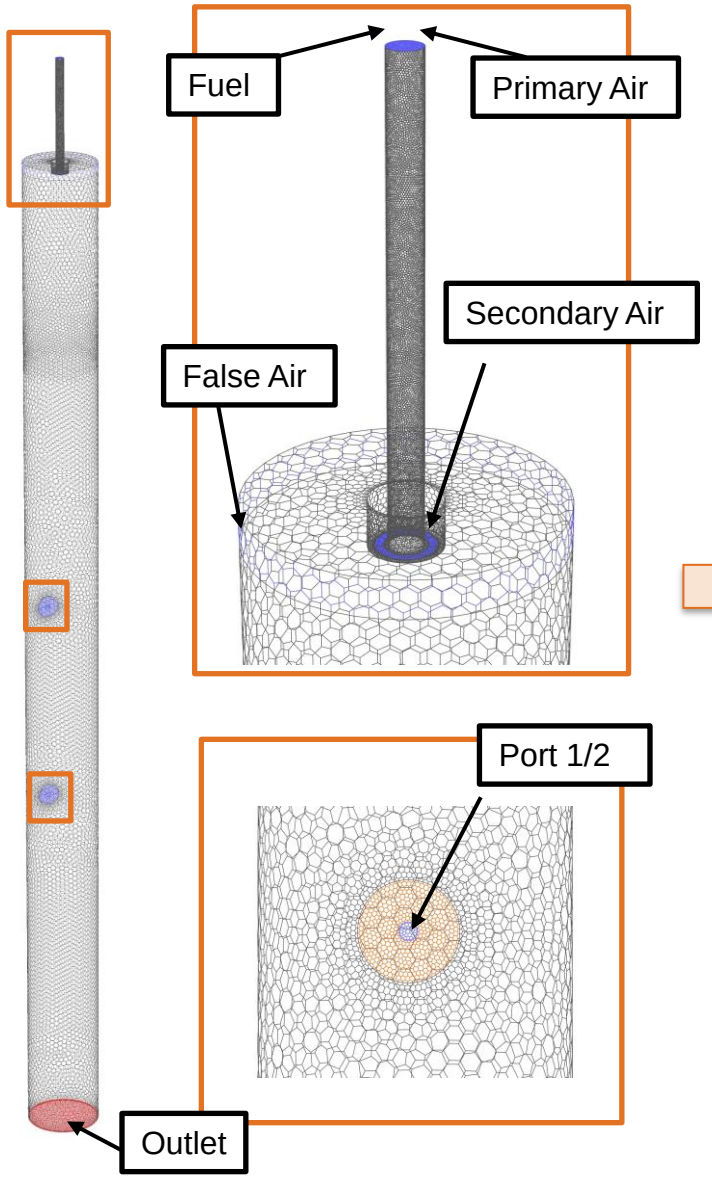
Entrained Flow Reactor

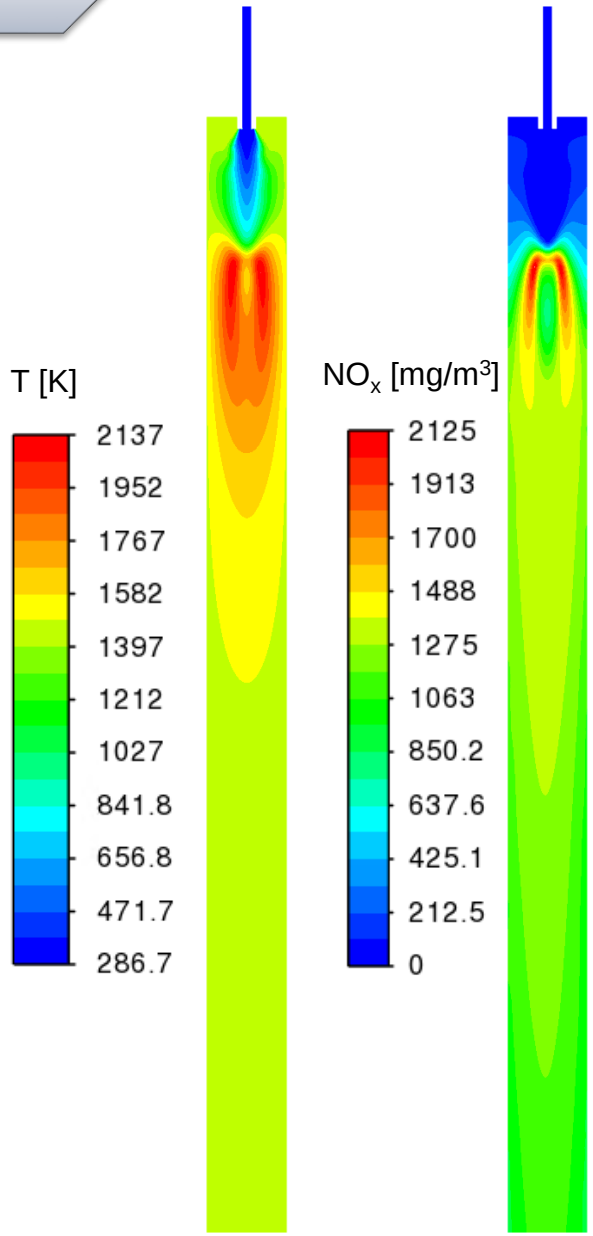


Source: U.Kleinhans, Dissertation TUM

Model

