

TORREFACTION + PRE- OR POST-TREATMENT TO ELIMINATE LIMITING FEATURES OF AGRICULTURAL BIOMASS

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IBTC/WBA webinar Agricultural Residues valorisation – Opportunities with torrefaction, 20 September 2021

› **PRESENTATION OVERVIEW**

POTENTIAL OF TORREFACTION FOR AGRICULTURAL RESIDUES

Torrefaction not a panacea, but has clear potential together with washing

- › Woody biomass under debate, agricultural residues largely unutilised
- › Properties agricultural biomass vs. clean wood (relevant for thermochemical applications)
- › Torrefaction not a panacea, but
- › Experimental assessment
- › Economics
- › Summary conclusions



› WOODY BIOMASS UNDER DEBATE

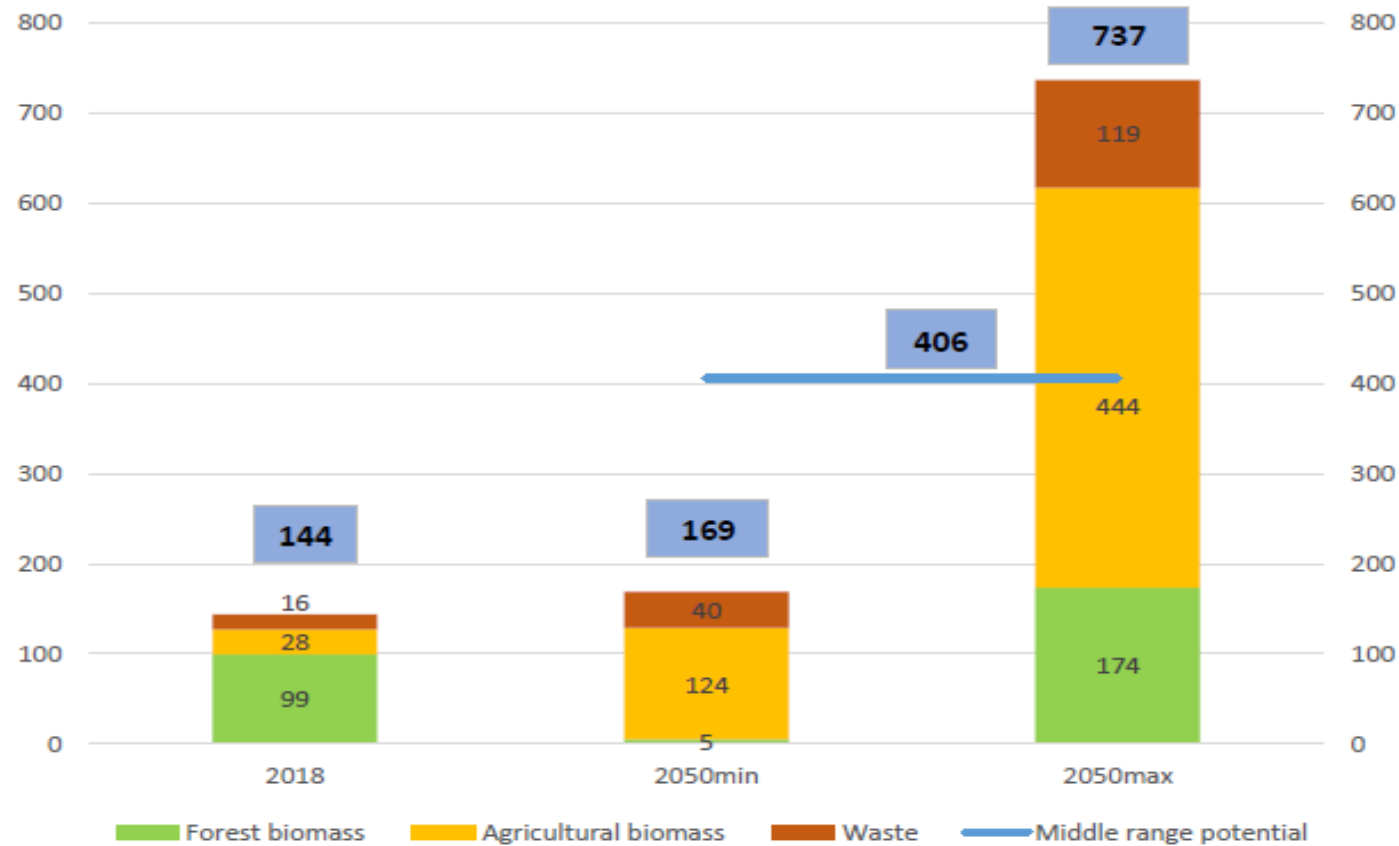
EU FIT-FOR-55 PACKAGE – REINFORCED CRITERIA FOR FORESTRY-BASED BIOENERGY



› AGRICULTURAL RESIDUES

HUGE POTENTIAL, STILL LARGELY UNUTILISED

Figure 1 Gross inland energy consumption of biomass in 2018 and potential in 2050 for the EU28 (in Mtoe)



Source: *Securing sustainable resource availability of biomass for energy applications in Europe; review of recent literature.*
 Prof. Dr. André P.C. Faaij



› **AGRICULTURAL BIOMASS MORE “DIFFICULT”** **COMPARED TO WOODY BIOMASS, FOR VARIOUS ENERGY APPLICATIONS**

- › Lower density
- › Inferior transport, handling and storage properties
 - › E.g., straw and empty fruit bunches
- › Higher moisture content
 - › Moisture evaporation poses a severe energy penalty
- › Higher inorganics/ash content
- › More problematic inorganics (higher levels of, e.g., chlorine, alkali metals (K, Na), sulphur and heavy metals)
 - › Leading to, e.g., pollutant emissions, slagging, fouling, corrosion, catalyst poisoning, negative impact on ash utilisation
- › Torrefaction does a great job in increasing (energy) density and improving transport, handling and storage properties, but:
 - › Wet processing (digestion, fermentation, hydrothermal processing) better for very wet biomass (typically >50 % moisture)
