A 1-D Simulation Tool for Biomass Co-Firing Development and Application

Company	Contribution
Eskom, South Africa	**Initiator** **Participation in development** **Matshela Koko (Speaker)**
SSE plc, UK (formerly Scottish & Southern Energy)	**Operational data from Fiddler's Ferry PP**
TU Clausthal, IEVB, Germany	**CFD simulation** **Academic advice**
Steinmüller Engineering, Germany	**Basis software** **Software development**

Top 5 messages

- **ESKOM Biomass to Electricity Project**
- Boiler performance predictive tools
  - 0 dimensional (well-stirred)
  - 1-dimensional (plug flow)
  - 3-dimensional (CFD)
- Validation of the plug-flow model
- Arnot PS case study
- Further development

ESKOM Biomass to Electricity Project

- ESKOM has plans to co-fire up to 10% of biomass in its coal fired units
- Currently, 124.68 million tonnes of coal are fired in these units resulting in 230.3 million tonnes of carbon dioxide emissions per annum
- 16 million tonnes per annum of biomass feedstock is targeted by 2025.
- Pelletized woody based products and Pelletized Torrefied biomass are being pursued in parallel
- A commitment to build a 50 000 tonnes torrefaction plant is expected in 2012 after the pilot test
- A request for proposal for 10 000 tonnes of torrefied product is currently in the global market

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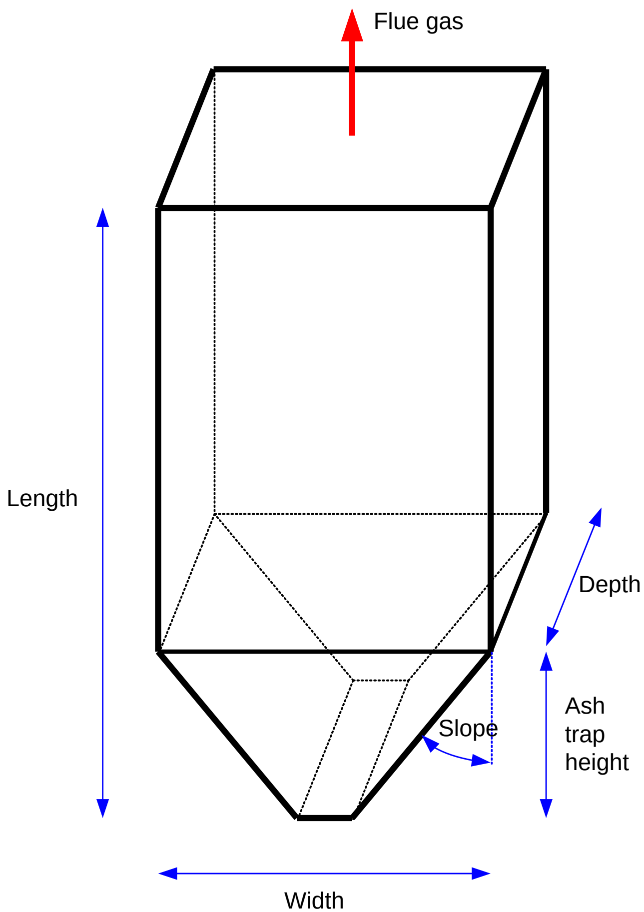
Well-stirred combustion chamber



$$\dot{Q}_{FG} = C \cdot A \cdot \left[\left(\frac{T_G}{100} \right)^4 - \left(\frac{T_W}{100} \right)^4 \right]$$

Q_{FG}	Flue gas heat release
C	**Radiation coefficient (C-Number)**
A	Heating surface
T_G	Flue gas temperature (mean)
T_W	Wall surface temperature (mean)

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Limitations of the well-stirred model

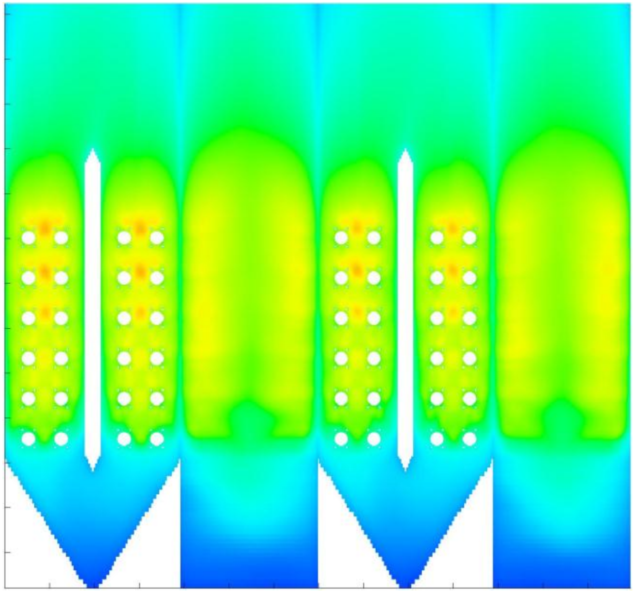
- Various parameters are not considered within the calculation, although they actually may have influence on heat transfer and flue gas furnace exit temperature:
  - Location and arrangement of burners
  - Air staging
  - Simultaneous or separate combustion of different fuels
  - Heat transfer between flame, flue gas and heating surface
  - Burning behaviour of solid fuel particles, e.g. burning time related to particle size

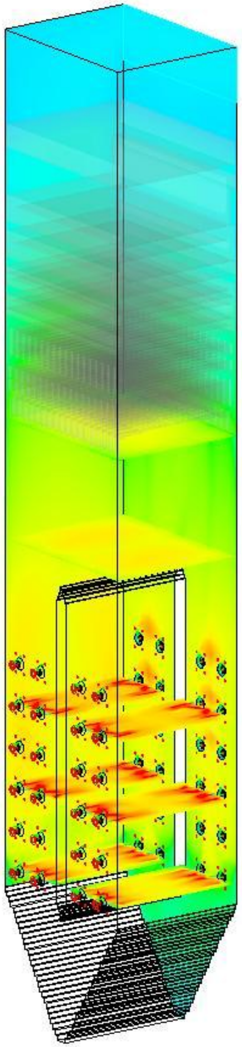
- Neither the flue gas temperature profile nor the local heat absorption of heating surfaces is examined.

- In general the model is simplified to a level that does not allow studying the effect of biomass co-firing on the furnace and the convective part downstream of the furnace.

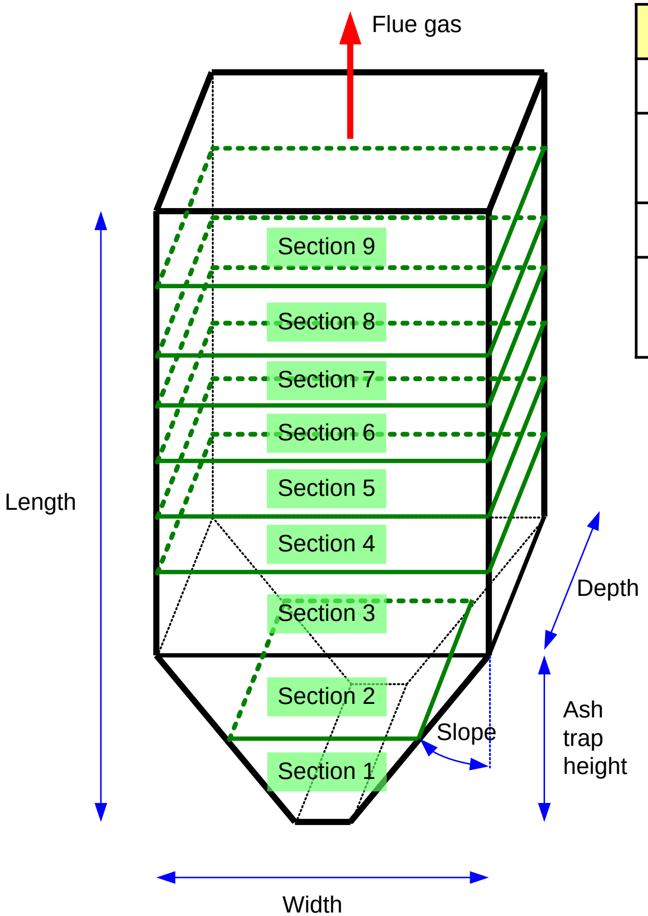
Furnace modelling with 3D CFD

- Resource (time, money, etc) consuming
- HPC requirements
- Difficult to integrate
- Difficult to prepare and to evaluate
- Highly sophisticated (Too high?)

