Experience with biomass firing for large scale power

Yves Ryckmans,
Chief Technology Officer, Biomass
Ottawa, 18 Sept 2017

TRACTEBEL ENGIE

ENGIE Laborelec

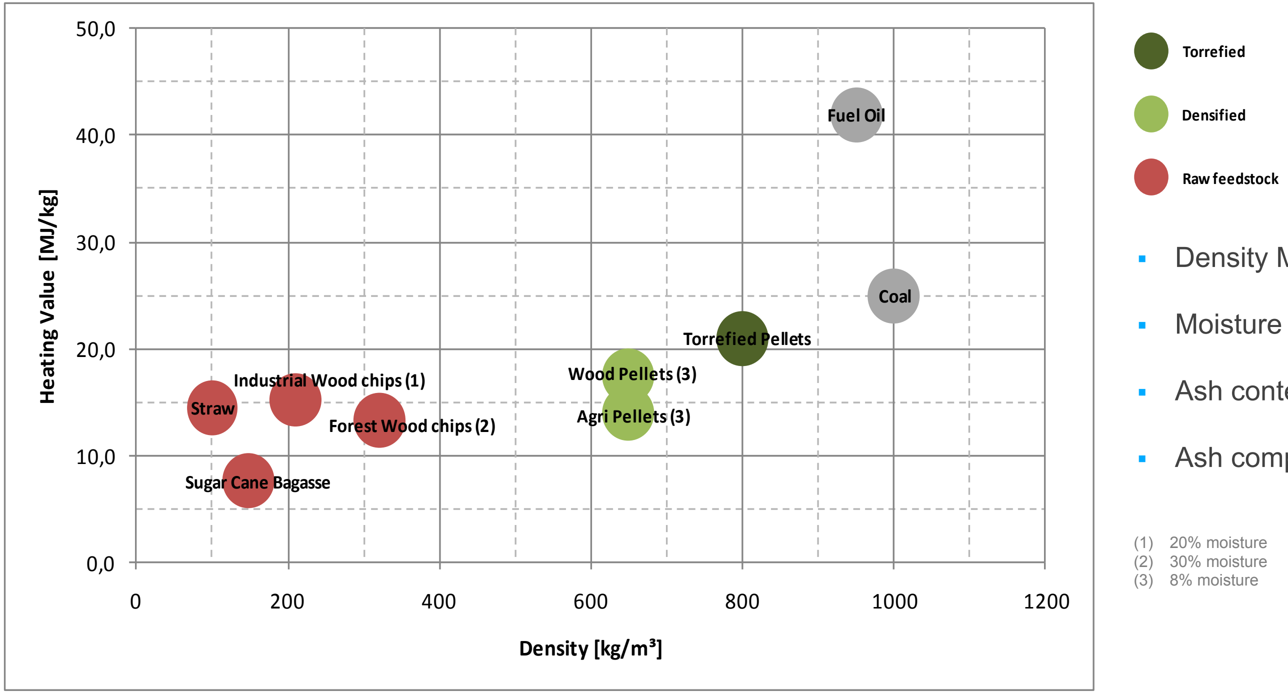
CONTENT

01

Experience of ENGIE with biomass firing in large scale plants

Biomass Energy Properties

Combustion is similar to coal, but energy content varies widely, with technical and economic consequences



- Density MJ/m^3
- Moisture content
- Ash content
- Ash composition

(1) 20% moisture
(2) 30% moisture
(3) 8% moisture

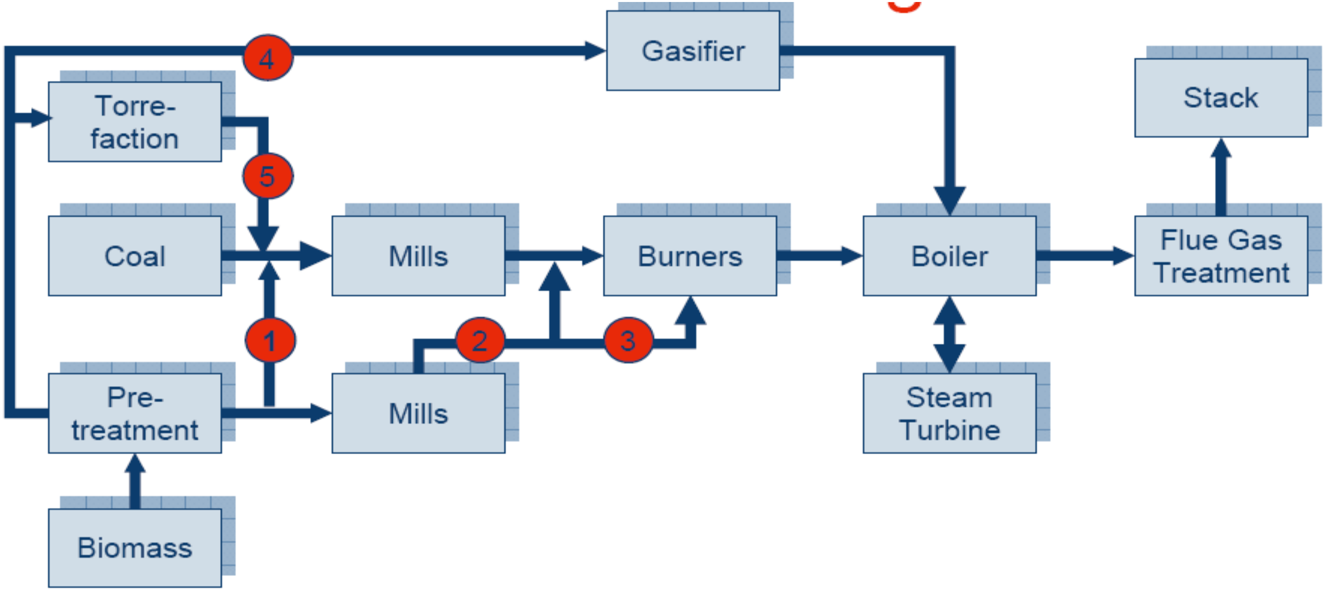
Source: BEEI Operations & EUBIA

New or retrofitted biomass plant

Main issues

- CAPEX and OPEX
- Fuel quality: specifications
- De-rating (nominal capacity with biomass)
- Handling (storage, fuel flow, milling, drying)
- Impacts on boiler (fouling, slagging, corrosion)
- NOx emissions, impact on SCR
- Ash quality (vs EN450 for coal)
- Safety risks (ATEX)

Experience of ENGIE with biomass cofiring

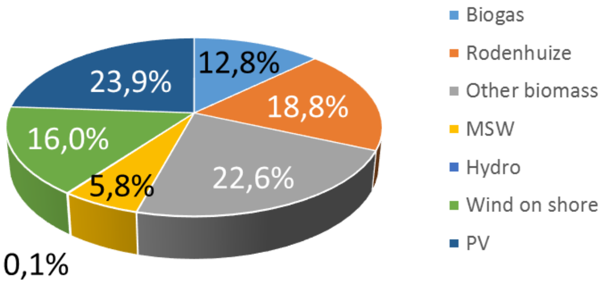


1. Co-milling of biomass with coal
2. Separate milling, injection in pf-lines, combustion in coal burners
3. Separate milling, combustion in dedicated biomass burners
4. Biomass gasification, syngas combusted in furnace boiler
5. Co-milling of torrefied biomass with coal

