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TNO innovation for life

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

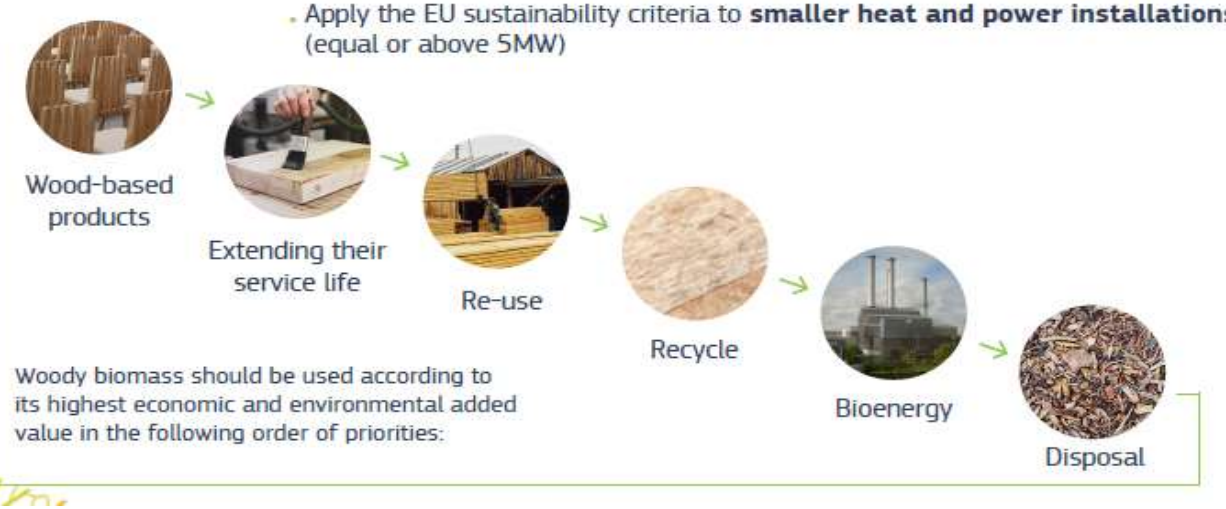
- Woody biomass under debate, agricultural residues largely unutilised
- Properties agricultural biomass vs. clean wood (relevant for thermochemical applications)
- Torrefaction not a panacea, but ….
- Experimental assessment
- Economics
- Summary conclusions

WOODY BIOMASS UNDER DEBATE

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

Sustainable bioenergy reinforced criteria in line with the EU Biodiversity Strategy will:

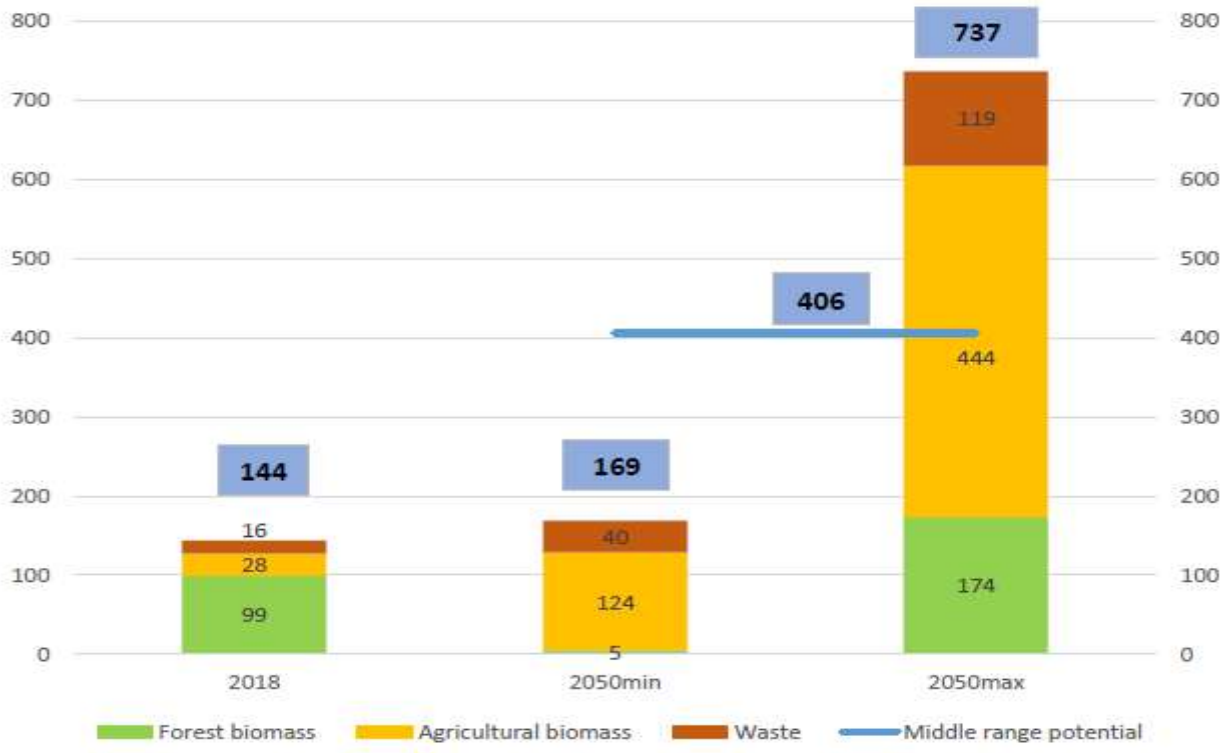
- Prohibit sourcing **biomass for energy production from primary forests**, peatlands and wetlands
- **No support** for forest biomass in **electricity-only installations** as of 2026
- Prohibit national **financial incentives for using saw or veneer logs, stumps and roots** for energy generation
- Require **all biomass-based heat and power installations** to comply with minimum greenhouse gas saving thresholds
- Apply the EU sustainability criteria to **smaller heat and power installations** (equal or above 5MW)



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

BIOENERGY EUROPE STATISTICAL REPORT 2020

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

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/m³	≥ 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 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

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

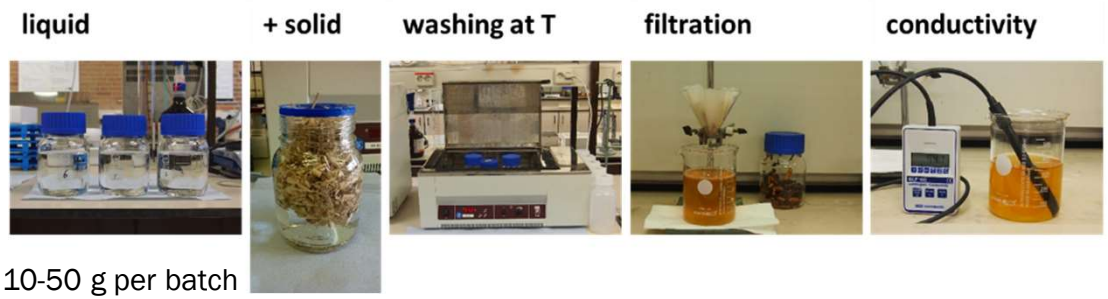
P. Abelha et al.: Low-grade biomass upgrading by washing and torrefaction – lab and pilot-scale results. 26th EUBCE, 14-17 May 2018, Copenhagen, Denmark.
P. Abelha et al.: Combustion improvements up upgraded biomass by washing and torrefaction. https://doi.org/10.1016/j.fuel.2019.05.050
P. Abelha, J.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

