IEA Bioenergy Task 32 Workshop – 06 June 2013

3D-CFD Modeling of Biomass Co-Firing and Conversion to 100% Biomass for Pulverized Fuel Boilers including NOx and Burnout Predictions

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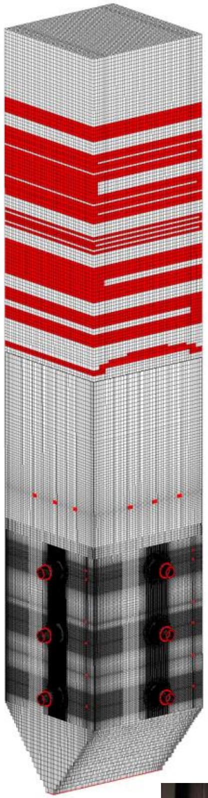
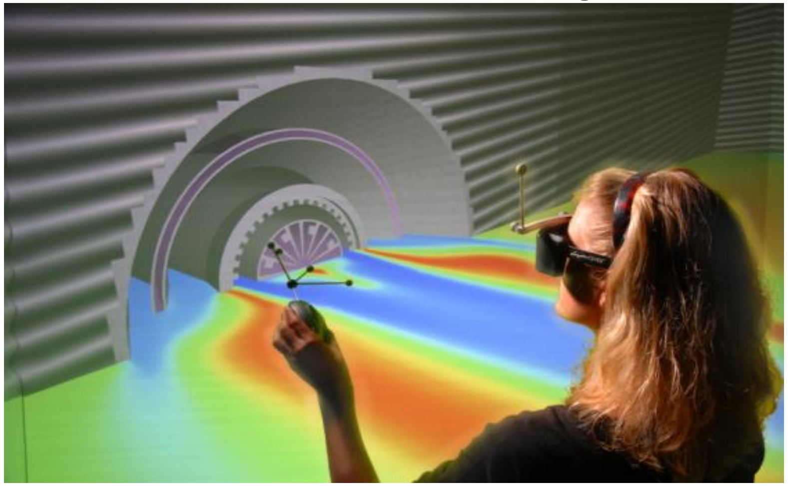
RECOM Services GmbH, Stuttgart, Germany

RECOM is a specialized company in 3D-CFD Boiler Simulation

3D-Boiler Model with 10-20 Mio. cells



3D-Visualisation of computational results in the Virtual Reality



Simulation on Supercomputer Cray XE6 System (> 100.000 cores) at HLRS in Stuttgart

Target:

- **Improved understanding of the physical/chemical processes**
- **Identification of the relevant mechanisms that lead to the phenomena observed in the field**

Background

- RECOM Services offers 3D-Combustion Modelling
  as a tool for the assessment of technical risks involved with:
  - Fuel Changes (Coal, Oil, Gas, Secondary Fuels)
  - Operational Changes (Air Distribution, Coal Bias, Particle Fineness)
  - Design Changes in Combustion Equipment (Low-NOx Burners, Overfire Air)

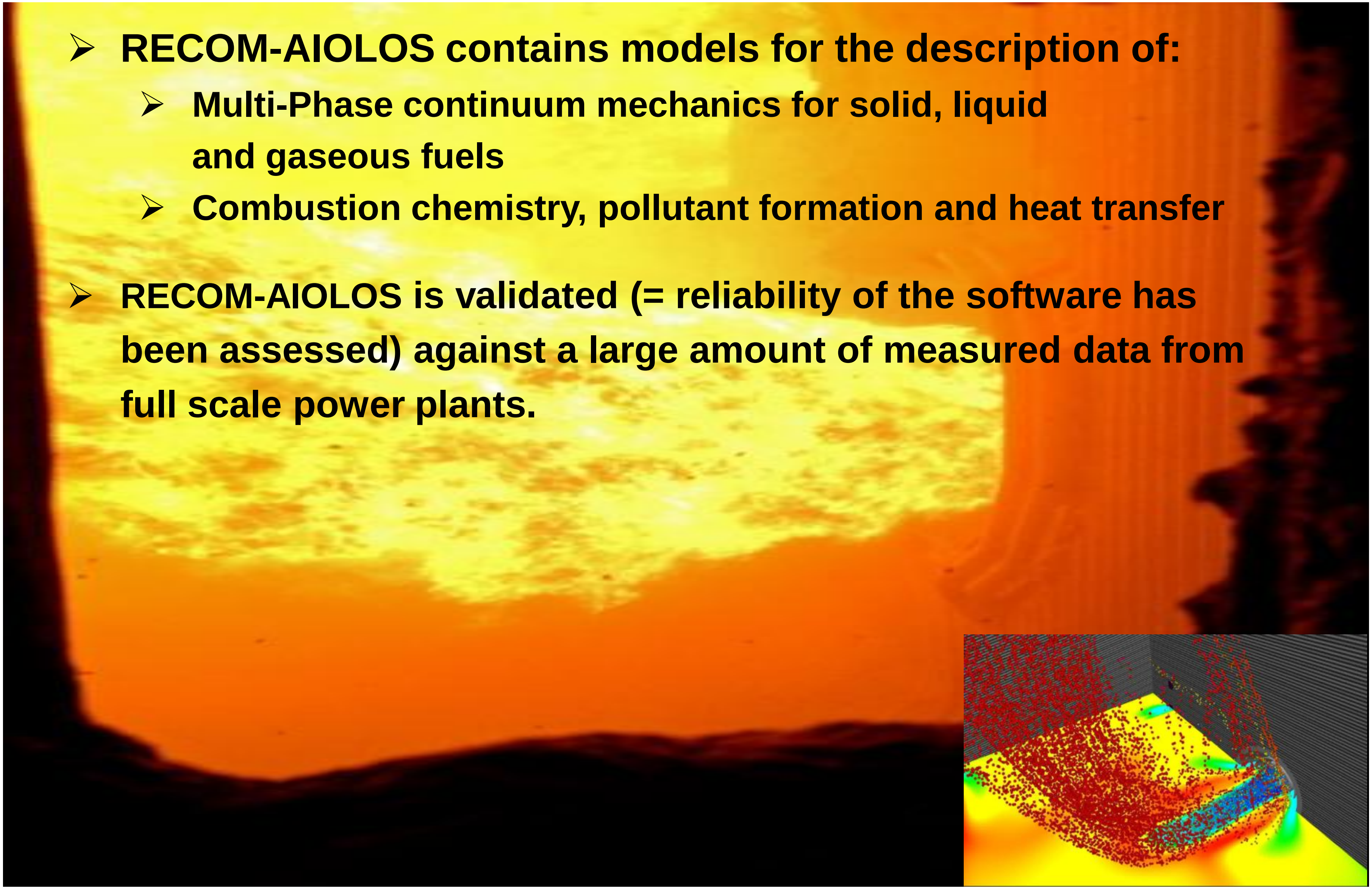
  for the Power and Process Industry

- RECOM Services is a Spin-Off from Stuttgart University (founded in 1999)

- RECOM Services uses an in-house developed CFD Code RECOM-AIOLOS, that is based on the AIOLOS code originally developed at Stuttgart University.

- RECOM-AIOLOS is a preconfigured CFD Software for the description of combustion processes in industrial-scale firing systems.

3D-CFD Simulation Software RECOM-AIOLOS

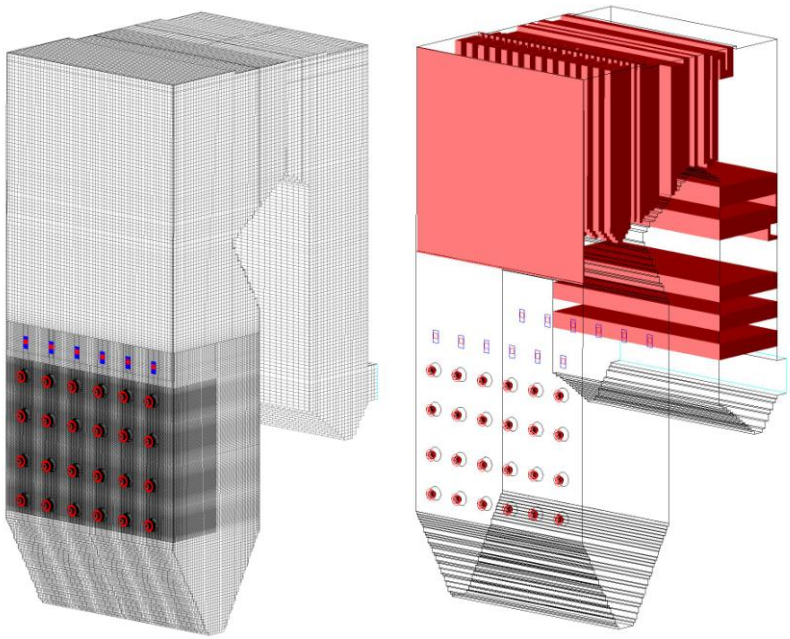


- RECOM-AIOLOS contains models for the description of:
  - Multi-Phase continuum mechanics for solid, liquid and gaseous fuels
  - Combustion chemistry, pollutant formation and heat transfer
- RECOM-AIOLOS is validated (= reliability of the software has been assessed) against a large amount of measured data from full scale power plants.

