IEA Bioenergy

Fuel pretreatment of biomass residues for thermal conversion

Webinar, 25 April 2019

- Jaap Koppejan, project coordinator, ProBiomass BV, NL
- Michael Wild, IBTC, Austria
- Evelyne Thiffault, BioFuelNet Canada & Laval Univ, Canada
- Kevin Whitty, Univ of Utah, USA
- Marcel Cremers, DNV GL, Netherlands
- Koen Meesters, Wageningen University & Research, NL

Aims and approach of the pretreatment project

- 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
- Multidisciplinary collaboration within IEA Bioenergy

Deliverables:

1. 5 case study reports
2. Database module on pretreatment in the existing IEA Bioenergy technology database
3. Policy report

See http://itp-fueltreatment.ieabioenergy.com/

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 (Univ of Utah)**, Inge Johansson (RISE), Dieter Stapf (KIT), Giovanni Ciceri
- CS4: Patrick Wolbers (DNVGL), **Marcel Cremers (DNVGL)**, 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+

Contents for todays webinar

- Introduction (Jaap Koppejan)
- Case studies
  - CS1: Biomass torrefaction as alternative to wood pellets for co-firing (Michael Wild)
  - CS2: Pretreatment of woody residues, both process and field residues (Evelyne Thiffault)
  - CS3: Pretreatment of SRF/RDF for waste gasification (Kevin Whitty)
  - CS4: Steam explosion for cofiring and full conversion (Marcel Cremers)
  - CS5: Sugar cane trash and palm oil mill residue leaching (Koen Meesters)
- Conclusions (Jaap)
- Q&A session

Background

- Transition from **fossil based** energy system to renewable and **biobased** energy system
- Enormous diversity in **chemical composition** and **physical appearance** of biomass resources, while current fossil fuels comply with narrow technical specifications. Mismatch in many cases!
- Bulky biomass material causes high transportation costs, higher **volumetric energy density** wanted
- Uncertainty about **availability of existing fossil based assets** on the long run makes asset owners hesitant to make large investments to accommodate diverse biomass fuels
- Various existing and new pretreatment technologies can help to **improve and enable** supply chains

Biomass availability in 2050

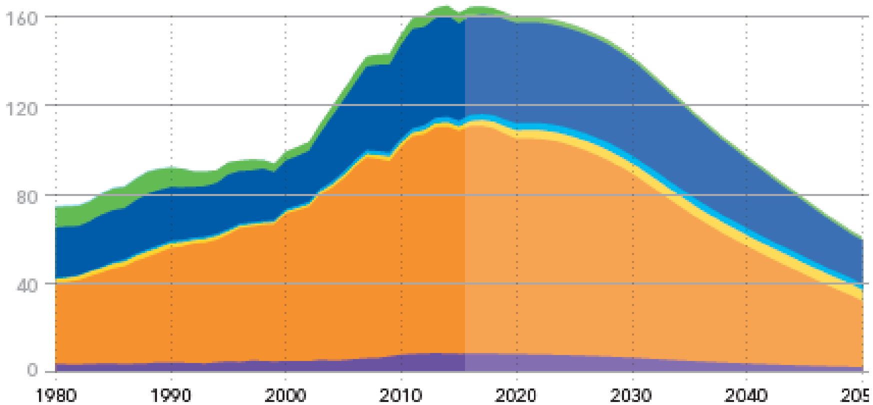
Resource	Range (EJ)	Comment
Dedicated bioenergy crops	44-133	High uncertainty, depends on yields, diets, technology, and climate change
Crop residues	49	Soil conservation issues need to be addressed; GHG balance might depend on soil carbon balance
Manure	39	Relatively small uncertainty and few, if any, environmental issues
MSW	11	Relatively small uncertainty and few environmental issues
Forestry residues	19-35	Competition for other uses may reduce availability of residues
Total, excl. aquatic biomass	162-267	

Rogner, H.-H., R. F. Aguilera, C. Archer, R. Bertani, S. C. Bhattacharya, M. B. Dusseault, L. Gagnon, H. Haberl, M. Hoogwijk, A. Johnson, M. L. Rogner, H. Wagner and V. Yakushev, 2012: Chapter 7 - Energy Resources and Potentials. In Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 423-512

World fossil energy demand by fuel and sector

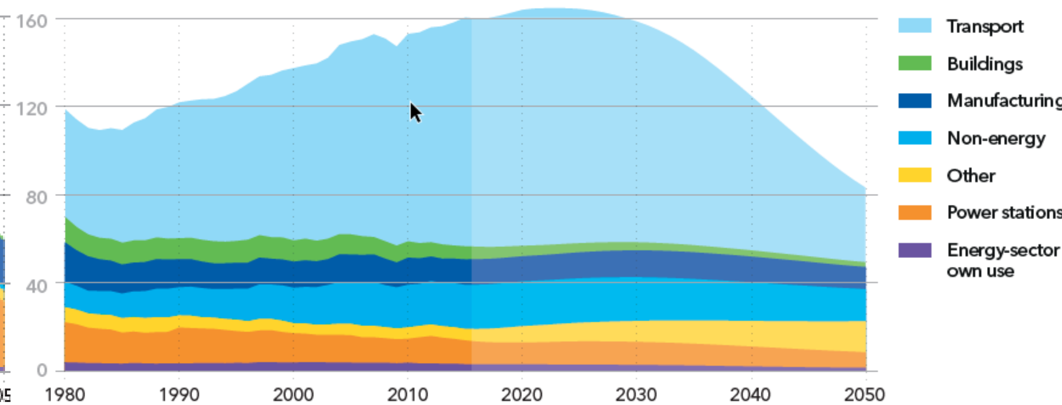
World coal demand by sector

Units: EJ/yr



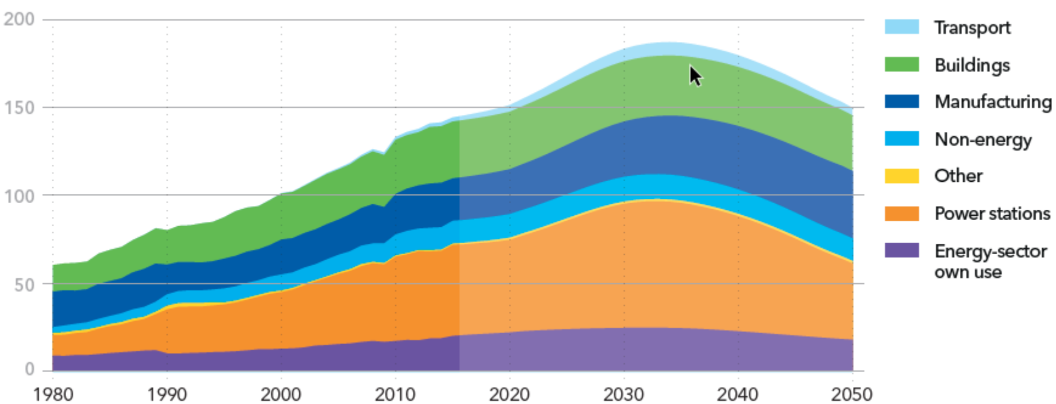
World oil demand by sector

Units: EJ/yr



World natural gas demand by sector

Units: EJ/yr



Source:
DNV GL, Energy Transition Outlook, 2018

Market opportunities for biomass pretreatment

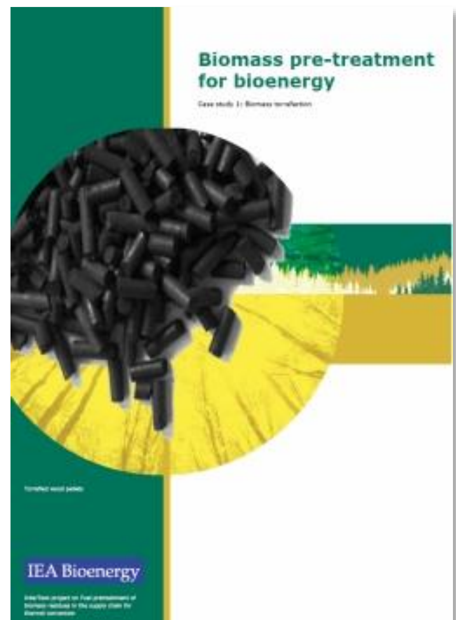
Sectors	EJ	Current fuels to be replaced	Biomass requirements	Pretreatment for woody biomass (19-35 EJ)	Pretreatment for herbaceous biomass (49 EJ)	Pretreatment for solid waste (11 EJ)
Electricity	100	Coal	High ash melting point, easy to grind, if possible hydrophobic, low logistical costs	White pellets Black pellets (cases 1 and 4)	Leaching White pellets Black pellets	Separation Drying Gasification Gas cleaning
	60	Gas	gaseous, clean, suitable heating value	Gasifier	Leaching, gasifier	
	10	Oil	Liquid, clean, suitable heating value	pellets, fast pyrolysis oil	Pyrolysis	Pyrolysis
Steel	20	Coal	biomass derived reducing agents	Carbonisation	-	-
Cement kiln	10	Coal (7 EJ), oil, natural gas, biomass/waste	Sufficient heating value and ash composition adequate	--	-	Selection of valorising wastes (case study 3)
Other industrial heat	70	Natural gas, oil, coal	Depending on application, easy logistics, reliable	Chips, pellets	Leaching + bales, pellets (case study 5)	
Space heating	120	Natural gas, oil	No contamination, high heating value	Chips, pellets (case study 2)	Bales, pellets	-