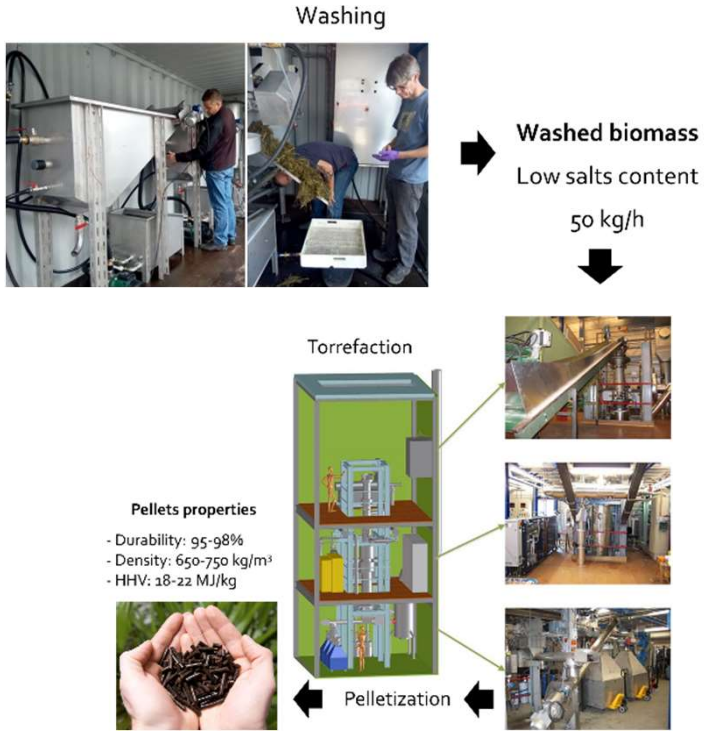
From lab scale…



10-50 g per batch

2 kg per batch

To pilot-scale!



TORREFACTION + WASHING

MASS AND ENERGY YIELD

	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	

	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	-

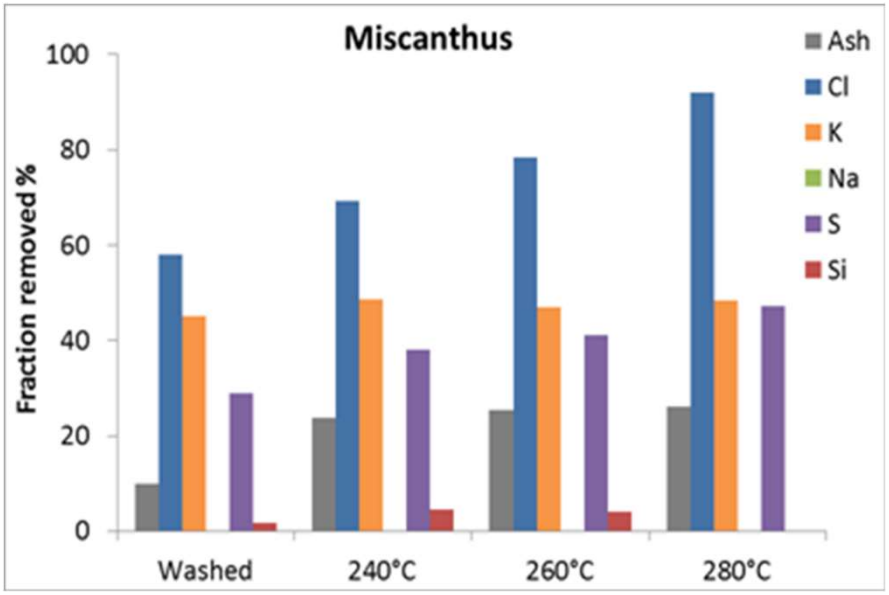
	Energy yield (%)			
Pre-treatment	Grass	Straw	Miscanthus	Bark
Washed	82	93	95	96
Washed+T240	80	-	92	-
Washed+T260	73	86	84	88
Washed+T280	67	-	77	-