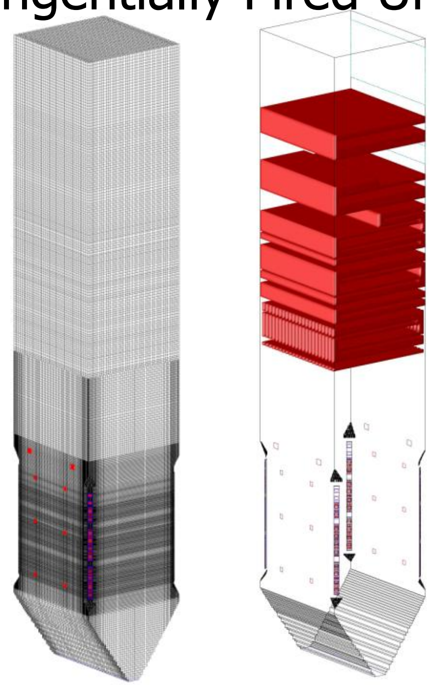
RECOM Combustion Modelling Expertise

- In the past years RECOM has performed 64 baseline simulations with comparison between field measurements and model predictions, and simulated more than 500 boiler variations
  - The RECOM boiler model data base has around 70 boiler models

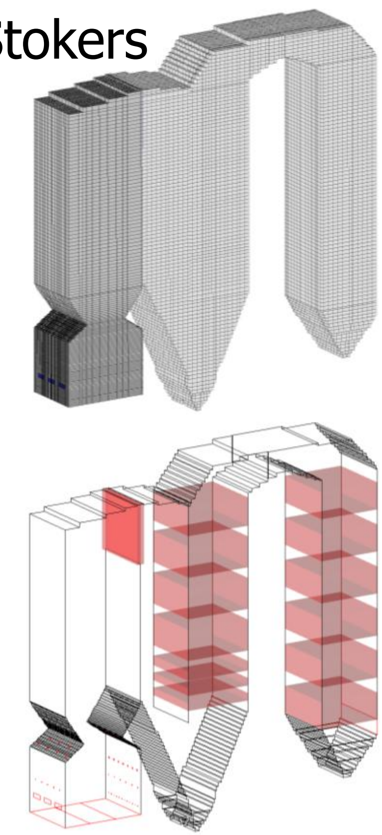
Wall-Fired Units



Tangentially Fired Units



Stokers



Customers that use RECOM – Modeling Technology

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CLYDE BERGEMANN

LABORELEC

RWE

essent

VATTENFALL

SAARENERGIE
Die Energiemacher

EnBW

TARONG ENERGY

e·on Engineering

MVV Energie

EDF
Electricité de France

HITACHI
Inspire the Next

SIEMENS

Eskom

Babcock Borsig Service

ALSTOM

steinmüller
engineering

DSC

Long term cooperation with LABORELEC

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Modeling projects for LABORELEC		
Year	**Unit**	**Problem**
2000	Langerlo #1	Fuel switching and analysis of impact on combustion performance, wall corrosion, slagging/fouling
2001	Ruien #5	Optimisa…
2002	Gelderland #13	Feasibilit…
2003	Rodenhuize #2	Combine… load operation (Fuel: Blast Furnace Gas & Heavy Fuel Oil)
2003	Kallo #2	Combined firside/steamside modelling for the analysis of minimum load operation (Fuel: Natural Gas & Heavy Fuel Oil)
2004/ 2005	Langerlo #1	Combined fireside/steamside modelling for the analysis of the impact of a burner retrofit together with co-firing wood dust and palm oil
2006	Rodenhuize #4	Combined fireside/steamside modelling for the analysis of the impact of design changes and fuel changes on combustion performance (Fuel: Blast Furnace Gas, Coal, Wood Pellets, Olive Residue)
2006	Polaniec #2 & #4	Combined fireside/steamside modelling for the analysis of the impact of design changes and fuel changes on combustion performance (Fuel: Coal, Biomass/Fresh Wood)

Model Validation was also done for operation scenarios with 30% biomass co-combustion in Amer 8 and 9 (Essent, The Netherlands)

Biomass Co-Firing References marked in red / 100% Biomass References marked in green

Long term cooperation with LABORELEC

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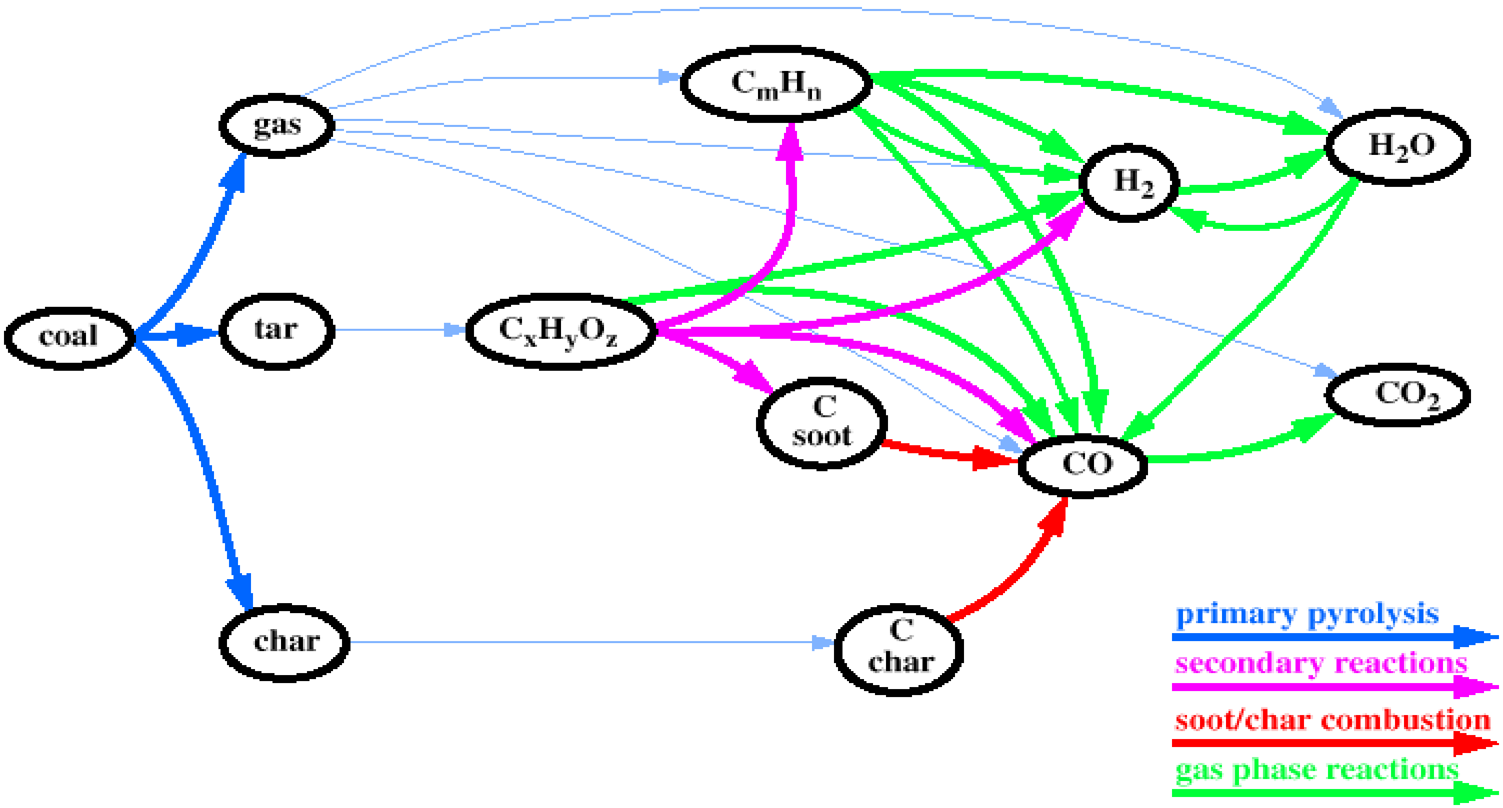
Modeling projects for LABORELEC		
Year	**Unit**	**Problem**
2007/ 2008	Kallo #2	Combined fireside/steamside modelling to assess the performance of new gas burners (Fuel: Natural Gas)
2008	Gelderland #13	Combined fireside/steamside modelling for assessing a co-firing scenario with Wood Pellets for full and partial load operation
2008	Rodenhuize #4	Combined fireside/steamside modelling for the evaluation of different burner designs for Wood Pellets/Blast Furnace Gas combustion
2008	Langerlo #2	Fireside modelling for assessing the performance of new burners (Fuel: Coal, Wood Pellets, Olive Residue)
2009	Awirs #4	Fireside modelling for assessing the predictive capabilties of the biomass combustion model. (Fuel: 100% Wood Pellets)
2010	Rodenhuize #4	Fireside modelling of a retrofit to 100% biomass (Fuel: Wood Pellets)
2011	Dunkerque #6	Fireside modelling for the assessment of different operation modes with a combination of different gases (Blast Furnace Gas/Coke Oven Gas/ Natural Gas)
2011/ 2012	Rugeley #7	Combined fireside/steamside modelling for assessing co-firing scenarios with biomass

Biomass Co-Firing References marked in red / 100% Biomass References marked in green

Biomass is treated analogous to coal and therefore undergoing the same combustion steps: Drying, devolatisation and char combustion.

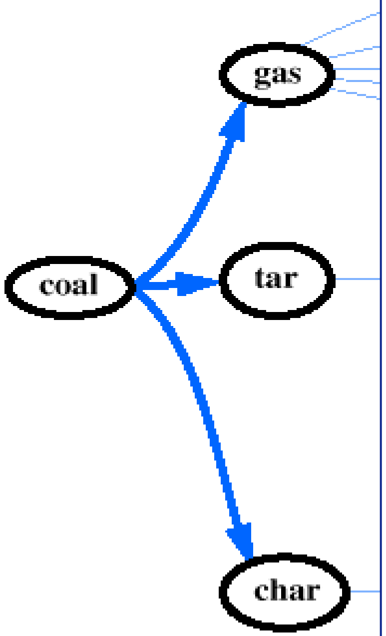
The global reaction scheme for coal combustion:



Our Approach to Biomass combustion modeling

Biomass is treated analogous to coal and therefore undergoing the same combustion steps: Drying, devolatisation and char combustion.

