IEA Bioenergy

Fuel pretreatment of biomass residues for thermal conversion

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Jaap Koppejan, task leader

IEA Bioenergy Task 32: Biomass Combustion and Cofiring

Aims and approach

- Demonstrate to market actors and policy makers how existing bioenergy chains can be made more fuel flexible, efficient and cost effective through the application of (a combination of) pretreatment technologies

Deliverables:

1. 5 case study reports (available)
2. Pretreatment technology database module (available)
3. Policy report (in draft)

Project team (32,33,36,40,43)

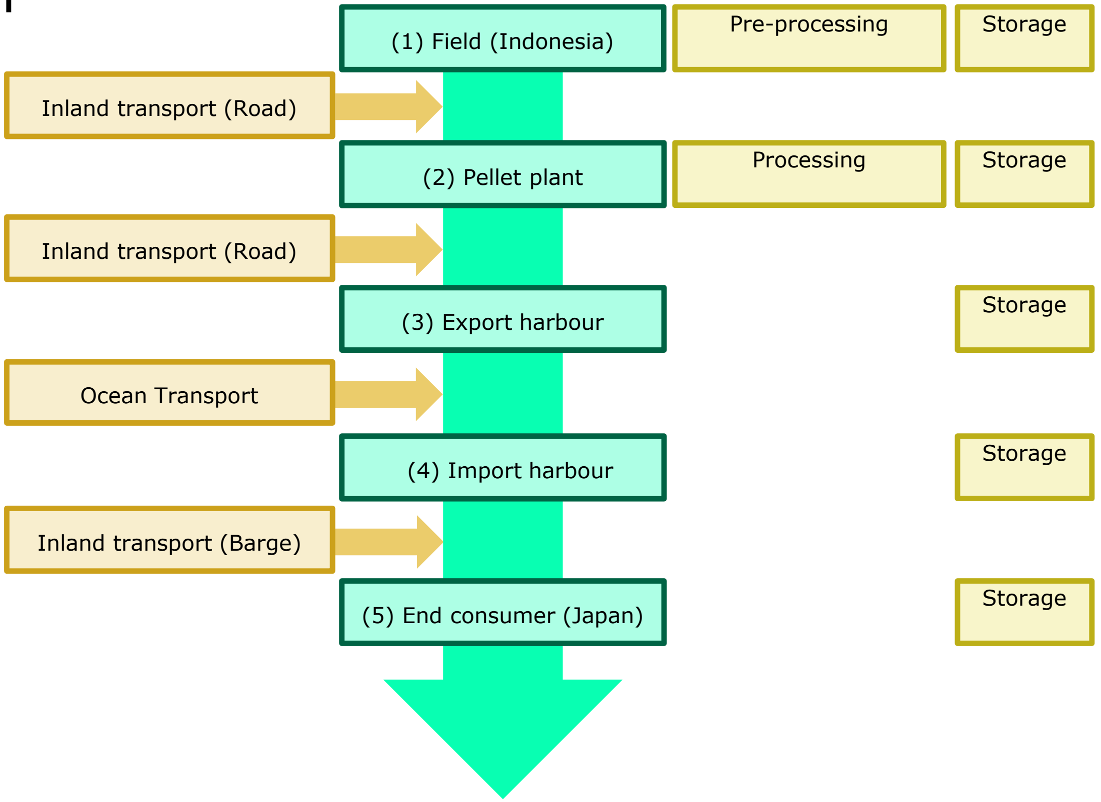
- CS1: Michael Wild (IBTC), Lotte Visser (Utrecht Univ)
- CS2: Evelyne Thiffault (Laval University, Can), Shahab Sokhansanj, Mahmood Ebadian, Hamid Rezaei, Ehsan Oveisi Bahman Ghiasi, Fahimeh Yazdanpanah (UBC, Can), Antti Asikainen and Johanna Routa (LUKE, Fin)
- CS3: Kevin Whitty, Inge Johansson, Dieter Stapf, Giovanni Ciceri
- CS4: Patrick Wolbers (DNV GL), Marcel Cremers (DNV GL), Travis Robinson (NRCan), Sebnem Madrali (NRCan), Guy Tourigny (NRCan), Rob Mager (OPG), Rune Brusletto (Arbaflame)
- CS5: Wolter Elbersen, Koen Meesters (WUR, NL)
- Coordination: Jaap Koppejan (Task 32)
- ExCo: Luc Pelkmans, Birger Kerkow, Paul Bennet
- Database: Dina Bacowsky, Bioenergy2020+

Activity 1: Case studies

- **CS1: Biomass torrefaction as alternative to wood pellets for co-firing**
- **CS2: Pretreatment of woody residues, both process and field residues**
- **CS3: Pretreatment of SRF/RDF for waste gasification**
- **CS4: Steam explosion for cofiring and full conversion**
- **CS5: Sugar cane trash and palm oil mill residue leaching**

CS1: Biomass torrefaction

- By Michael Wild (IBTC) and Lotte Visser (Utrecht Univ)
- Value chain: (torrefied)wood pellets from Kalimantan to Japan



Torrefaction is like roasting coffee beans….

