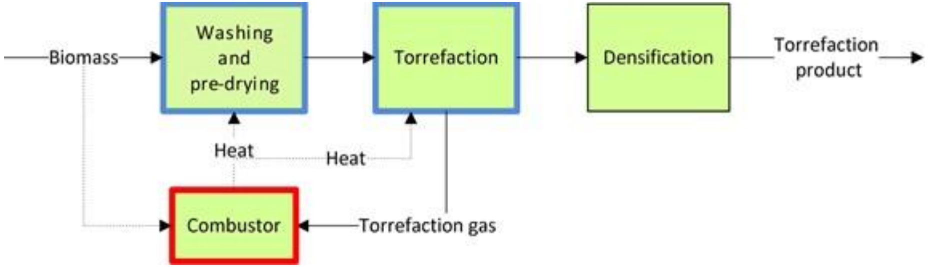
COMBUSTION IMPROVEMENTS OF UPGRADED BIOMASS

12th ECCRIA 2018| Dr. P.M.R. Abelha

SCOPE OF THE WORK

- Upgrade several low-grade biomass materials at **lab-scale** (washing and torrefaction):
  - Tomato foliage
  - **Road-side grass**
  - **Miscanthus**
  - **Wheat straw**
  - **Spruce bark**
  - Sunflower husks, etc…
- Promotes the interest for low-cost alternative biomass sources
- Enhances energy density, homogeneity, hydrophobicity, grindability, transport, etc.
- Reduces alkalis and chlorine contents
- Reduces equipment maintenance cost – corrosion, fouling, slagging

SCOPE OF THE WORK



- Produce representative upgraded biomass at **pilot** plant level
  - Batches between 500-800 kg

- **Lab-scale** Combustion tests with the upgraded biomass at pilot plant level
  - Emissions, slagging and fouling

MATERIALS

- List of feedstocks
  - Empty Fruit Bunches
  - Miscanthus
  - Sun flower husk
  - Road side grass
  - Wheat straw
  - Spruce bark
  - Tomato foliage

METHODS

- Variables:
  - Liquid/Solid ratio (L/S)
  - Temperature
  - Time

From lab scale…

liquid + solid washing at T filtration conductivity

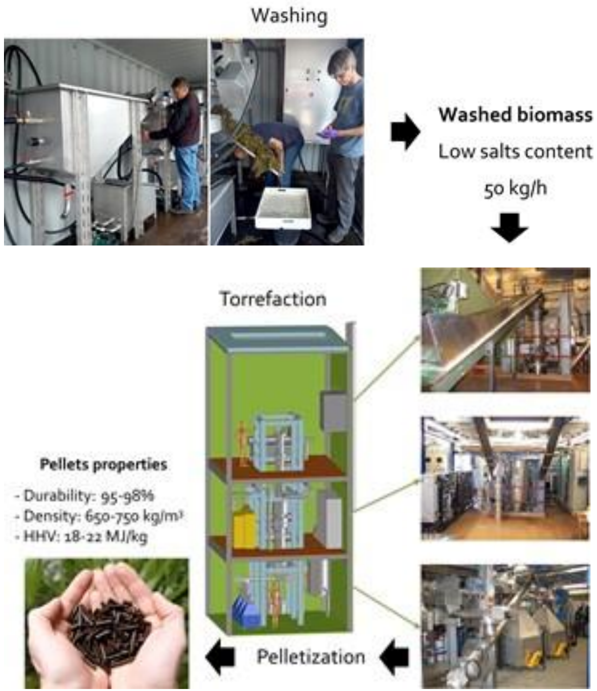
10-50 g per batch

Biomass Washing Torrefaction

2 kg per batch

4 material selected

To pilot-scale!