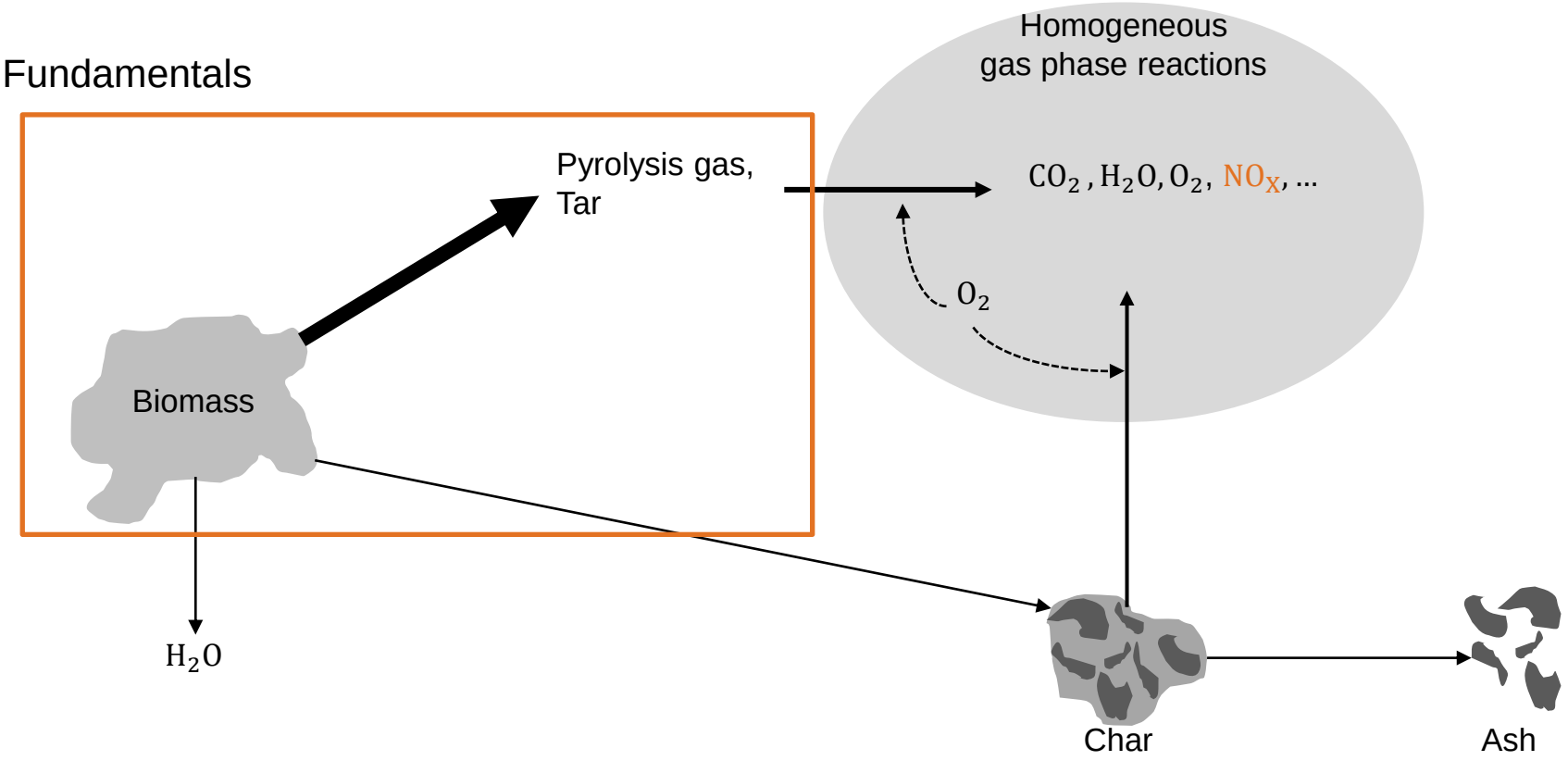
Entrained Flow Reactor





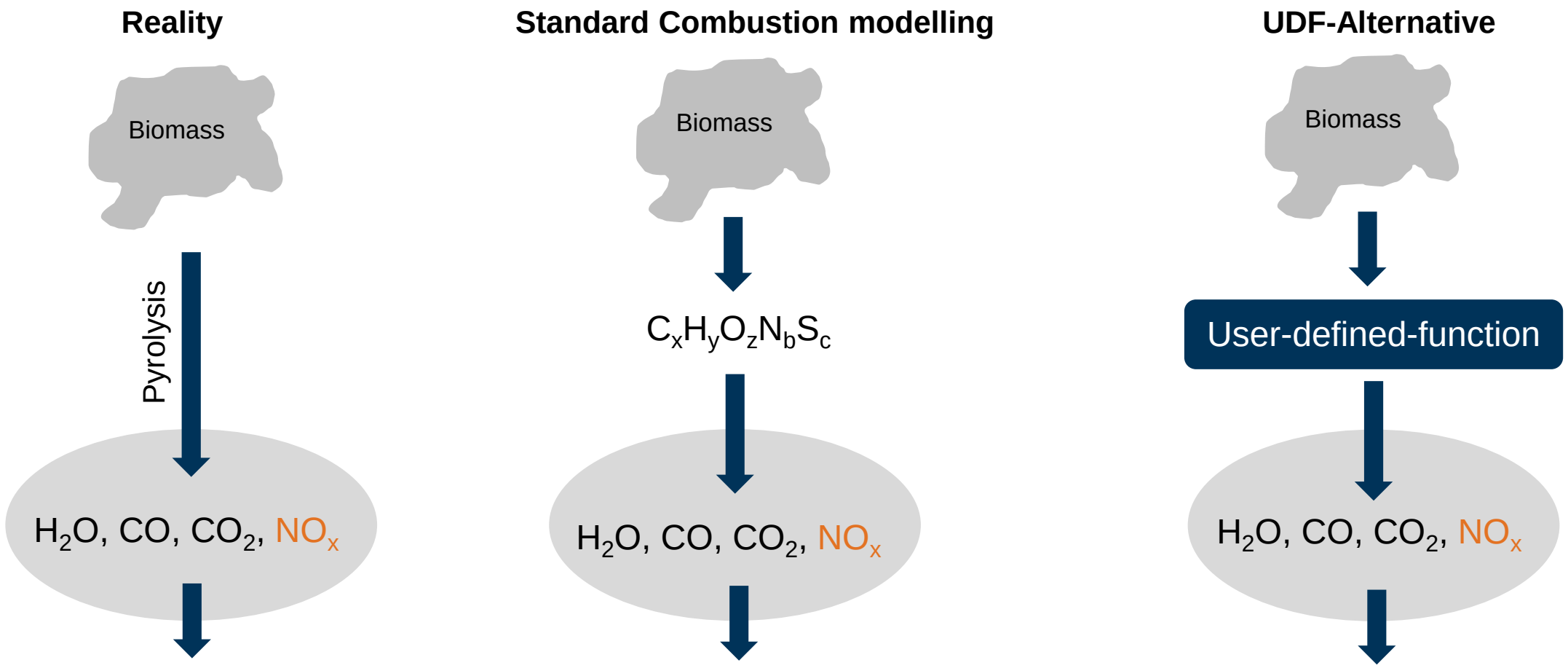
Model

Combustion Fundamentals