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**

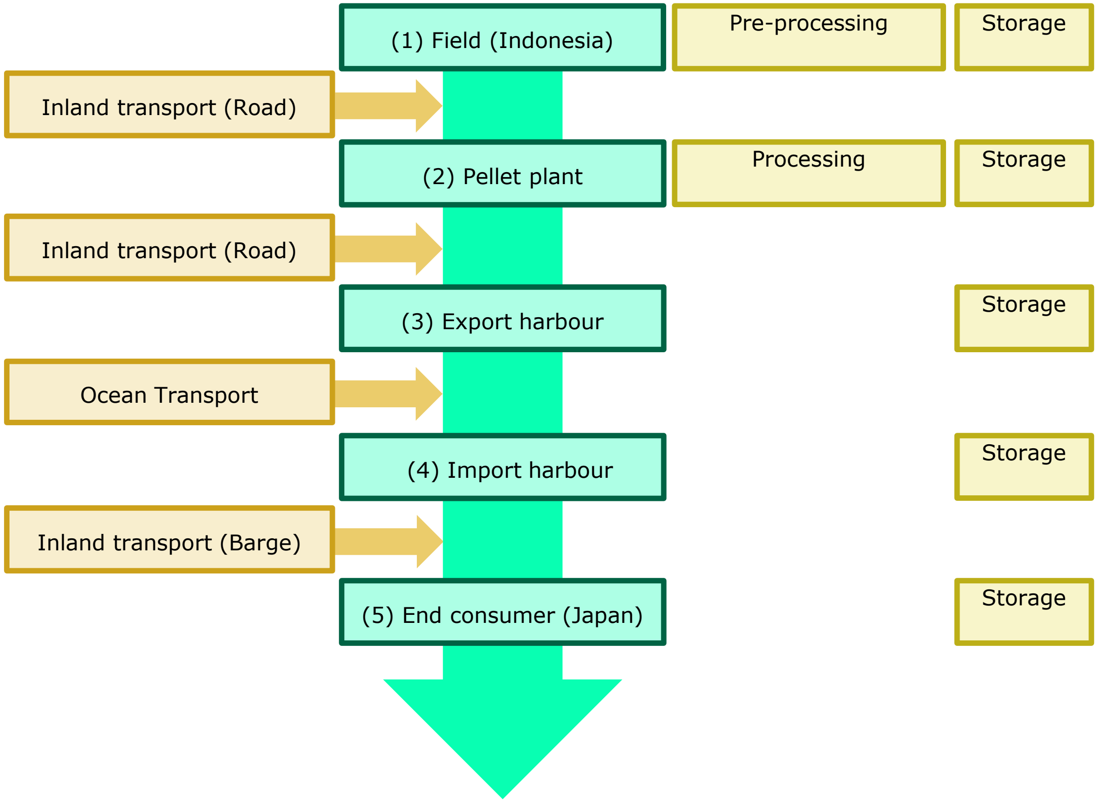
CS1: Biomass torrefaction as alternative to wood pellets for co-firing

- **Michael Wild (IBTC, Austria)**
- Lotte Visser (Utrecht Univ, Netherlands)



Value chain

- (torrefied) wood pellets from Kalimantan to Japan

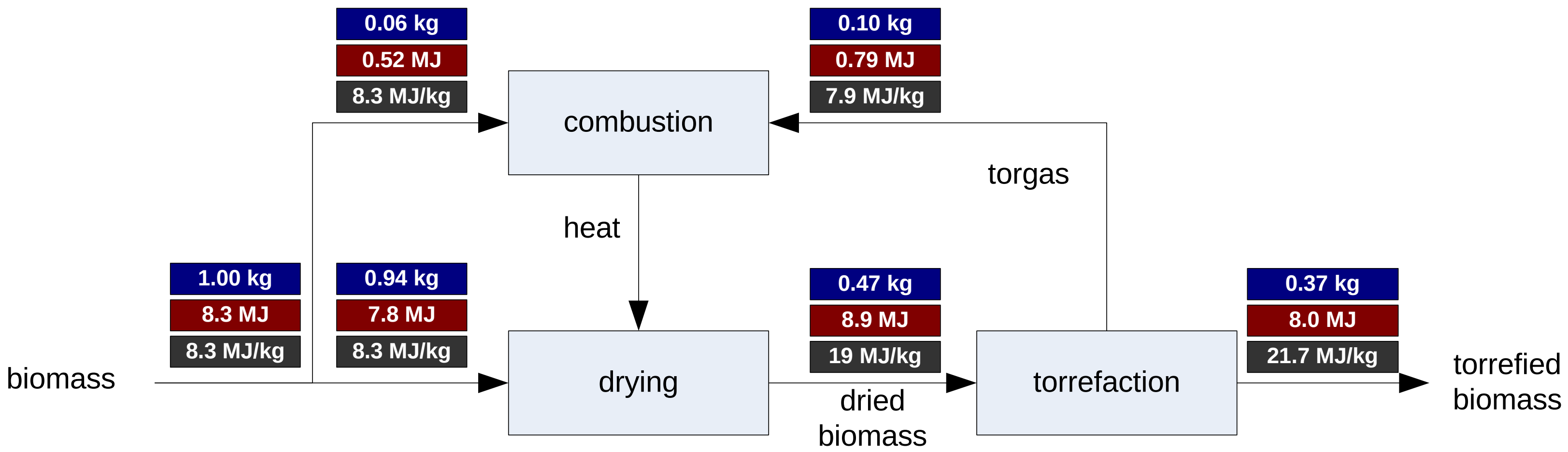


Torrefaction is like roasting coffee beans....

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

roasting

Heat energy balance (LHV basis)

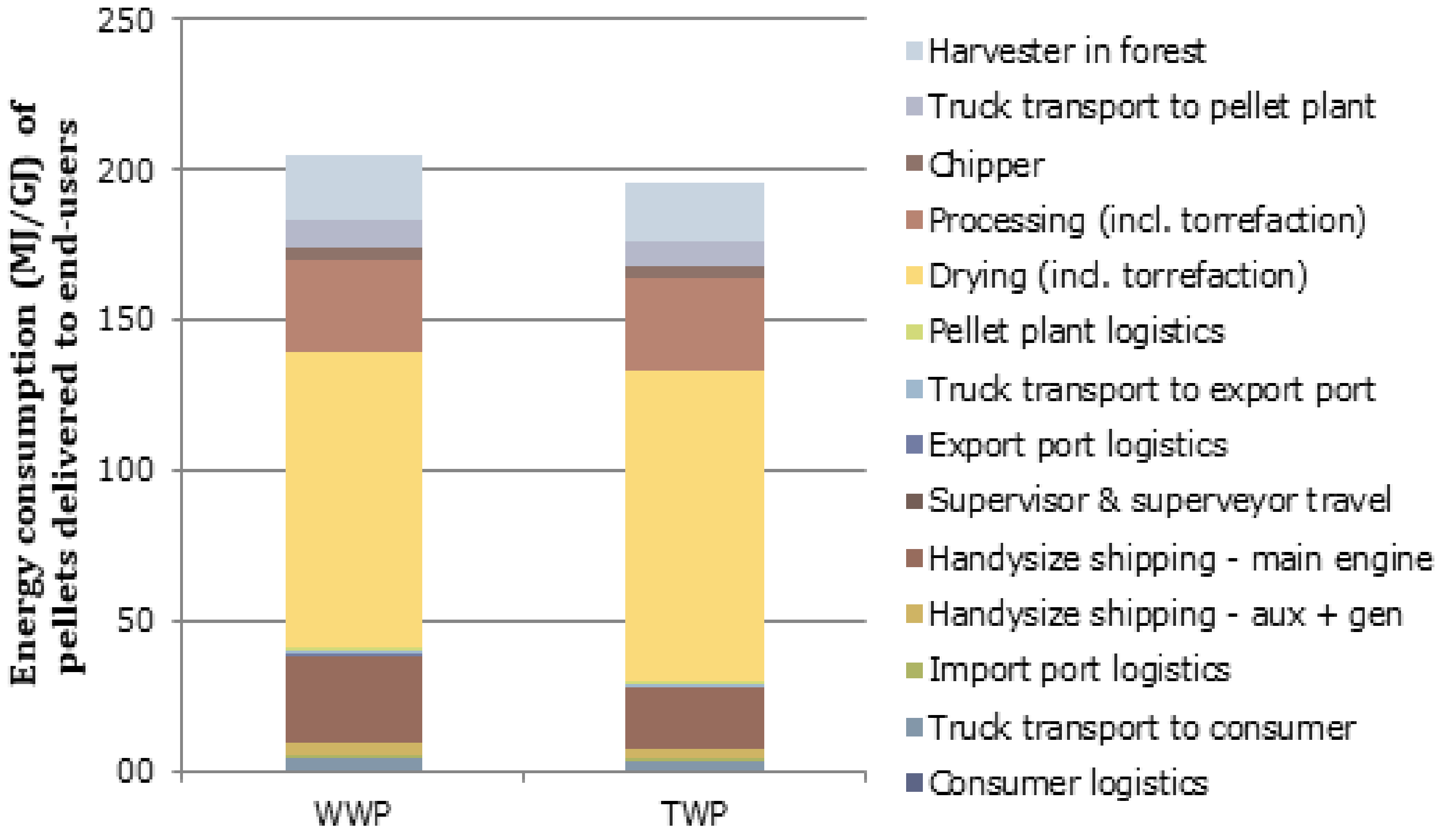


Assumptions: fresh clean wood (0,5% ash content, 50% moisture content) as raw material and a dryer requiring 2.9 MJ per kg of water evaporated