RESULTS (UPGRADING)

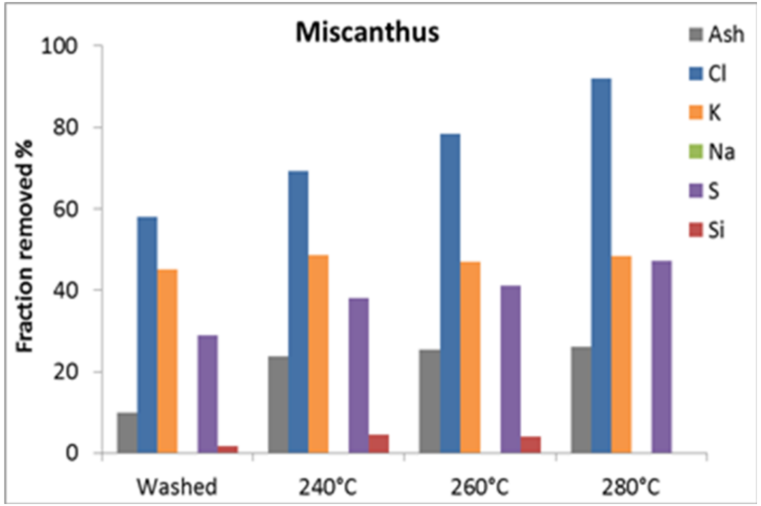
	HHV (MJ/kg)			
Pre-treatment	Grass	Straw	Miscanthus	Bark
Original	16,5	17,5	18,3	19,9
Washed	16,7	17,7	18,6	20,1
Washed+T240	18,1		19,7	
Washed+T260	18,3	19,2	19,5	21,5
Washed+T280	19,0		20,3	

- Higher heating contents
- Limited mass loss
- High energy yields (> 85%)

	Mass yield (%)			
Pre-treatment	Grass	Straw	Miscanthus	Bark
Washed	81	92	93	95
Washed+T240	73	-	85	-
Washed+T260	66	78	79	82
Washed+T280	58	-	69	-

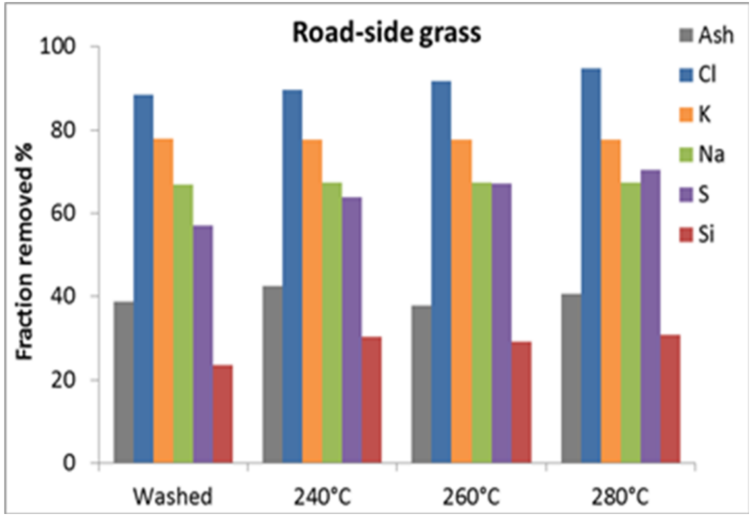
	Energy yield (%)			
Pre-treatment	Grass	Straw	Miscanthus	Bark
Washed	82	93	95	96
Washed+T240	80	-	92	-
Washed+T260	73	86	84	88
Washed+T280	67	-	77	-

RESULTS (UPGRADING)



- Torrefaction has limited effect in Cl removing
- Torrefaction has no effect in K removing

- Combined effect of washing and torrefaction:
  - Removal of 90-95% Cl, 50-80% K, 30-60% S and 30% P