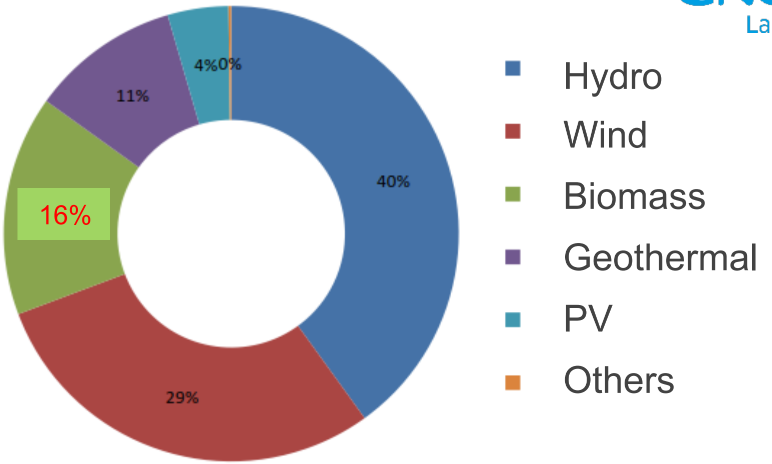
Experience ENGIE with large scale RETROFITS

PLANT	NAME MW	CAPACITY BIOMASS	CAPEX
	AWIRS, BE UNIT 4, PF 130 MW → 80 MW	400 000 ton pellets **1st full coal to bio conversion**	10 mio € 125 €/kW
	RODENHUIZE, BE MaxGreen, PF 240 MW →210 MW	850 000 ton pellets **Lowest emissions ever reached: @6% O_2** 15 mg/Nm^3 dust and 90 mg/Nm^3 NO_x	150 mio € 800 €/kW
	POLANIEC, PL Green Unit, CFB brown field, 205 MW	1,1 mio ton wood chips 250 000 ton agri-biomass	230 mio € 1100 €/kW

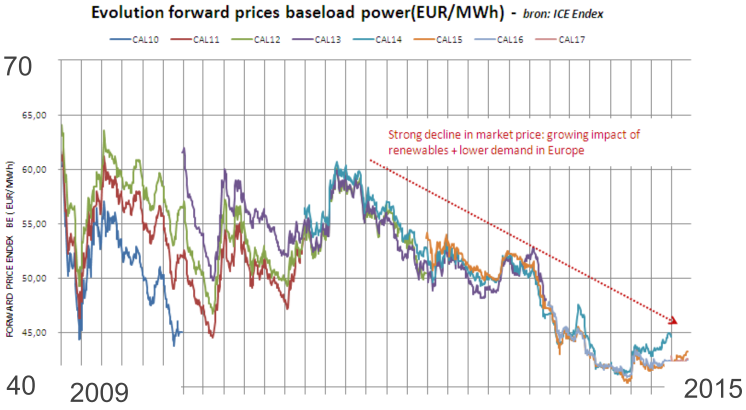
Belgium: 28% green power in 2015
but declining power prices, reduced GC value, limited contribution of large scale biomass share

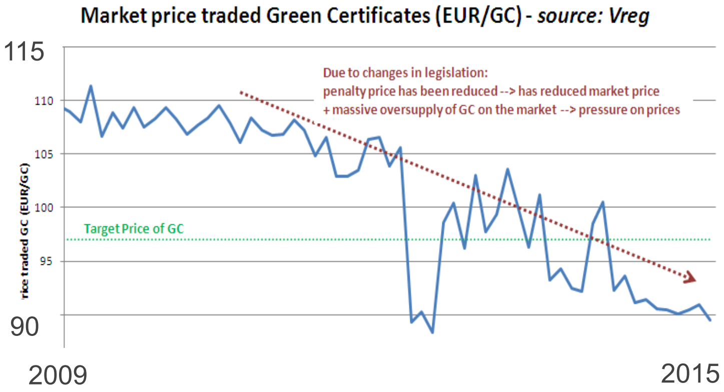


Green Power Share Flanders 2015



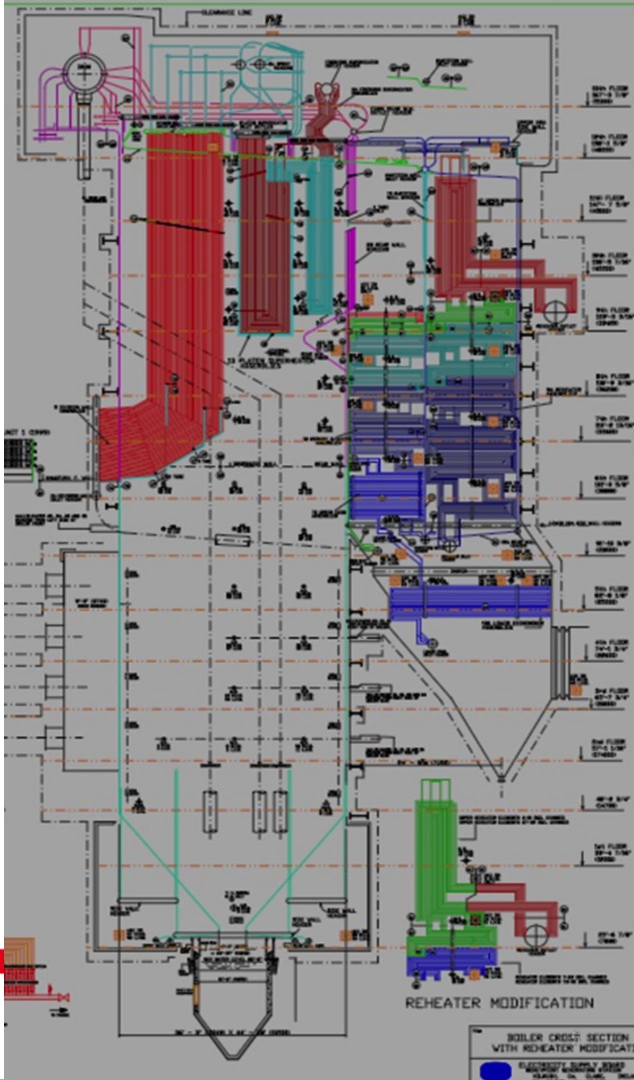
Green Power Share Belgium 2015





02

What is a quick scan for retrofit or root cause analysis



Basis of quick scan: based on chemistry, empirical formulas and other references

<u>Approach</u>

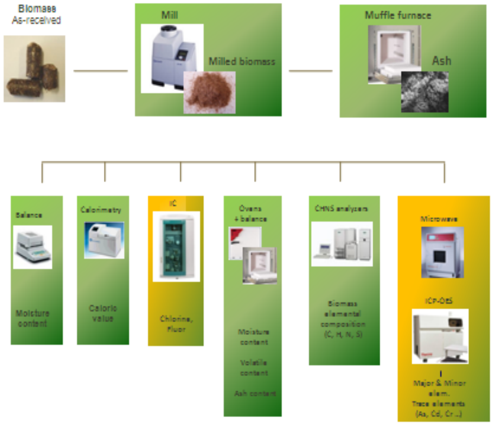
- Fuel specifications and indices based on ash composition of representative samples
- Ash Fusion Temperature (IT, ST) vs furnace exit gas temperature (FEGT)
- FEGT is measured or estimated with a model like Thermoflow
- Evaluation of flue gas flow based on excess air
- Boiler design vs residence time and burn-out

<u>Results</u>

- Evaluate risks of slagging, fouling and resulting corrosion
- De-rating estimation
- Impact on other assets: handling, milling, SCR, FGD, ESP
- Fly ash quality (ref. EN450)

Biomass analysis program based on EN/ISO standard

1. Mechanical properties
   - particle size distribution
   - durability (for pellets only)
2. Basic properties
   - heating value
   - moisture, volatiles, ash composition
3. Fuel elementary composition
   - C, H, O, N, S, Cl, F, P
4. Ash preparation at 550°C
5. Alkali oxides in ash
   - Al_2O_3, CaO, Fe_2O_3, K_2O, Na_2O, P_2O_5 SiO_2, MnO, MgO, TiO_2
6. Trace elements in ash
   - As, B, Cd, Cu, Hg, Ni, Pb, Sb, Se, Zn, V
7. Ash melting T
   - under oxidising and reductive conditions



EXTENSIONS : coal and bio-liquids

ISO Specs for industrial pellets I1/I2/I3 designed in agreement with suppliers and users in EU

<u>Initiative Wood Pellets Buyers 2010-2012</u>

Fuel specs for industrial wood pellets

- developed by LBE
- agreed with utilities RWE, E.ON, VATTENFALL, DONG, DRAX, ENGIE,
- discussed and agreed with pellets suppliers in Europe (EIPS), USA (USIPA), Canada (WPAC)
- endorsed by ISO in 2012
- is the reference for 80% of the market

- other specs invented by users in Korea, Japan should be avoided !