The global reaction scheme for coal combustion:



Main differences of coal combustion to biomass combustion:

- **Amount of volatile matter released**
- **Composition of the volatile matter released (CO, H2, CH4 and higher hydrocarbons)**
- **Particle size and shape of particles**
- **Reaction rate of the devolatilisation process and the char combustion**

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Extended reaction scheme that includes oxydising and gasification reactions

$\Phi C + O_2 \rightarrow 2 \cdot (\Phi - 1) CO + (2 - \Phi) CO_2$

$C + H_2O \rightarrow CO + H_2$ (heterogenous steam reaction)

$C + CO_2 \rightarrow 2\,CO$ (Boudouard reaction)

$C_mH_n + m/2\,O_2 \rightarrow m\,CO + n/2\,H_2O$

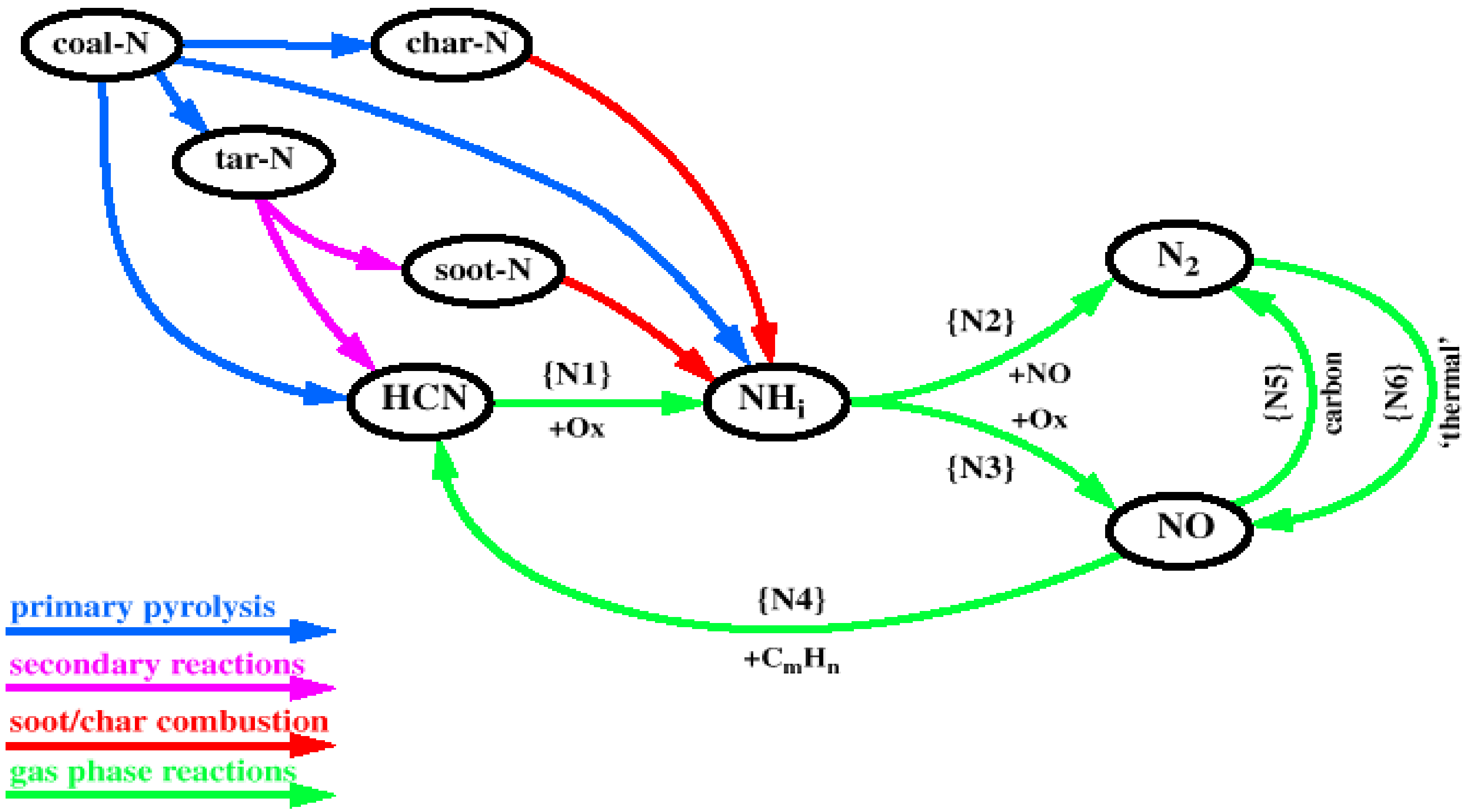
$C_mH_n + m\,H_2O \rightarrow m\,CO + (m+n/2)\,H_2$ (methane/steam reaction)

$CO + H_2O \leftrightarrow CO_2 + H_2$ (homogenous steam reaction)

$H_2 + ½\,O_2 \leftrightarrow H_2O$ (oxidation of hydrogen)

$CO + ½\,O_2 \rightarrow CO_2$

The global reaction scheme for fuel nitrogen conversion:



Key aspect: Biomass specific reaction kinetics

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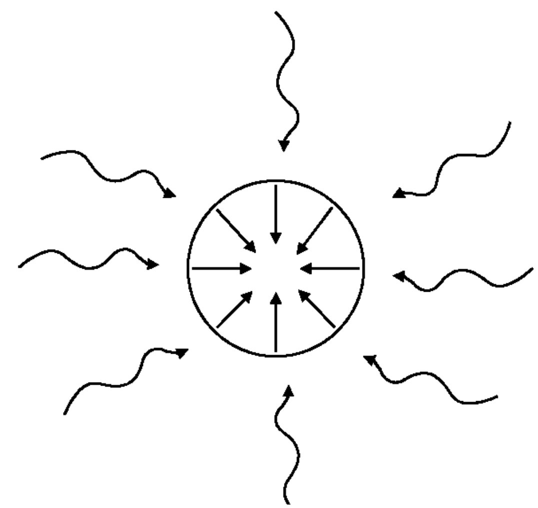
Co-operation with LABORELEC and the University of Louvain (Belgium):

- Determination of apparent kinetics for the devolatisation process (Arrhenius parameters)
- Determination of the volatile yield and the composition of the pyrolysis products of biomass combustion

for each particle size using experimental data together with a comprehensive chemical and physical model that includes internal and external heat transfer in the particle

Internal : conduction and convection

External : convection and radiation

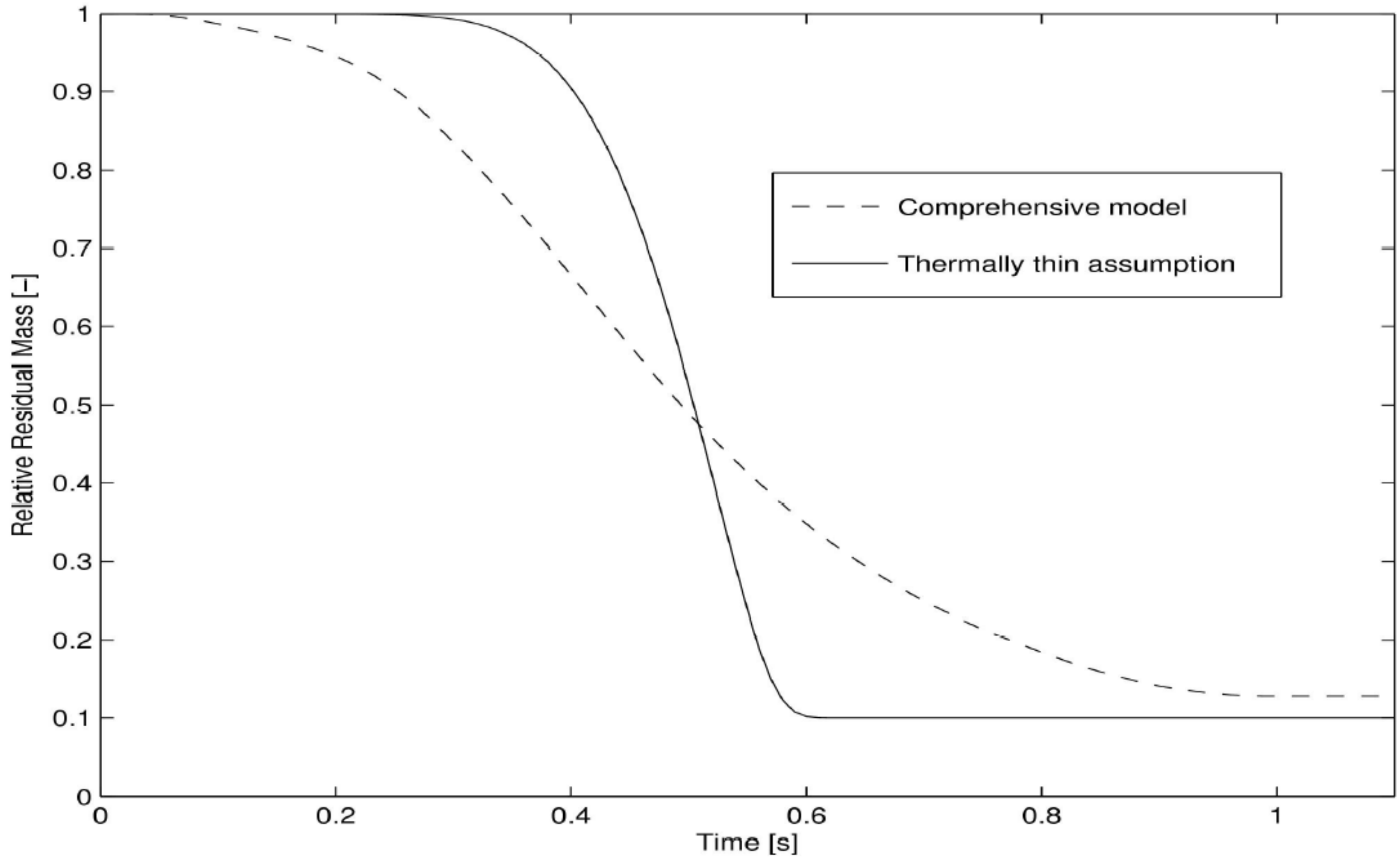


Co-operation with ECN (The Netherlands)

- Determination of individual char combustion characteristics for chars originating from biomass pyrolysis.