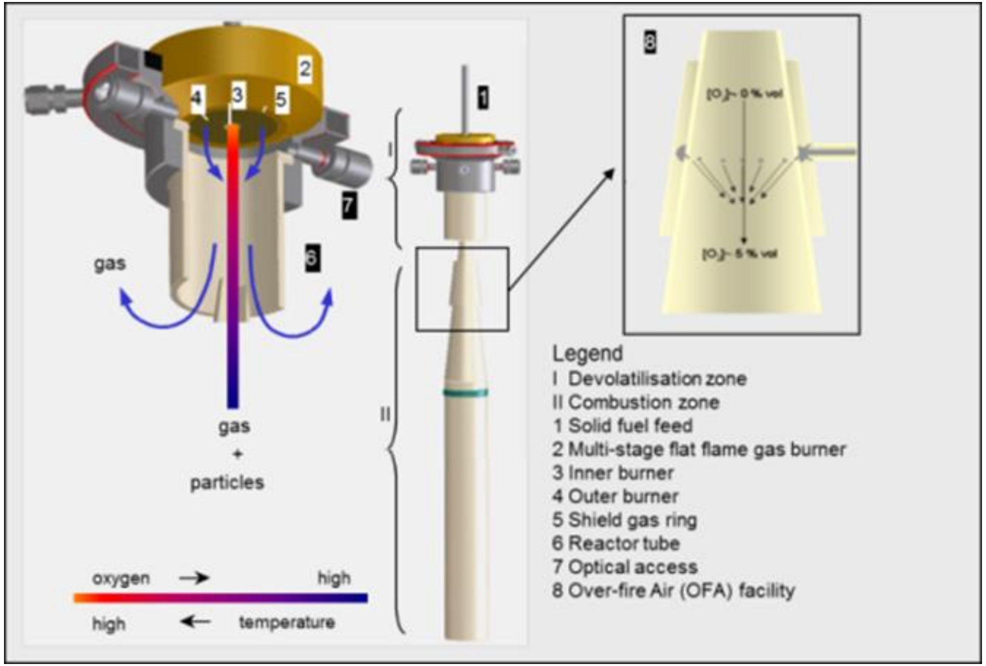
RESULTS (CHARACTERISATION)

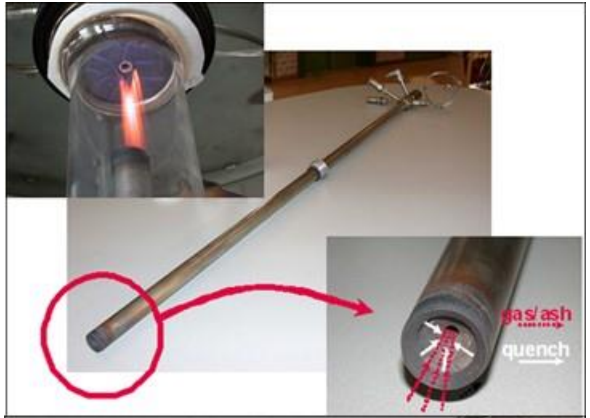
Ultimate and proximate analysis

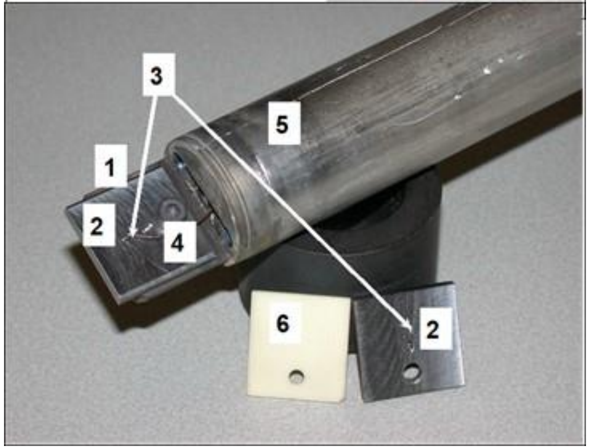
(RSG = road side grass)