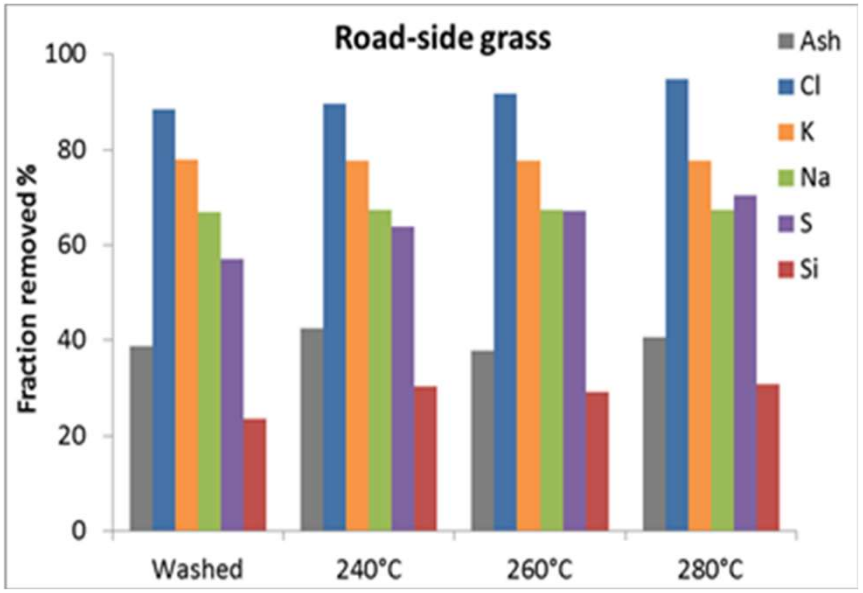
- Higher heating value
- Limited mass loss
- High energy yield






TORREFACTION + WASHING
FRACTIONAL INORGANICS REMOVAL



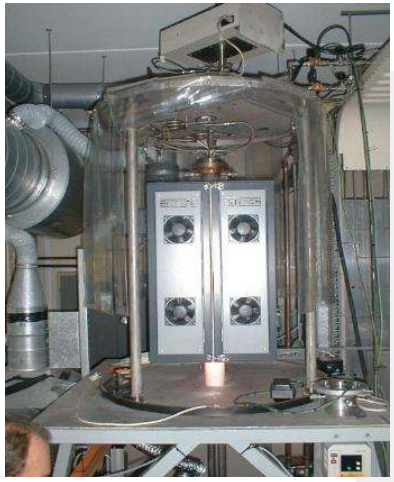


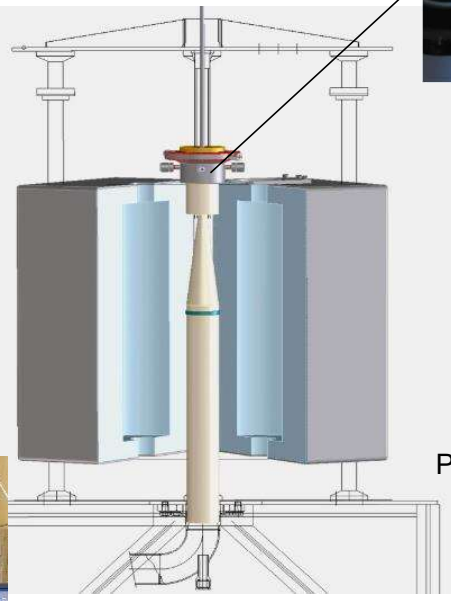
- Torrefaction has limited effect on Cl
- Torrefaction has no effect on K
- Combined effect of washing and torrefaction:
  - Removal of 90-95% Cl, 50-80% K, 30-60% S and 30% P