- Heating biomass to 250-300 °C in absence of oxygen
- Drying + removal of part of the volatiles

roasting

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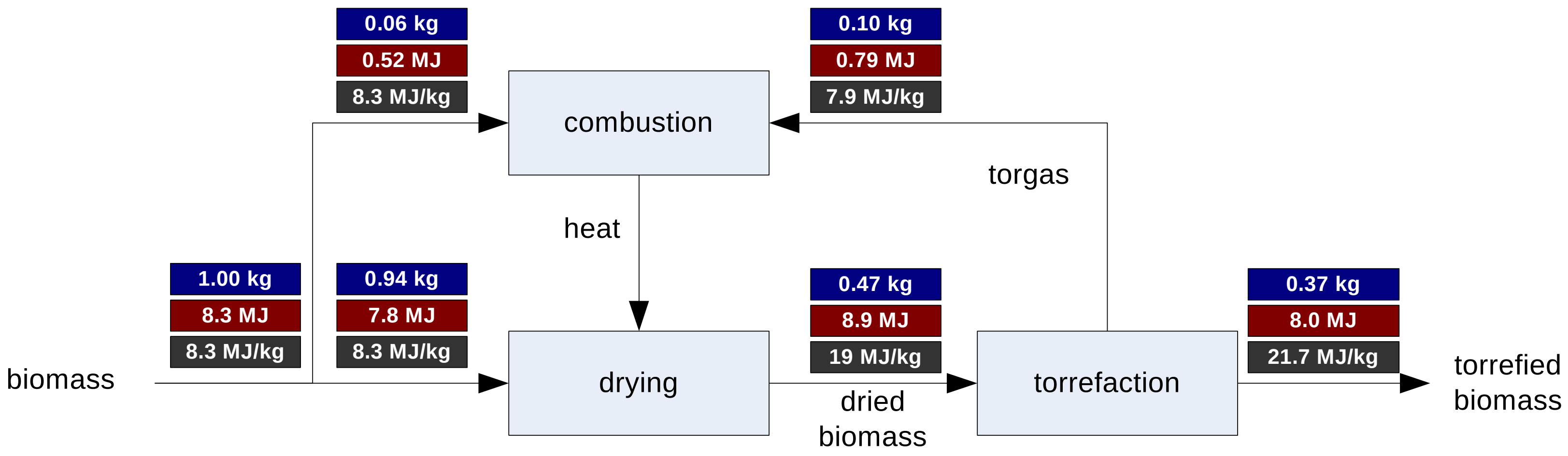
Heat energy balance (LHV basis)



Assumptions: fresh clean wood (0,5% ash content, 50% moisture content) as raw material and a dryer requiring 2.9 MJ per kg of water evaporated