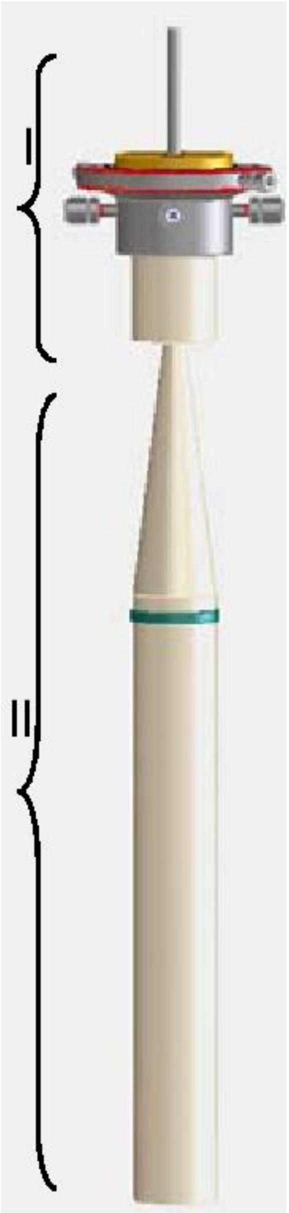
Effect of considering heat transfer within large particles

Comprehensive versus standard thermal treatment for a 1 mm biomass particle



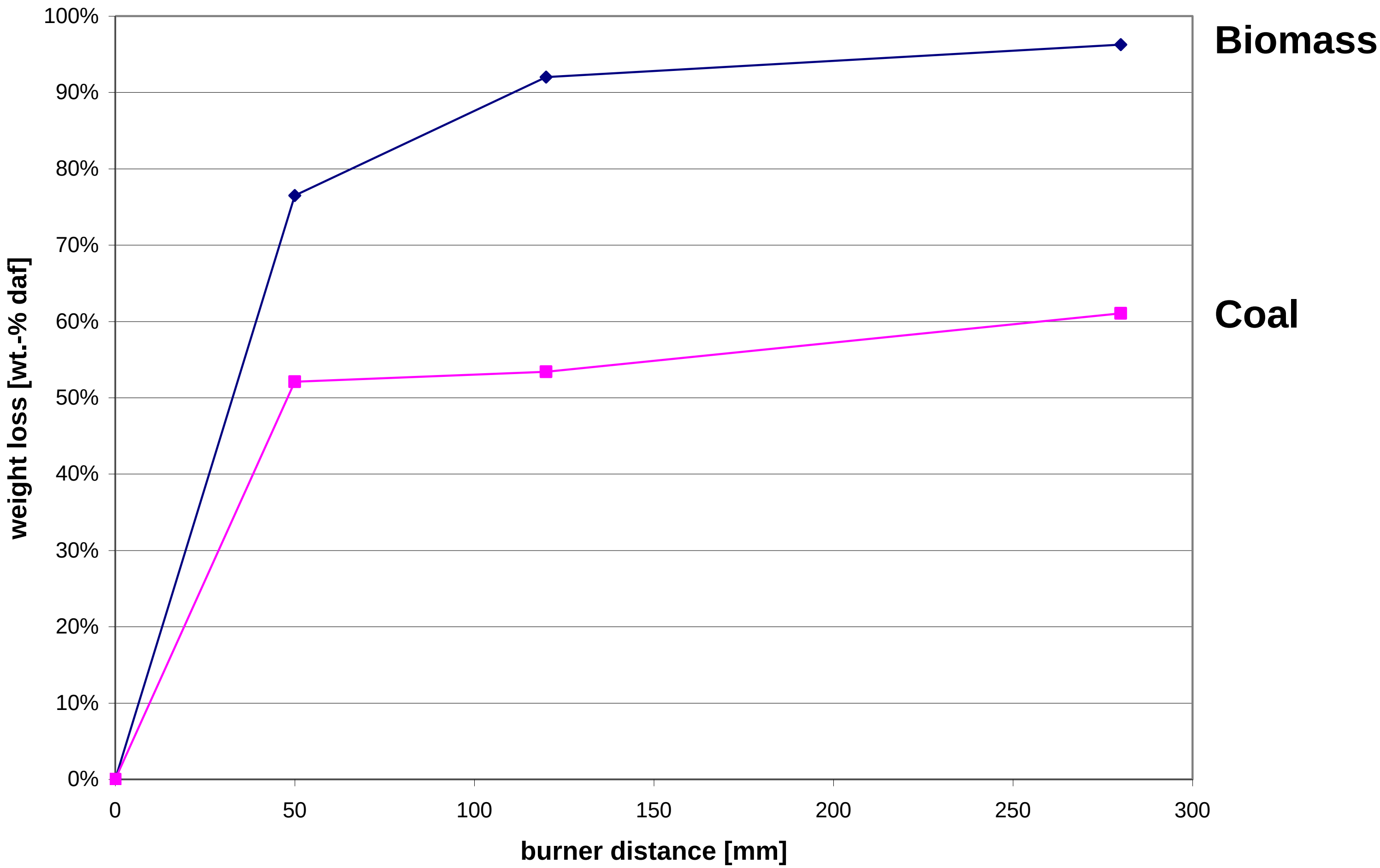
As a result of the comprehensive thermal treatment, the fuel conversion starts earlier but needs more residence time