 - › Torrefaction has limited potential to mitigate problematic inorganics – washing as additional unit operation may help out

Parameter	Unit	EN Plus A1	IWPB-I2	Wood Pellets	Grass Raw	Reed Raw
Additives	wt%	0	< 3	none	none	none
Water	wt%	≤ 10	≤ 10	8.3	variable	variable
Bulk density	kg/m ³	≥ 600	≥ 600	636	-	-
NCV	GJ/ton DM	≥ 16.5	≥ 16.5	18.6	16.7	17.9
Ash	wt% DM	≤ 0.7	≤ 1.5	0.3	4.4	2.3
Cl	wt% DM	≤ 0.020	≤ 0.05	0.012	0.470	0.227
K	mg/kg DM			380	13 000	4924

› **TORREFACTION + WASHING**

- › Essential: optimize overall process layout, including minimizing fresh washing water consumption, washing water recycling, counter-current washing, dewatering after washing and finding a proper solution for the washing effluent
- › Torrefaction + pre-washing
 - › Better solubility, thus higher removal efficiencies
 - › Dewatering more difficult / energy consuming
 - › Preferable for relatively wet biomass
- › Torrefaction + post-washing
 - › (slightly) lower removal efficiencies
 - › Easier dewatering due to hydrophobic nature after torrefaction
 - › Lower organic load in effluent
 - › Preferable for relatively dry biomass

› TNO STUDY TORREFACTION + WASHING

› Feedstocks considered:

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



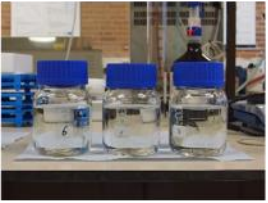




P. Abelha et al.: Low-grade biomass upgrading by washing and torrefaction – lab and pilot-scale results. 26th EUBCE, 14-17 May 2018, Copenhagen, Denmark.
P. Abelha et al.: Combustion improvements up upgraded biomass by washing and torrefaction. <https://doi.org/10.1016/j.fuel.2019.05.050>
P. Abelha, J. Kiel: Techno-economic assessment of biomass upgrading by washing and torrefaction. <https://doi.org/10.1016/j.biombioe.2020.105751>

› TORREFACTION + WASHING

EXPERIMENTAL APPROACH (PREWASH AND POSTWASH)

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

From lab scale...

liquid	+ solid	washing at T	filtration	conductivity
				

10-50 g per batch

To pilot-scale!