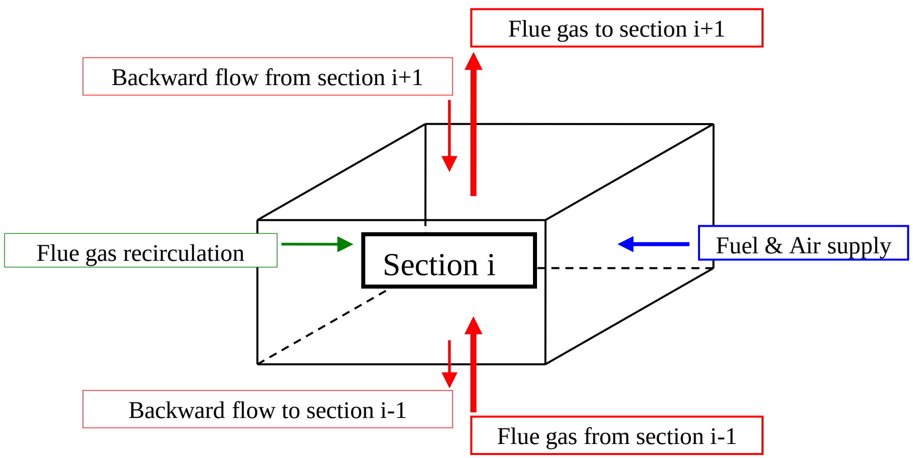




Sectional furnace model (plug flow)



Description	No. of sections
Hopper	1-2
Section between hopper and 1st burner level	1, in case of large distance between hopper and 1st burner level
Burner levels	1 (at least, each)
Burn-out area	As many as required to get heights which do not significantly exceed the burner level heights



$$\Delta\dot{Q}(i) = \dot{Q}_R(i) + \dot{Q}_C(i) + \dot{Q}_O(i) - \dot{Q}_I(i) - \dot{Q}_F(i)$$

$$\dot{Q}_R(i) = A_W(i) \cdot \frac{\sigma \cdot \varepsilon_W}{1-(1-\varepsilon_W)\cdot(1-\lambda_G)} \cdot \left[\varepsilon_G \cdot (T_G(i))^4 - \lambda_G \cdot (T_W(i))^4\right]$$

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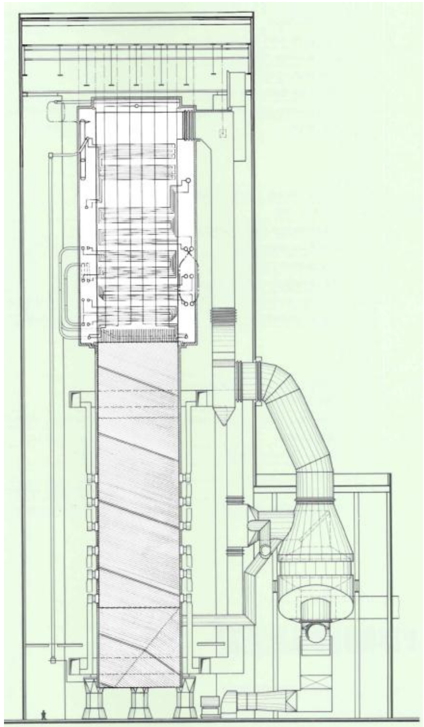
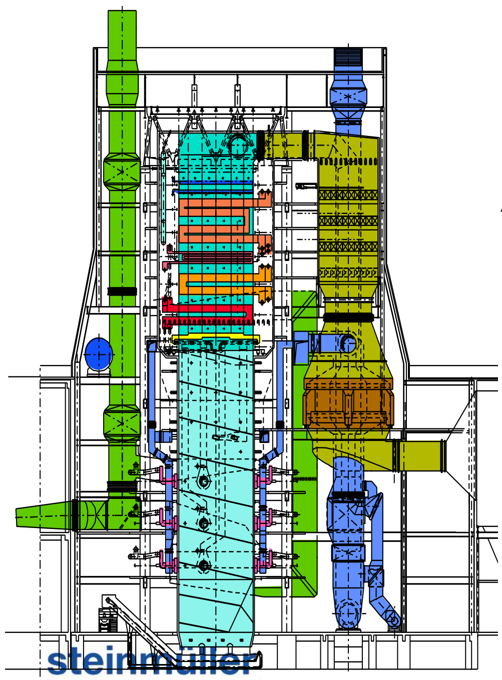
Sectional model validation for coal fired power plants



Mehrum III

- 700 MW Unit
- Once-through steam generator
- Bituminous coal (29.0 MJ/kg)
- 535/535°C, 199/42 bar



Altbach HKW2

- 330 MW Unit
- Once-through steam generator
- Bituminous coal (29.3 MJ/kg)
- 545/568°C, 264/58 bar

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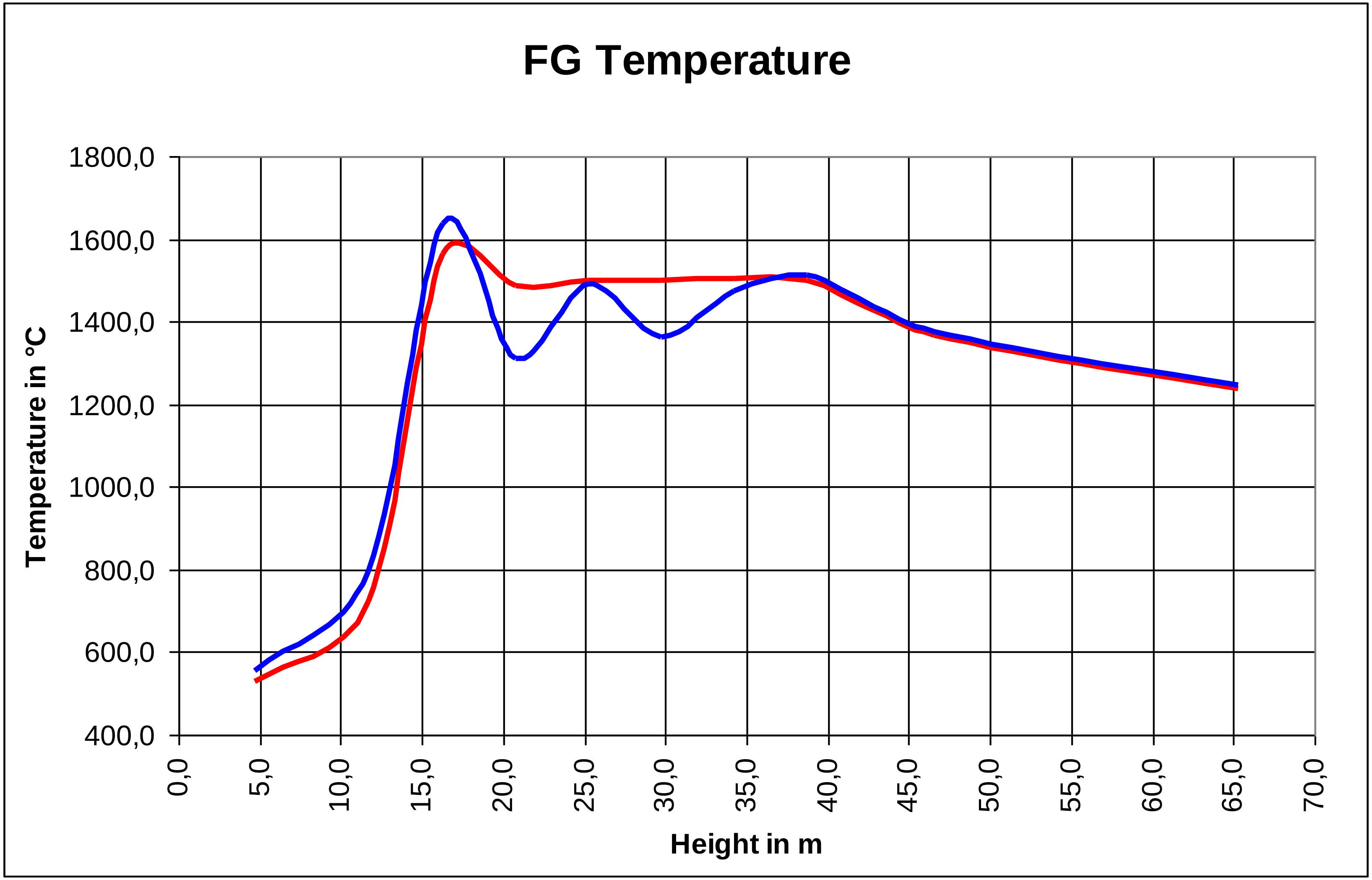
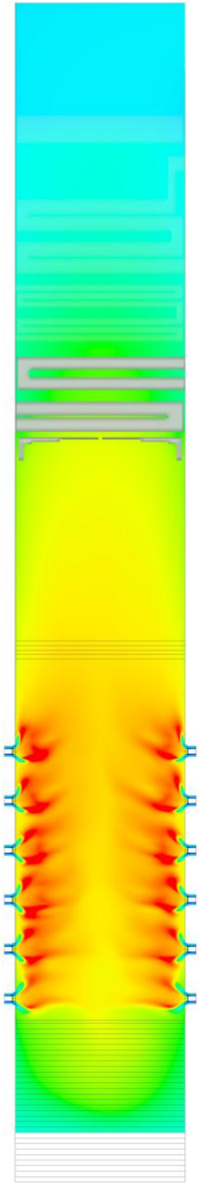
Validation for Mehrum III