Fuel Characterisation by ECN – Devolatilisation

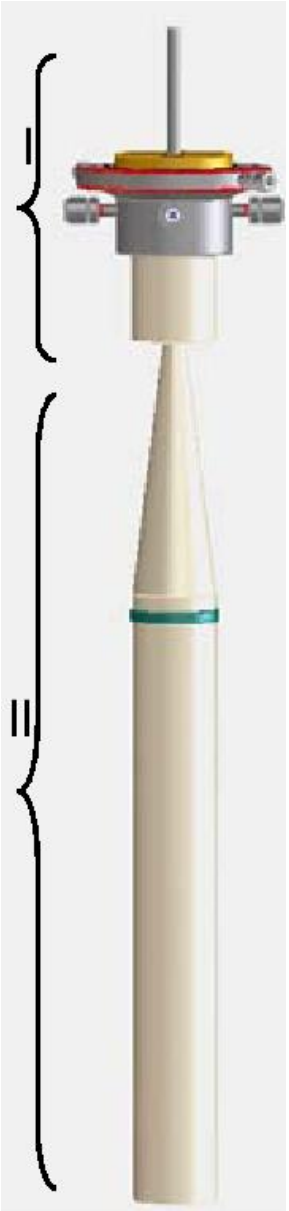


I Devolatilisation Zone

II Combustion Zone

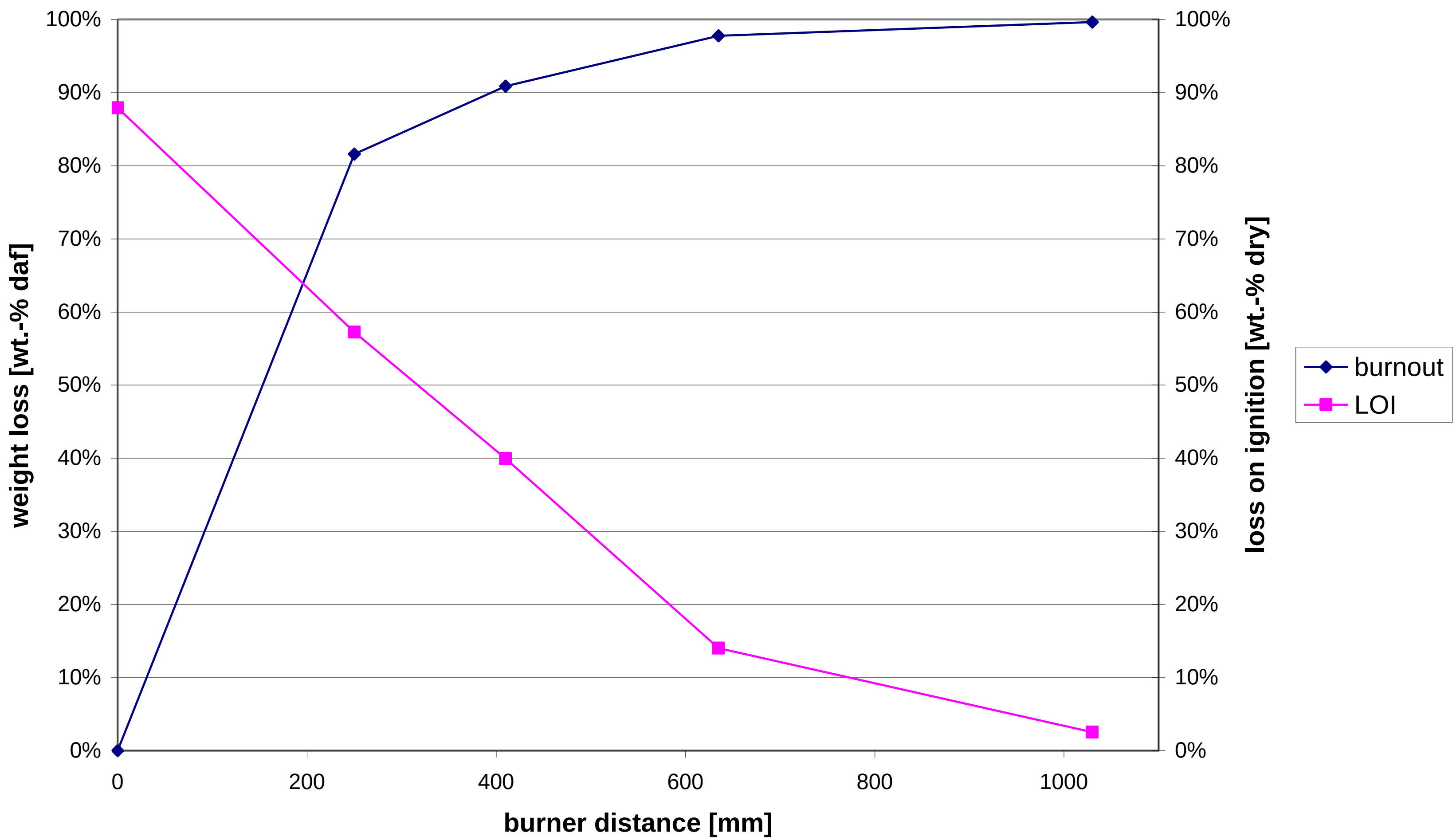


Fuel Characterisation by ECN – Combustion of Char from Coal



I Devolatilisation Zone

II Combustion Zone



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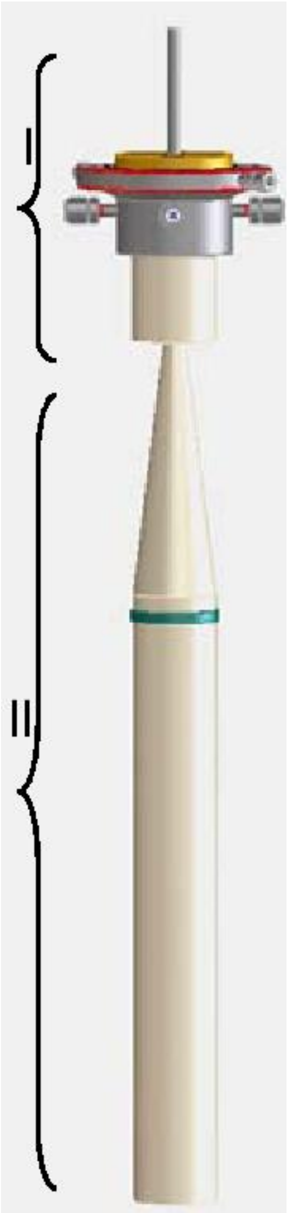

I Devolatilisation Zone

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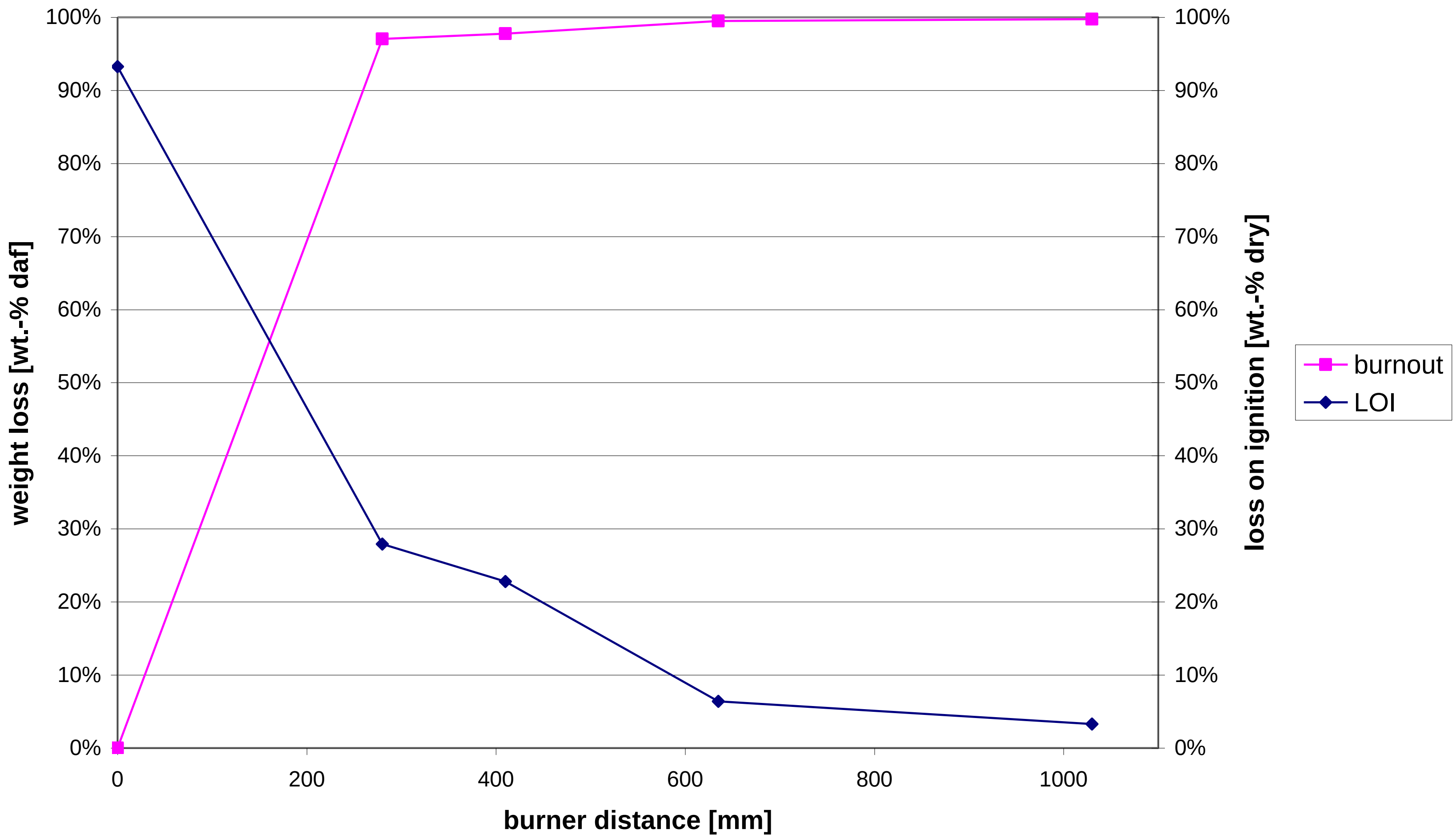
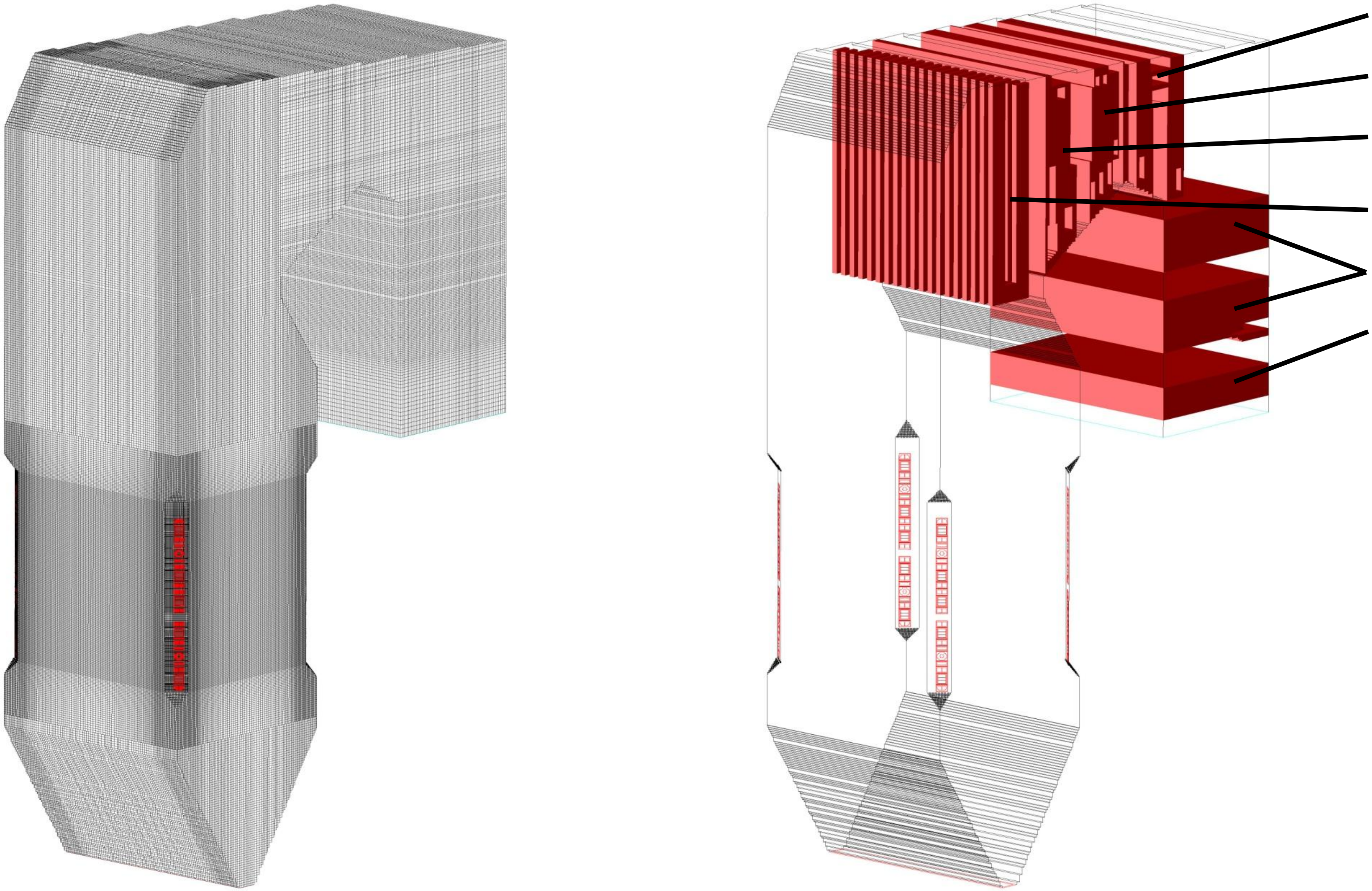