› TORREFACTION + WASHING

MASS AND ENERGY YIELD

Pre-treatment	HHV (MJ/kg)			
	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 value
- › Limited mass loss
- › High energy yield

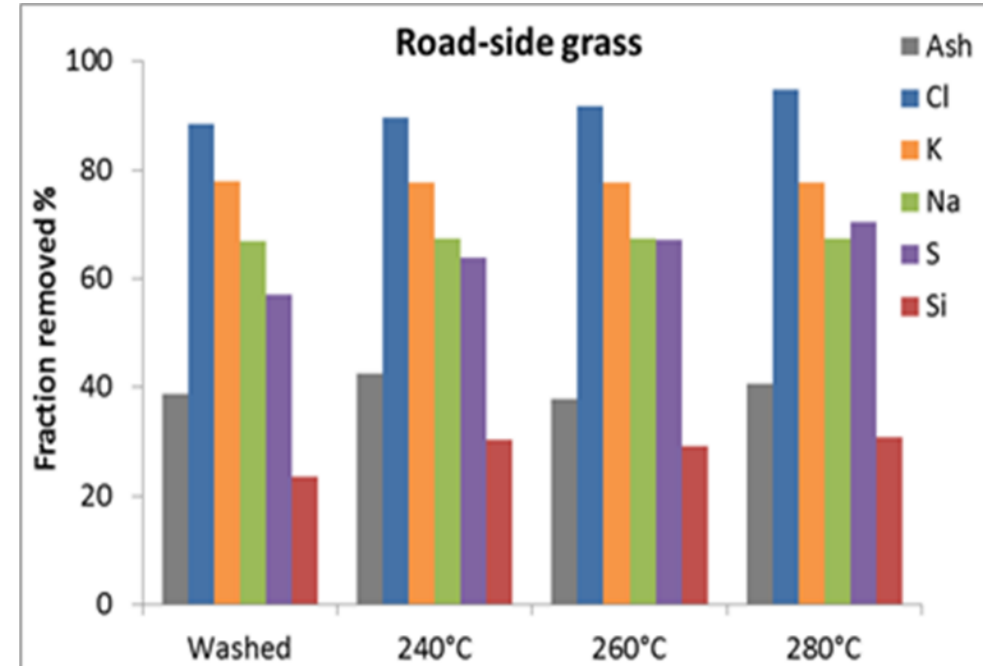
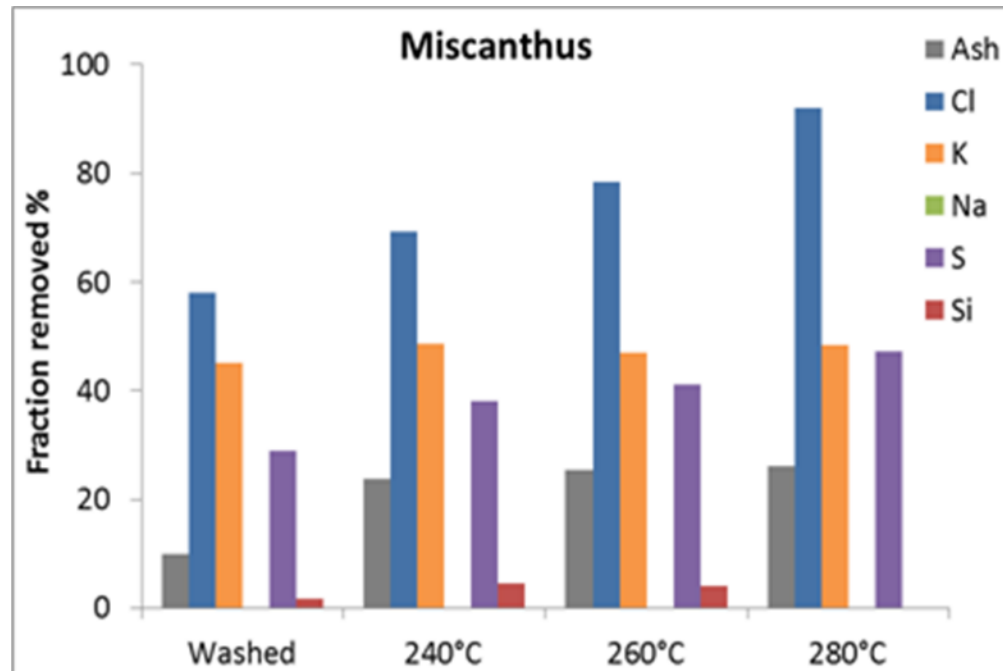
Pre-treatment	Mass yield (%)			
	Grass	Straw	Miscanthus	Bark
Washed	81	92	93	95
Washed+T240	73	-	85	-
Washed+T260	66	78	79	82
Washed+T280	58	-	69	-

