Manipulating biomass ash content and ash quality in herbaceous biomass

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Outline

- Why do we need to improve the biomass quality for thermal conversion?
- Solving the problem up-stream or down-stream?
- Up-stream options for manipulating biomass quality
- Discussion: what is needed?

Biomass demand in 2020 (Mton DM) based on NREAPs

		Total	Byproducts and waste	EU crops	Imports
Ethanol	**Carbohydrates 1e generation**	**17.73**	1.77	10.46	**5.50**
	Sugars from lignocellulse 2e gen	**1.55**	0.85	0.39	**0.31**
	oils and fats	**29.49**	1.47	19.17	**8.85**
Biogas	**Biogas substrate: manure, crop, by-products**	**125.94**	*88.16*	*36.52*	***1.26***
Lignocellulose	**Solids for thermal conv: chips + pellets mainly**	**469.76**	*258.37*	*117.44*	***93.95***
	Black liquor	**11.26**	*11.26*	*0.00*	***0.00***
	Total biomass demand	**655.74**	**361.89**	**183.98**	**109.87**

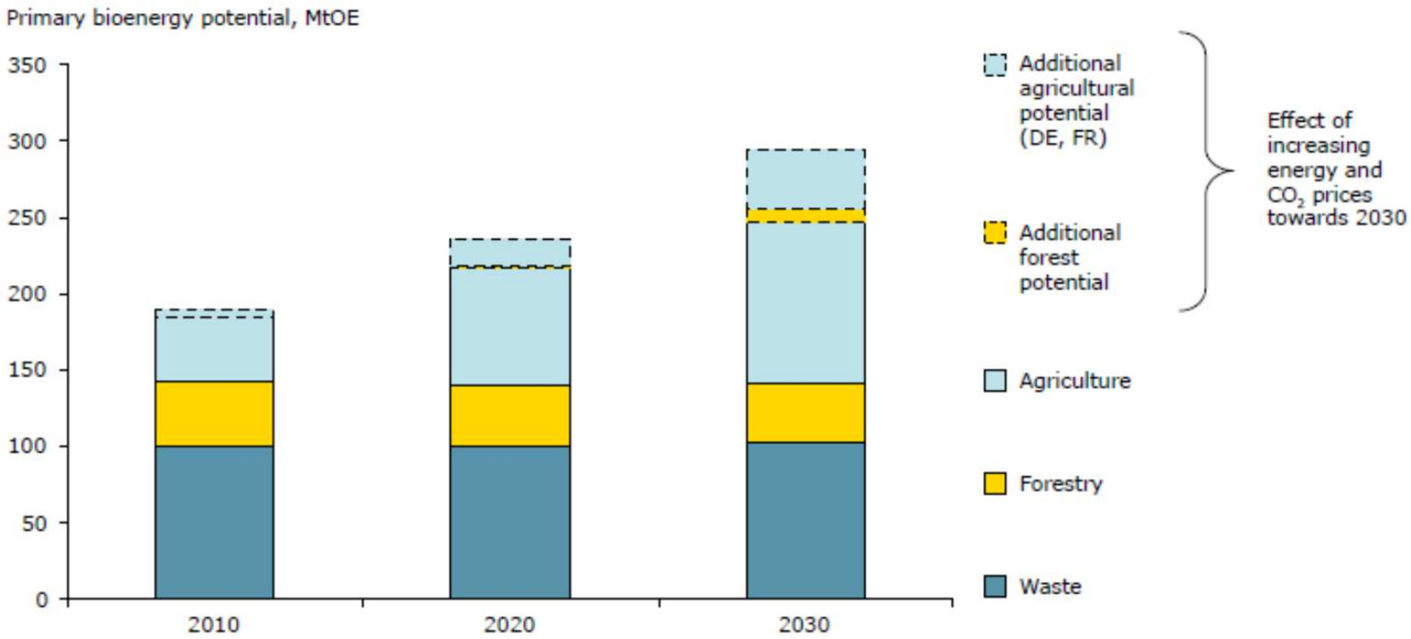
NB. Biomass demand for chemicals is not included!
Imports > 100 million tons mainly solid biomass, pellets from where?