Validation: 3D-Boiler Model Les Awirs #4



Elementary Analysis of Biomass (Wood Pellets)

	dry
C [%]	51.03
H [%]	5.95
O [%] (by difference)	42.63
N [%]	0.07
S [%]	0.00
Ash [%]	0.32
Moisture [%]	7.48 (as received)
Volatiles [%]	84.3 (daf)
Hu [MJ/kg]	17.095 (as received)

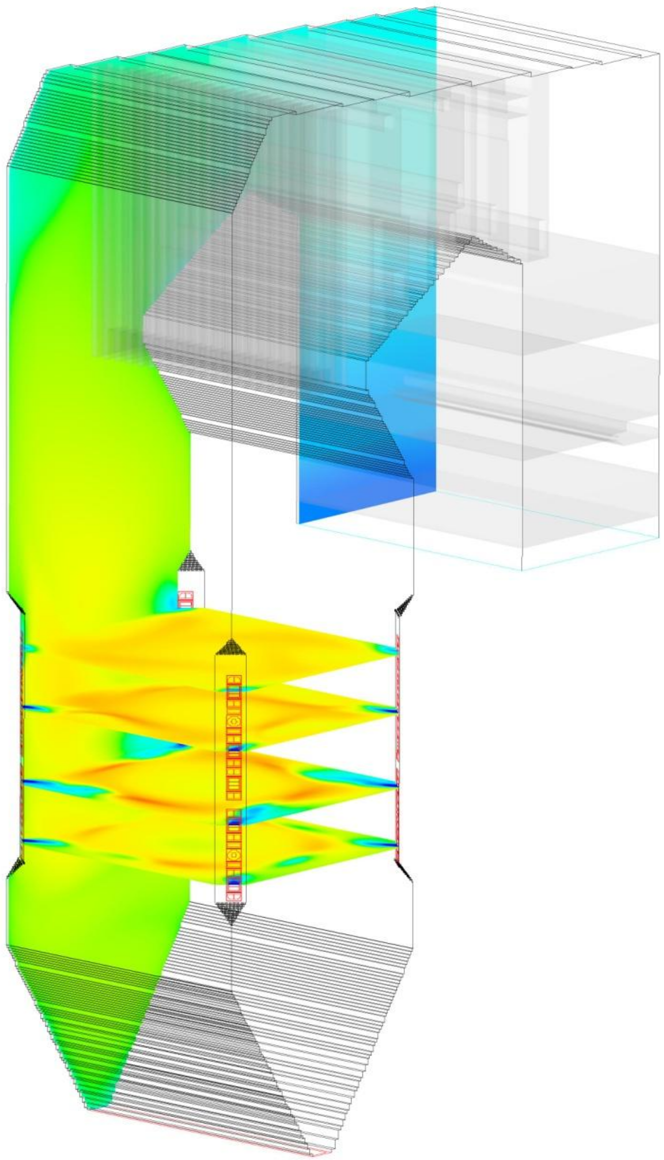
Les Awirs #4 Validation: Boiler Exit

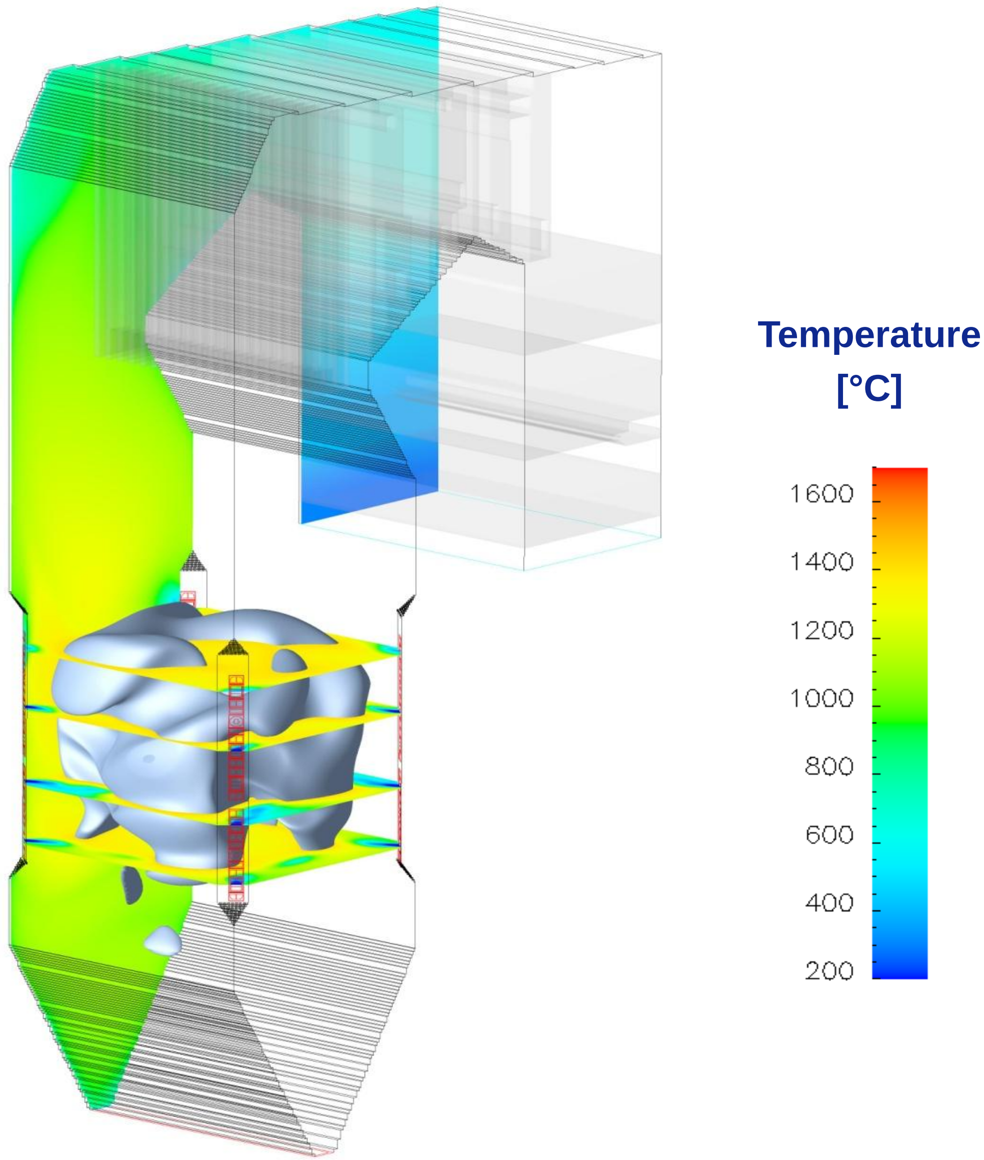
	100% Wood Pellets			
	Measured	Model Setup 1	Model Setup 2	Model Setup 3
NOx [mg/Nm^3 ,@ 6% O_2]	137	149	135	136
CO [mg/Nm^3,@ 6% O_2]	28 (8 – 305)	24	33	18
Carbon in Fly Ash [wt.-%]	17 – 18	48	60	24

Model Setup:

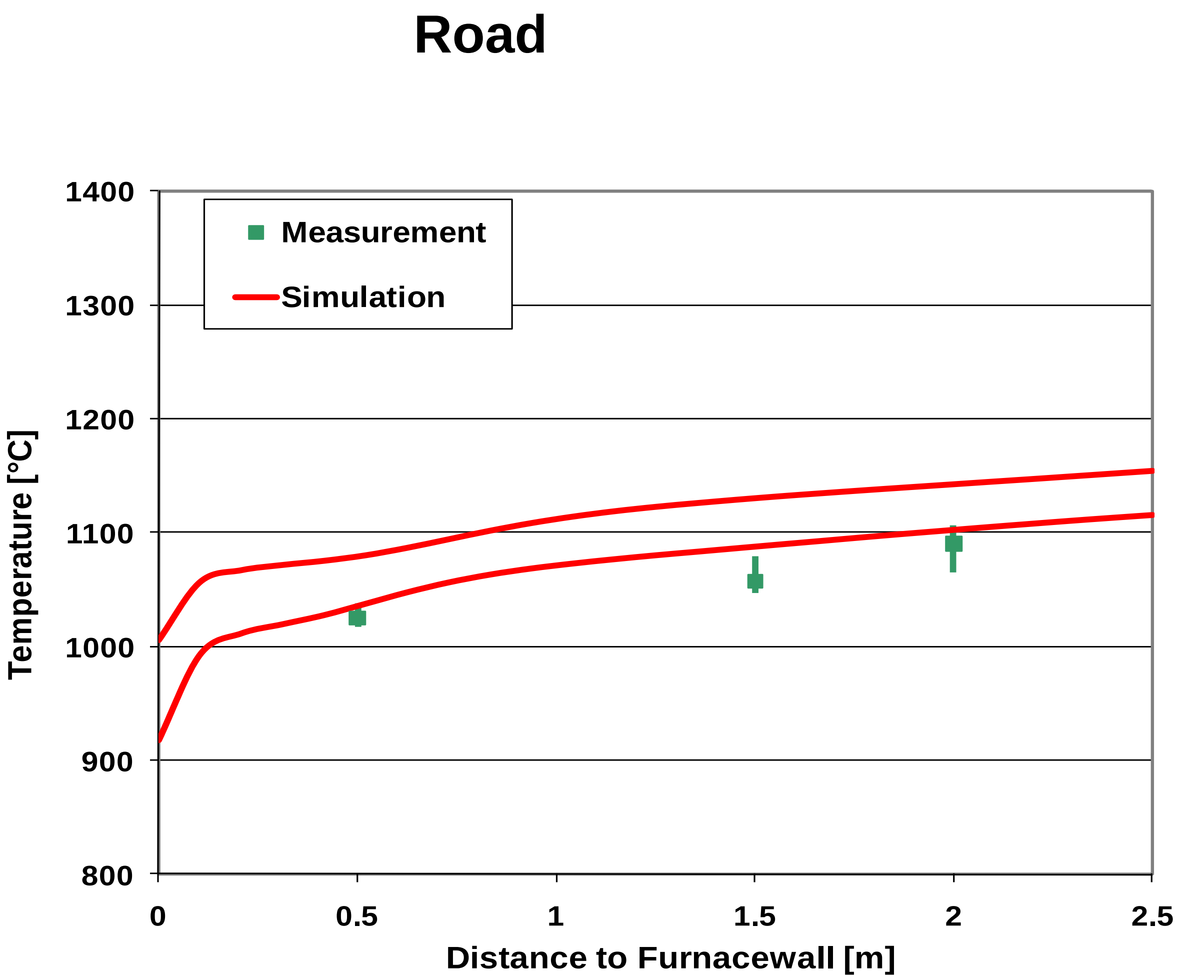
1. Fuel specific apparent kinetic parameters with estimated volatile yields from literature
2. Fuel specific apparent kinetic parameters and gaseous species yields from detailed model
3. Fuel specific apparent kinetic parameters and gaseous species yields from detailed model as well as fuel specific char combustion kinetics determined by combustion experiments at ECN in the Netherlands.