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



› TORREFACTION + WASHING

FRACTIONAL INORGANICS REMOVAL

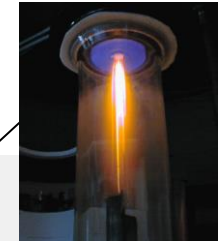
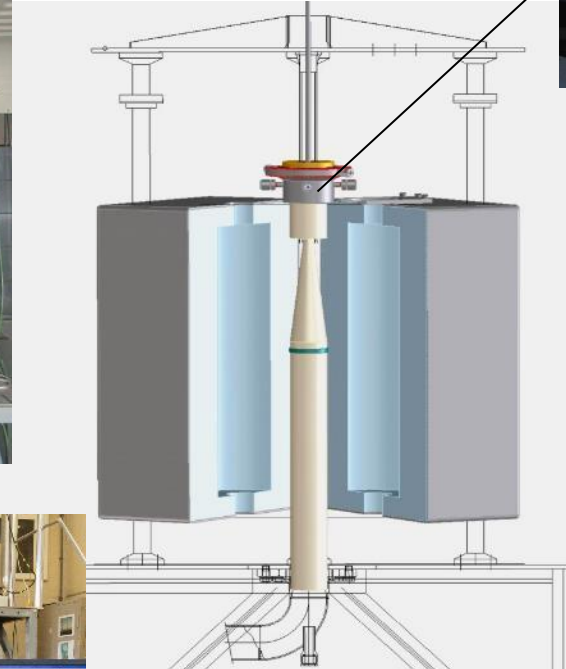


- › Torrefaction has limited effect on Cl
- › Torrefaction has no effect on K
- › Combined effect of washing and torrefaction:
 - › Removal of 90-95% Cl, 50-80% K, 30-60% S and 30% P

› LAB-SCALE COMBUSTION SIMULATOR

MIMIC PULVERSED-FUEL AND LIQUID-FUEL COMBUSTION CONDITIONS

- › Pulverised fuel/entrained-flow reactor with integrated, premixed and multi-stage flat flame burner
 - › for solids and liquids
 - › high particle heating rates
 - › high flame/particle temperature
 - › realistic gas temperature / environment history
 - › controllable, long particle residence time