	Property class, Analysis method	Unit	I1	I2	I3
Normative	**Origin and source**, ISO 17225-1 		1.1.3 Stemwood 1.2.1 Chemically untreated wood residues [a]	1.1.1 Whole trees without roots 1.1.3 Stemwood 1.1.4 Logging residues 1.2.1.5 Bark 1.2.1 Chemically untreated wood residues [a]	1.1 Forest, plantation and other virgin wood 1.2 By-products and residues from wood processing industry 1.3 Used wood
	Diameter, D [b] **and Length L** [c], ISO 17829 According Figure 1	mm	D06, 6 ± 1; 3,15 ≤ L ≤ 40 D08, 8 ± 1; 3,15 ≤ L ≤ 40	D06, 6 ± 1; 3,15 ≤ L ≤ 40 D08, 8 ± 1; 3,15 ≤ L ≤ 40	D06 6 ± 1; 3,15 ≤ L ≤ 40 D08 8 ± 1; 3,15 ≤ L ≤ 40
	Moisture, M, ISO 18134-1, ISO 18134-2	as received, w-% wet basis	M10 ≤ 10	M10 ≤ 10	M10 ≤ 10
	Ash, A, ISO 18122	w-% dry	A1.0 ≤ 1,0	A1.5 ≤ 1,5	A5.0 ≤ 5,0
	Mechanical durability, DU, ISO 17831-1	as received, w-%	DU96.5 ≥ 96,5	DU96.5 ≥ 96,5	DU95.0 ≥ 95,0
	Fines, F [d], ISOWD XXXXX (hand sieving)	w-% as received	F5.0 ≤ 5,0	F5.0 ≤ 5,0	F7.0 ≤ 7,0
	Additives [e]	w-% dry	≤ 2 w-% Type and amount to be stated	≤ 2 w-% Type and amount to be stated	≤ 2 w-% Type and amount to be stated
	Net calorific value, Q, ISO 18125	as received, MJ/kg	Q16.5 ≥ 16,5	Q16.0, ≥ 16,0	Q15.5, ≥ 15,5
	Bulk density, BD [f], ISO 17828	kg/m^3	BD600 ≥ 600	BD600 ≥ 600	BD600 ≥ 600
	Nitrogen, N, ISO 16948	w-% dry	N0.3 ≤ 0,3	N0.5 ≤ 0,5	N1.5 ≤ 1,5
	Sulphur , S, ISO 16994	w-% dry	S0.05 ≤ 0,05	S0.05 ≤ 0,05	S0.05 ≤ 0,05
	Chlorine, Cl, ISO 16994	w-% dry	Cl0.05 ≤ 0,05	Cl0.05 ≤ 0,05	Cl0.05 ≤ 0,05
	Arsenic, As, ISO 16968	mg/kg dry	≤ 2	≤ 2	≤ 6
	Cadmium, Cd, ISO 16968	mg/kg dry	≤ 1,0	≤ 1,0	≤ 10
	Chromium, Cr, ISO 16968	mg/kg dry	≤ 15	≤ 15	≤ 15
Informative	**Ash melting behaviour** [g], CEN/TS 15370-1 [4]	°C	Should be stated	Should be stated	Should be stated
	Particle size distribution of disintegrated pellets, ISO 17830	w-%	Should be stated	Should be stated	Should be stated

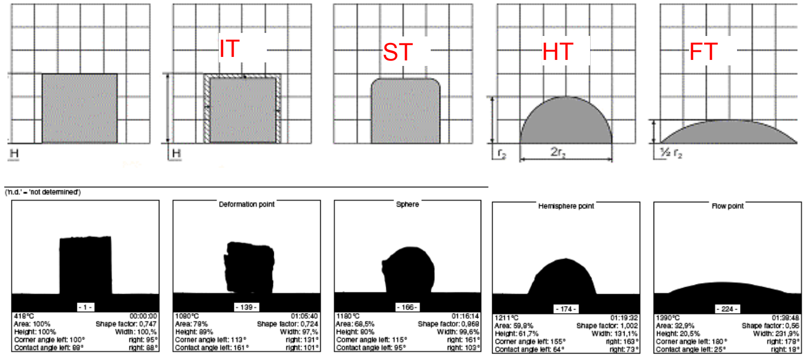
Slagging and fouling risk vs AFT and basic ratio in ash

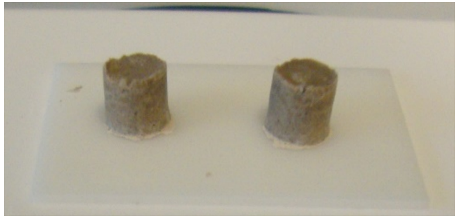
Fuel type All resultats on dry base (except moisture)	GORDINNE 04.0512 Wood pellets Canada	GORDINNE 5 010 238 Woodpellets ESTELVA Uruguay	GORDINNE 04.0109 Rubber tree pellets	Eucalyptus wood & bark (Asia - Sth-A) pellets	Gordinne 602.0.405 Lignine Lithuania raw material
ash content	0,3	0,95	2,25	8,20	10,63
melting T	1470	1170	1230	1220	1530
Al_2O_3-Al (acid)	1,81	4,23	3,39	2,85	4,89
CaO-Ca (base)	46,99	24,37	37,12	33,40	2,27
Fe_2O_3-Fe (base)	1,93	18,44	4,90	5,31	1,12
K_2O-K (base)	17,88	6,59	5,43	6,95	2,24
MgO-Mg (base)	12,53	3,56	6,89	2,78	0,32
Na_2O-Na (base)	0,44	4,09	0,73	0,79	0,86
P_2O_5-P (acid)	3,30	1,89	3,78	4,60	0,24
SiO_2-Si (acid)	7,33	31,76	31,04	43,95	85,59
SO_3-S (acid)	2,16	3,13	3,51		
TiO_2-Ti (acid)	0,07	0,39	2,00	0,25	0,23
basic oxides	79,77	57,05	55,07	49,23	6,81

$$R\frac{B}{A} = \frac{CaO + K_2O + MgO + Na_2O + Fe_2O_3}{SiO_2 + Al_2O_3 + TiO_2}$$