LAB-SCALE COMBUSTION SIMULATOR

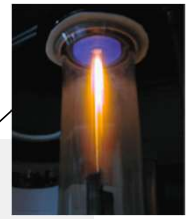
MIMIC PULVERSED-FUEL AND LIQUID-FUEL COMBUSTION CONDITIONS

- 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





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



Staged gas burner: high heating rate + proper gas atmosphere

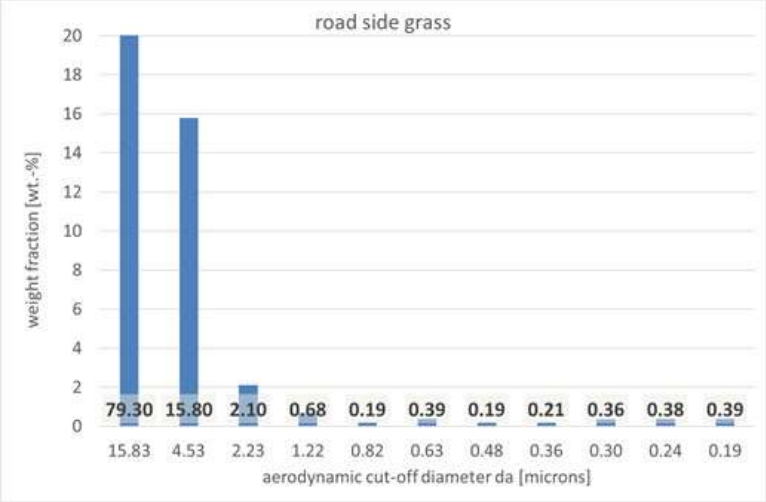
Particle sampling probe

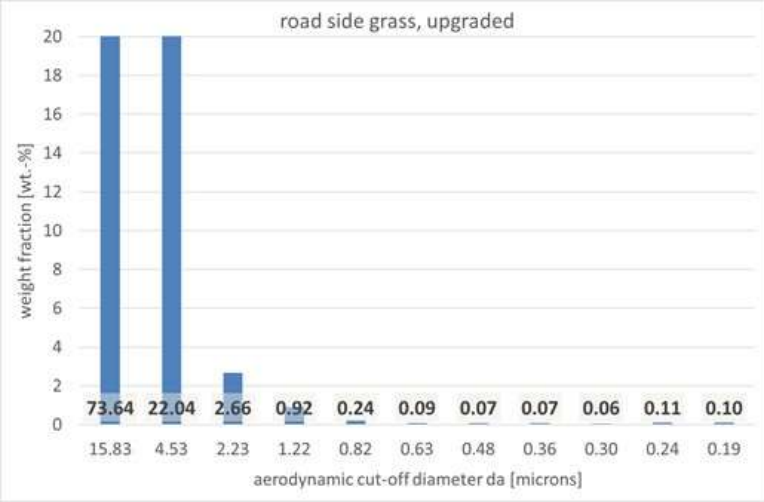
Fouling probe

TORREFACTION + WASHING

COMBUSTION PERFORMANCE – PARTICULATE EMISSIONS

Pilat Mark V cascade impactor





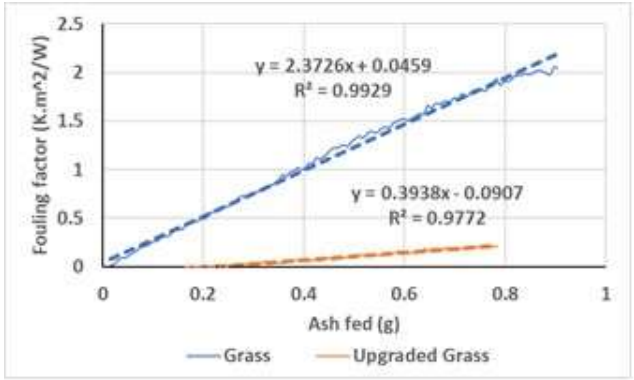
- Upgrading: Clear decrease in the sub-micron particles emissions for all biomasses
- Expected reduction in fouling tendency as well

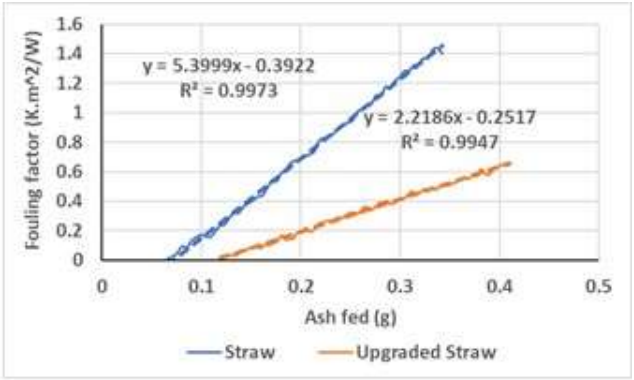
	Reduction in sub-micron particles after upgrading (% wt)
Wheat straw	66.8%
Miscanthus	78.3%
Spruce bark	44.4%
Road side grass	64.6%