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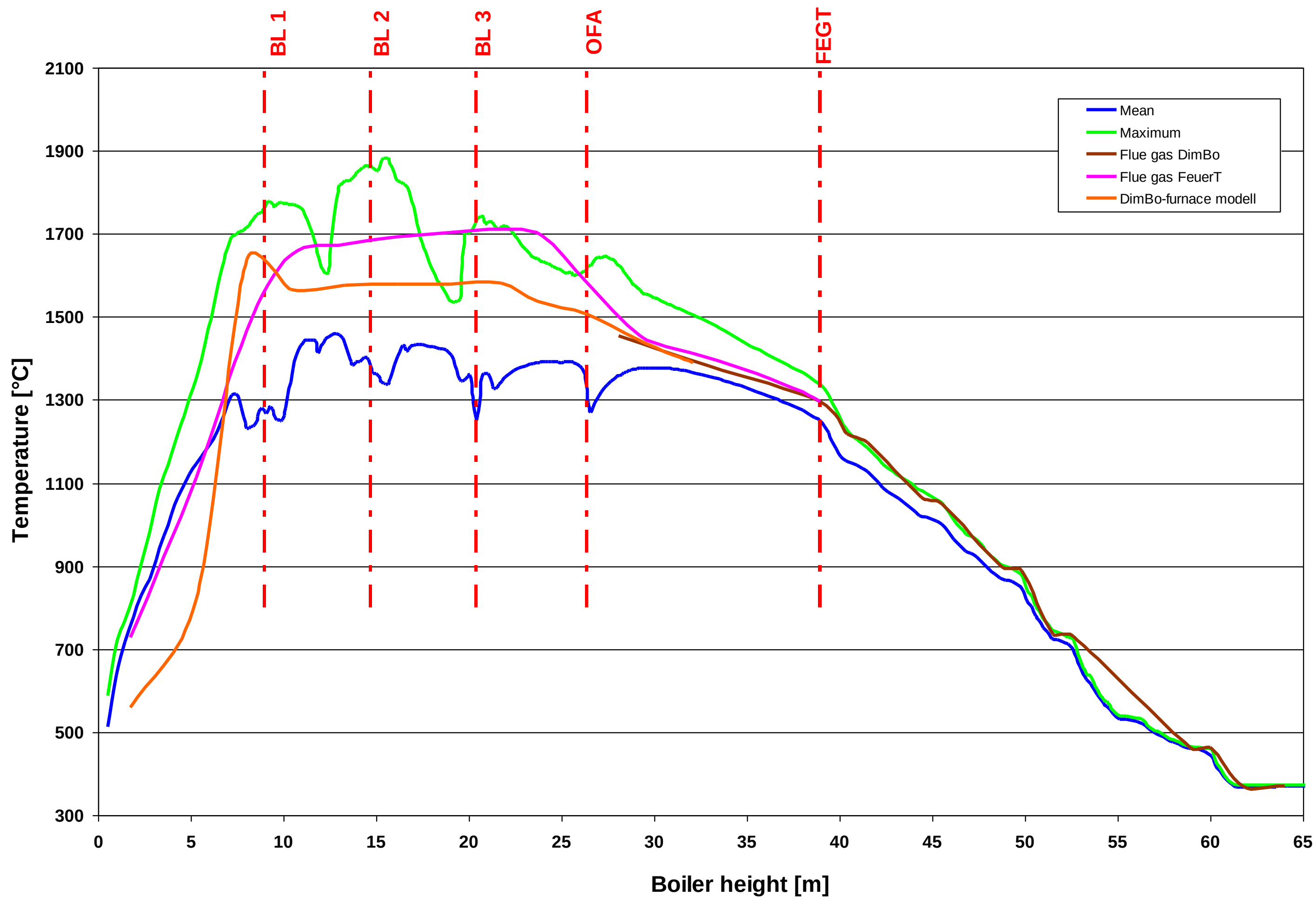
Validation for Altbach HKW2