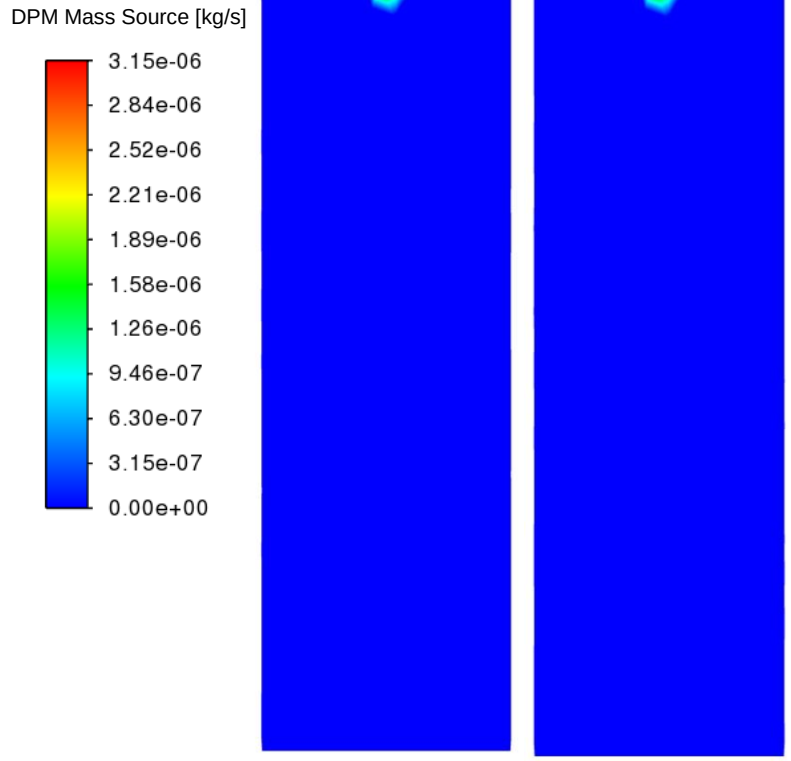
Drying **Pyrolysis** **Burnout**

Model

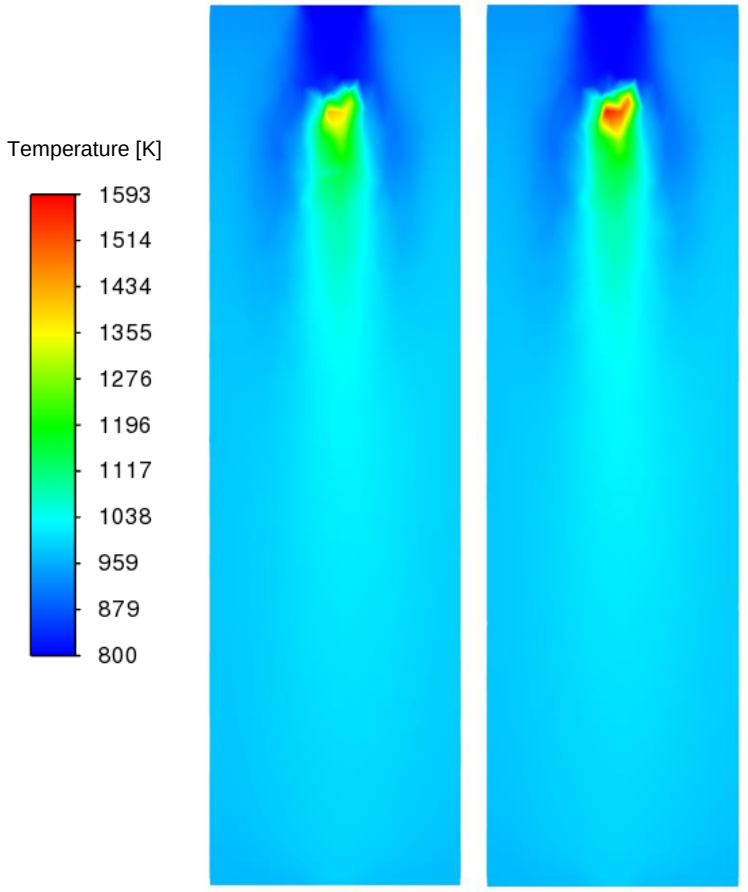

Reality
Biomass
Pyrolysis
H_2O, CO, CO_2, NO_x
Standard Combustion modelling
Biomass
$C_xH_yO_zN_bS_c$
H_2O, CO, CO_2, NO_x
UDF-Alternative
Biomass
User-defined-function
H_2O, CO, CO_2, NO_x