Staged gas burner: high heating rate + proper gas atmosphere



Particle sampling probe



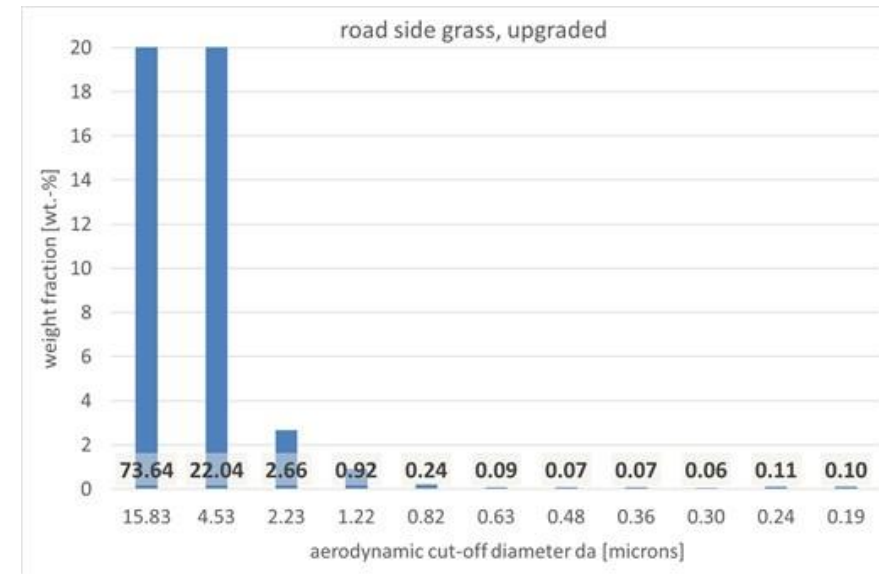
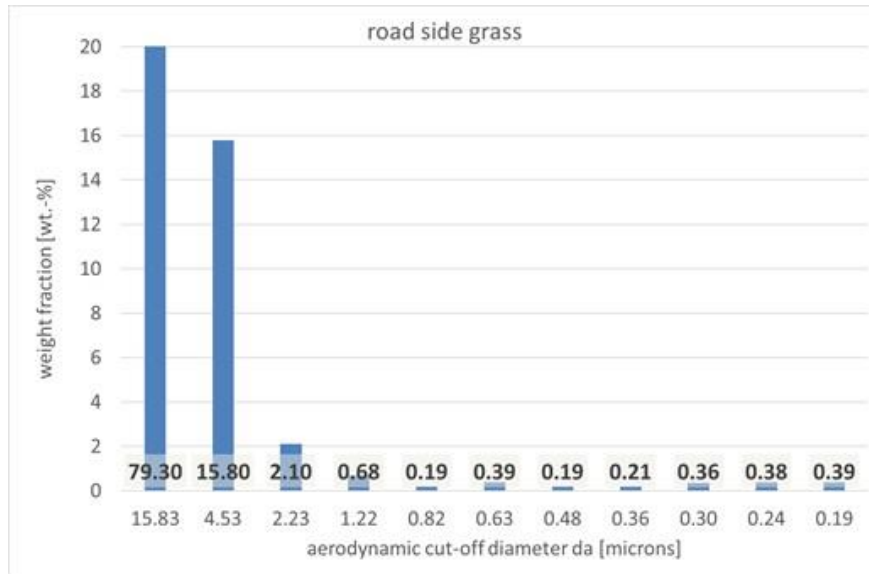
Fouling probe

Special reactor design:
1-2s residence time
with only limited total
reactor length

› TORREFACTION + WASHING

COMBUSTION PERFORMANCE – PARTICULATE EMISSIONS

Pilat Mark V cascade impactor



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

	Reduction in sub-micron particles after upgrading (% wt)
Wheat straw	66.8%
Miscanthus	78.3%
Spruce bark	44.4%
Road side grass	64.6%