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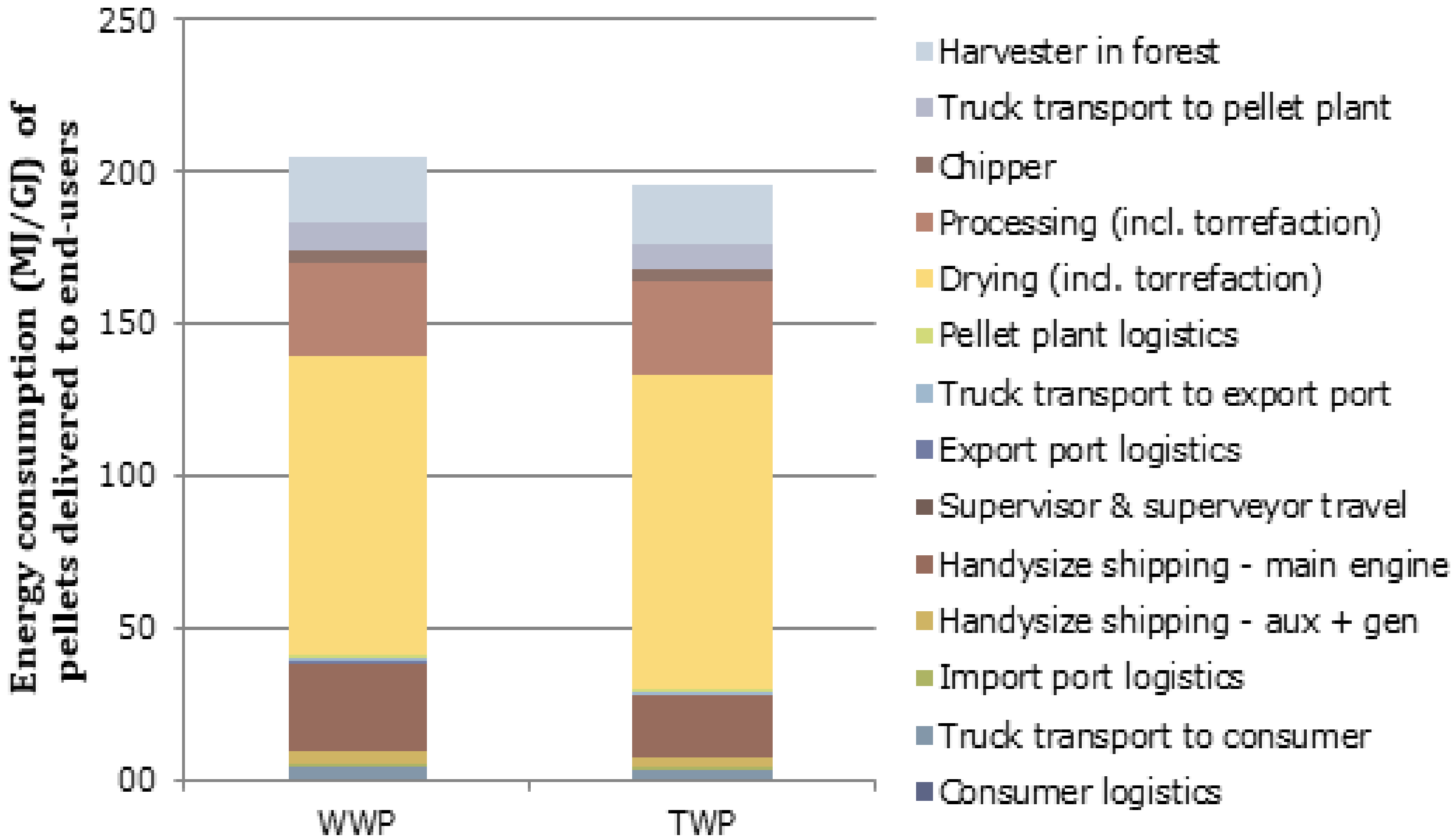
Improved product characteristics

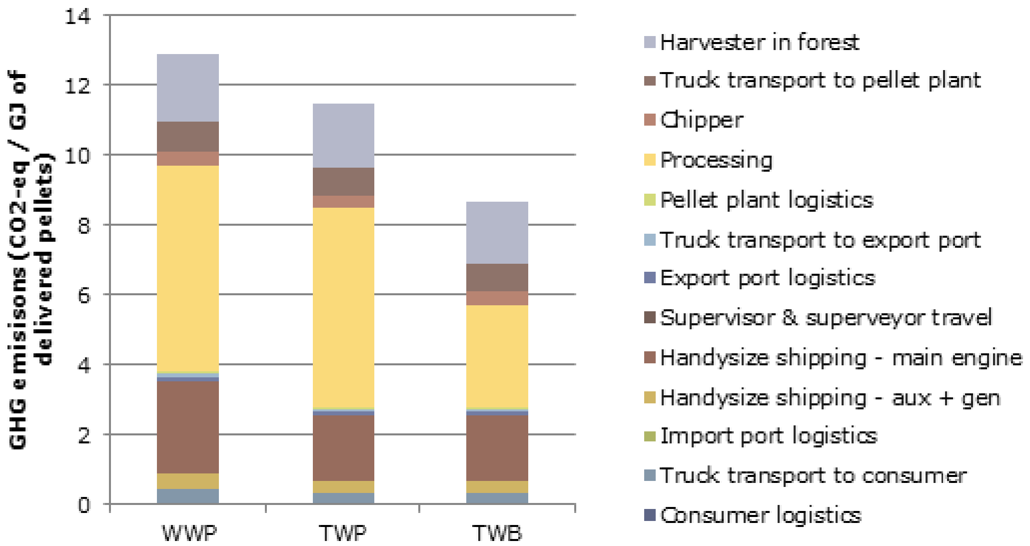
- Heating value increase by 25% (17.5 – 22.2 MJ/kg)
- Bulk density increases by 15-20% (650 – 750 kg/m3)
- Volumetric energy density increases by approx 40%
- Hydrophyllic – hydrophobic
- Limited/no biodegration
- lower logistical costs
- Better grindability
- Product characteristics tailored to clients needs
- Thermal behaviour more similar to coal
- …

Energy consumption



GHG comparison

- 11% savings according to BIOGRACE model
- Case becomes better when using briquettes/cubes instead of pellets