Improved product characteristics

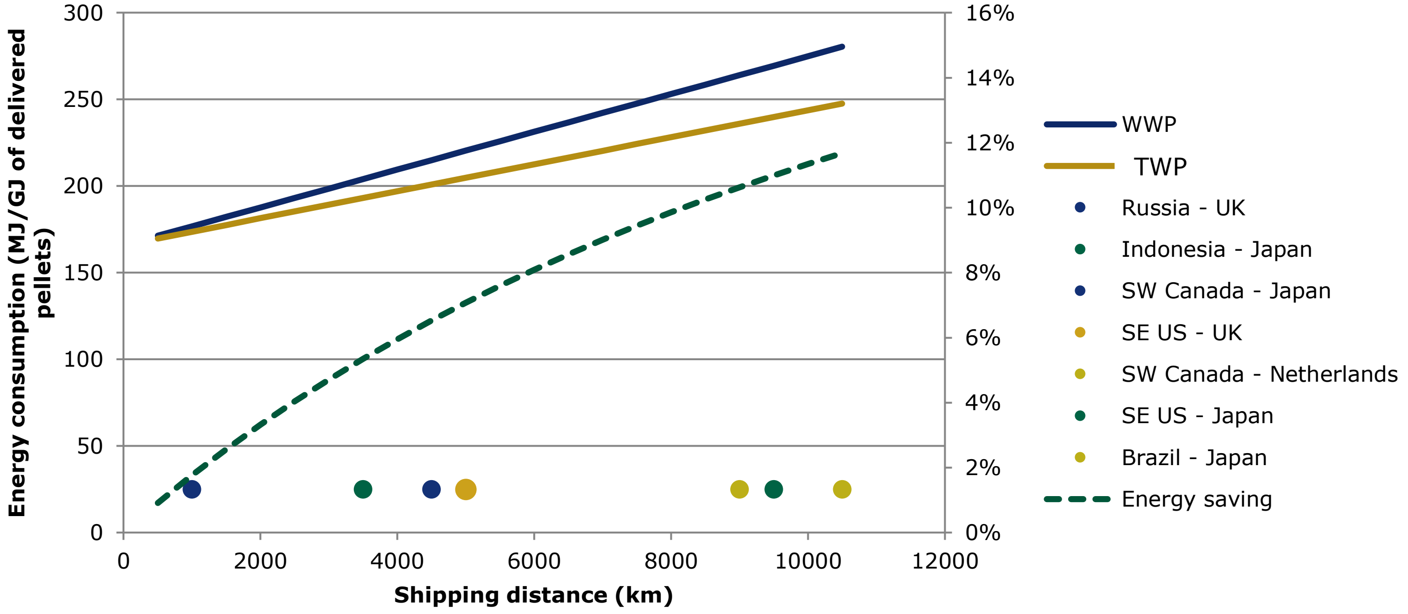
- Heating value increase by 25% (17.5 → 22.2 (30)MJ/kg)
- Bulk density increases by 15-20% (650 – 750 kg/m3)
- Volumetric energy density increases by approx 40%
- Hydrophyllic – hydrophobic
- Limited/no biodegration
- lower logistical costs
- Better grindability
- Product characteristics tailored to clients needs
- Thermal behaviour more similar to coal
- …

Energy consumption



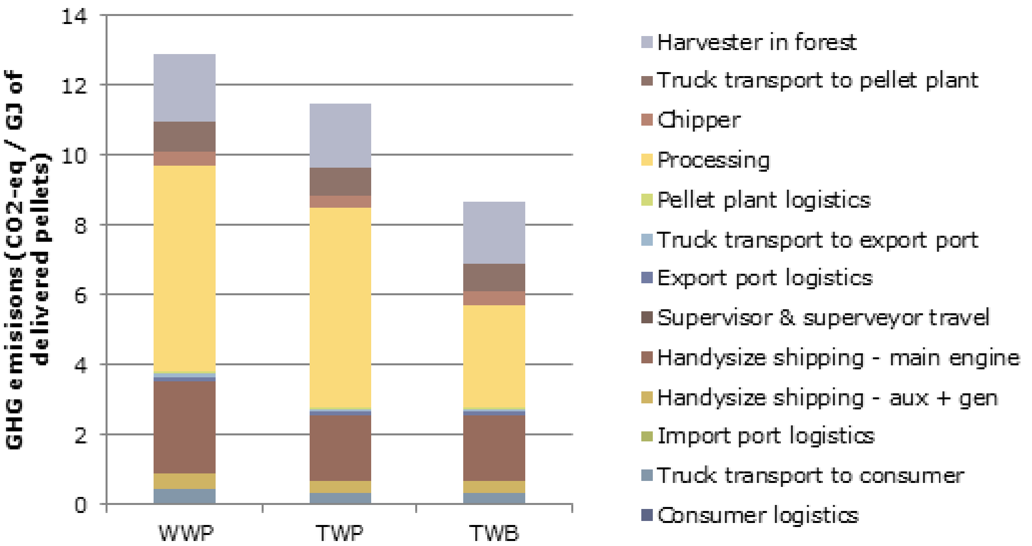
Advantage increasing with distance

- Up to 12% savings against WWP in Handymax vessel
- Same savings expected for smaller vessel types in shorter distance routes



GHG comparison

- 11% savings applying BIOGRACE model
- Briquetting/cubing instead of pelleting improves balance further especially if higher torrefied



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

- Most advanced higher biomass processing technology

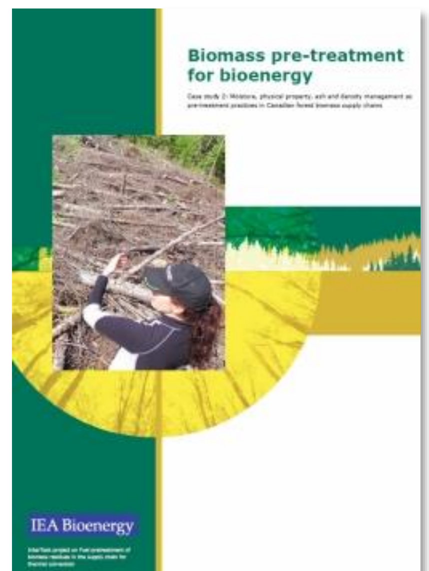
- Can increase effectiveness in terms of costs, CO_2 mitigation and energy in logistics with growing advantage in longer distances.