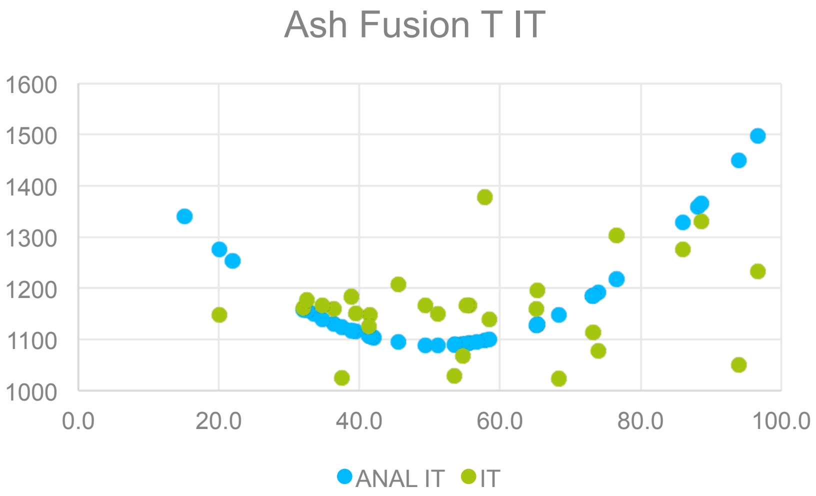
Determination and use of Ash Fusion Temperature

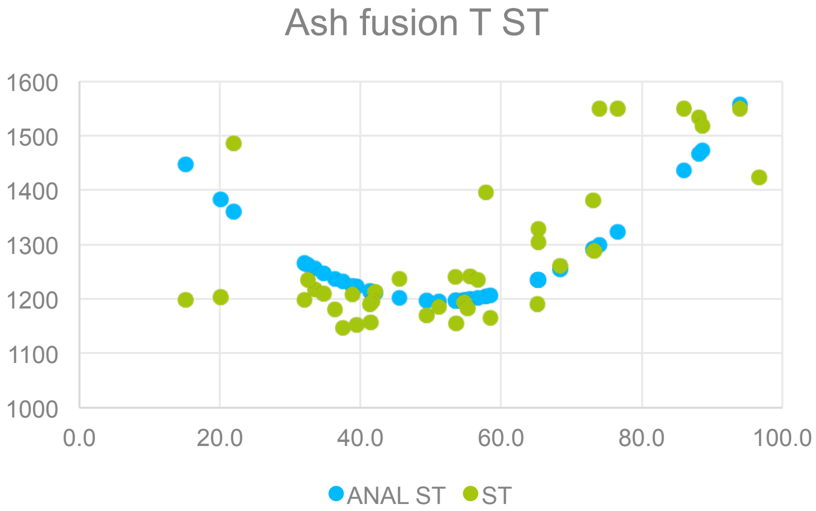
- Method derived from coal analysis (ASTM, DIN)
  - Preparation of biomass **ash cylinder**
  - Thermal program in high temperature oven (550°C – 1550°C)
  - Monitoring of deformations of the cube by automated **image analysis**
  - Initial deformation temperature (IT) is the level where the cylindrical sample begins to round;
  - Softening temperature (ST) also sometimes called the spherical temperature is the level where the base of the cylindrical sample is equal to its height;
  - Hemispherical temperature (HT) is the level where the base of the cylindrical sample is twice its height.
  - Fluid temperature (FT) the cylindrical sample has spread to a fused mass no more than 1.6 mm in height.





Evolution of IT and ST in function of % basic oxides





- Mainly influenced by KCl
- Difficult to measure with precision and reproducibility

- Mainly influenced by CaO vs SiO_2
- More accurate measurement

Eutectics with Ca, Si, K

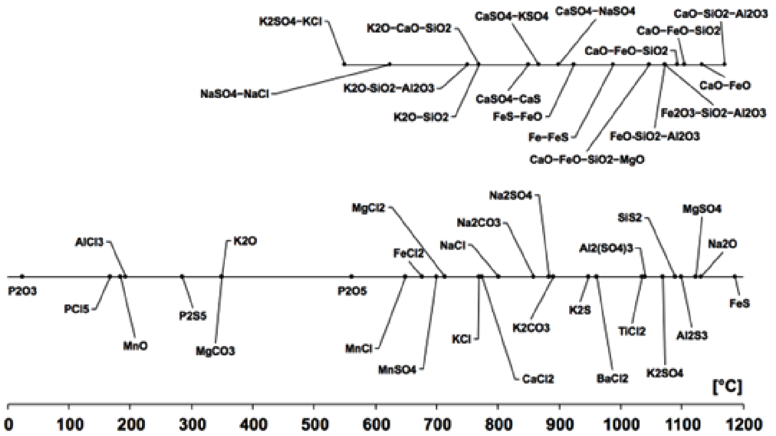
1. Oxide mixtures

$CaO + Fe_2O_3$	1205°C
$CaO + FeO$	1133°C
$CaO + SiO_2$	1435°C

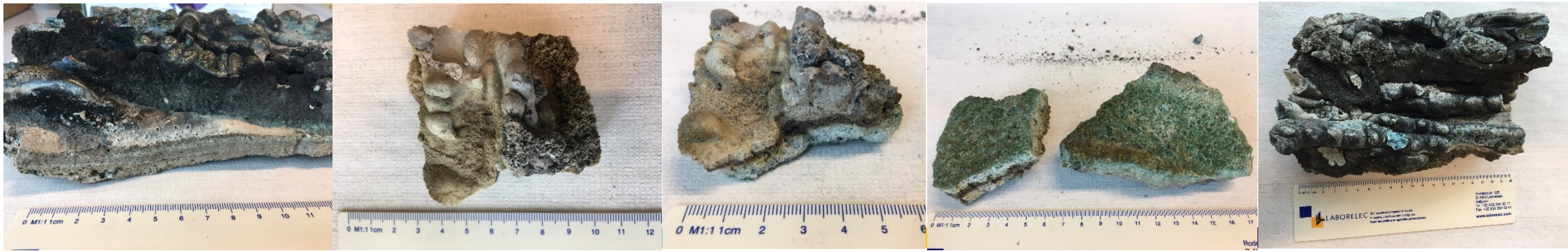
2. Silicates

$SiO_2 + Al_2O_3 + Fe_2O_3$	1073°C
$SiO_2 + Al_2O_3 + K_2O$	695°C
$SiO_2 + CaO + K_2O$	730°C
$SiO_2 + MgO + K_2O$	700°C
$SiO_2 + Na_2O + K_2O$	540°C