Economic aspects (USD/GJ)

Cost components	Wood Pellets	Torrefied Pellets	Savings
Cost of Biomass	4.28	4.28	0.00
Cost of Electricity	0.60	0.74	-0.14
Cost of Labour	0.47	0.47	0.01
Financial costs	1.01	1.49	-0.49
Other costs	0.40	0.43	-0.02
COST PRICE AT PRODUCTION SITE	6.76	7.41	-0.65
Inland logistics from the plant to port	1.12	0.57	0.55
Deep sea shipment	2.04	1.28	0.76
Inland logistics from the port to utility	0.94	0.55	0.39
COST PRICE DELIVERED AT THE UTILITY	10.87	9.81	1.06
Extra costs at the power plant	1.93	-	1.93
Total costs of coal replacement	12.80	9.81	2.99

Source: IEA Bioenergy T32 torrefaction report, 2011

Conclusions on torrefaction

- Can increase effectiveness in terms of costs, CO_2 mitigation and energy in case of longer distances.
- Particularly interesting for coal plants that are not already converted to pellets
- Technology is on the edge of commercial availability

CS2: wood residue pretreatment in Canadian forests

- Evelyne Thiffault. BioFuelNet Canada, Department of wood and forest sciences, Research Centre on Renewable Materials, Laval University, Canada
- Shahab Sokhansanj, Mahmood Ebadian, Hamid Rezaei, Ehsan Oveisi Bahman Ghiasi, Fahimeh Yazdanpanah, Biomass and Bioenergy Research Group, University of British Columbia, Canada.
- Antti Asikainen and Johanna Routa. LUKE, Finland

Forest residues are a large resource

- 0.48 EJ currently produced from forest biomass in Canada, 0.17 EJ yet unused
- Potential is estimated at
  - 0.68-4.43 EJ per year in Canada,
  - in North America, Europe and Oceania: 4.94 to 28.01 EJ/year

- Challenges for forest biomass:
  - low in energy and bulk densities
  - heterogeneous in physical, chemical and thermal properties
  - high in moisture, mineral and oxygen content
  - highly hygroscopic and difficult to handle

Key pretreatment opportunities

- **moisture management** by passive and active drying, covering, blending, and monitoring and modelling of moisture content;
- **physical property management** by chipping, grinding, sieving and machine visualization;
- **ash content management** by washing;
- **density** management by pelletizing.

About natural and artificial drying

Natural drying:

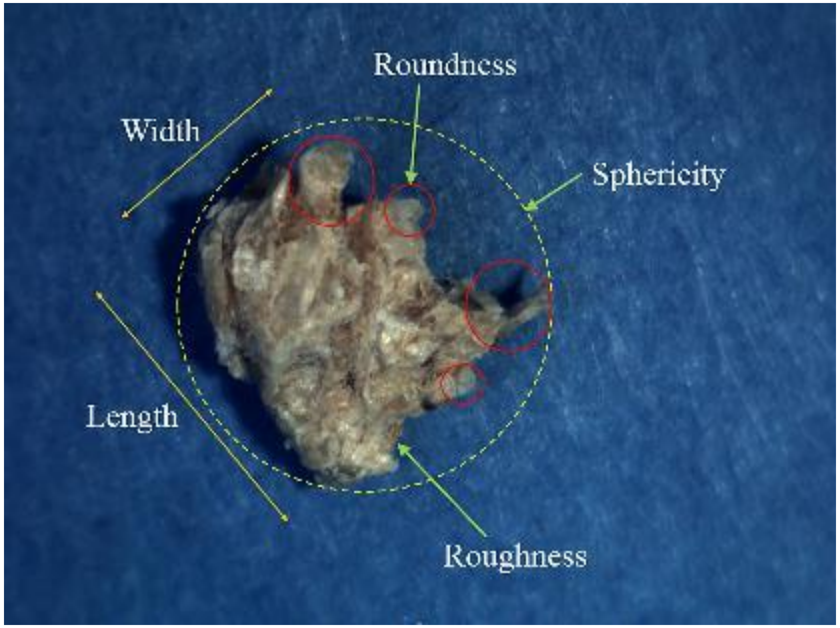
- Covering of residue piles at roadside prevents re-moistening in autumn and winter
- Reliable models available that correlate weather data with moisture content development over time
- Case study of natural drying for operation of UBC gasifier: costs 23 k USD, benefits > 50 kUSD