		wheat straw	wheat straw, upgraded	miscanthus	miscanthus, upgraded	spruce bark	spruce bark, upgraded	RSG	RSG, upgraded
ash content (550°C)	[wt.-%, dry]	10.3	9.3	2.1	3.1	3.4	4	18.1	14.8
ash content (815°C)	[wt.-%, dry]	10.2	8.8	2	2.8	3.2	3.5	16.9	14.1
volatile matter	[wt.-%, dry]	71.8	70.9	81.7	75.7	74.5	69.2	66.1	61.5
moisture	[wt.-%, ar]	1.6	3	1.5	1.5	0.5	0.5	1	1.5
HHV	[MJ/kg, dry]	17.5	19.2	19.3	20.4	19.9	21.5	16.5	20
carbon	[wt.-%, dry]	42.9	47.7	47.7	50.1	49.4	54.3	41.4	49.9
nitrogen	[wt.-%, dry]	0.4	0.4	0.3	0.2	0.4	0.4	1.8	1.7
hydrogen	[wt.-%, dry]	5.6	5.5	5.9	5.6	5.8	5.6	5.3	5.3
oxygen	[wt.-%, dry]	38.6	35.9	43.3	38.9	40.2	36.2	35.4	30.7
chlorine	[mg/kg, dry]	2800	540	1300	420	100	88	9500	1300
Al	[mg/kg, dry]	45	180	79	160	470	580	1700	1400
B	[mg/kg, dry]	1.8	2	1.9	12	11	11	40	15
Ba	[mg/kg, dry]	0.73	6.8	8.2	4.4	220	250	25	33
Ca	[mg/kg, dry]	2800	3800	1000	1700	11000	14000	18000	13000
Fe	[mg/kg, dry]	49	250	61	330	280	370	1800	1400
K	[mg/kg, dry]	8400	3400	2300	1800	2000	1000	17000	4400
Mg	[mg/kg, dry]	560	560	360	420	810	850	2000	1600
Mn	[mg/kg, dry]	17	42	22	15	650	680	530	140
Na	[mg/kg, dry]	140	440	260	470	160	500	1600	1000
P	[mg/kg, dry]	830	610	220	250	510	430	4000	2200
S	[mg/kg, dry]	820	520	480	360	330	310	3400	1400
Si	[mg/kg, dry]	36000	34000	6500	14000	1900	2300	45000	46000
Sr	[mg/kg, dry]	11	23	5.3	10	44	55	91	55
Ti	[mg/kg, dry]	350	41	220	18	120	87	930	220
Zn	[mg/kg, dry]	6.4	29	9.1	50	140	170	39	78

RESULTS (COMBUSTION)