Validation for biomass co-firing

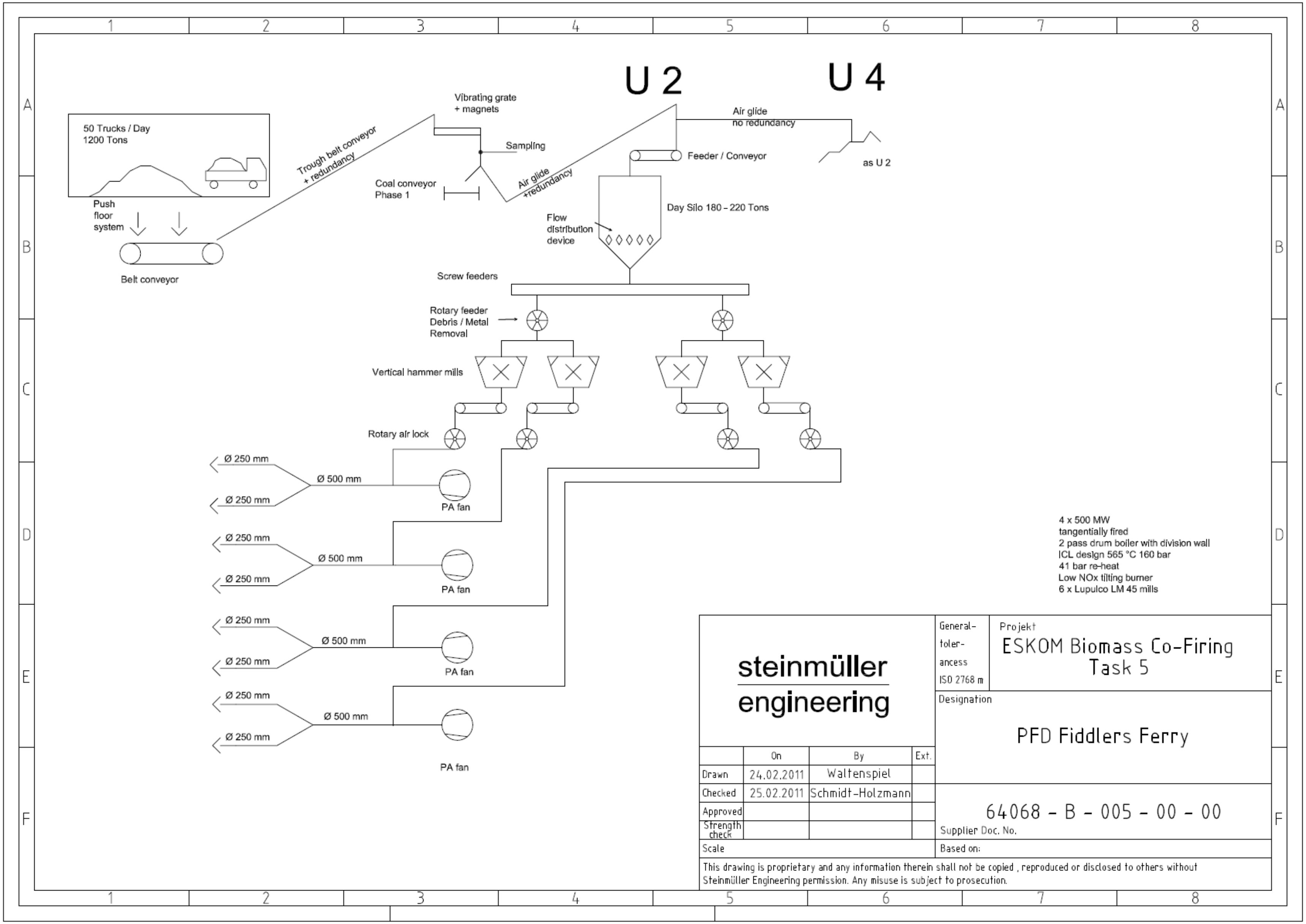
Fiddler‘s Ferry PS
SSE plc

- 4 x’s 500 MW units, tangentially fired
- ICL design, 565 degrees, 160 bar, 36% efficiency
- Low NOx tilting burners @ 400 MG/Nm3 with OFA
- 6 x’s Lopulco LM 45 mills, n-1 for full load, each mill supplies 8 burners
- Biomass direct injection installed on 2 units (U2 & U4).
- 4 vertical Buehler hammer mills per unit deliver 20% i.e. 100 MW
- 1 mill supplies 2 burners and 2 mills always operate together.
- Biomass firing is at 3rd level from the top (Row C, B, Biomass, D, E, A, F)

Source	From geograph.org.uk; transferred by User:Fintan264 using geograph_org2commons.
Author	Alan Godfree

Test period
2009-05-12 to -05-14

A 1-D Simulation Tool for Biomass Co-Firing - Development and Application



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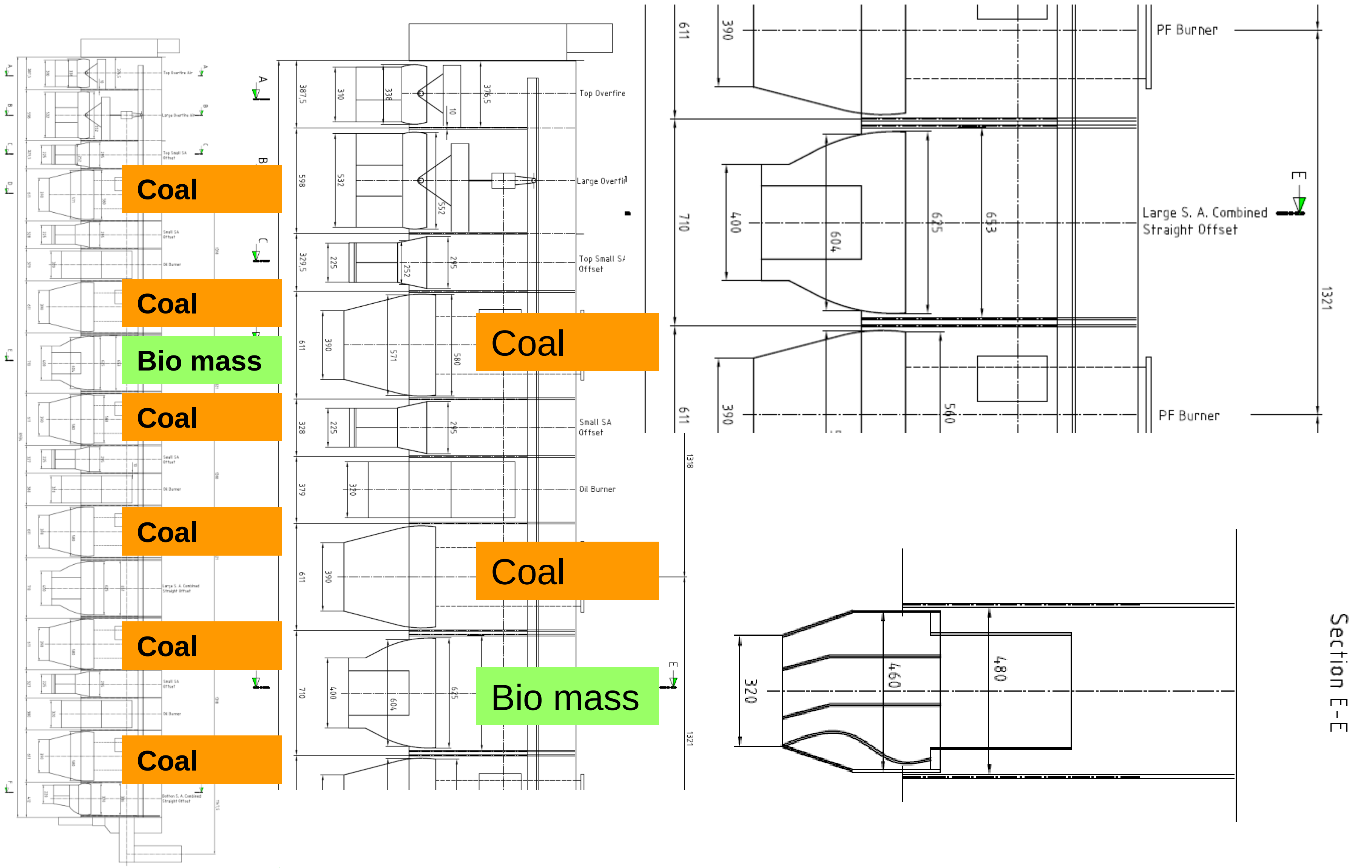

Differences between coal and combined coal and biomass firing

Test case		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Boiler load	%	**100**		**82.5**		**70**	
Mills in operation	-	5	4	5	4	4	4
Coal mass flow rate	kg/s	41,7	33,4	34,6	29,5	30,0	24,3
Biomass flow rate	kg/s		15,8		9,2		8,1
Mill inlet temperature	° C	207,3	185,7	192,7	168,0	201,6	164,2
Flue gas flow rate	kg/s	503,7	522,7	420,1	448,7	353,0	369,0
Furnace exit gas temperature	° C	1426,8	1375,4	1372,0	1308,1	1342,2	1292,2
Off gas temperature	° C	120,8	129,8	119,0	125,6	112,7	124,9