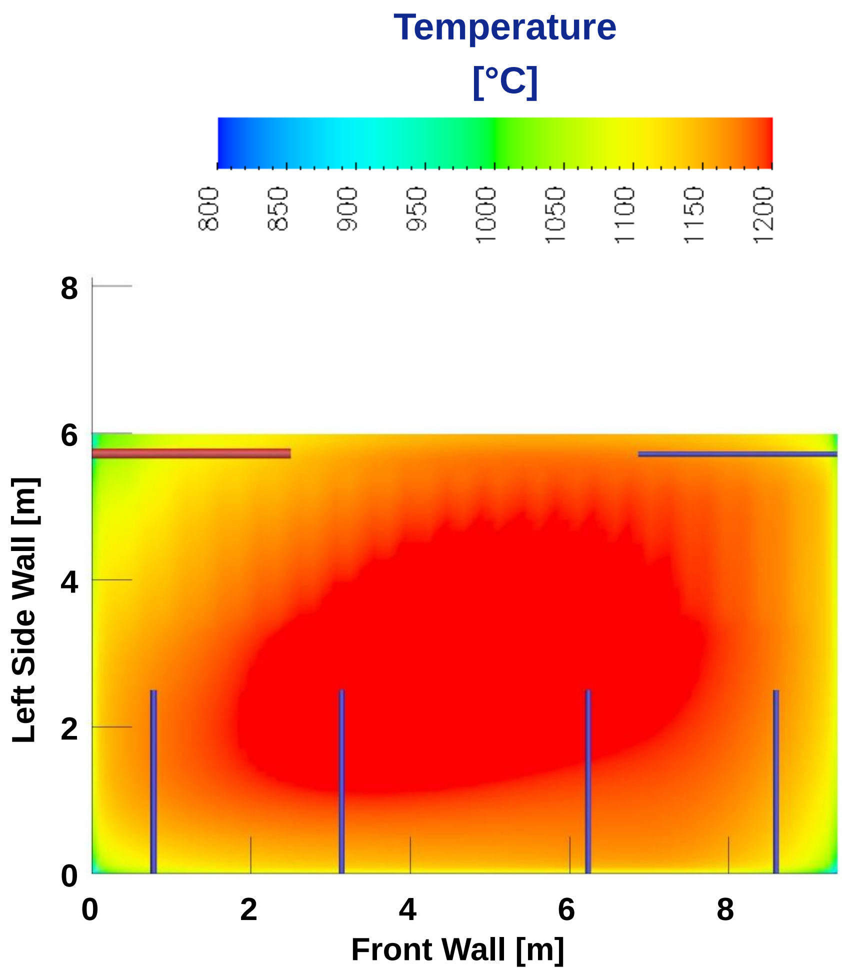
Les Awirs #4: Temperature distribution & isosurface 1400°C





Les Awirs #4 Validation: Temperature distribution @ Nose Level





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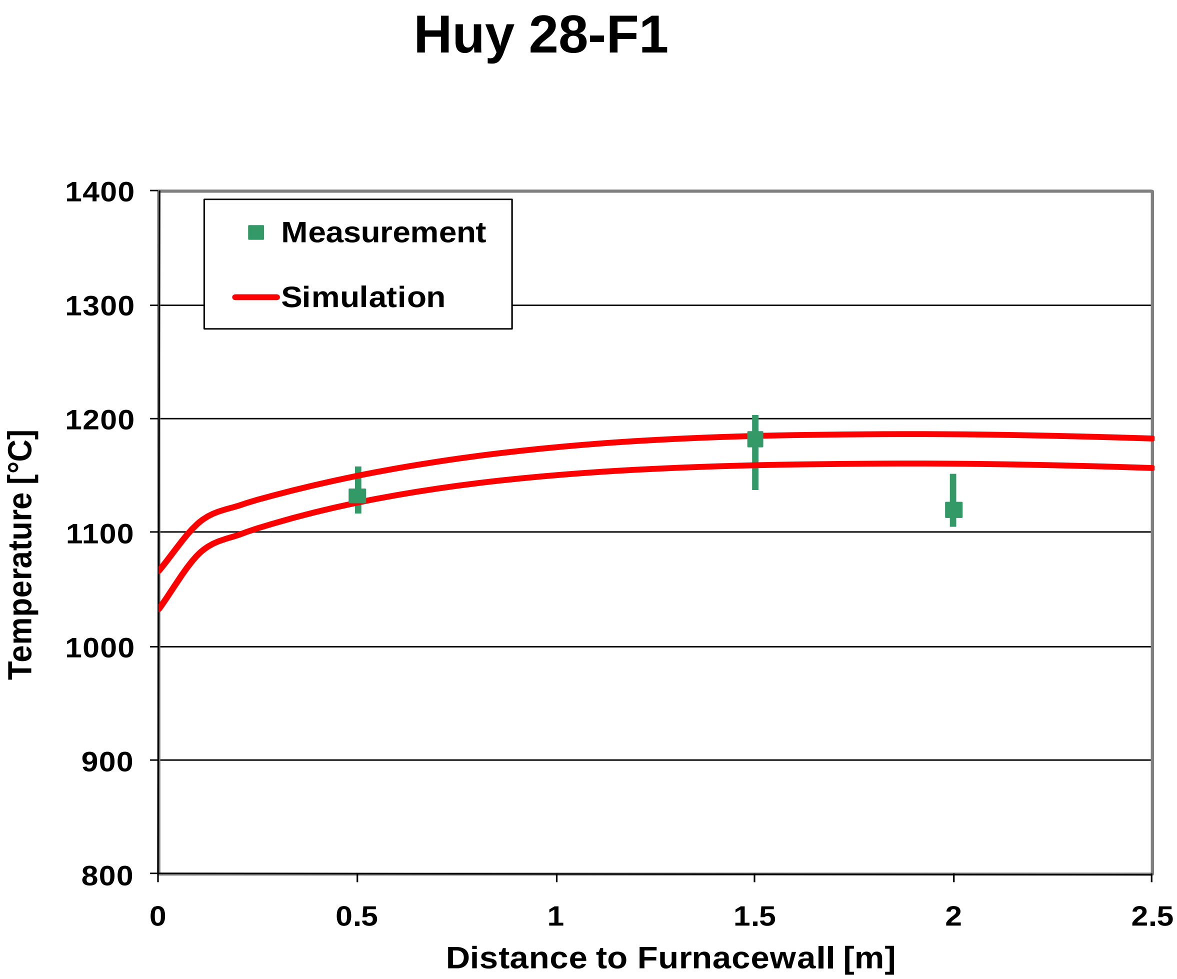