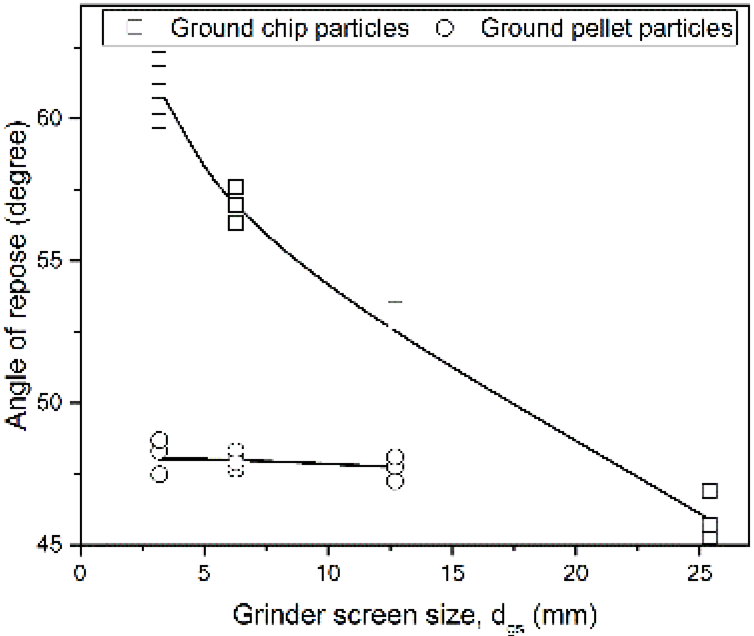
Artificial drying:

- cost savings of 1.33-3.54 USD/MWh, depending on the supply chain, moisture content and procurement volume.

Particle size and shape

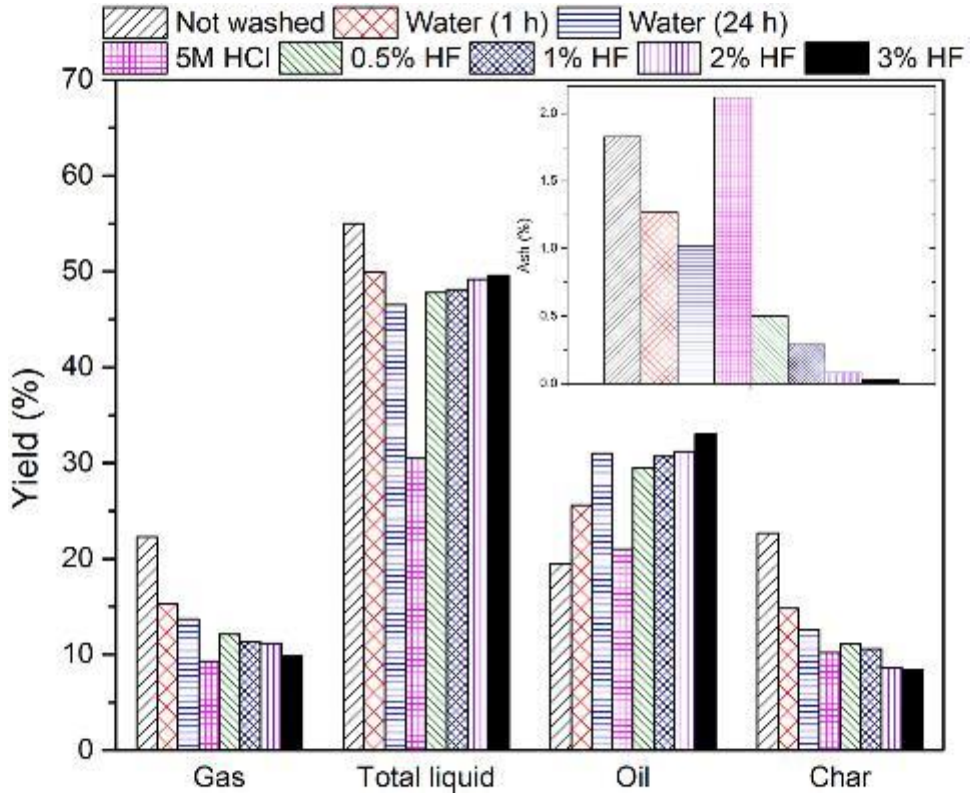
- Size reduction (chipping, milling) + screening improves handling and flowability/bridging aspects
- Flowability depends on ratio between loose and tapped bulk density
- Sieving out smaller particles reduces both ash and moisture content significantly, resulting in better combustion behaviour and higher energy content





Impacts of washing

- Washing biomass may reduce fouling and corrosion problems in boilers.
- In case of producing pyrolysis oil, it may improve product composition and reduce aging of the oil produced



Pelletization

- Better bulk density, flowability, energy density grindability than chips
- Production costs 1.8-3.0 USD/GJ of pellets, excl raw material
- Pelletisation particularly interesting for cases of higher fuel supply costs :
  - 1.70-3.18 USD GJ^{-1} for heat plants,
  - 7.21-**41.39** USD GJ^{-1} for power plants,
  - 13.39-**29.45** USD GJ^{-1} for combined heat-and-power plants

CS3: Pretreatment of SRF for gasification

- State of the art gasifiers mainly run on clean biomass
- Does it make sense to produce Solid Recovered Fuel and run gasification units on this fuel instead of biomass?