- Particularly interesting for coal plants, steel mills and other large scale thermal users of coal

- Product is available from smaller commercial plants, larger plants (>100.000 kt/a) in construction

CS2: Pretreatment of woody residues, both process and field residues

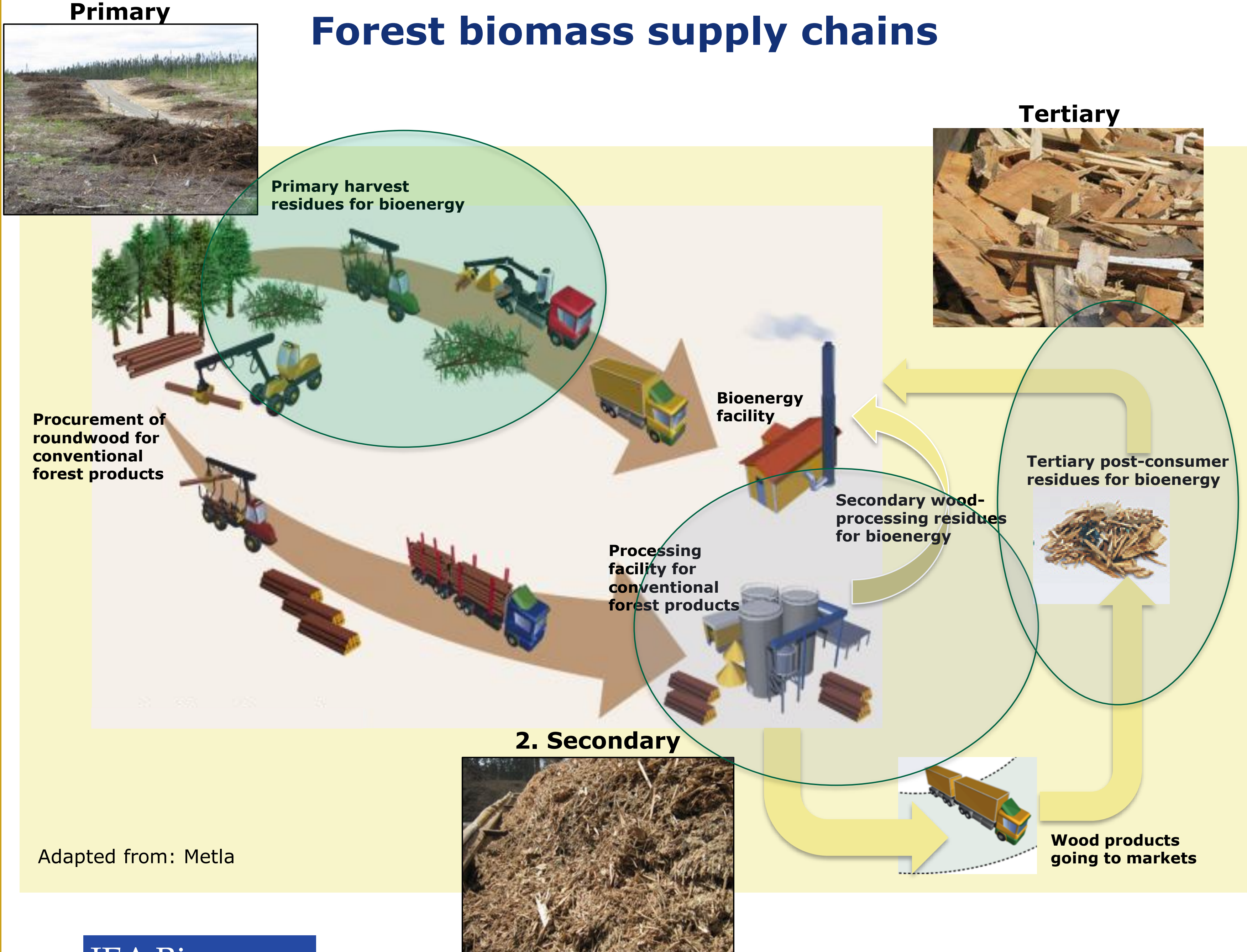
- **Evelyne Thiffault,** Research Centre on Renewable Materials, Laval University, Canada
- Shahab Sokhansanj, Mahmood Ebadian, Hamid Rezaei, Ehsan Oveisi Bahman Ghiasi, Fahimeh Yazdanpanah, Biomass and Bioenergy Research Group, University of British Columbia, Canada.
- Antti Asikainen and Johanna Routa.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



CS2: Pretreatment of woody residues in forest biomass supply chains

- Evelyne Thiffault. 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 biomass supply chains



Main challenges

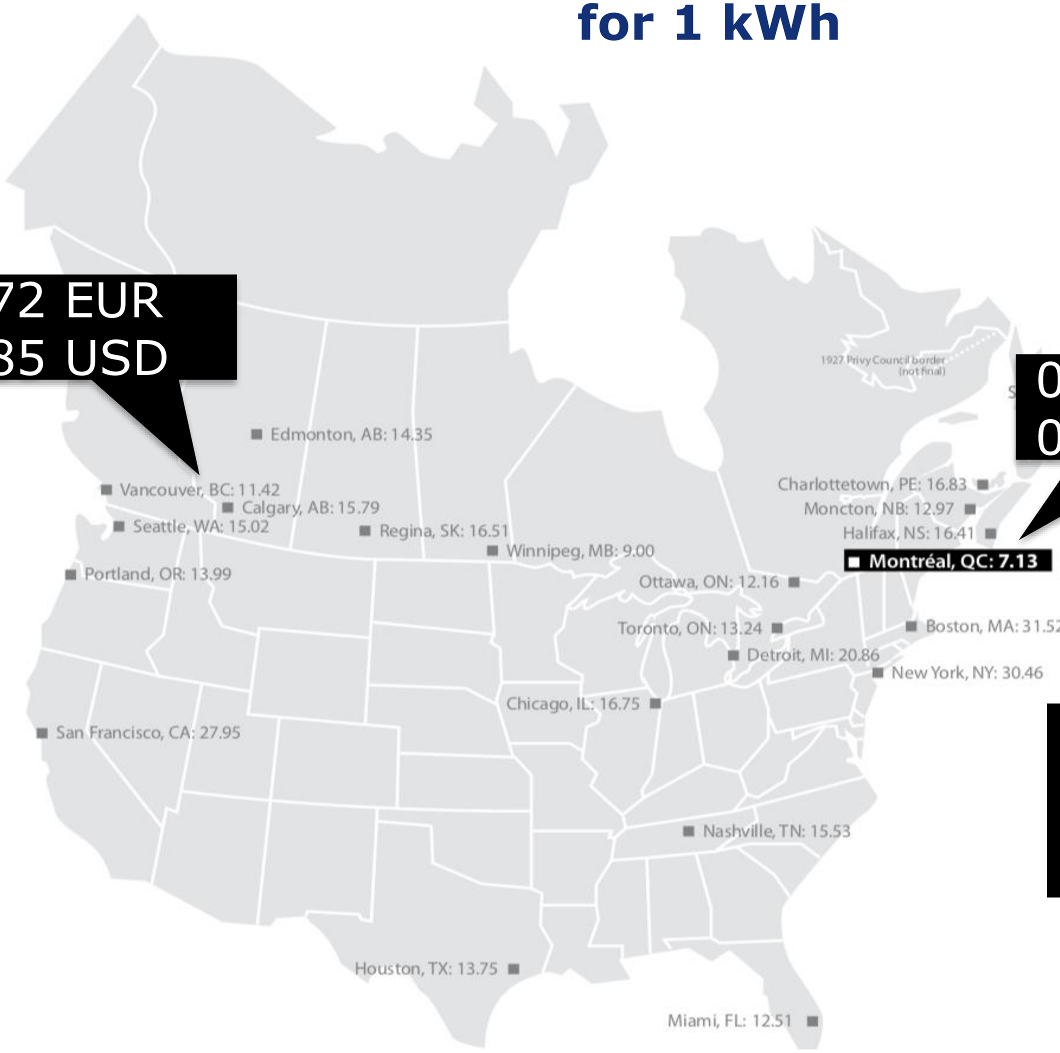
Woody residues:

- low energy and bulk densities
- heterogeneous physical, chemical and thermal properties
- high moisture, mineral and oxygen content
- highly hygroscopic and difficult to handle