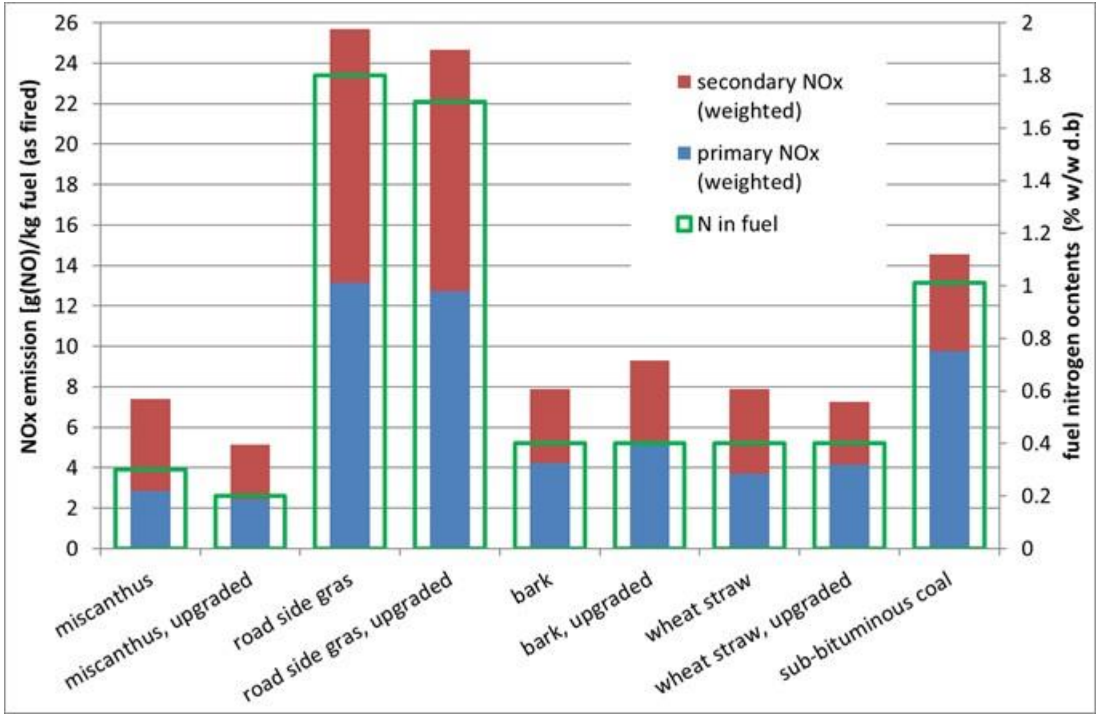


RESULTS (COMBUSTION)

NOx

- Primary NOx – volatiles combustion
- Secondary NOx – char combustion

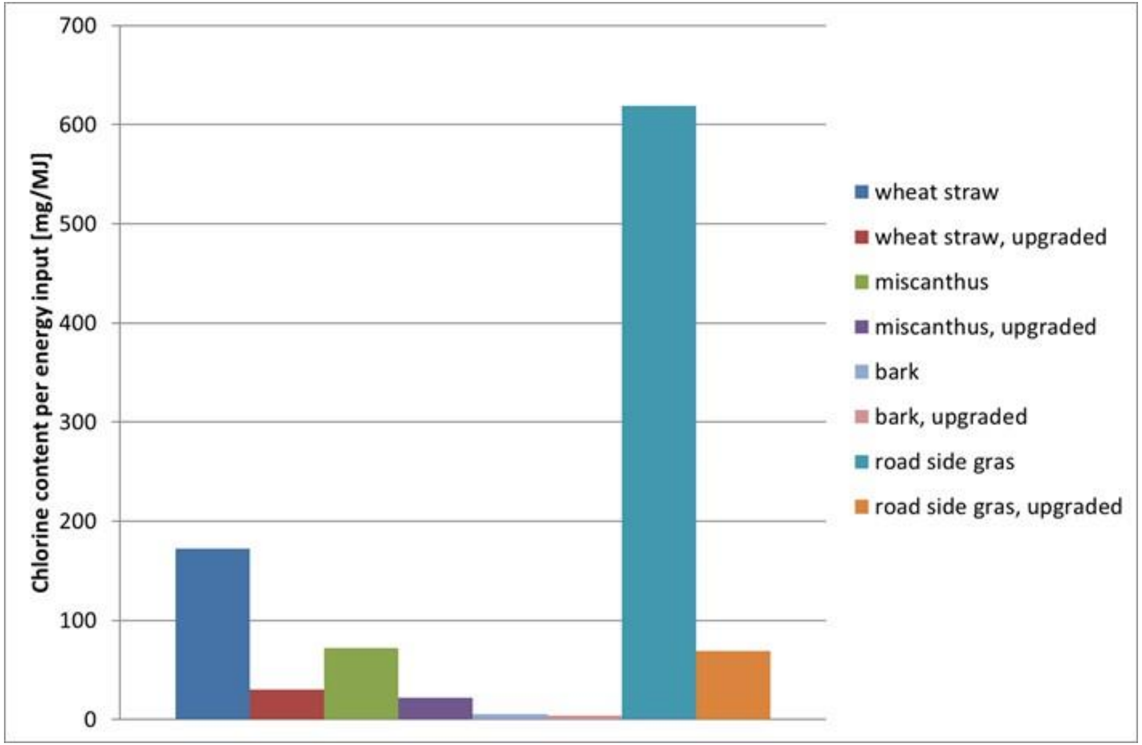
- Upgrading doesn't increase NOx emissions
- Higher NOx for grass, but still with margin for primary NOx reduction
- Upgraded miscanthus leaded to the lower NOx emissions