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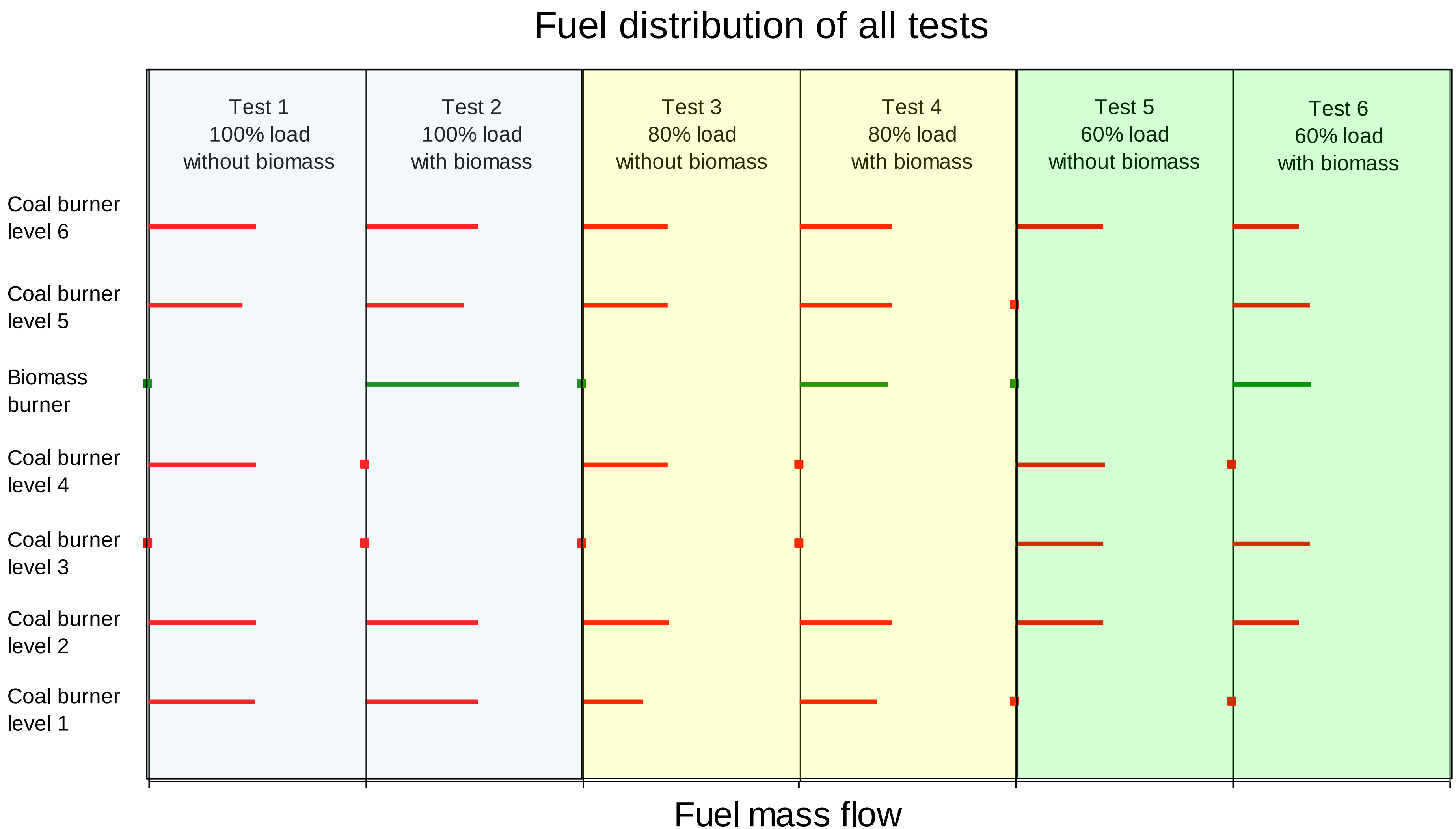
Test program May 2009



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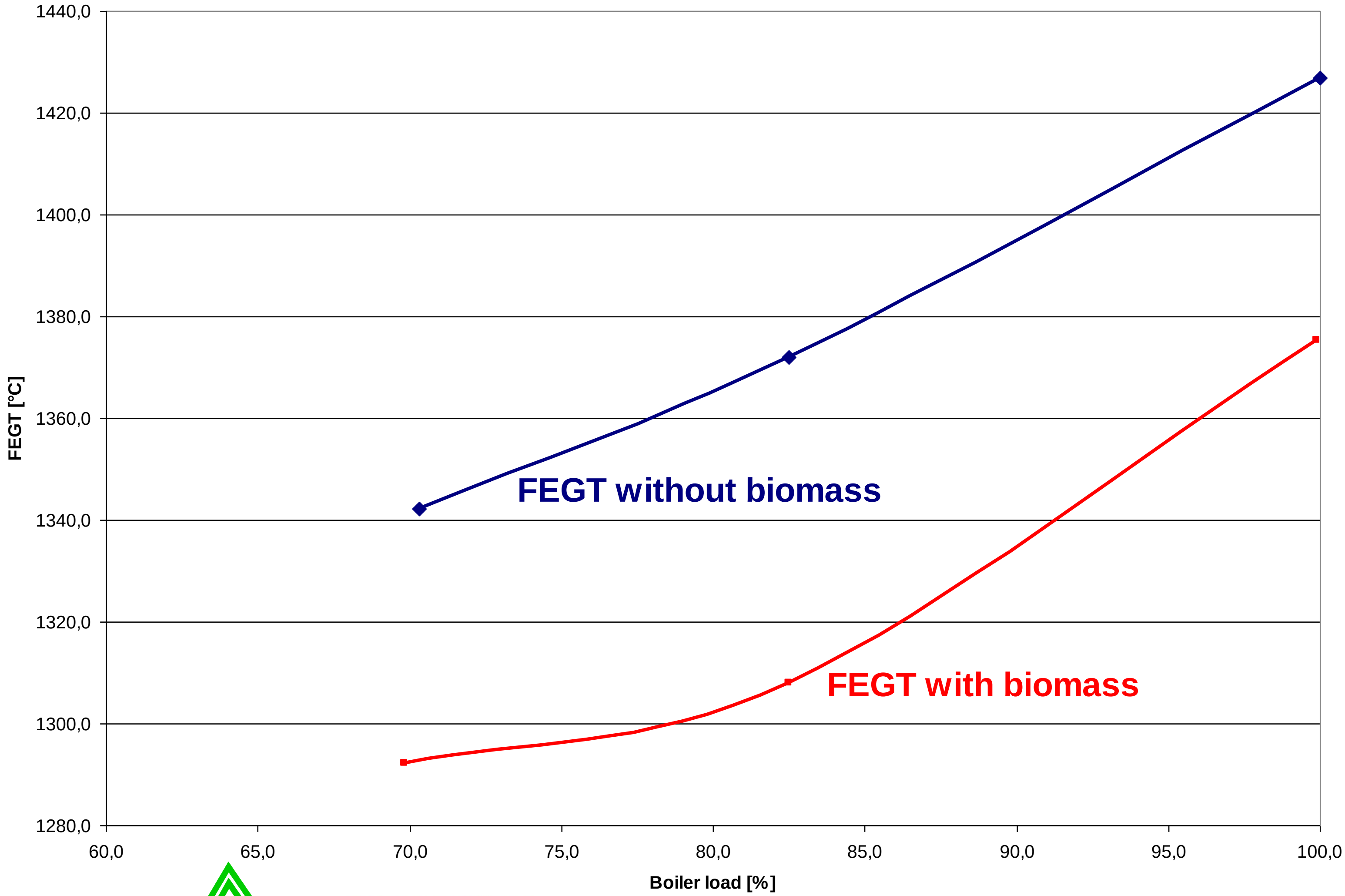
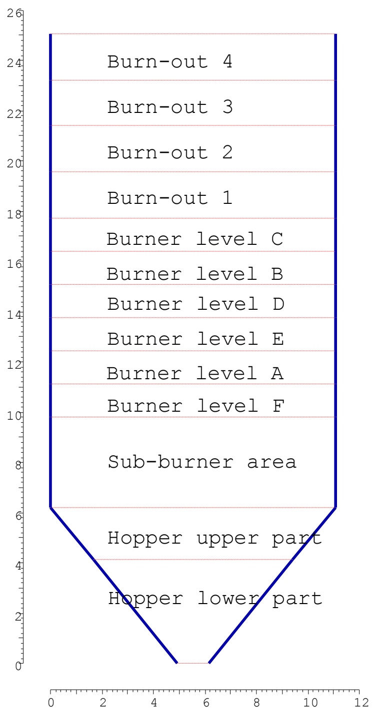
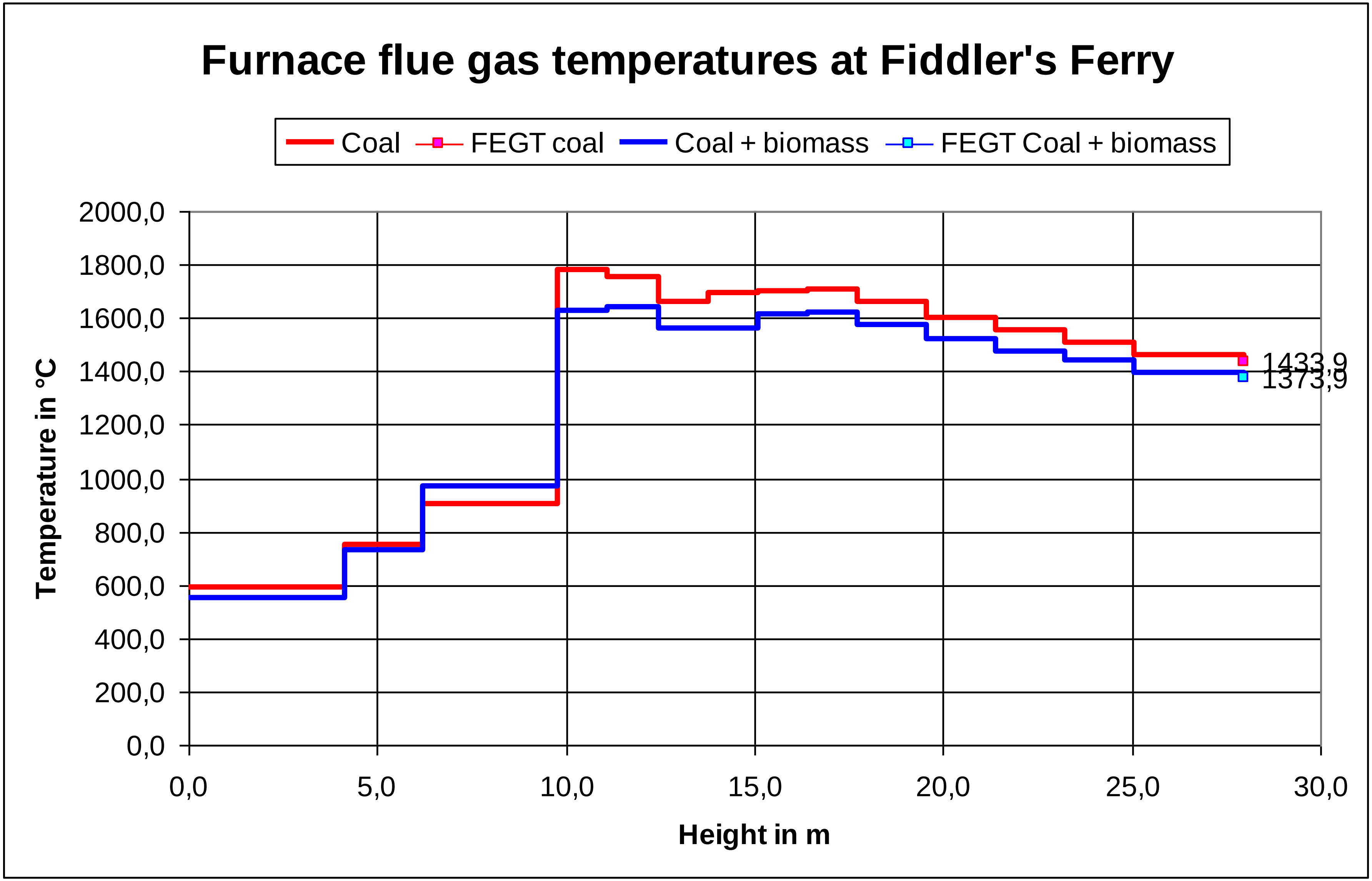
Furnace exit gas temperature (FEGT) for Fiddler's Ferry PS