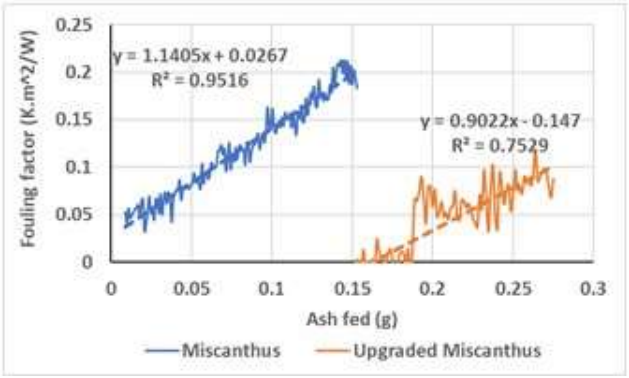
TORREFACTION + WASHING
COMBUSTION PERFORMANCE – FOULING PROPENSITY

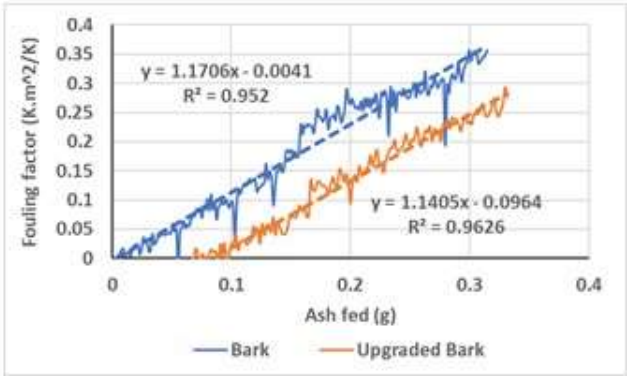
Fouling probe

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





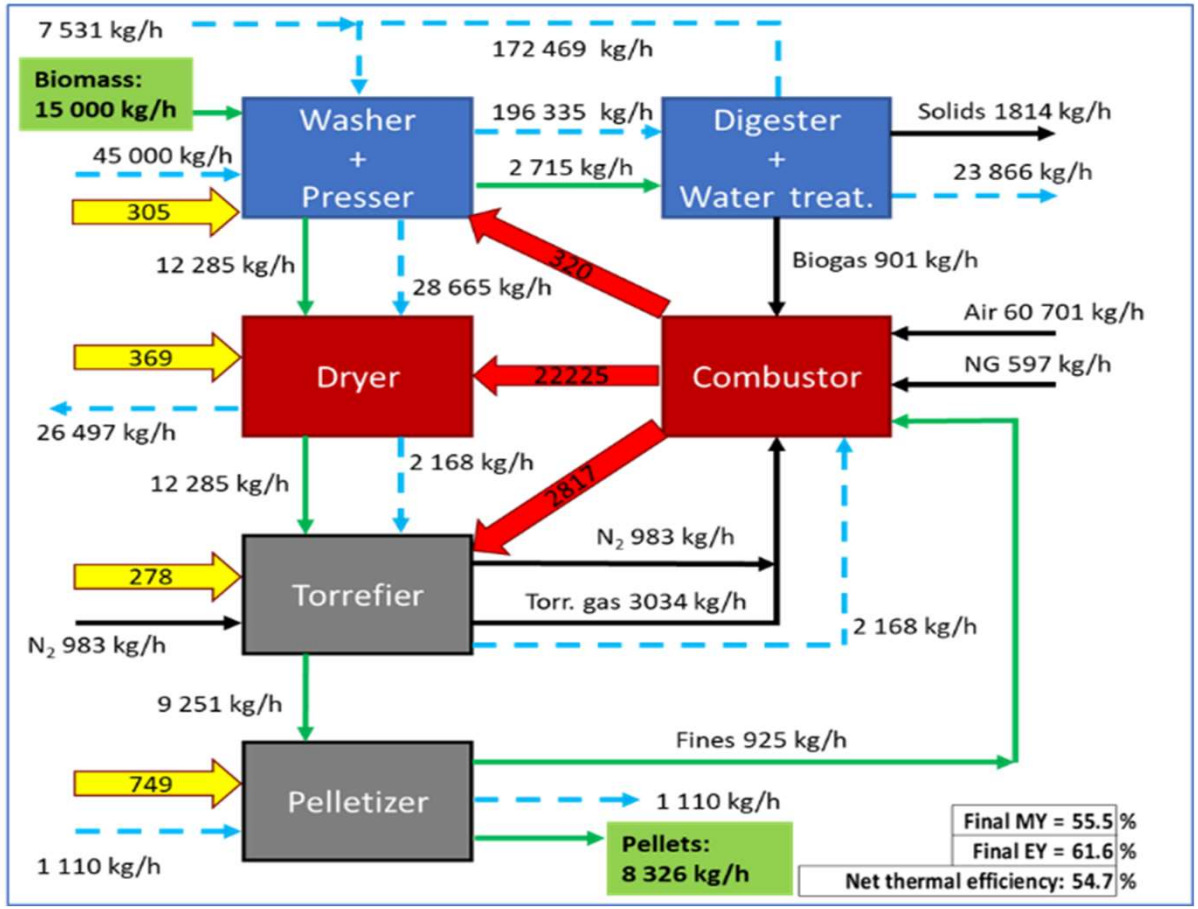




TORREFACTION + WASHING