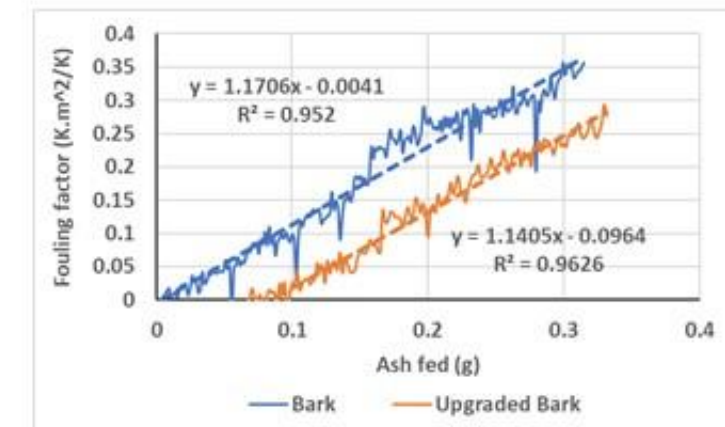
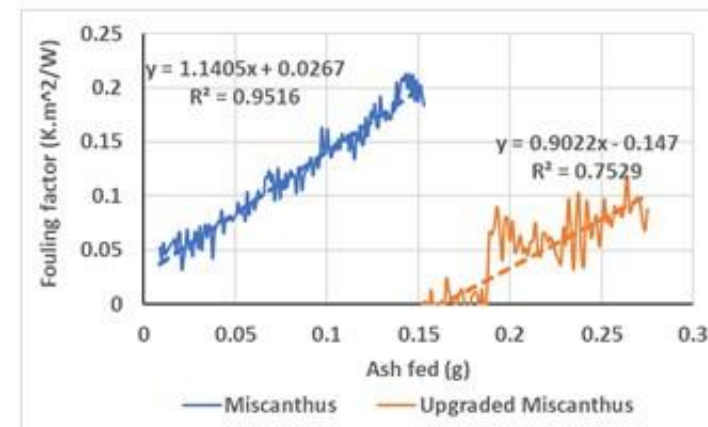
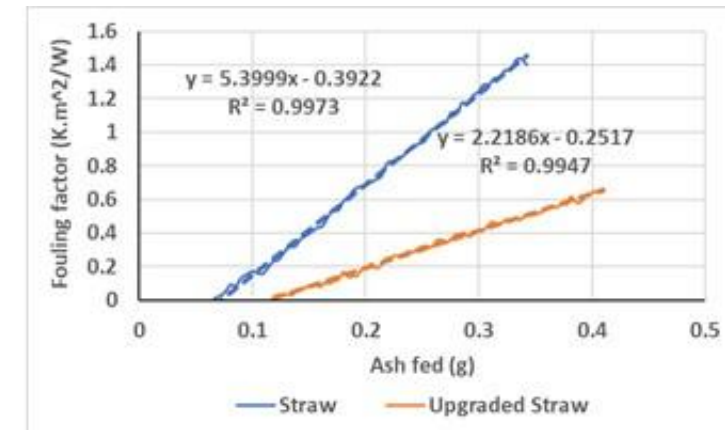
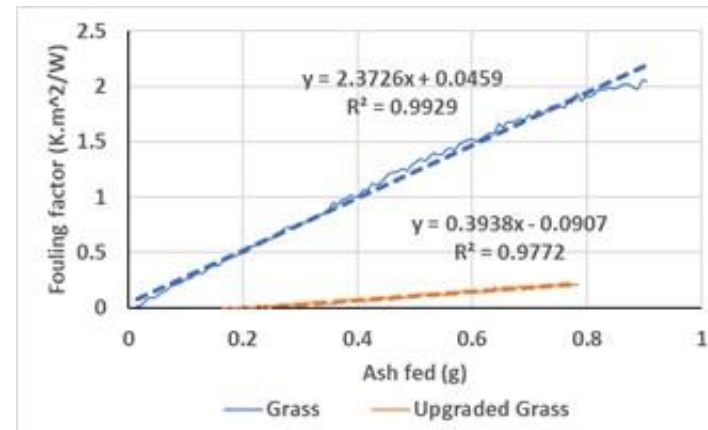
TORREFACTION + WASHING