Model - Validation

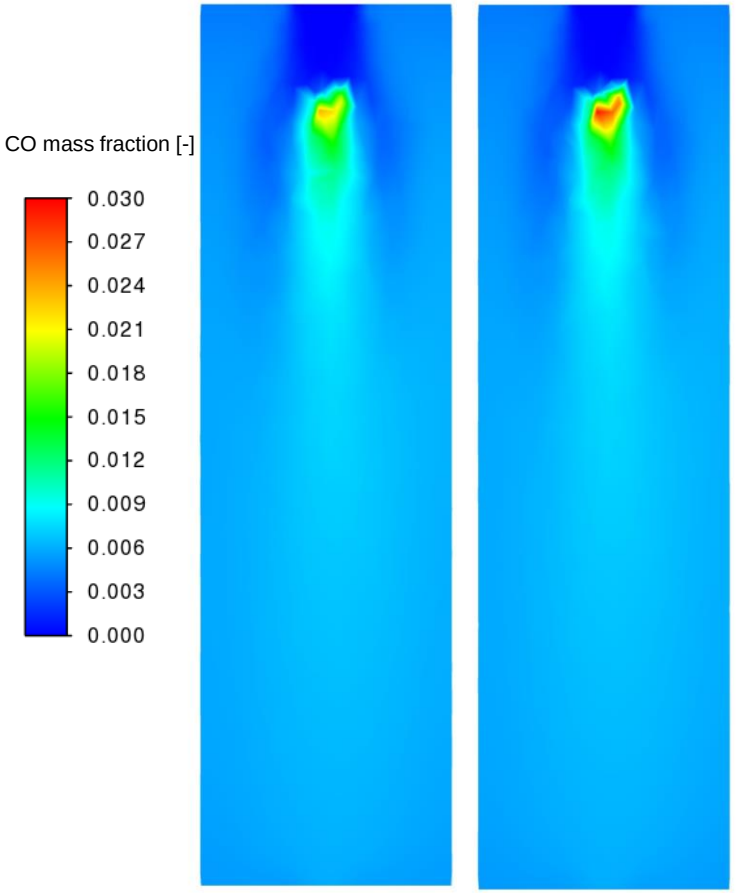
Standard **UDF**



Standard **UDF**



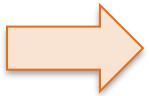
Standard **UDF**



Model – NO_x Simulation

Combustion Simulation:

- Energy equation
- Turbulence Model (*k-ε Model; Standard Wall Functions*)
- Radiation Model (*Discrete Ordinates*)
- Particle Tracking (*Discrete Phase Model; Discrete Random Walk Model*)
- Reaction Model (*Eddy Dissipation Concept; ISAT*)



Pollutant Simulation:

- Fixed temperature and velocity field
- Reaction Model (*Eddy Dissipation Concept; ISAT*)