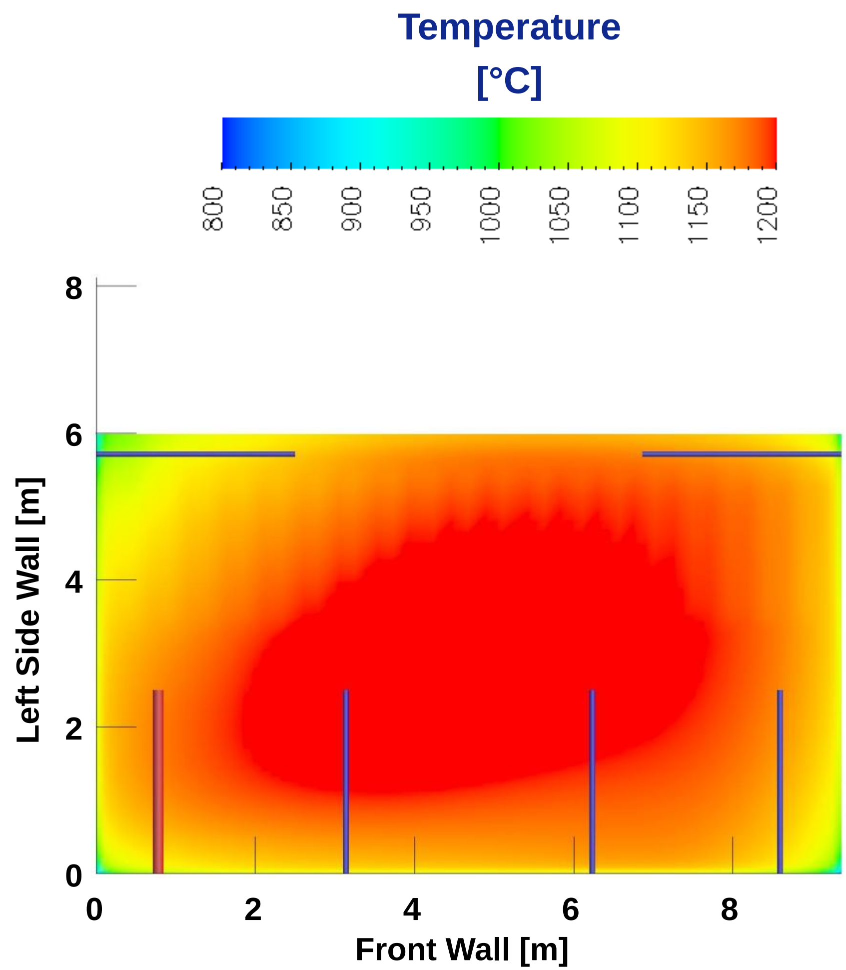

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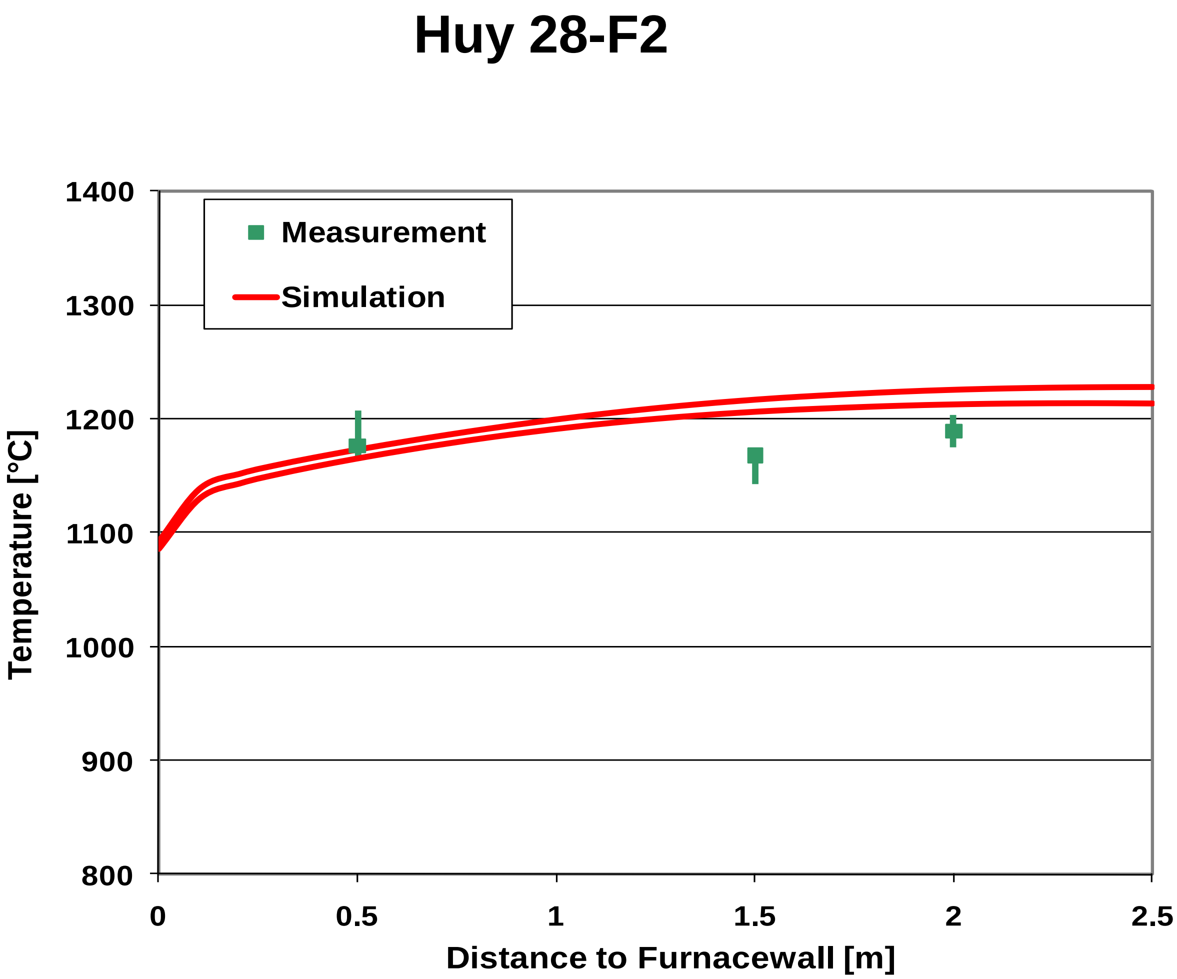
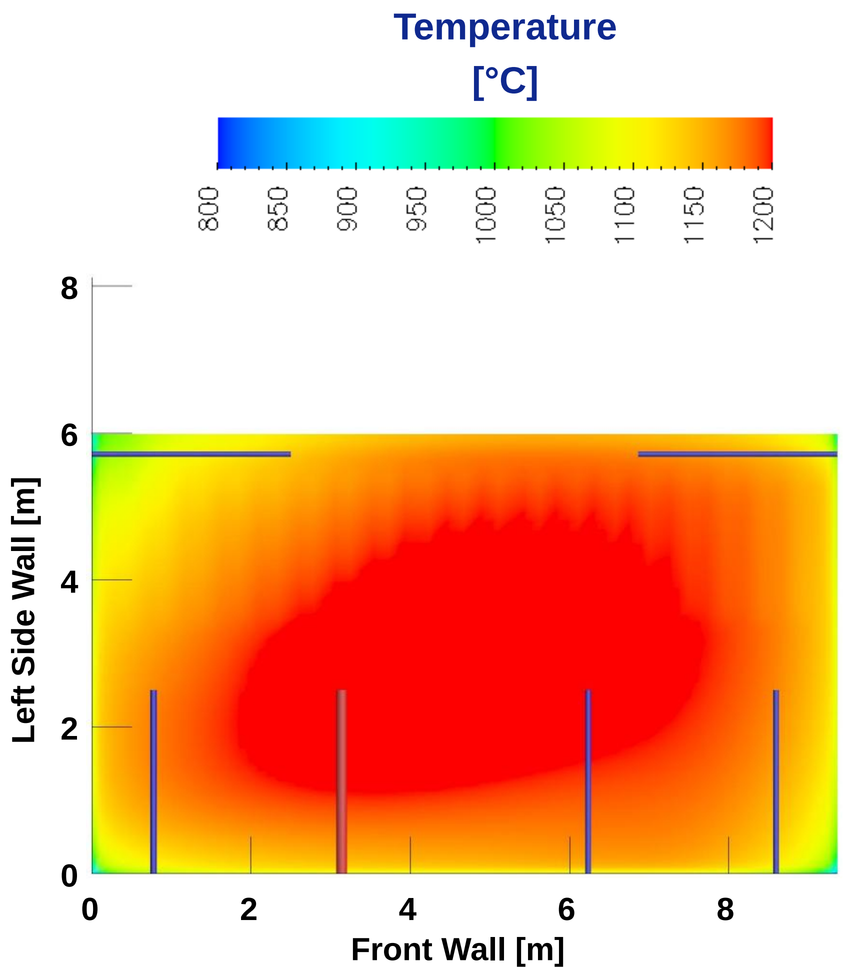
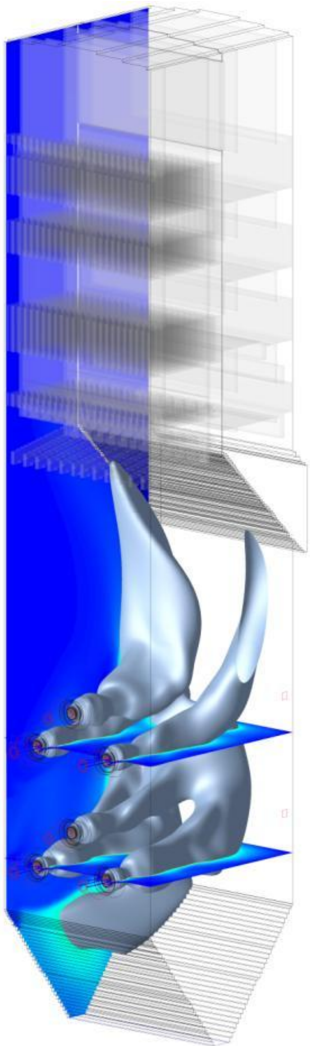


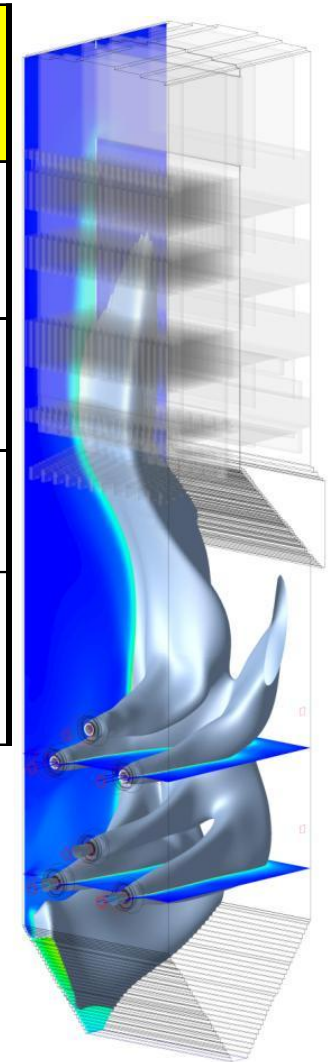


Front Wall Fired Boiler - Validation: Boiler Exit

Coal



Coal & Biomass



	100% Coal		80% Coal 20% Biomass	
	Measured	Simulation	Measured	Simulation
NOx [mg/Nm³,6% O_2]	374	343	321	297
CO [mg/Nm³ ,6% O_2]	14	19	21	34
Carbon in Fly Ash [wt.-%]	9 (8-10)	8,1	16,8	16,7

Conclusions

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- The presented methodology for biomass combustion modeling has shown to accurately reproduce the effects of biomass combustion in full scale pulverized fuel systems.

- Experience in predicting performance values before and after retrofit has also confirmed the reliability of the methodology.

- Future projects aiming at the replacement of the conventional fuel base by biomass (either co-firing or 100%) can use this methodology to identify design or operational problems early in advance in the virtual reality of a 3D-boiler model before these problems become expensive reality.