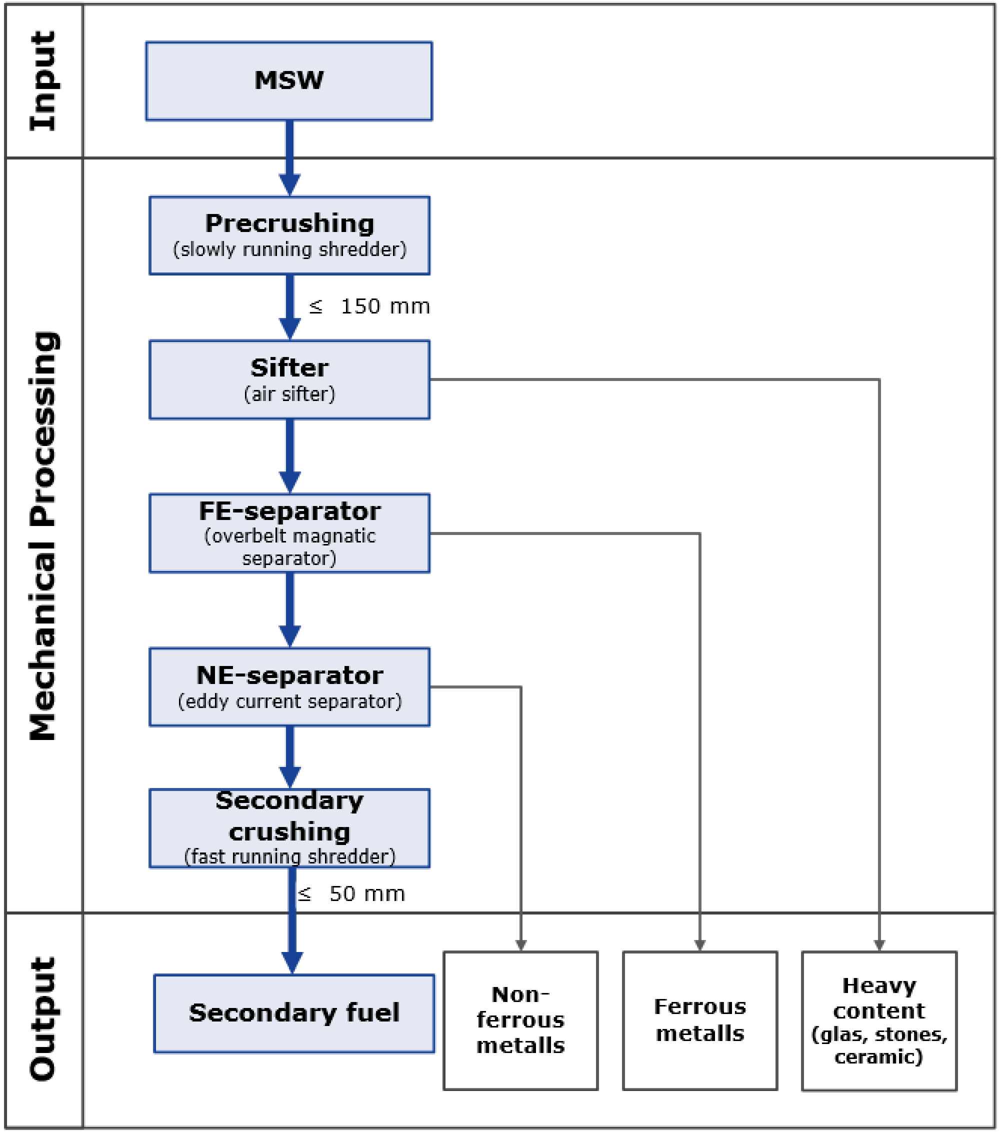
Parameter		CFB – Feedstock	Municipal Solid Waste
Particle size			
Maximum diameter	[mm]	50	> 300
Proximate analysis			
Moisture content	[wt-%]	≤ 35	15 - 35
Volatile matter	[wt-%]	≤ 75	
Ash content	[wt-%]	≤ 25	25 - 35
Ultimate analysis			
Sulfur	[wt-%]	< 1	0.3 – 0.5
Chlorine	[wt-%]	< 2	0.4 – 1.0
Mercury	[mg/kg]	< 1.5	0.5 - 11
Ash melting point	[°C]	≥ 960	
LHV	[MJ/kg]	~ 10 - 20	7 - 15
Bulk density	[t/m³]	0.25	0.1

RDF is not directly SRF!