Electricity price for household customers for 1 kWh

0.072 EUR
0.085 USD

0.045 EUR
0.053 USD

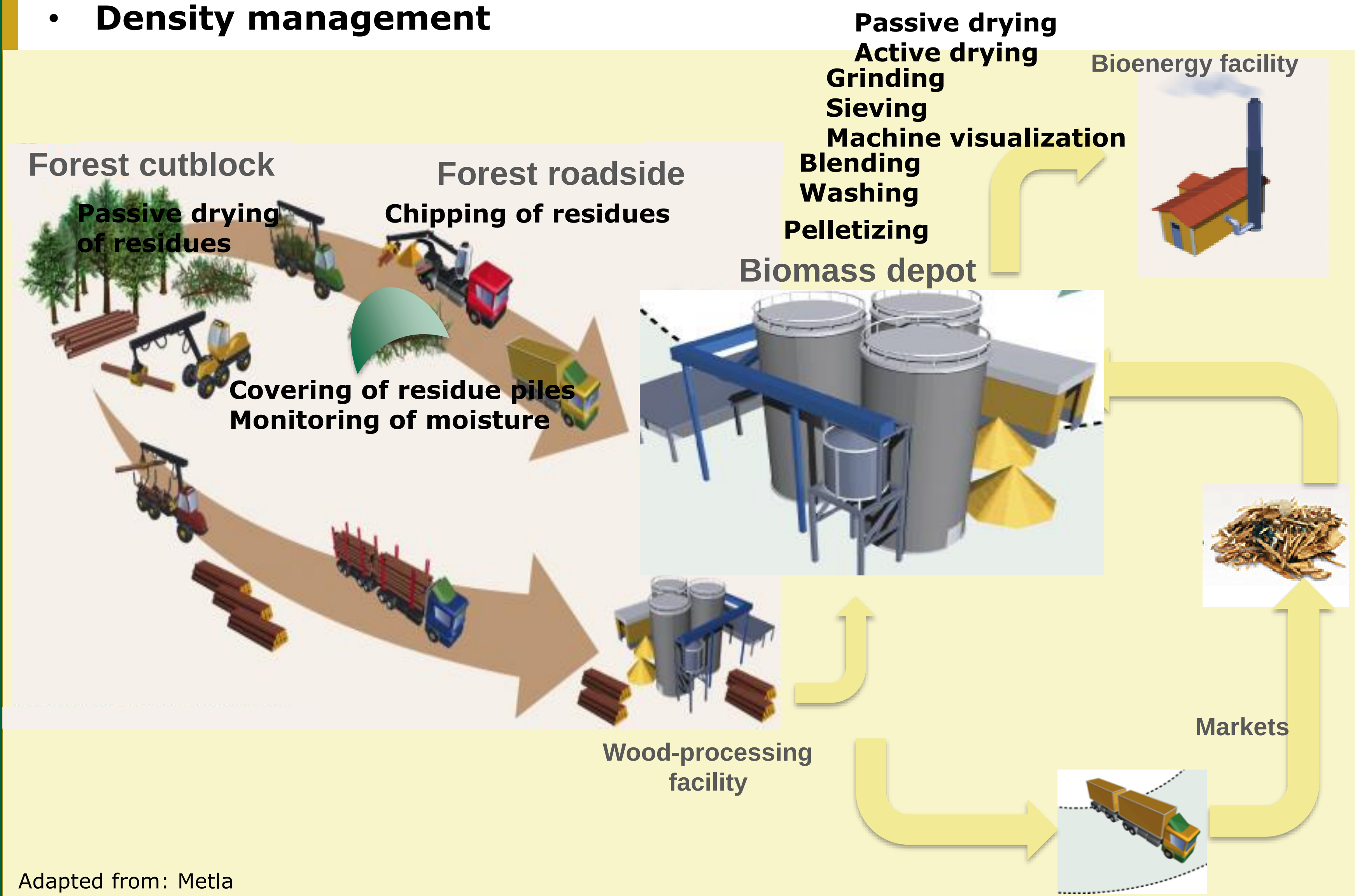


European Union
0.205 EUR
0.230 USD

Sources: Comparison of Electricity Prices in Major North American Cities
Rates in effect April 1, 2018. Hydro-Quebec.
Eurostat, Electricity prices statistics 2018.

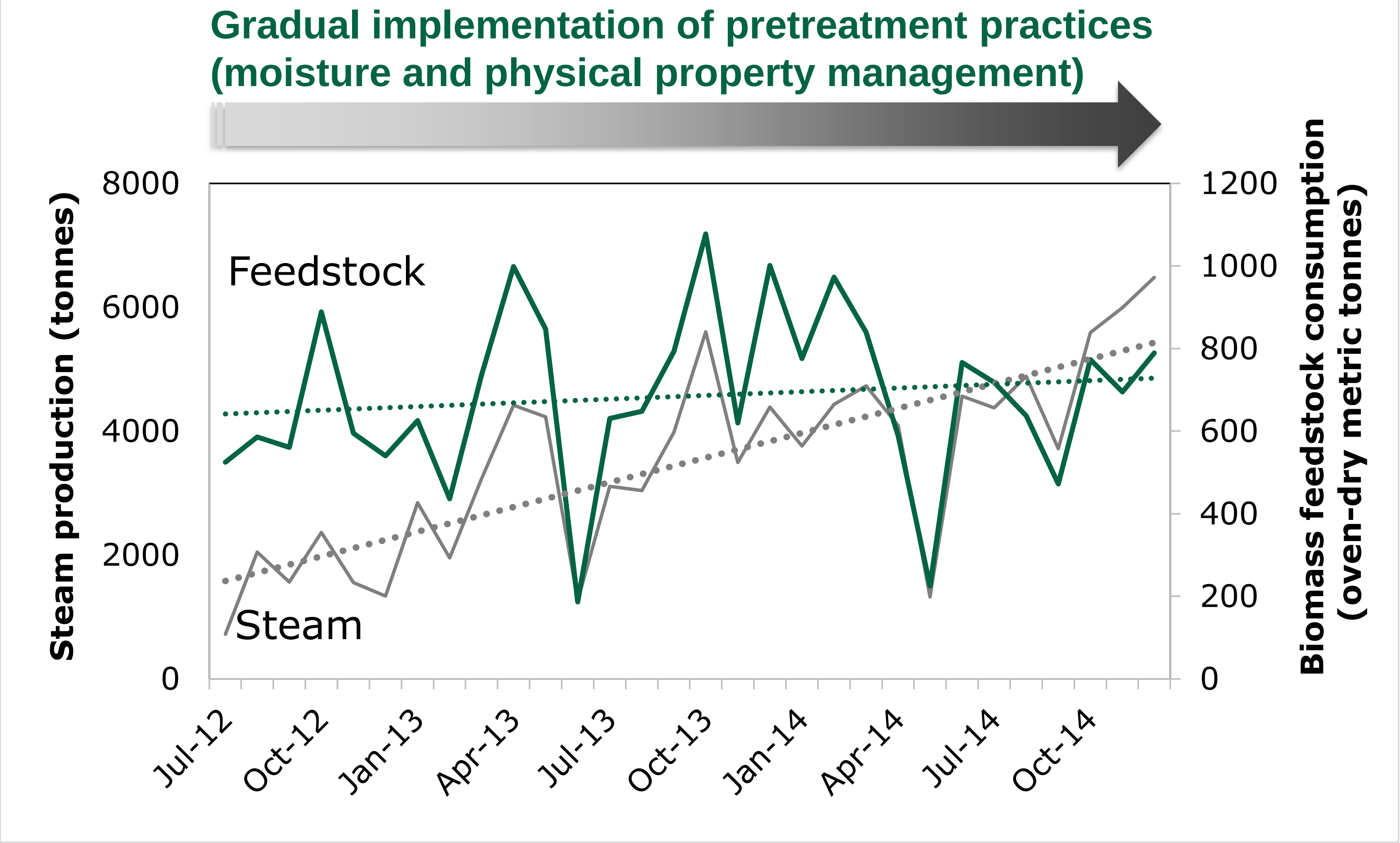
Key pretreatment opportunities

- **Moisture management**
- **Physical property management**
- **Ash content management**
- **Density management**



Adapted from: Metla

Steam production
Gasification system based on woody residues
University of British Columbia
(Sokhansanj, Ebadian et al.)



Profit increase: 16%

Biomass depot: cost reductions of 11-31% (Gautham et al. 2017)

CS3: Pretreatment of Municipal Solid Waste (MSW) for Gasification

- **Kevin Whitty (Univ of Utah, USA)**
- Inge Johansson (RISE, Sweden)
- Dieter Stapf (KIT, Germany)
- Giovanni Ciceri (RSE, Italy)

CS3: Pretreatment of Municipal Solid Waste (MSW) for Gasification

- State of the art gasifiers mainly run on clean biomass
- Biomass works well, but is increasingly more expensive
- Is there an opportunity to use MSW as a feedstock, either alone or co-firing with biomass?

(Alex Marshall 2004, Clarke Energy Ltd)

Pretreatment

Rüdersdorf CFB gasifier, Germany

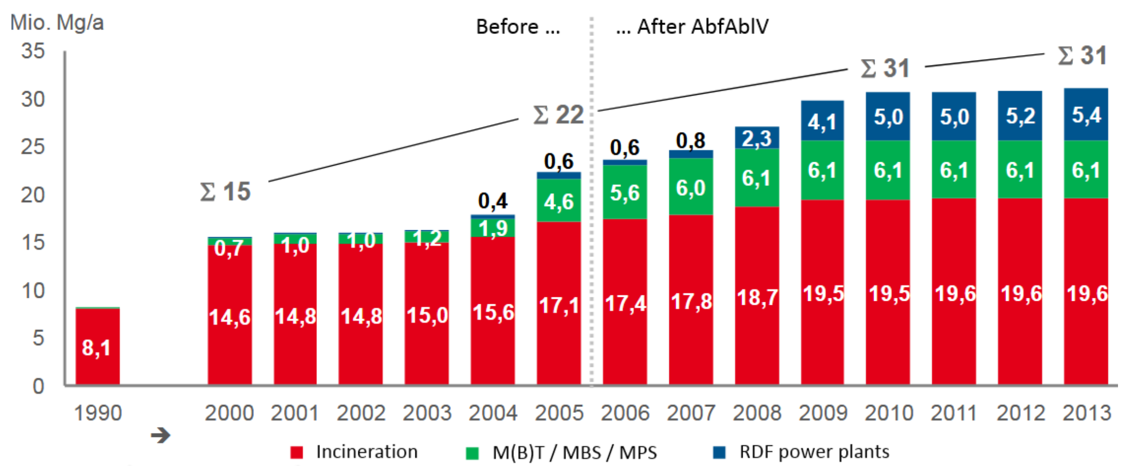
Raw Fuel Properties versus Gasifier Requirements