COMBUSTION PERFORMANCE – FOULING PROPENSITY

Fouling probe

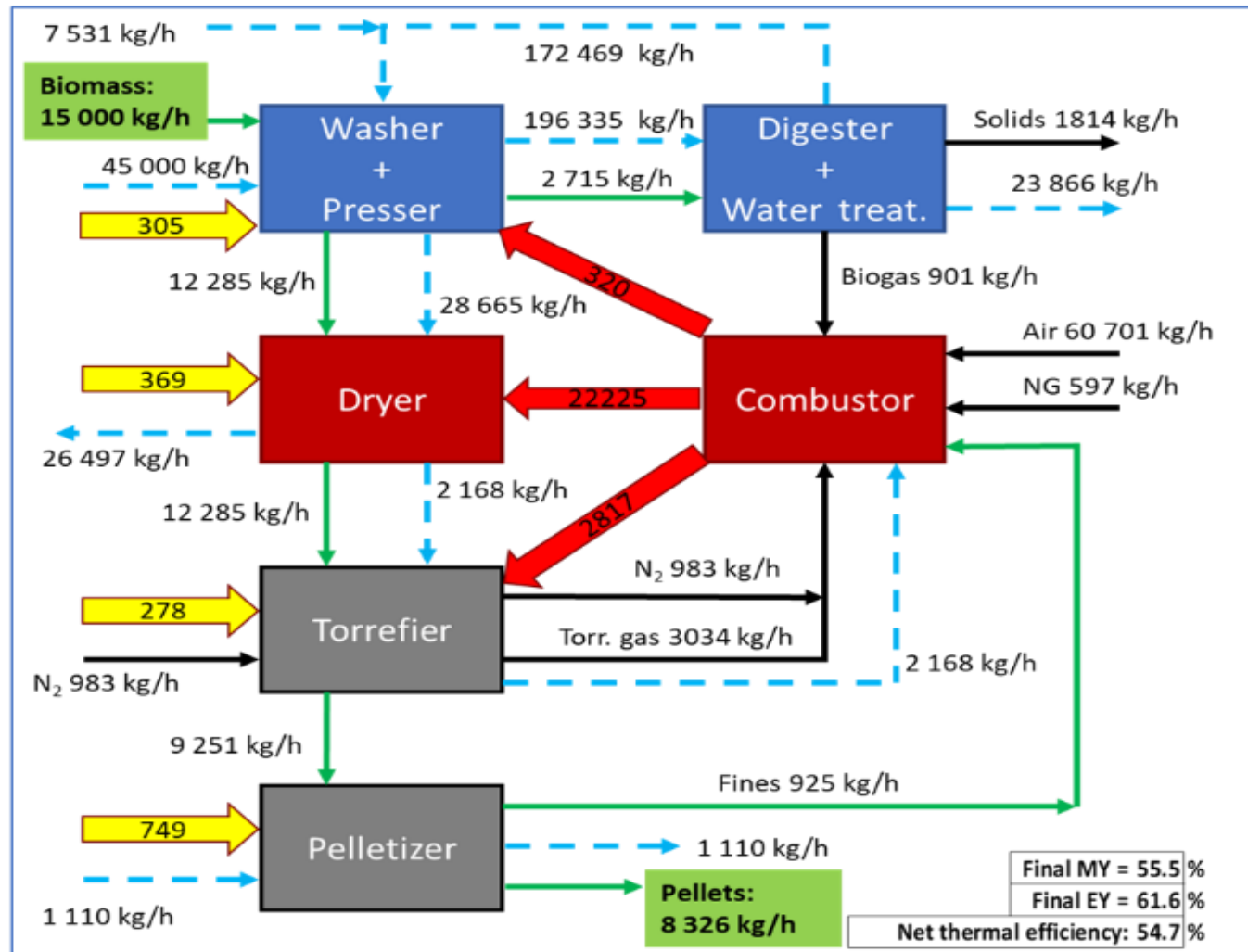


- › Upgrading: Clear decrease in fouling of heat transfer surfaces for all biomasses, although for bark only small decrease