RESULTS (COMBUSTION)

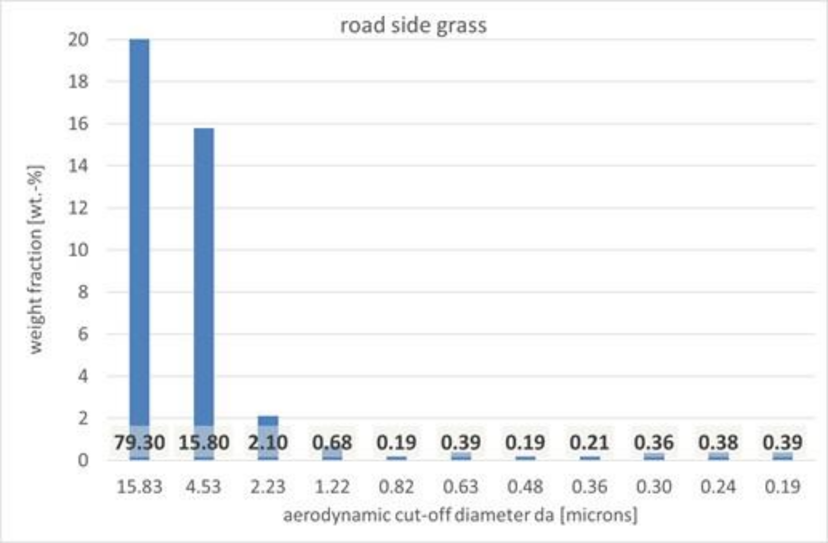
High temperature corrosion risk (Cl content)

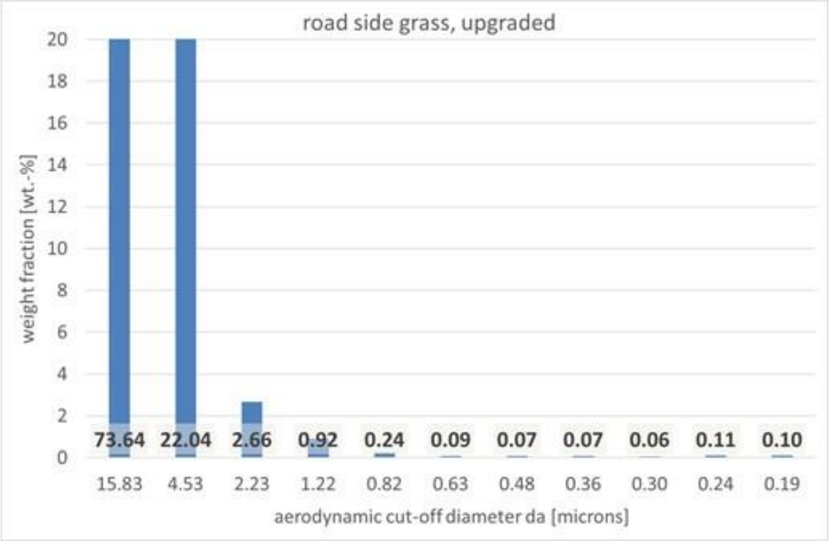
- Miscanthus and Bark with lower Cl contents gave lower Cl emissions
- Upgrading decreases significantly the Cl contents and therefore the Cl emissions
- No significant high temperature chlorine corrosion is expected after upgrading. Exception: upgraded grass (Cl > 50 mg/MJ)



RESULTS (COMBUSTION)

Submicron particles
(Pilat Mark V cascade impactor)





- Upgrading: Clear decrease in the sub-micron particles emissions for all biomasses
- Expected reduction in fouling tendency as well