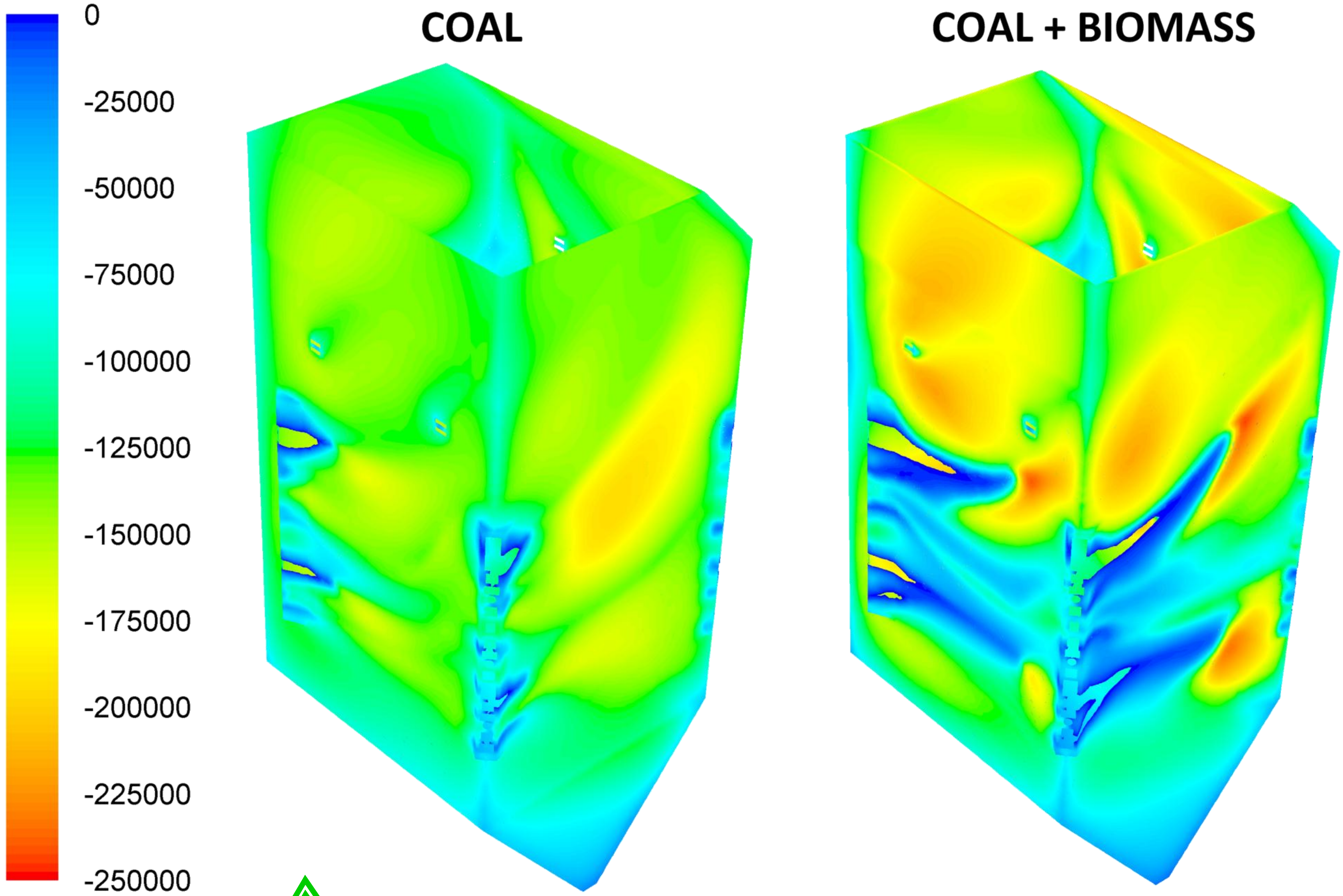
Model adjustment for Fiddler‘s Ferry



		Coal firing			Biomass co-firing		
		Test 1	Test 3	Test 5	Test 2	Test 4	Test 6
FEGT in ° C		1426.8	1372.0	1342.2	1375.4	1308.1	1292.2
Adjusted Fouling	Fouling in m²K/kW	3,3	4,54	>5	3.00	2.50	3.74
	FEGT in ° C	1426.8	1372.0	1342.2	1375.4	1308.1	1292.2
	Steam flow in kg/s	389.8	313.8	263.8	390.1	314.9	264.4
Mean Fouling	Fouling in m²K/kW	4.3			3.1		
	FEGT in ° C	1450.9	1364.8	1280.8	1375.6	1317.6	1290.5
	Deviation in K	+24.1	-7.2	-61.4	+0.2	+9.5	-1.7
	Steam flow in kg/s	388.2	314.2	266.2	390.1	314.3	264.4
	Deviation in %	-0.41	+0.12	+0.91	+-0.00	-0.19	+0.02