Global Reaction Mechanism: 10 species and 4 reactions

Skeletal NO_x Mechanism: 38 species and 168 reactions

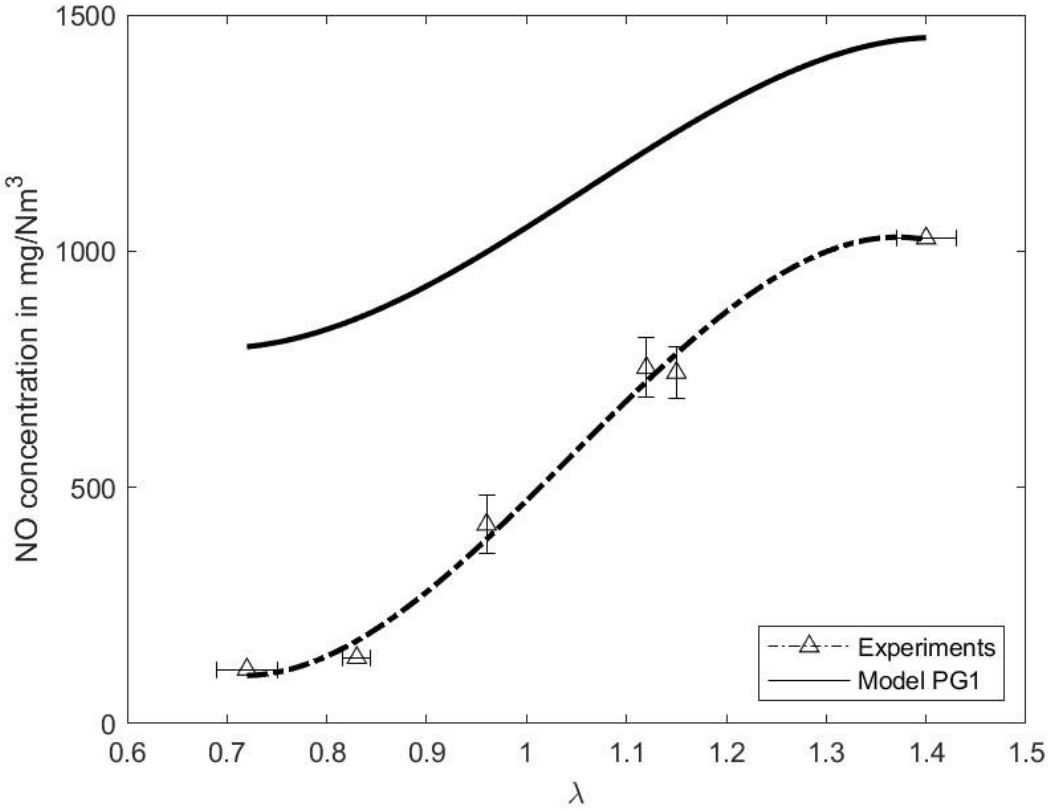
Mesh independence study ✓

Reaction Mechanism independence study ✓