- To use as a gasifier fuel, pretreatment/upgrading of MSW is necessary
  - Refuse-derived fuel (RDF) – no particular specification
  - Solid recovered fuel (SRF) – specifications of EN 15359

Parameter		Municipal Solid Waste	CFB Feedstock Needs
Particle size			
Maximum diameter	[mm]	> 300	50
Proximate analysis			
Moisture content	[wt-%]	15 - 35	≤ 35
Volatile matter	[wt-%]	30 - 60	≤ 75
Ash content	[wt-%]	25 - 35	≤ 25
Ultimate analysis			
Sulfur	[wt-%]	0.3 – 0.5	< 1
Chlorine	[wt-%]	0.4 – 1.0	< 2
Mercury	[mg/kg]	0.5 - 11	< 1.5
LHV	[MJ/kg]	7 - 15	~ 10 - 20
Bulk density	[t/m³]	0.1	0.25

Scope of Study

- Two pretreatment technologies considered
  - Mechanical pretreatment
  - Mechanical-biological pretreatment
  - Consideration for fluidized bed gasifier in Rüdersdorf, Germany
- Two country cases: Germany, Italy
- Preliminary economic assessment



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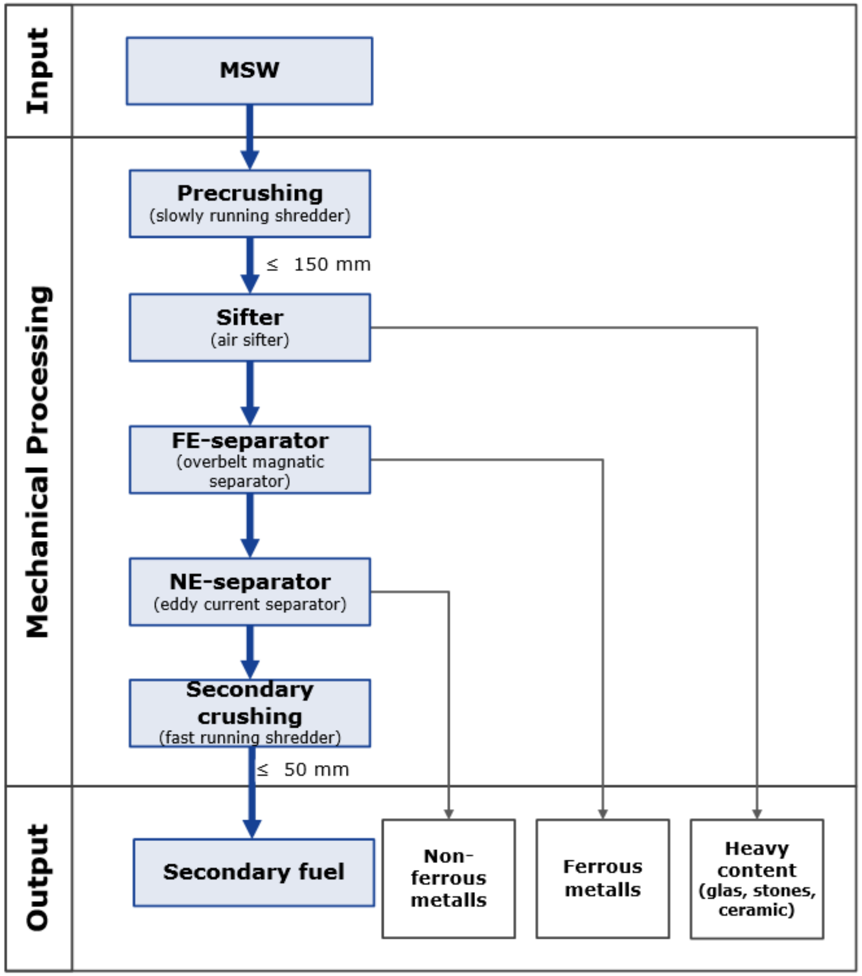
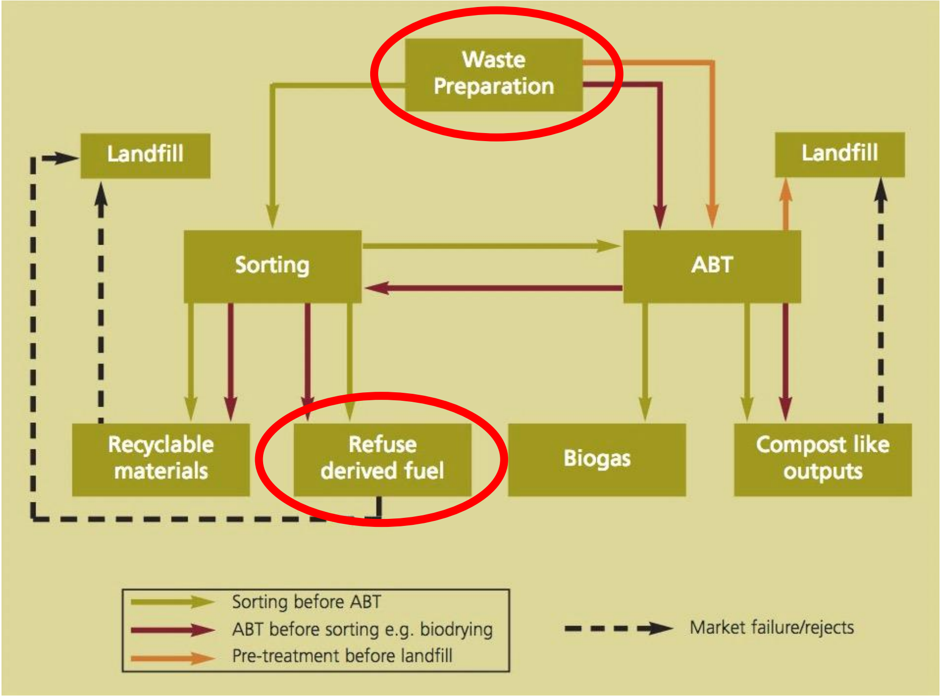
Mechanical Pretreatment

- Initial feedstock: MSW
- Multiple stages
  1. Initial Crushing
  2. Removal of glass, stones, ceramic
  3. Removal of ferrous metals
  4. Removal of non-ferrous metals
  5. Final crushing
- Final fuel
  - Lower ash
  - Higher heating value



Mechanical-Biological Pretreatment

- Combines mechanical sorting, biological treatment
- BT before or after MT
- Multiple product streams
  - Recyclable materials
  - Biogas
  - Compost
  - Refuse-derived fuel
- RDF available for gasifier feed



Cost study: MT for Rüdersdorf 100 MW fluidized bed 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

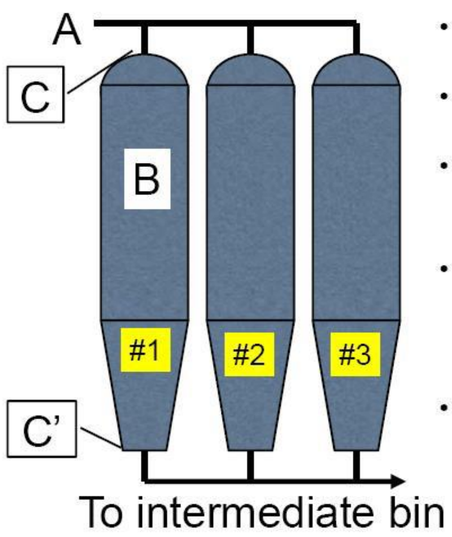
	Parameter	Value
Operation of plant	Operating hours	8,000 hr/a
	Electricity	0.1 €/kWh
Annual costs	Depreciation Period	10 years
	Depreciation rate	10 % of invest/a
	Capital costs	10 % of invest/a
	operating costs	5 % of invest/a
Revenues & Fees	Revenue: Ferrous Metals	25 €/t
	Revenue: Non-Ferrous Metals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

- Patrick Wolbers and **Marcel Cremers (DNVGL)**
- Travis Robinson, Sebnem Madrali, Guy Tourigny (NRCan)
- Rob Mager (OPG)
- Rune Brusletto (Arbaflame)

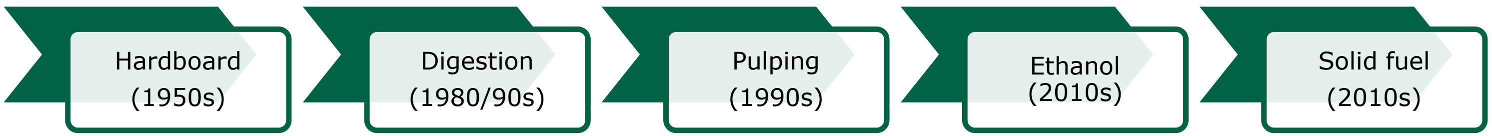
Steam explosion process



- 10 - 30 bar
- 190 – 230 °C
- Sudden pressure release

Source: Zilkha

Not a new process



1700 publications

430 relate to pretreatment, ethanol production, fermentation, and enzymatic hydrolysis

Increasing methane yields

Increasing ethanol yields

Product claims

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

Can be stored outdoors

Low on CAPEX?