3. KCl 762°C

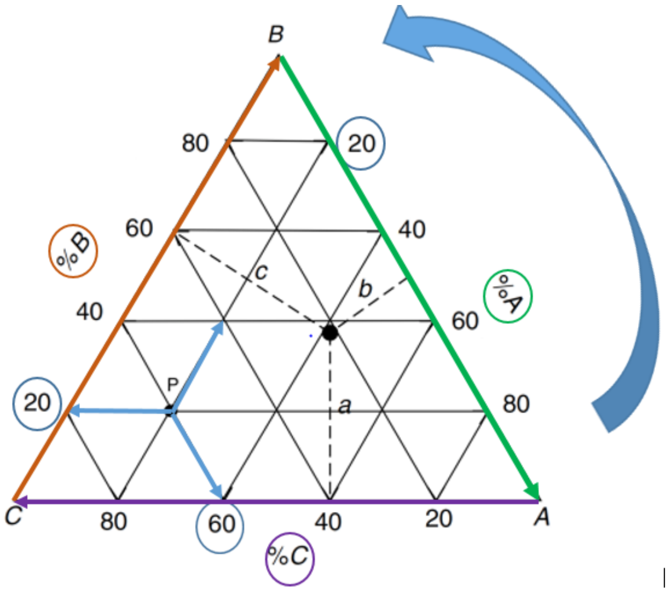


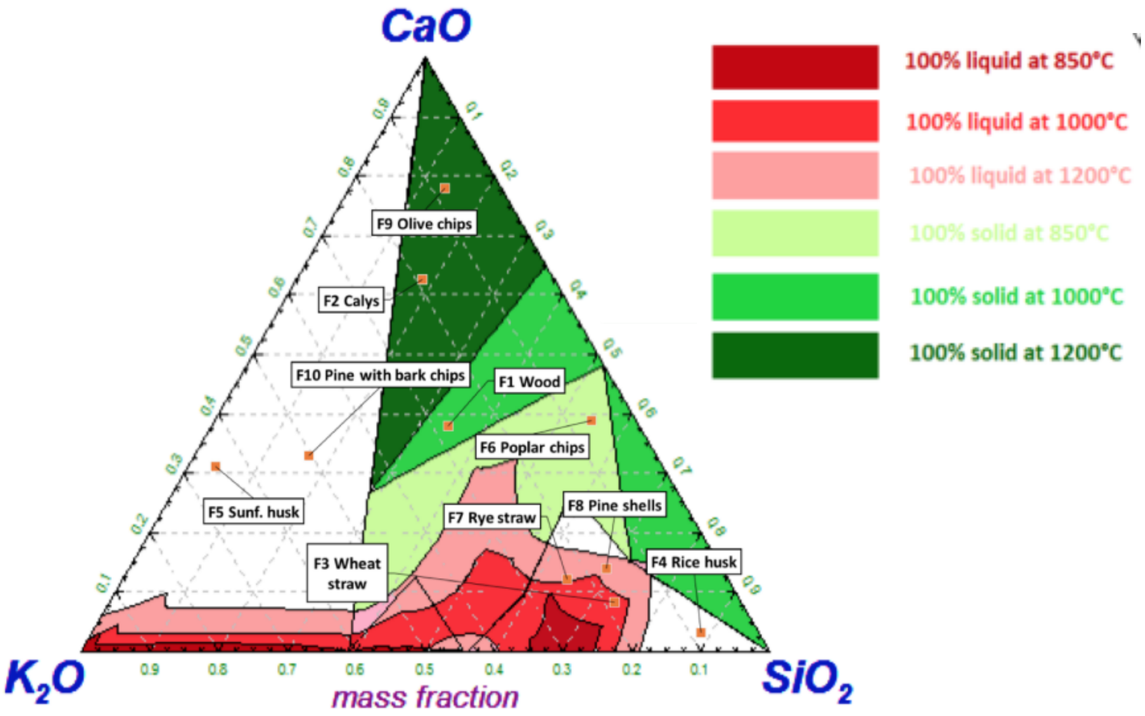
- Mineral form of Si:
  - In most coals: Si as kaolinite ($Al_2Si_2O_5(OH)_4$) or
    illite (clay minerals)($(K_2H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}$)
  - **quartz** instead of clay mineral: with FeO, K_2O and CaO low melting eutectic (glass!)
  - Risk can be derived from the Si/Al ratio
    theoretical: < 1.5 : no presence of quartz



Use of phase diagrams for complex fuel mixes

Thesis Dr Lucio De Fusco, UCL, 2017





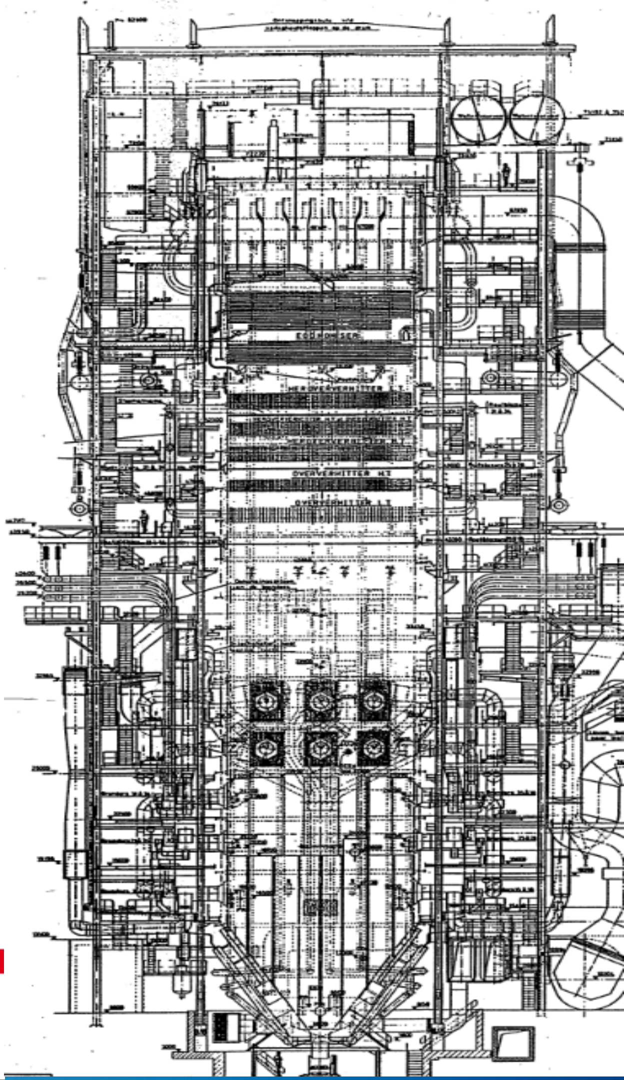
Wood hardness

- Wood hardness influences the throughput of the hammer mills as well as the electricity use for grinding the pellets.
- The Janka hardness test measures the resistance of a sample of wood to denting and wear. It measures the force required to embed an 11.28 mm (.444 in) steel ball into wood to half the ball's diameter.
- The resulting measure is always one of force. In the United States, the measurement is in pounds-force (lbf). In Sweden it is in kilograms-force (kgf), and in Australia, either in newtons (N) or kilonewtons (kN).

Janka Hardness		
Species	Pounds-Force	Force in Newtons
Brazilian Ebony	3,692 lbf	16,420 N
Cumaru, Brazilian Teak	3,540 lbf	15,700 N
Ebony	3,220 lbf	14,300 N
Live Oak	2,680 lbf	11,900 N
Mesquite	2,345 lbf	10,430 N
Merbau	1,712 lbf	7,620 N
Wenge, Red Pine, Hornbeam	1,630 lbf	7,300 N
True Pine, Timborana	1,570 lbf	7,000 N
Sweet Birch	1,470 lbf	6,500 N
Hard maple, Sugar Maple	1,450 lbf	6,400 N
Natural Bamboo	1,380 lbf	6,100 N
White Oak	1,360 lbf	6,000 N
American Beech	1,300 lbf	5,800 N
Red Oak Northern	1,290 lbf	5,700 N
Heart pine	1,225 lbf	5,450 N
Brazilian Eucalyptus, Rose Gum	1,125 lbf	5,000 N
Red Maple	950 lbf	4,200 N
Eastern Red Cedar	900 lbf	4,000 N
Southern Yellow Pine Longleaf	870 lbf	3,900 N
Radiata Pine	710 lbf	3,200 N
Southern Yellow Pine Loblolly and Shortleaf	690 lbf	3,100 N
Douglas Fir	660 lbf	2,900 N
Western Juniper	626 lbf	2,780 N
Western White Pine	420 lbf	1,900 N
Eastern White Pine	380 lbf	1,700 N

03

Results of the quick scan



COAL

Proximate analysis		COAL 1	COAL 2	Average
Water (total - a.r.)	[%]	11,62	14,00	12,2
Ash (dry)	[%]	12,47	6,50	9,3
Volatile matter (dry)	[%]	37,24	40,60	38,7
Net calorific value ar	[kJ/kg]	24,66	24,79	25,18
Elementary analysis (dry)		**COAL 1**	**COAL 2**	**Average**
Carbon (total)	[%]	71,03	74,6	72,3
Hydrogen	[%]	5,01	4,87	5
Oxygen	[%]	9,17	11,8	11,1
Nitrogen	[%]	1,52	1,58	1,5
Sulfur	[%]	0,77	0,65	0,66
Chlorine	[ppm]	300	100	300
Ash analysis		**COAL 1**	**COAL 2**	**Average**
SiO_2	[%]	60,49	52,06	58,3
Al_2O_3	[%]	20,4	20,89	19,97
TiO_2	[%]	0,99	0,93	0,94
Fe_2O_3	[%]	8,14	10,71	8,91
CaO	[%]	2,09	5,41	2,82
MgO	[%]	1,97	1,94	1,8
K_2O	[%]	2,05	0,27	1,75
Na_2O	[%]	0,64	3,25	1,6
P_2O_5	[%]	0,22	0,34	0,84
SO_3	[%]	2,1		2,54