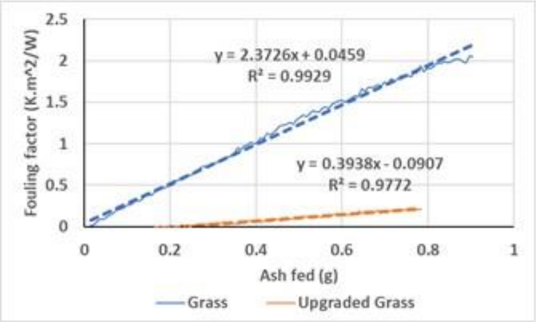
RESULTS (COMBUSTION)

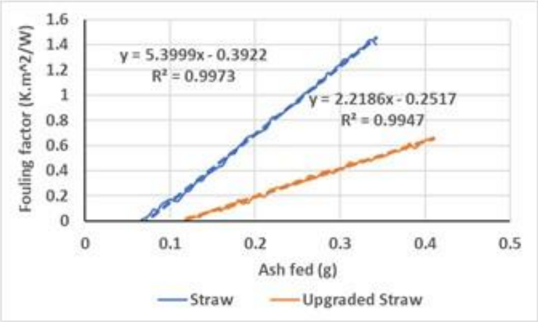
Sub-micron particles

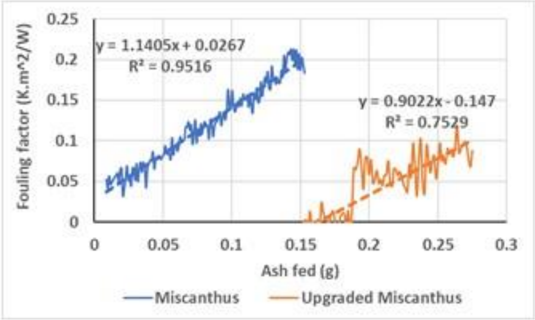
	Reduction in sub-micron particles, by mass
Wheat straw	66.8%
Miscanthus	78.3%
Spruce bark	44.4%
Road side grass	64.6%

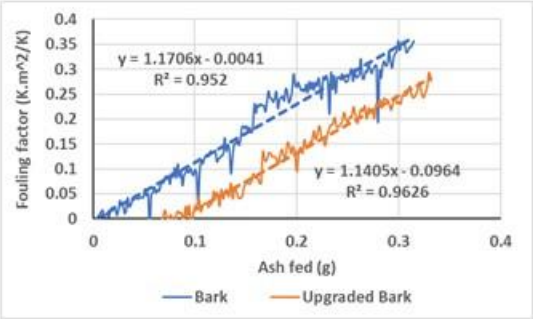
RESULTS (COMBUSTION)

Fouling probe





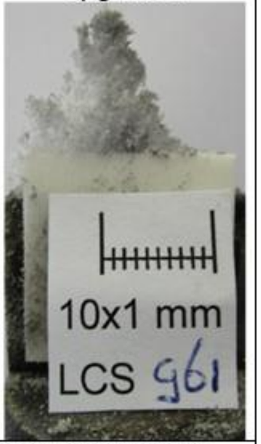




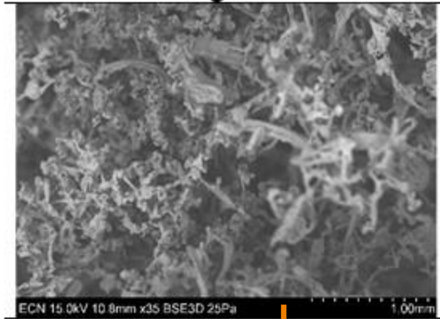
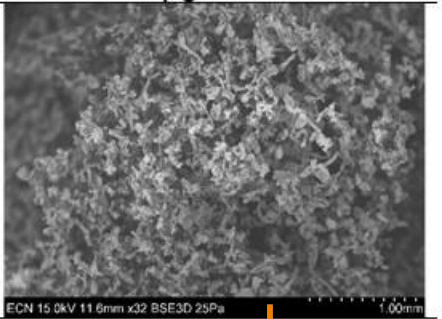
- Upgrading: Clear decrease in fouling of heat transfer surfaces for all biomasses, although for bark only small decrease.