Furnace flue gas temperatures at Fiddler's Ferry
Coal
FEGT coal
Coal + biomass
FEGT Coal + biomass
Temperature in °C
Height in m
2000,0
1800,0
1600,0
1400,0
1200,0
1000,0
800,0
600,0
400,0
200,0
0,0
0,0
5,0
10,0
15,0
20,0
25,0
30,0
1433,9
1373,9

- Heat flux (W/m²)



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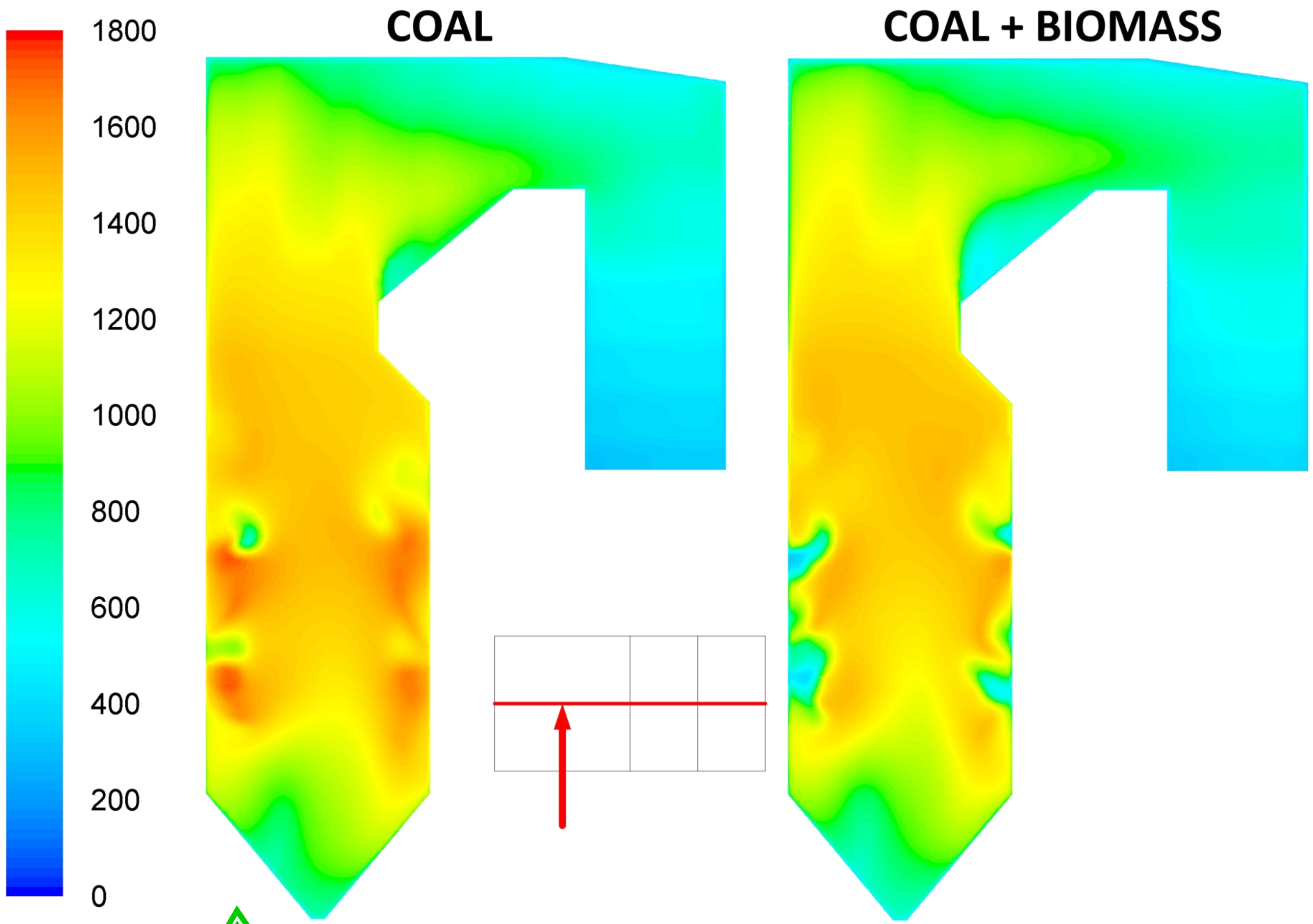
- Temperatures in der Mitte (°C)



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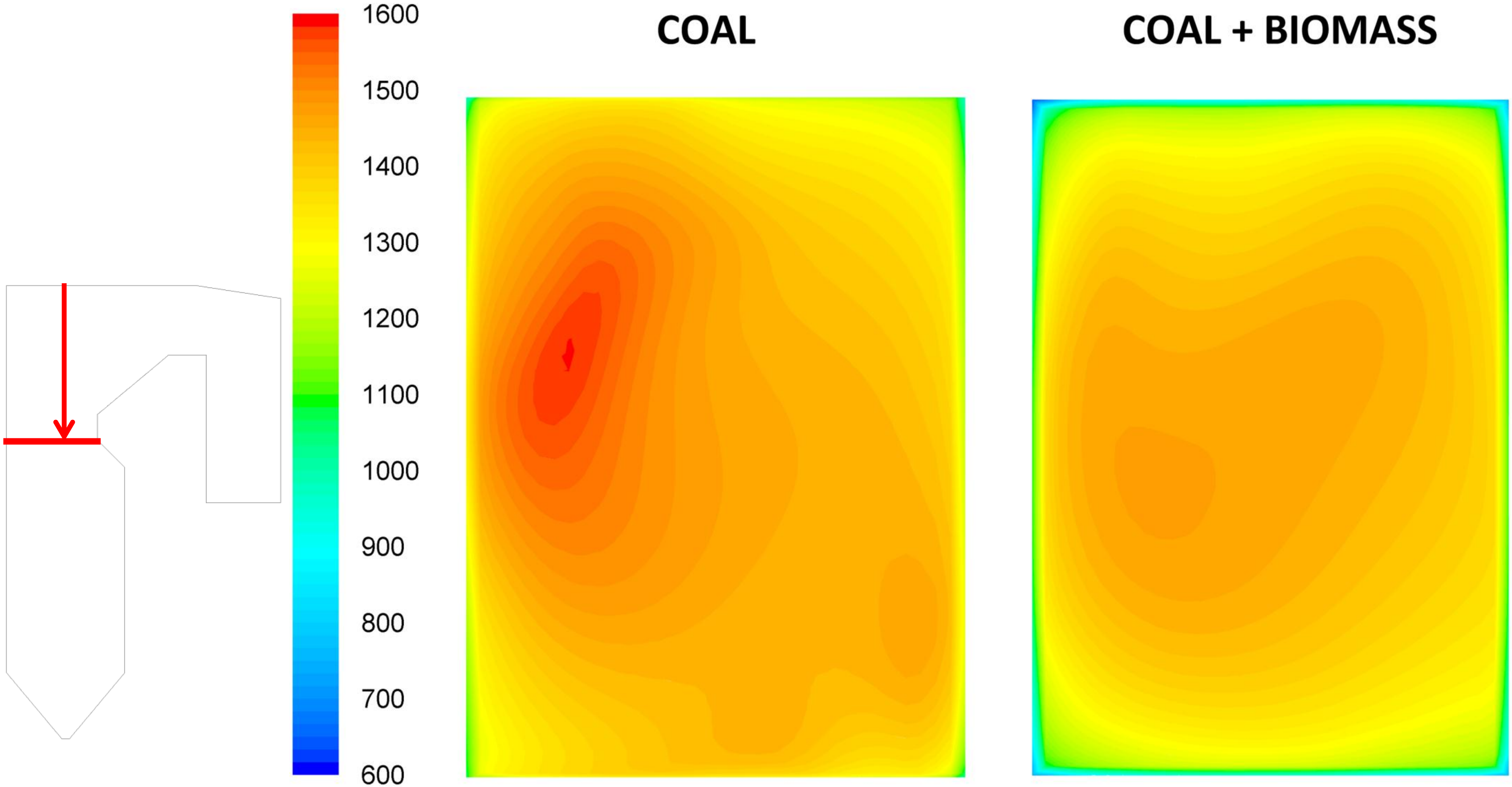
- FEGT(°C)