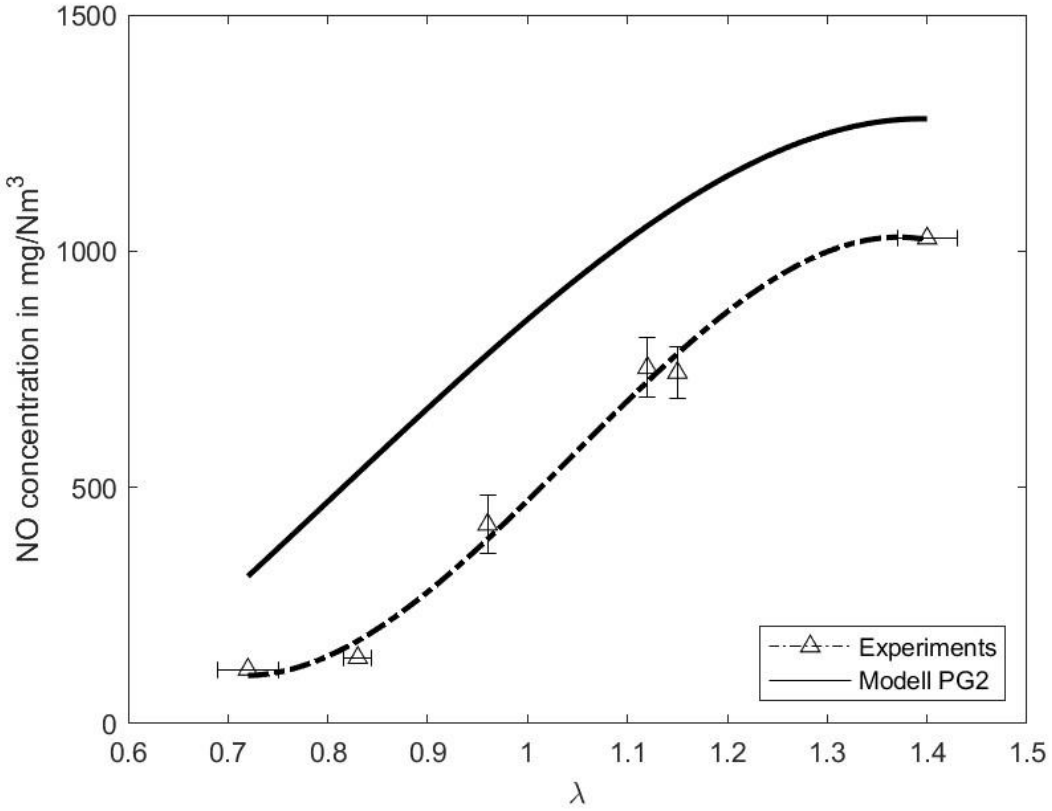
Results

Alder Wood at 1200 °C (Nitrogen content: 0.36 wt.%)

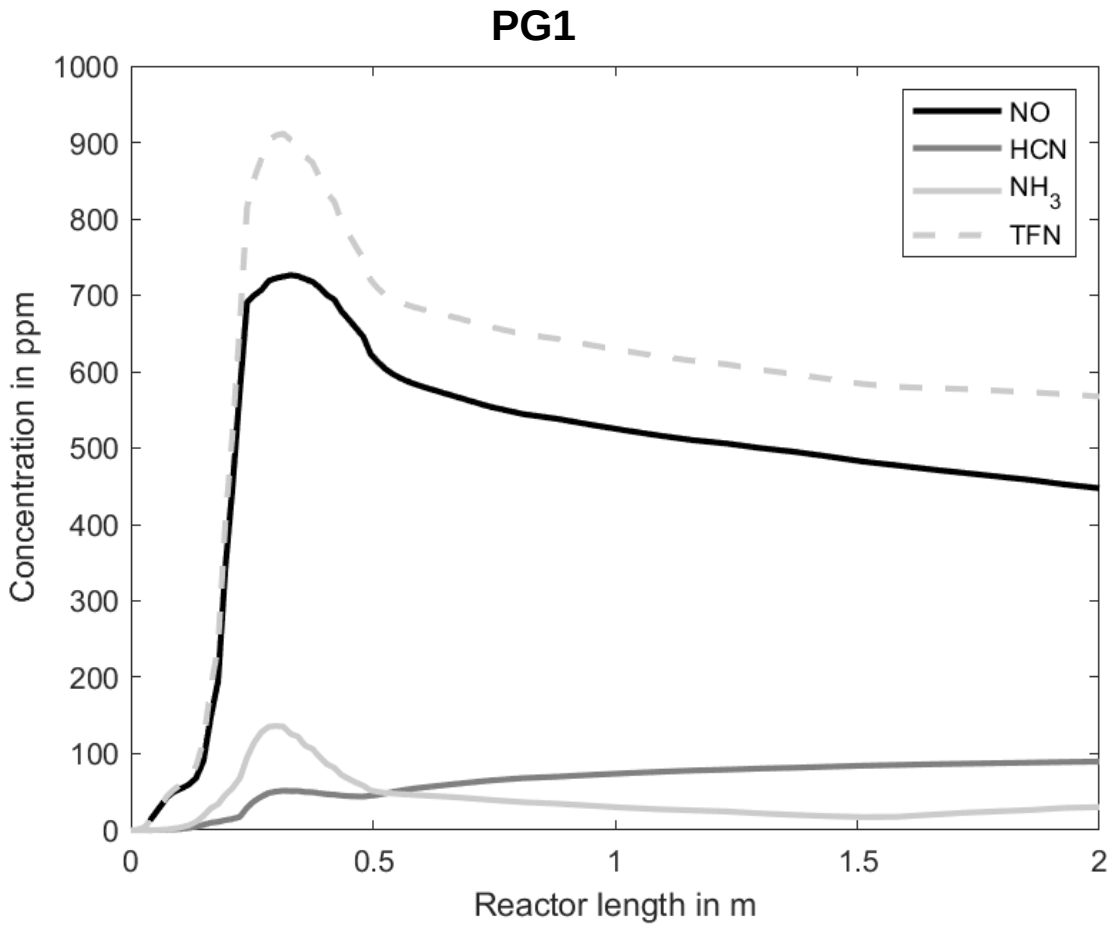
PG1 (CO: 81 wt-%; CH_4: 12 wt-%,…)