RESULTS (COMBUSTION)

Slagging probe (near burner conditions)

Wheat straw	original	upgraded
		
Visual appearance	White deposit, highly sintered; individual particles clearly recognisable	White/grey deposit, highly sintered; individual particles clearly recognisable

SEM micrographs

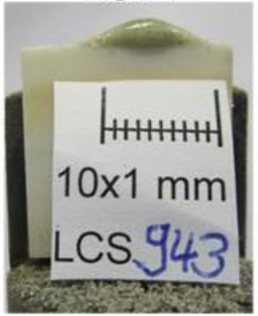
Wheat straw	
original	upgraded
	

	Wt%
O	49.2
Si	43.8
C	3.1
K	2.1
Ca	1.9

	Wt%
O	50.2
Si	42.4
Ca	4.0
C	2.5
K	0.9

RESULTS (COMBUSTION)

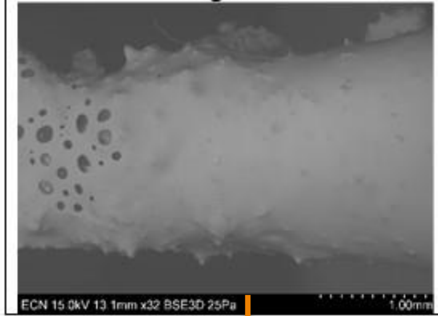
Slagging probe

Grass	original	upgraded
		
Visual appearance	Light green, fully molten deposit	White/grey, highly sintered deposit; individual particles visible

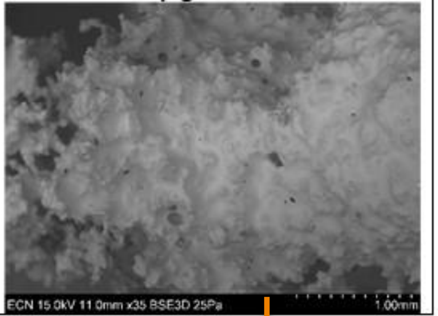
SEM micrographs

Road side grass

original



upgraded



	Wt%
O	44.8
Si	30.7
Ca	10.6
K	5.0
C	2.4
Fe	1.4
Mg	1.3
Al	1.2
Ti	0.9
Na	0.8
P	0.7
Mn	0.3

	Wt%
O	48.0
Si	30.1
Ca	9.8
C	3.5
K	2.7
Fe	1.6
Mg	1.3
Al	1.3
Na	0.8
P	0.7
Ti	0.2

CONCLUSIONS

- Low-grade biomasses like grass, straw, miscanthus and bark were upgraded by washing and torrefaction with success.
- The upgraded biomasses showed good properties for energy use applications; lab and pilot scale results are consistent.
- About 90-95% of Cl, 50-80% K, 30-60% S and 30% P can be removed during upgrading.
- Wash step crucial to the removal of K.
- Post-wash seems to be a viable route to upgrade dry-type biomasses.

CONCLUSIONS

- NOx emissions are not a matter of concern for the fuels under investigation. Exception: road side grass.
- Fine particulate matter (submicron/aerosols) formation is strongly reduced by upgrading the fuels, effectively reducing the risk of alkali induced fouling.
- High temperature chlorine corrosion can be effectively mitigated. Exception: road side grass, still exposes some corrosion risk.
- Slagging tests revealed that pre-washing and torrefaction has minor impact on the slagging propensity of the fuel. Only, slightly reduced slagging is observable.
- Recommendation: use mineral combustion additives, or smart blending with other fuels in order to further mitigate the slagging risks.

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THANK YOU FOR YOUR ATTENTION

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