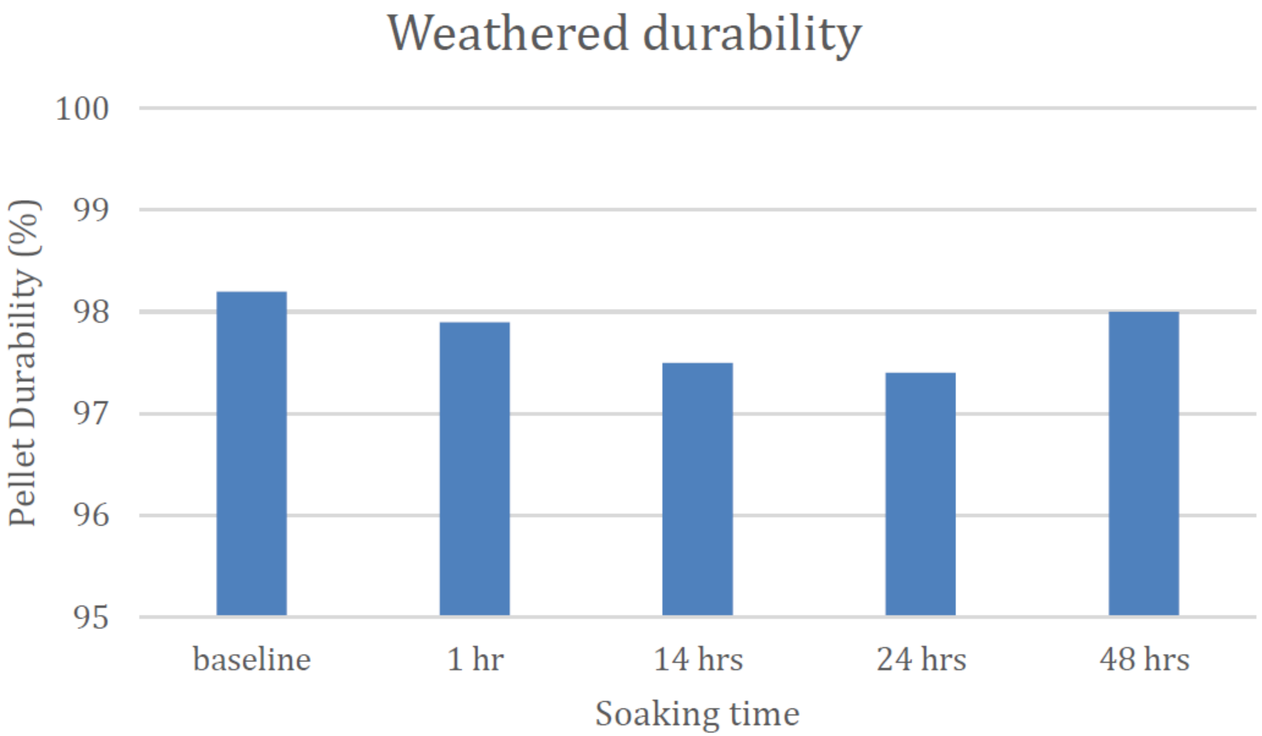
Project Comparison

- **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

Durability



ONTARIO POWER GENERATION

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Cost competitiveness

- Steam explosion vessels and condensate treatment facilities
- Energy density slightly higher than that of wood pellets
- Unlikely to compete with wood pellets on a cost/GJ basis

- Attractive option for peaking plants

CS5: Sugar cane trash and palm oil mill residue leaching

- Wolter Elbersen, **Koen Meesters (WUR, NL)**

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CS5: Leaching herbaceous biomass

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

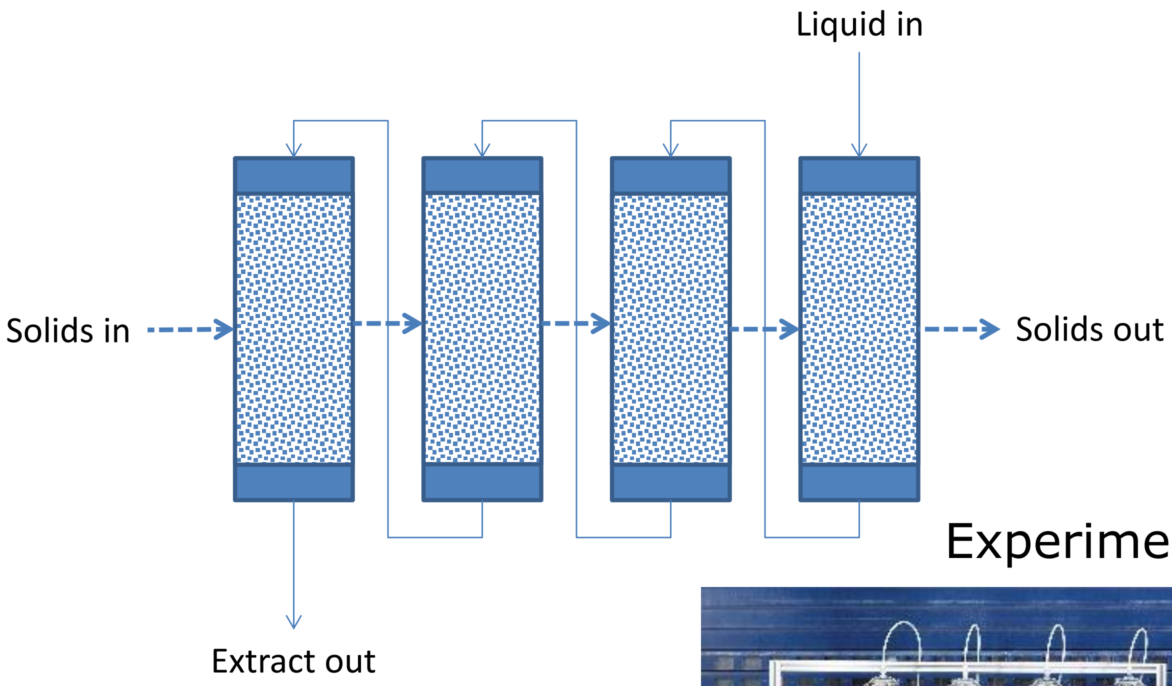
	Current potential	Used potential
	Million tons dry matter per year	
Wood from forests	325	350
Other forest biomass (forest industries)	185	140
Agricultural residues (field and agro-industries)	**342**	**15**
Waste	89	60
Cropped biomass	152	2

Panoutsou et al., 2016

Challenges for incineration of 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% of dry matter
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% of dry matter	0.03% to 1% of dry matter
Ash	Ash content of herbaceous biomass depends on soil and tissues type. Ash will lower efficiency and increase operating costs.	1 to 15% of ash	0.5 to 3.5% of ash