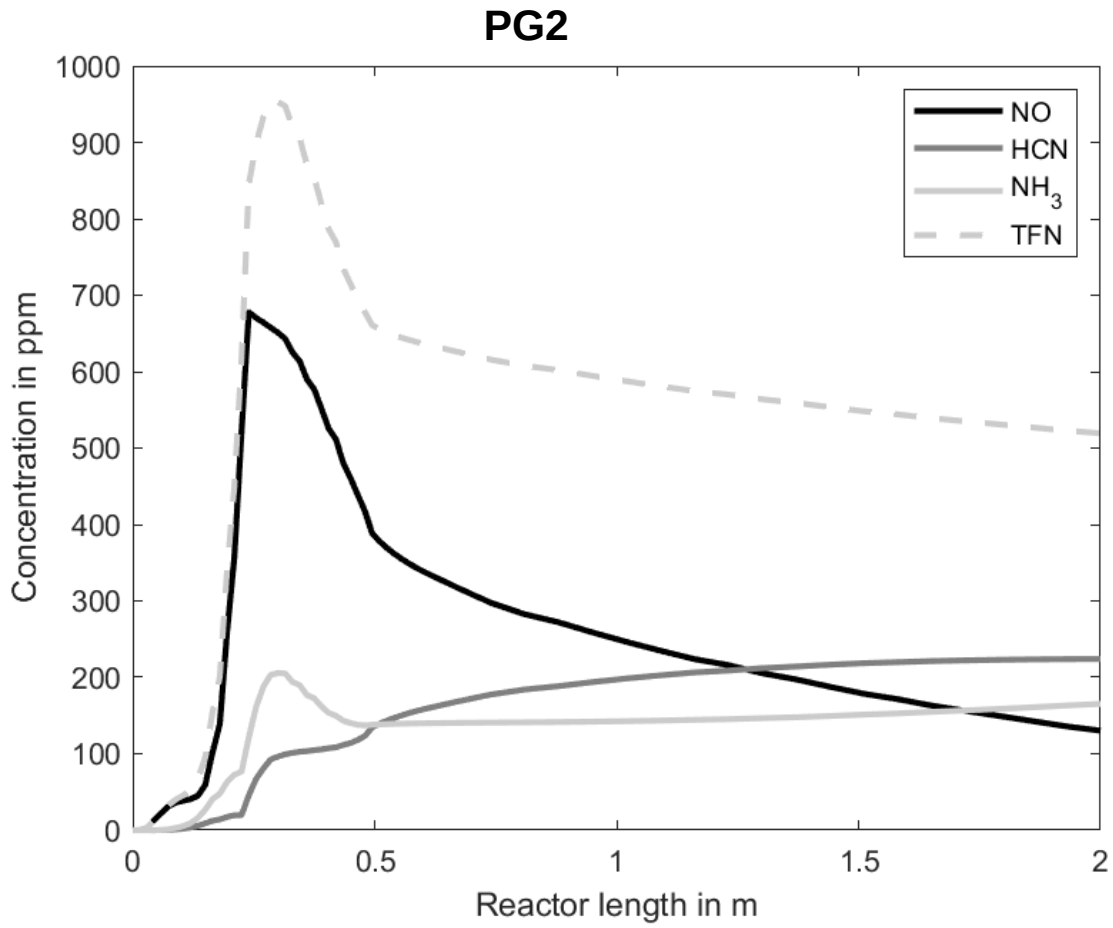


PG2 (CO: 55 wt-%; CH_4: 27 wt-%,…)



Results


PG1
Concentration in ppm
Reactor length in m
NO
HCN
NH3
TFN
0
100
200
300
400
500
600
700
800
900
1000
0
0.5
1
1.5
2


PG2
Concentration in ppm
Reactor length in m
NO
HCN
NH3
TFN
0
100
200
300
400
500
600
700
800
900
1000
0
0.5
1
1.5
2

Outlook

Comparison

- alternative Model was validated against the standard modelling approach
- Composition of the pyrolysis gas has a high influence on the resulting NO_x emissions
- Influences such as TFN conversion factor and composition of the NO_x precursor species need to be analyzed

Next Steps:

- Couple releases of NO_x precursor species to the local conditions in the flame (Temperature, Oxygen Content)
- Implement variable kinetic models for the different species

Thank you for your attention!

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