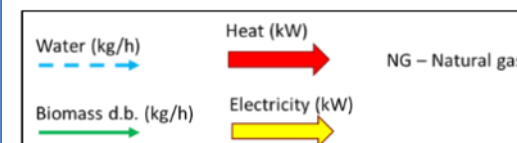
TORREFACTION + WASHING

ROADSIDE GRASS PREWASH – MASS & ENERGY BALANCES



Assumptions

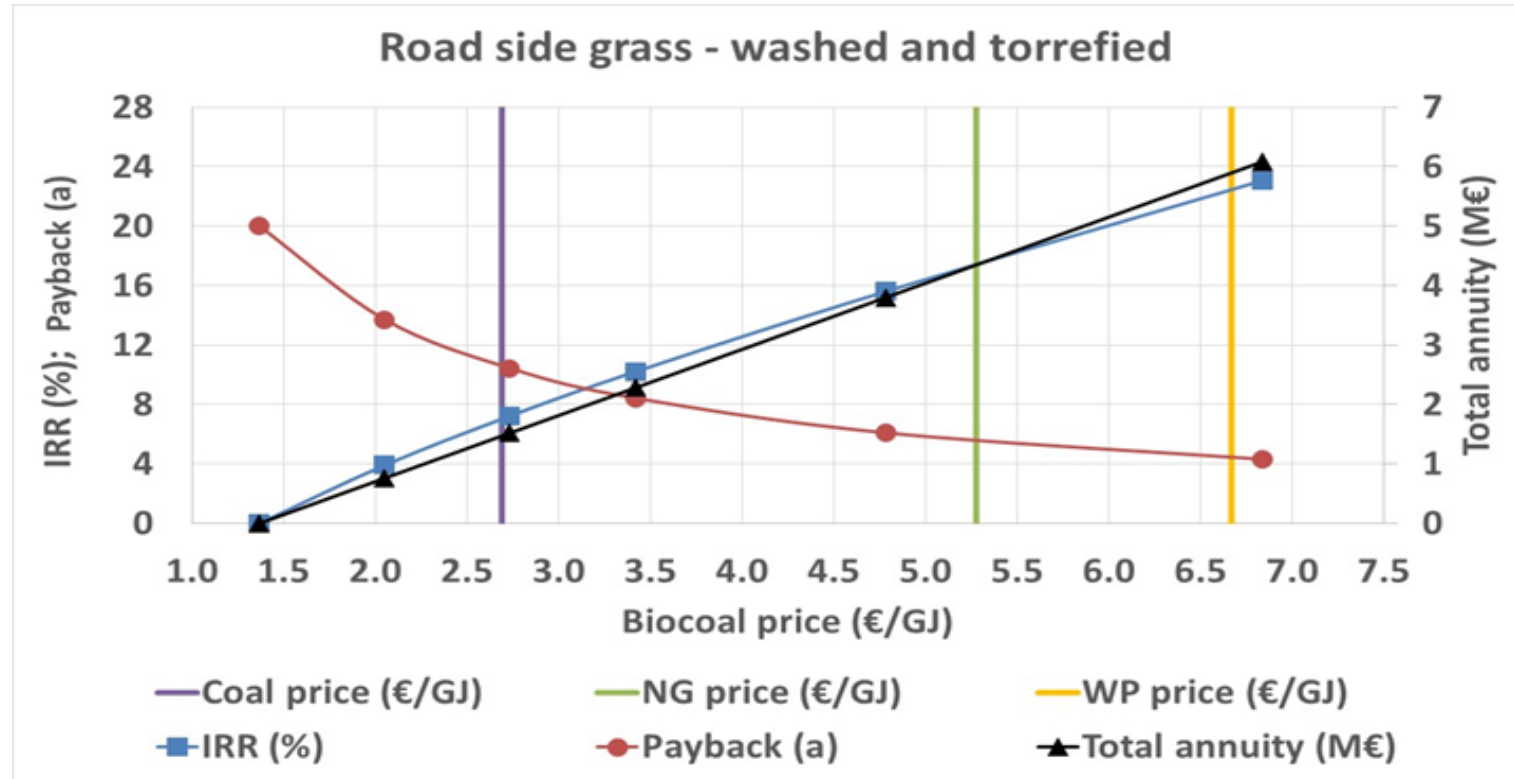
- › 120 kt/a dry biomass input
- › Upflow anaerobic digester
- › Dedicated water treatment plant allowing wash water recycling
- › Mechanical + thermal dewatering (to 15%)
- › Also silage storage explored to overcome seasonality



› TORREFACTION + WASHING

ROADSIDE GRASS PREWASH – ECONOMICS

P. Abelha, J. Kiel: Techno-economic assessment of biomass upgrading by washing and torrefaction.
<https://doi.org/10.1016/j.biombioe.2020.105751>



- › In NL: At a plant size of 100-150 kt/a dry input and a negative gate fee of 25 €/t, biocoal from roadside grass can be offered at an attractive price (80 €/t or 4.8 €/GJ) compared to both wood pellets and coal prices, while still showing a good business case with an IRR of 15.6%.

› SUMMARY CONCLUSIONS

- › Agricultural biomass: huge potential, largely unutilised, for energy applications more “difficult” than woody biomass
- › Torrefaction is not a panacea, but combination with washing has potential
- › Essential: optimize overall process layout (fresh washing water consumption, washing water recycling, counter-current washing, dewatering after washing and washing effluent processing)
- › Prewash preferable for relatively wet biomass, postwash for relatively dry biomass
- › Attractive business cases appear feasible (but largely dependent on local conditions)



› **THANK YOU FOR YOUR TIME**

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