Coal: 1432 °C

Coal + Biomass: 1377 °C

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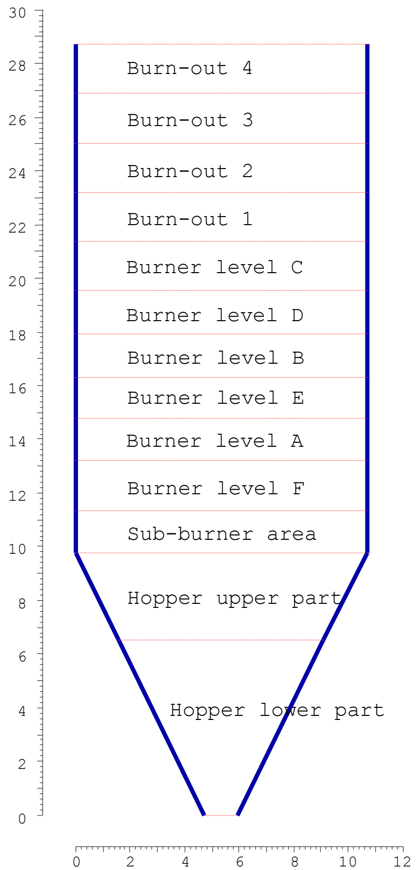
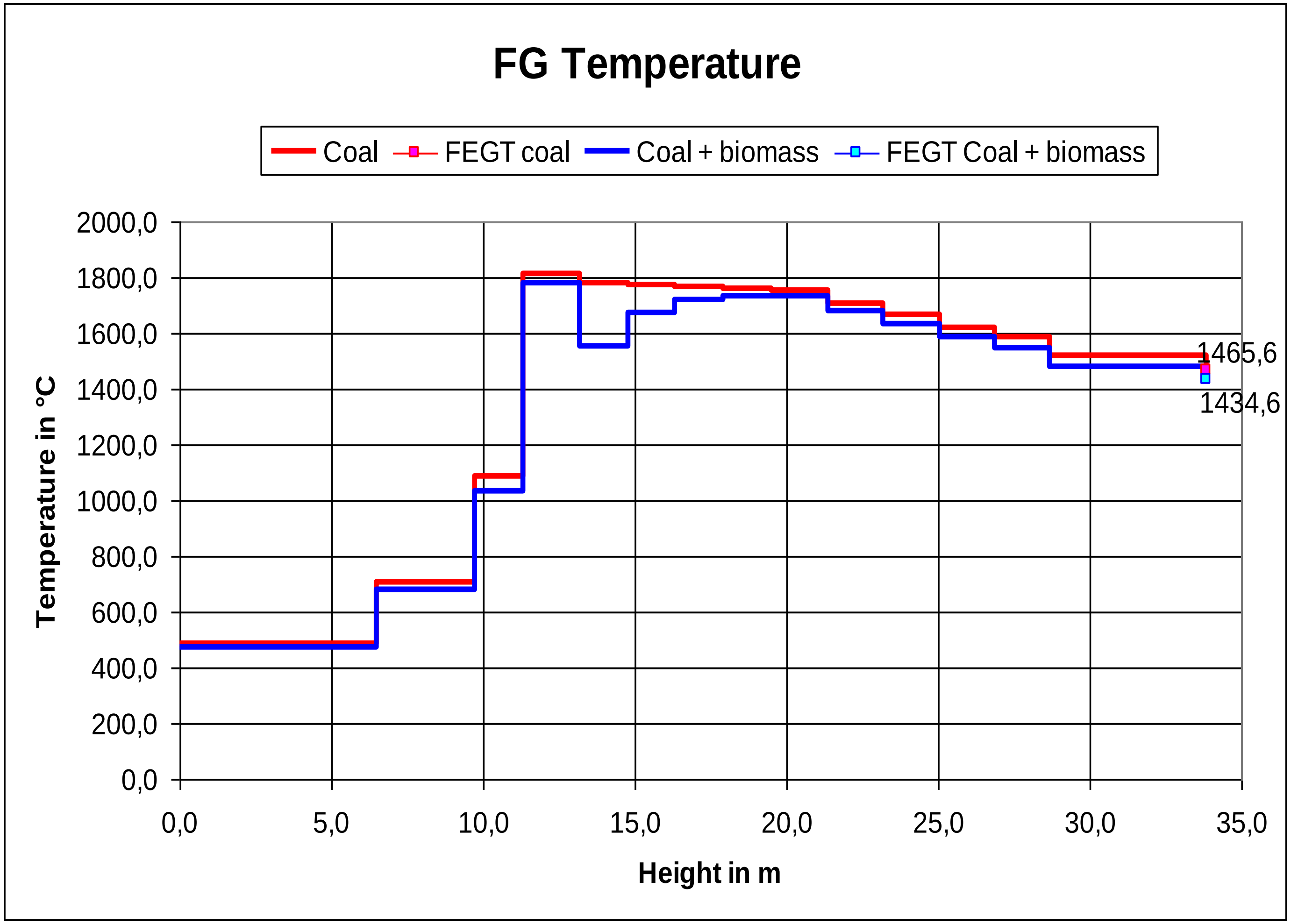
Arnot PS

6 x 350MW
(increased 400 MW)
Fuel: Bituminous coal
LCV: 21.4 MJ/kg
Double tangentially fired furnace
Drum type boiler
HP: 514°C / 162 bar
RH: 530°C / 38 bar
No. of mills: 6
No. of burners: 6 x 8
Design efficiency: 35.60%
Commissioning: 1971

Sectional furnace model for Arnot PS





Co-firing results for Arnot PS

Parameter	Unit	Calculation				
		1	2	3	4	*5*
Fuel						
Coal flow rate	kg/s	49.3	44.7	44.6	44.7	44.6
Biomass flow rate	kg/s		5.55	5.55	5.55	5.55
Biomass LCV	MJ/kg		16.7	17.2	16.7	17.2
Biomass PF loading	kg/kg		0.5	0.5	1.0	1.0
Combustion air						
AH outlet temperature	° C	269.9	273.4	272.4	270.8	270.8
Flue gas						
FEGT	° C	1465.6	1432.1	1434.5	1434.6	1434.7
Off gas temperature	° C	130.6	134.9	133.9	132.3	132.3
Water/Steam						
HP injection flow rate	kg/s	35.20	28.09	28.55	28.53	28.45
RH injection flow rate	kg/s	2.63	0.82	0.99	0.92	0.95

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Notice

The topic of the presentation is intended as part of a Ph.D. Thesis by Mr. Matshela Koko from Eskom Enterprises, South Africa.

Mr. Koko initiated the development of a sectional furnace model. He takes part in the development and supports the validation by supply of operational experience from Eskom‘s coal fired power plants in South Africa.