- SRF meets criteria of EN 15359 “SRF – Specification and Classes”, designed as fuel within narrow specifications suitable for particular applications
- ISO TC300 aims to make such specs global
- Review of gasificier specs yields limited bandwith in specs

Classification Property	Statistical Measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg/(ar)	≥ 25	≥20	≥15	≥10	≥ 3
Classification Property	Statistical Measure	Unit	Classes				
			1	2	3	4	5
Chlorine (Cl)	Mean	% (d)	≤0,2	≤0,6	≤1,0	≤1,5	≤3
Classification Property	Statistical Measure	Unit	Classes				
			1	2	3	4	5
Mercury (Hg)	Median	mg/MJ (ar)	≤0,02	≤0,03	≤0,08	≤0,15	≤0,50
	80^{th} percentile	mg/MJ (ar)	≤0,04	≤0,06	≤0,16	≤0,30	≤1,00

SRF production from MSW



Rüdersdorf 100 MW CFB gasifier

Treatment step	Manufacturer; Model	Price	Electrical Power
		[€]	[kW]
Precrushing	WEIMA; PreCut 3000	400,000	350
Sifter	Sutco; 2-Wege-Windsichter	250,000	23.1
FM-separator	IFE Aufbereitungstechnik; -	100,000	5
NF-separator	IFE Aufbereitungstechnik; -	100,000	10
Secondary crushing	WEIMA; FineCut 2500 (2x)	640,000	2 x 250

	Parameter	Value
Operation of plant	Operating hours	8,000 hr/a
	Electricity	0.1 €/kWh
Annual costs	Depreciation Period	10 years
	Depreciation rate	10 % of invest/a
	Capital costs	10 % of invest/a
	operating costs	5 % of invest/a
Revenues & Fees	Revenue: Ferrous Metals	25 €/t
	Revenue: Non-Ferrous Metals	250 €/t
	Landfill Fees: Heavy Content	30 €/t

- Resulting treatment costs: 10 Euros per ton of secondary fuel
- Gate fee of 100 Euro/ton makes SRF production attractive compared to biomass

CS4: steam explosion process

- By Patrick Wolbers (DNV GL), Marcel Cremers (DNV GL), Travis Robinson (NRCan), Sebnem Madrali (NRCan), Guy Tourigny (NRCan), Rob Mager (OPG), Rune Brusletto (Arbaflame)
- known from other applications in the past
- Simple reactor technology (batch) and process control
- Requires size reduction and drying before the biomass is fed in the steam explosion vessel
- only few developers built plants
- Needs to be proven at scale for non-woody biomass types.

Steam exploded pellets

- Can be stored outdoors for a longer duration with no significant impact on mechanical durability
- Requires measures for dust prevention
- Has a calorific value slightly higher than that of wood pellets but below that of torrefied pellets

Property	Value
Lower Calorific value (LHV)	17 - 19 MJ/kg
Moisture Content	2 – 4 % wet basis
Volatile content	70 – 80 % dry basis
Bulk density	650 - 780 kg/m3

- Two companies with significant experience:
- Arbaflame (Norway): 50 kton/y plant in Norway, 130 kton produced so far, tested at 14 utilities
- Zilka (USA): 275 kton/y plant in USA, cofired at several EU PC boilers. Refinanced the plant and will resume production shortly

Project Comparison

- **Atikokan GS**
- 205 MWe – White Pellets
- Project Duration
- • 18 months (9 month outage)
- Conversion CapEx
- • $170M ($830 / kW)

- **Thunder Bay GS Unit 3**
- 150 MWe – Advanced Biomass
- Project Duration
- • 7 months (2 month outage)
- Conversion CapEx
- • $3M ($20 / kW)

ONTARIO POWER GENERATION

CS5: Leaching herbaceous biomass

- Wolter Elbersen, Koen Meesters (WUR)
- Lignocellulosic biomass potential in EU27