BIOMASS

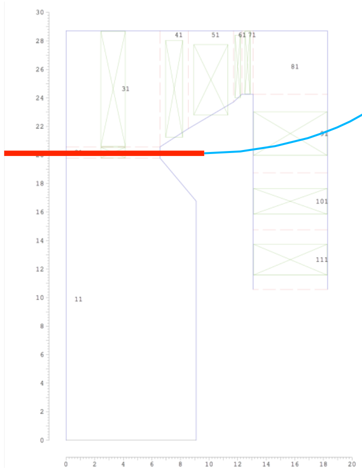
ENGIE Laborelec

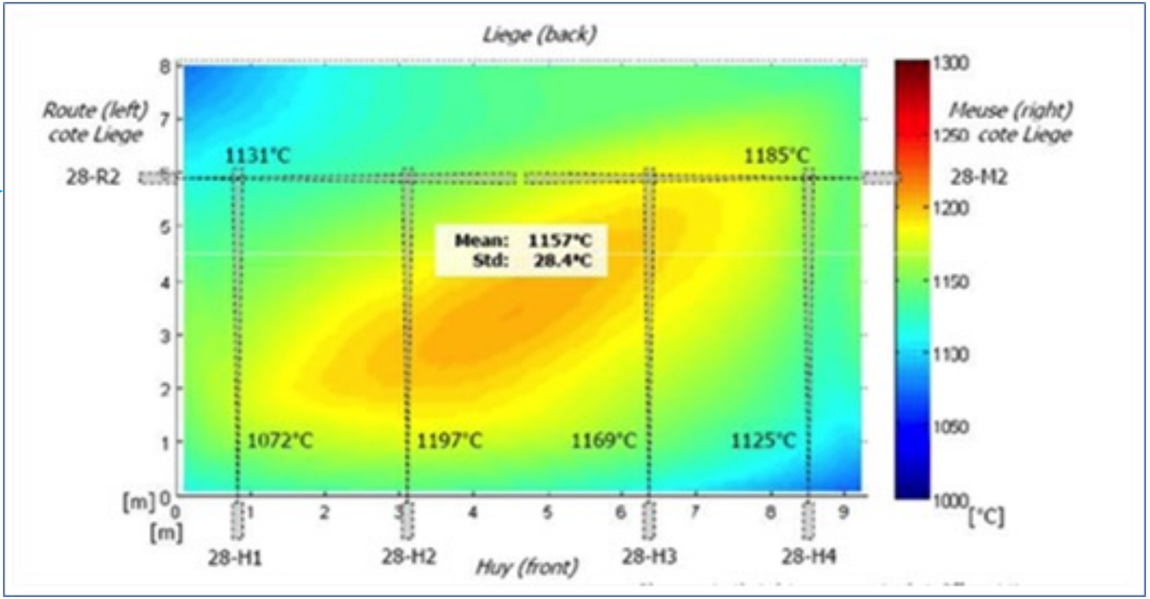
Proximate analysis		Black pellets	White pellets	Wood chips
Water (total - a.r.)	[%]	5,20	5,80	54,44
Ash (dry)	[%]	0,60	0,50	1,67
Volatile matter (dry)	[%]	78,70	83,70	81,89
Net calorific value (a.r.)	[kJ/kg]	19,22	17,75	8,90
Elementary analysis (dry)		**Zilkha**	**White pellets**	**Wood chips**
Carbon (total)	[%]	52,6	50,4	50,86
Hydrogen	[%]	5,9	6,1	6,14
Oxygen	[%]	40,7	43	40,95
Nitrogen	[%]	0,06	0,05	0,23
Sulfur	[%]	0,016	0,014	0,09
Chlorine	[ppm]	46	53	360
Ash analysis		**Zilkha**	**White pellets**	**Wood chips**
SiO_2	[%]	23,4	26,8	14,22
Al_2O_3	[%]	3,2	3,4	0,96
TiO_2	[%]	0,2	0,8	0,07
Fe_2O_3	[%]	3,4	1,1	1,87
CaO	[%]	34,9	36,3	45,3
MgO	[%]	9,3	4,8	5,42
K_2O	[%]	14,6	14	10,2
Na_2O	[%]	0,5	1,8	1,57
P_2O_5	[%]	3,4	2,7	7,79
SO_3	[%]	3	2,9	4,76

TYPICAL Furnace Gas Exit Temperature (FEGT) 2D measurements at nose level with EU-Flame

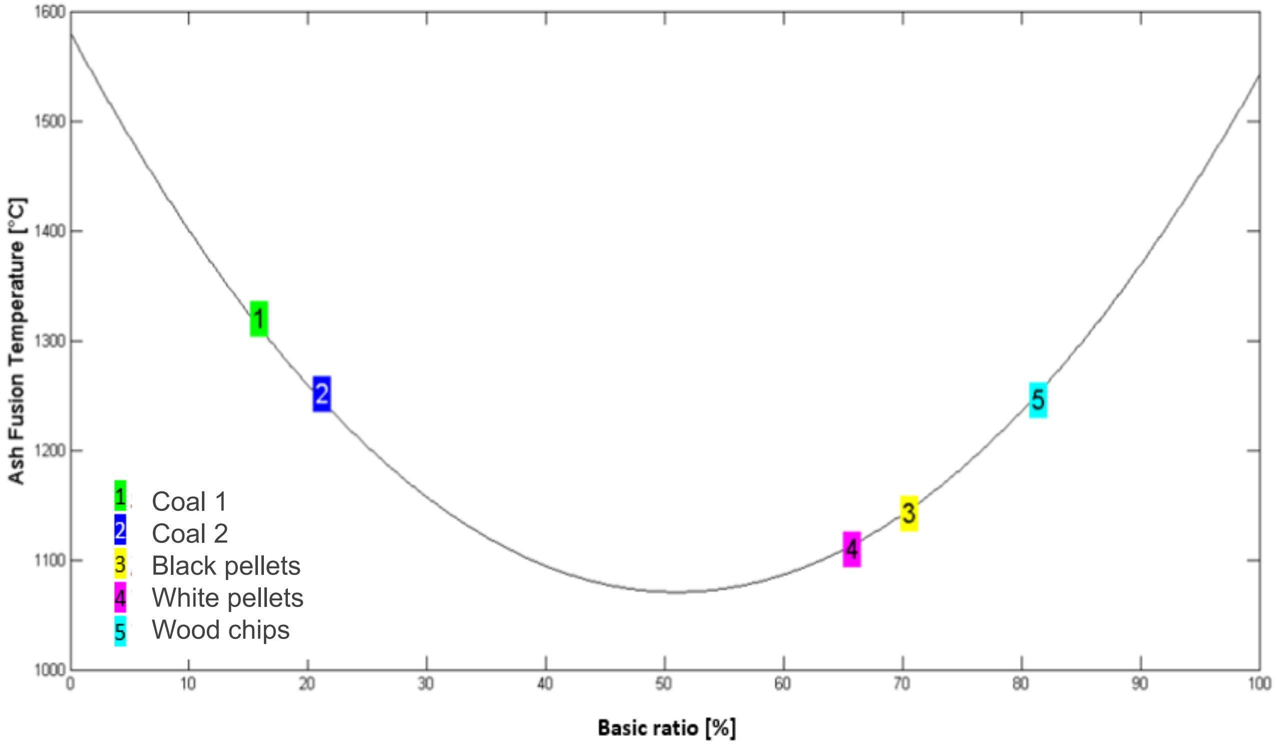
Reference values:

- Design: 1050°C
- Current: 1150°C
- Simulated Thermoflow 100% biomass: 1200°C

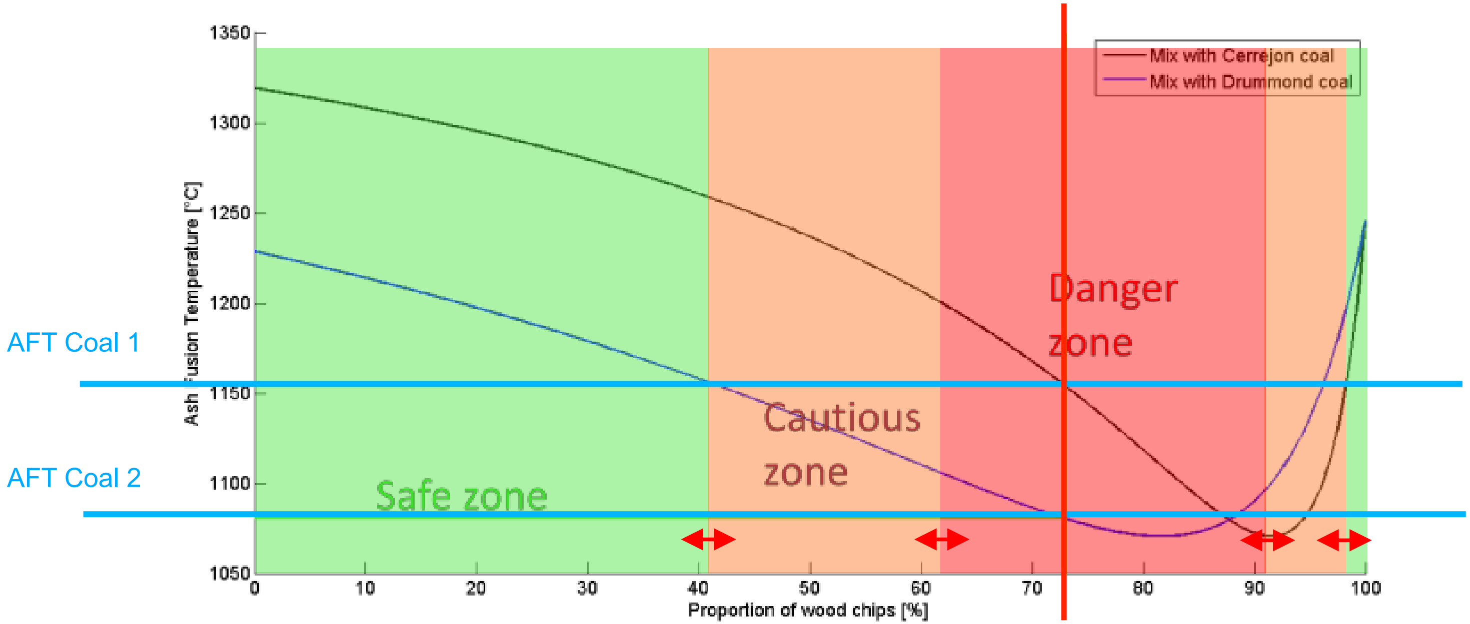




Ash Fusion Temperature coal vs biomass

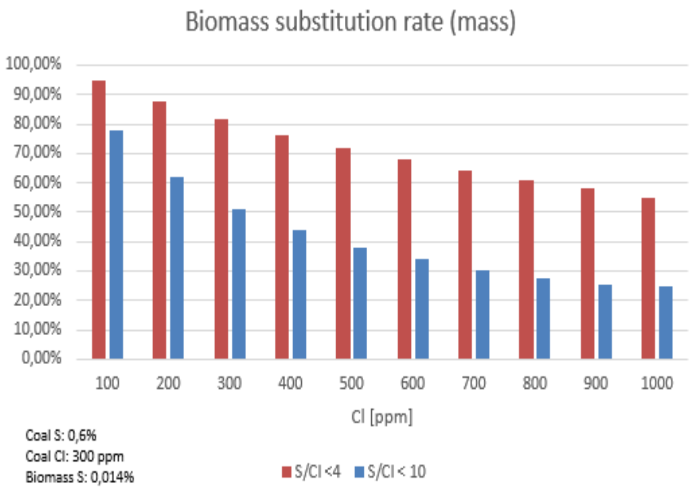


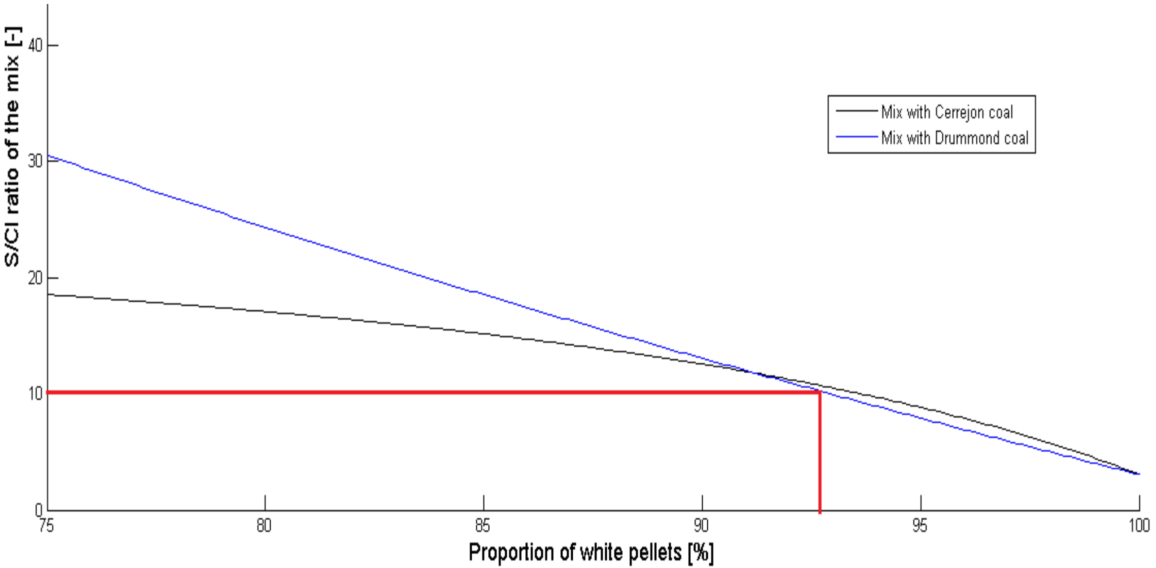
Ash Fusion Temperature vs FEGT



- Advised to keep AFT (IT) above a minimum to exclude any slagging risk, then it is advised to limit co-firing ratio