ROADSIDE GRASS PREWASH – MASS & ENERGY BALANCES

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

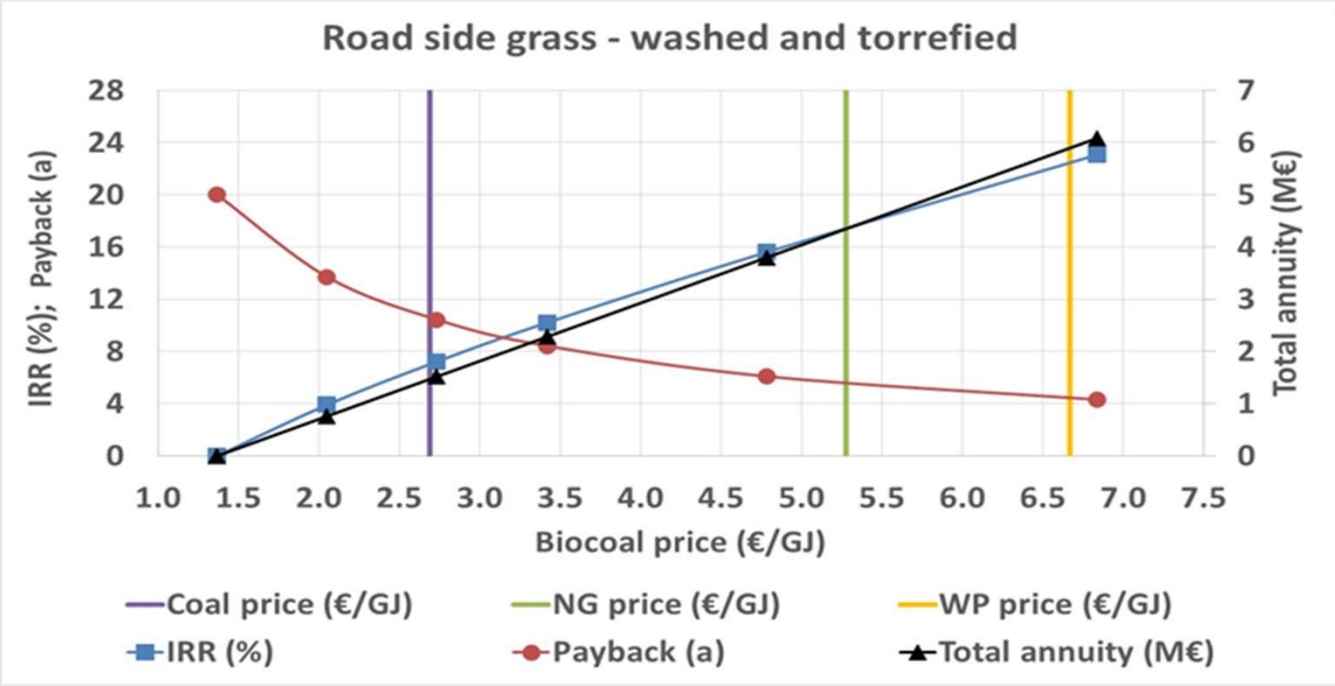


Assumptions

- 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

TNO Energy Transition

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