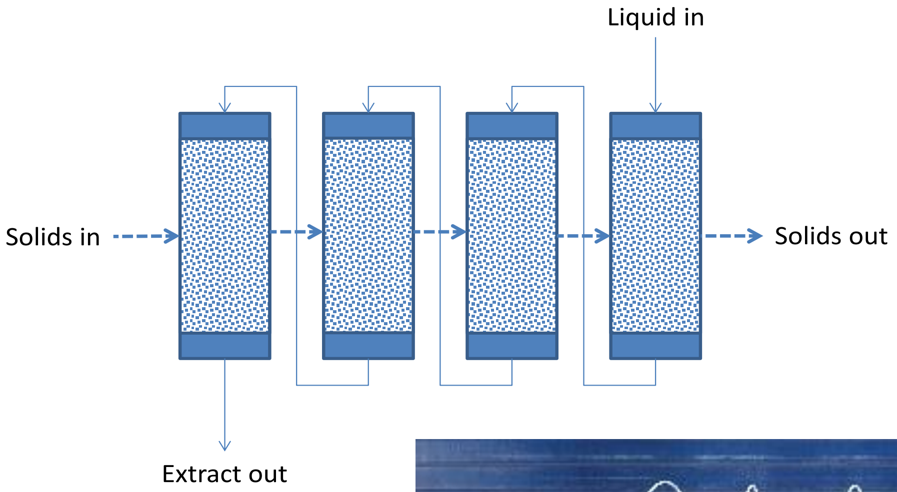
	Current potential	Used potential
	Million tons dry matter per year	
Wood from forests	325	350
Other forest biomass (forest industries)	185	140
Agricultural residues (field and agri-industries)	**342**	**15**
Waste	89	60
Cropped biomass	152	2

Panoutsou et al. 2016

Challenges for burning herbaceous biomass

Inorganic compound	Explanation and effects	Typical content	Norms or desirable contents
Chlorine (Cl)	Variable in living tissue, depends mainly on soil Cl content. Causes corrosion, HCl and dioxin emission.	0.3 to 2% of dry matter	< 0.02% or <0.3%
Potassium (K)	Essential in living tissue. Causes corrosion and lowering of ash melting point	0.6 to 2 % of dry matter	Difficult to quantify but < 0.03 % K+Na is sometimes mentioned
Sodium (Na)	Variable in living tissue, depends mainly on soil Na content.	0 to 1% of dry matter	See above
Nitrogen (N)	Essential in living tissue. Contributes to NOx emissions. Measures can be taken to limit effects	0.5 to 2%	0.03% to 1%
Ash	Ash content of herbaceous biomass depends on soil and tissues type. Ash will lower efficiency and increase operating costs.	1 to 15%	0.5 to 3.5 %.

Counter current extraction



Experimental setup at WUR

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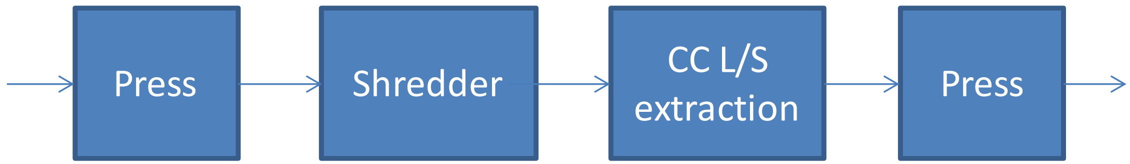
Results for EFB

EFB		Before	After
Ash (550 ^{o}C)	(% of DW)	4.64	1.85
Ash (815 ^{o}C)	(% of DW)	3.77	1.73
S	(% of DW)	0.063	0.023
Cl	(% of DW)	0.38	0.024
SiO_2	(% of ash 815 ^{o}C)	30.8	33.5
Al_2O_3	(% of ash 815 ^{o}C)	0.53	0.92
TiO_2	(% of ash 815 ^{o}C)	< 0,1	< 0,1
P_2O_5	(% of ash 815 ^{o}C)	4.87	10.1
SO_3	(% of ash 815 ^{o}C)	1.89	9.54
Fe_2O_3	(% of ash 815 ^{o}C)	0.99	1.11
CaO	(% of ash 815 ^{o}C)	4.35	17.9
MgO	(% of ash 815 ^{o}C)	9.51	12.7
Na_2O	(% of ash 815 ^{o}C)	2.93	0.78
K_2O	(% of ash 815 ^{o}C)	37.8	12.7
Mn_3O_4	(% of ash 815 ^{o}C)	0.12	0.26
SST	^{o}C	990	1080
DT	^{o}C	1210	1120
HT	^{o}C	1250	1160

Feasilibility in an industrial setting



- Use washing water for irrigation
- 40 $kton_{dm}$ of EFB: 8 USD/ton, of which 70% capital cost

Other work currently finalised:

Policy synthesis report

- Currently in draft, available by end of 2018
- Summarises effect of pretreatment technologies on broadening resource base
- Contains policy recommendations

Pretreatment technology database

- New module in existing IEA Bioenergy technology database containing examples of complete industrial biomass pretreatment facilities

General lessons learned

- Whole range of pretreatment technologies available; some common/simple and some new/advanced
- Pretreatment can effectively increase resource flexibility by broadening the resource base or improving fuel quality to enable easier end use.
- Reducing logistical costs may also help in unlocking remote biomass pockets
- Being locked into expensive end user equipment (WTE plants, coal plants converted to wood pellets) may restrict potential for pretreatment on the short term

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Thank you for your attention!

Questions?

Contact Details

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