Counter current extraction



Experimental setup at WUR

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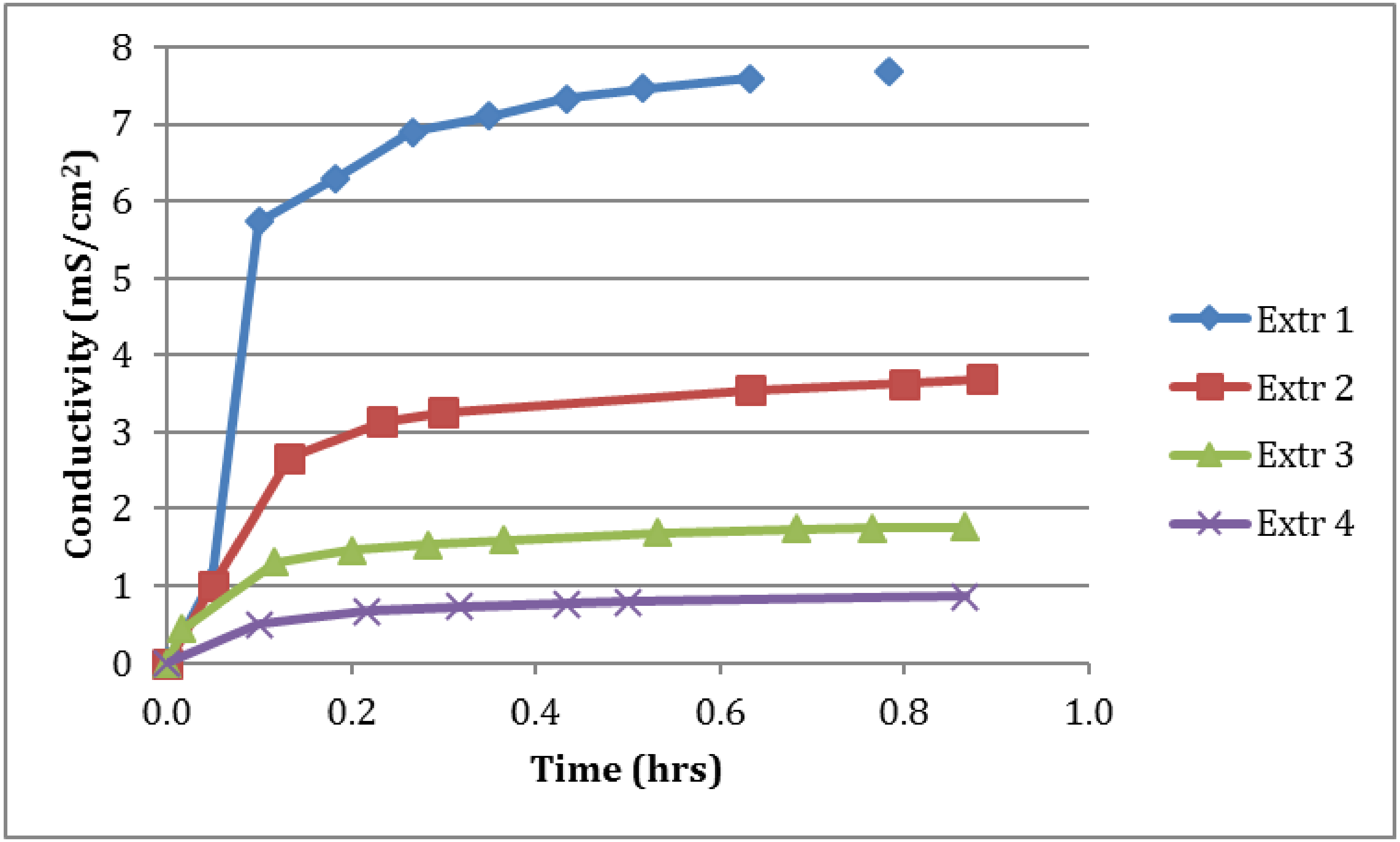
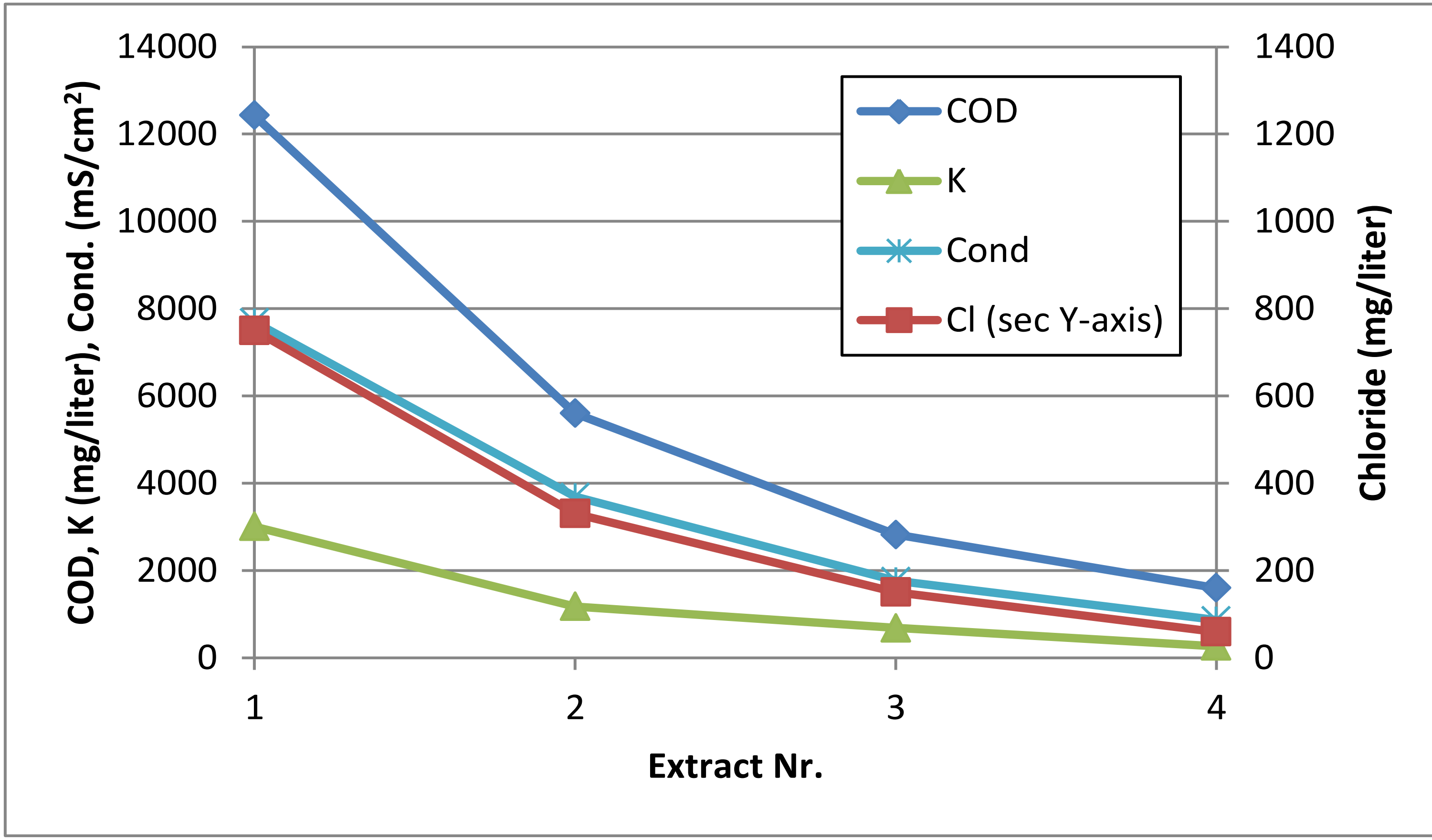
Repeated extraction of EFB



- Equilibrium is reached after 0.5 hours
- Conductivity is reduced by 50% each stage

Repeated extraction EFB

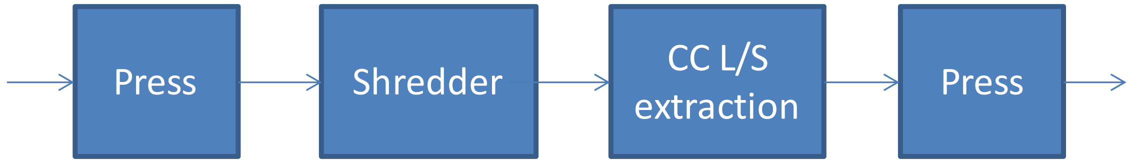


- 80-90% reduction of K, Cl and conductivity after 4 extractions

Results for EFB

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

Feasibility in an industrial setting



Process scheme for EFB washing

Assumptions

- EFB: 40 kton dry matter per year
- 10 Stages, heap leaching
- Use washing water for irrigation at zero costs

Cost estimate

- Investment: 940 k€, OPEX: 73 k€/year
- Lumpsum cost: 6.5 €/ton DM (= 8 US$/ton DM)

Conclusions on leaching

- Large amount of agro residues is available but unused
- This biomass needs to be upgraded
- Ash, K and Cl may be strongly reduced by washing with water
- Counter current extraction strongly reduces the amount of extraction liquid
- Costs of counter current extraction are reasonable in view of the total biomass supply chain

General conclusions (1)

- It is important to **diversify the resource base** for bioenergy to **lower grades of biomass**, reducing **logistic costs** and increasing the **fuel flexibility** of various conversion technologies.
  - On resource side, particularly **herbaceous biomass** residues available and underutilised (49 EJ potential)
  - On the demand side, particularly **coal based power stations** represent a large demand (100 EJ)
- Whole range of pretreatment technologies available; some common/simple and some new/advanced
- Biomass pre-treatment steps such as washing, drying, sieving, leaching or thermal pre-treatment may significantly **improve chemical characteristics** of lower grade biomass.

General conclusions (2)

- **Logistical challenges** and high transportation costs involved when using bulky biomass can be reduced through baling, pelletisation, thermal pretreatment.
- Several pretreatment technologies have the objective to convert a biomass into a fuel that has **technical specifications closer to that of the original fossil fuel**, hence reducing the need for new infrastructures and lowering the impact on plant performance.
- Being **locked into expensive end user equipment** (WTE plants, coal plants converted to wood pellets) may restrict potential for more advanced pretreatment on the short term
- Adequate policy support instruments should be available to accelerate further development of **innovative pretreatment** technologies

Jaap Koppejan

Michael Wild

Évelyne Thiffault

Kevin Whitty

Marcel Cremers

Koen Meesters

IEA Bioenergy

Thank you for your attention!

Questions?

Contact Details

Jaap Koppejan

IEA Bioenergy Task 32

task32.ieabioenergy.com

jaapkoppejan@probiomass.nl