CORROSION RISK





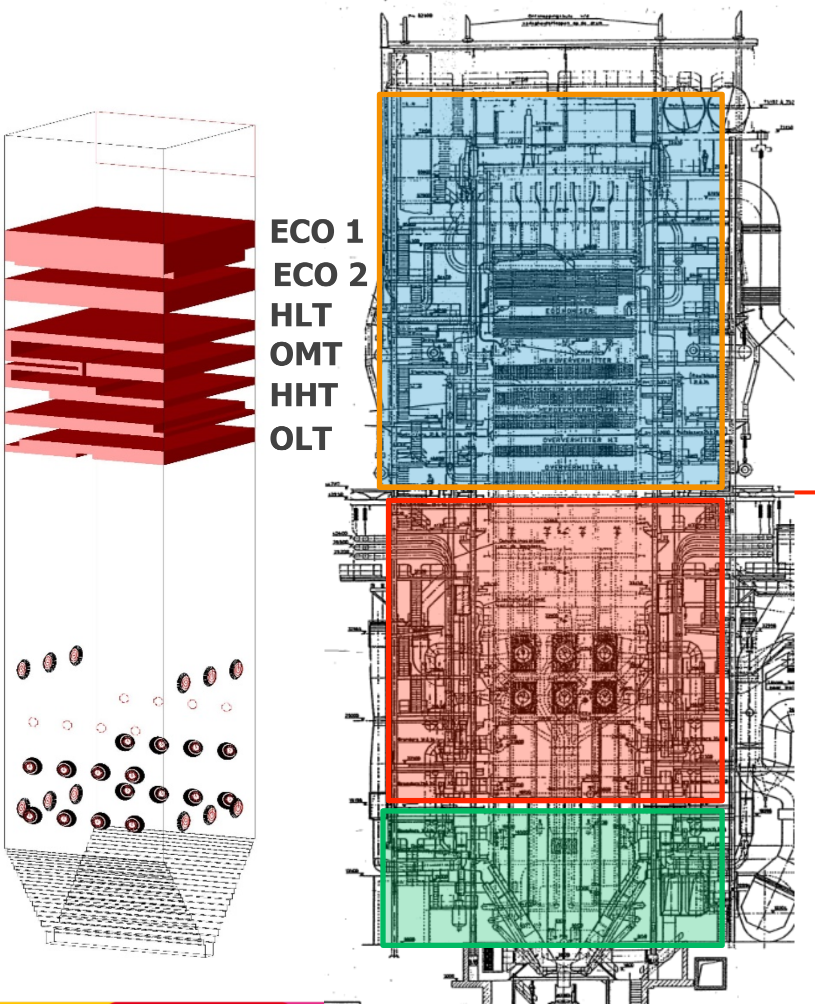
- Steam T to be selected 450°C .. 550°C
- Concerning the corrosion risk when some mass % coal are still fired, corrosion risk will be completely excluded when S/Cl ratio is greater than 10.

RESIDENCE TIME: 1D model

- In case of a two pass boiler, following two reference volumes can be considered for residence time (RT):
  1. Red rectangle called V_centerline
  2. red + green rectangle + orange rectangles called V_furnac

- for Rodenhuize, we obtain following volumes and recommended Residence Time:
  - Vcenterline , RT > 2 sec
  - Vfurnace, RT > 4 sec

RESIDENCE TIME	Rodenhuize	
Mean flue gas temperature	1200°C	1400°C
Flue gas flow	1311 m³/s	1489 m³/s
Residence time for $V_{centerline}$	2,5 s	2,2 s
Residence time for $V_{furnace}$	3,2 s	2,8 s



04
Sustainability

BIOMASS SOURCING ACCORDING TO HIERARCHY
availability, sustainability, technical applicability and economic feasibility

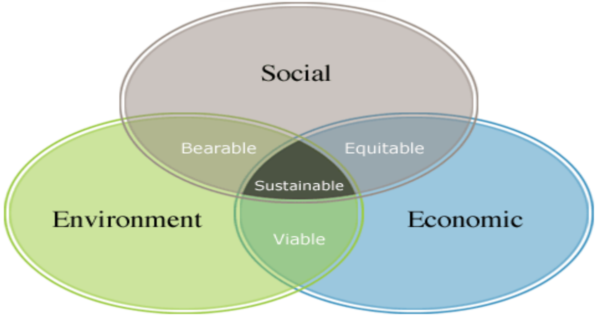
SBP
Sustainable Biomass Partnership

- Origination of biomass
- Selection on sourcing, availability & logistics

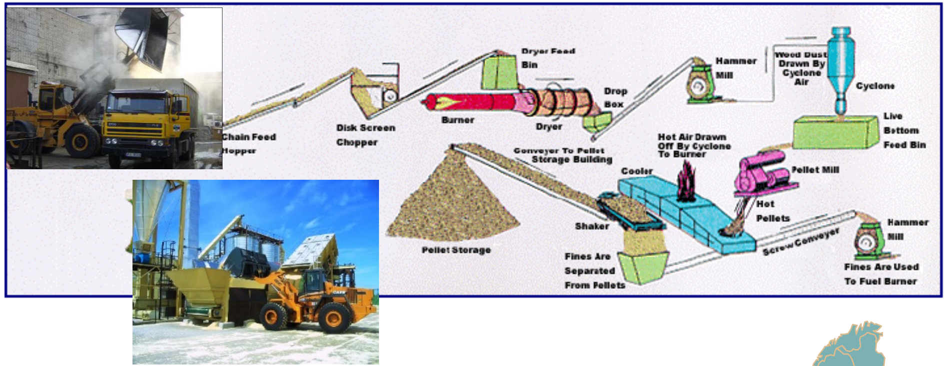
- Selection available on sustainability criteria
- Selection on local stakeholders

- Sample lab testing on chemical & physical properties
- Pilot testing for boiler assessment
- Selection on technical criteria for firing or co-firing

- Selection on commercial feasibility
- Integrated in business modeling



Energy and GHG balance for biomass supply



Clean Energy Package – RED-II – Annex on FFC by JRC

- In page 71: For biomass fuels used for electricity production, for the purposes of the calculation referred to in point 3, the fossil fuel comparator ECF(el) shall be **183 gCO2eq/MJ** electricity.
- For biomass fuels used for useful heat, for heating and/or cooling production, for the purposes of the calculation referred to in point 3, the fossil fuel comparator ECF(h) shall be **80 gCO2eq/MJ heat**.
- For biomass fuels used for useful heat production, in which a direct physical substitution of coal can be demonstrated, for the purposes of the calculation referred to in point 3, the fossil fuel comparator ECF(h) shall be **124 gCO2eq./MJ heat**.

Transport of raw material:
- Avg. distance
- Max. distance

Pelleting:
- Electricity/ton pellets

Drying:
- Fossil/ton pellets
- Biomass/ton pellets

Transport of pellets:
- Distance to harbour
- Truck or train

Sea/River transport:
- Capacity in tons
- Distance in miles
- Number of days of se
- Consumption/sea day

Flatboat from ARAG:
- Avg. diesel use

GHG balance threshold in % savings for Canada, RED-II method

Pellets to ARAG

107	CAN1A	05/04/2016	76,56%
108	CAN1B	05/04/2016	76,30%
109	CAN01	05/04/2016	77,27%
110	CAN02	10:06/2014	79,67%
111	CAN03	07/06/2012	79,88%
112	CAN04	20/11/2009	83,69%
113	CAN05	25/07/2013	78,80%
114	CAN07	16/10/2013	83,46%
115	CAN08	07/09/2016	78,27%
116	CAN08	07/09/2016	79,29%
117	CAN08	26/10/2012	80,15%
118	CAN09	27/05/2008	82,01%
119	CAN10	15/09/2008	88,30%
120	CAN11	10/01/2014	79,13%
121	CAN12	11/08/2011	70,54%
122	CAN13	06/06/2012	77,07%
123	CAN14	09/01/2013	76,22%
124	CAN15	17/04/2014	82,27%
125	CAN16	01/04/2015	68,92%
126	CAN17	30/08/2016	42,42%

yves.ryckmans@engie.com
www.laborelec.com
+32 (2) 382 03 03