Ref: Elbersen et al., 2011

Available biomass is often of low quality:

	2020	2030	
By-products and Waste	370	370	EEA, 2006
Non-food crops	184 to 230	250 - 390	EEA, 2006 ; Ganko and Kopczynski, 2010
Total:	554 - 600	620 - 760	

2020: 20. 2 million ha @ 10 ton/ha est. = 202 Mton DM
2030: 24,6 million ha @12 ton/ha est. = 295 Mton DM
Unconventional options not included



Ref: EEA, 2006

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Why do we need to improve the biomass quality for thermal conversion?

- We need to use the whole biomass potential to get close to the EU 2020 ambitions
- Much of the biomass potential is not wood in Europe
- A substantial part of the EU biomass potential is "herbaceous" biomass (Straw, Reed, Verge grass, Grass from semi-natural areas, biomass grasses) = 100 to 300 million tons?
- Thermal conversion is in volume the most important / efficient option

Why do we need to improve the biomass quality for thermal conversion?

- Ash amount and ash quality are the main problems

Low Quality?

Parameter	Effect
Ash ☹	Cost of transport . Cost of ash removal. Higher dust emissions. Clogging ash removal system
N ☹	Easily volatile and release in gas phase during combustion at temperatures between 800 – 1100 C - NOx emissions – corrosion? - Loss of nutrients
S ☹	Easily volatile and release in gas during combustion. Produces gaseosus compounds SO3and SO4 - SOx emissions - Corrosive effects
Cl ☹	Easily volatile and release in gas during combustion - HCl formation → corrosion - Cl influences the formation of polychlorinated dibenzodioxins and furans (PCDD/F) - Agglomeration (with K)
Ca ☺	- Increase the melting temperaturte of ash - Relevant plant nutrient, ash can be recycled as a fertiliser
Mg ☺	- Increase the melting temperature of ash
K ☹	Lowering ash melting point: - Slagging and deposit formation in furnaces and boilers Main aerosol forming during combustion - Lowering of the efficiency, higher operating cost KCL formation in the gaseous phase - Raise emission of fine PM and increases fouling in the boiler. - KCL causes corrosion of heating surfaces and it is a catalyst of NOx Can be recycled as fertiliser
Na ☹	Lowering ash melting point: - Slagging and deposit formation in furnaces and boilers Main aerosol forming during combustion - Raise emission of fine particulate matter PM - Increases fouling in the boiler

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Solutions?

<u>Don't burn it</u>: Make biogas or bioethanol or ABE or fibre products? This is not a solution for all the herbaceous biomass

<u>Solve the problem down-stream</u>

- Low temperature combustion → low pressure → less efficient electricity generation
- Only heat production
- Adapt combustion system?
- Other tricks: Ammonia sulphate into flue gases → chlorides converted into sulphates,
- Etc.

<u>Solve the problem up-stream</u>

manipulate the biomass........

Manipulating biomass quality

Phase	Method	Mechanism
Plant	Plant Type	C4 vs C3 crops, select crop, breed for better quality,
	Plant Fraction	Leaves have more ash and nutrients than stems
	Soil type	Clay soil leads to higher ash content than sandy soil
	Use of fertilizers	KCL leads to more CL content than K_2SO_4
Harvest / field	Delayed harvest	Overwintering leads to leaching out of salts
	Natural leaching	Rain leaches out salts after harvest
	Strip harvesting	Straw is left standing in the field to leach out salts
Pre-processing	Mechanical leaching	
	Biorefinery- dry fractionation	Fractioning leaves vs stems: leaves are returned to the soil
	Adding chemicals	Add Ca, Mg, Coals ash? → higher ash melting point
	Pyrolysis?	
	Mixing biomass	Mix wood + low quality biomass

Reduce / change ash content in the plant

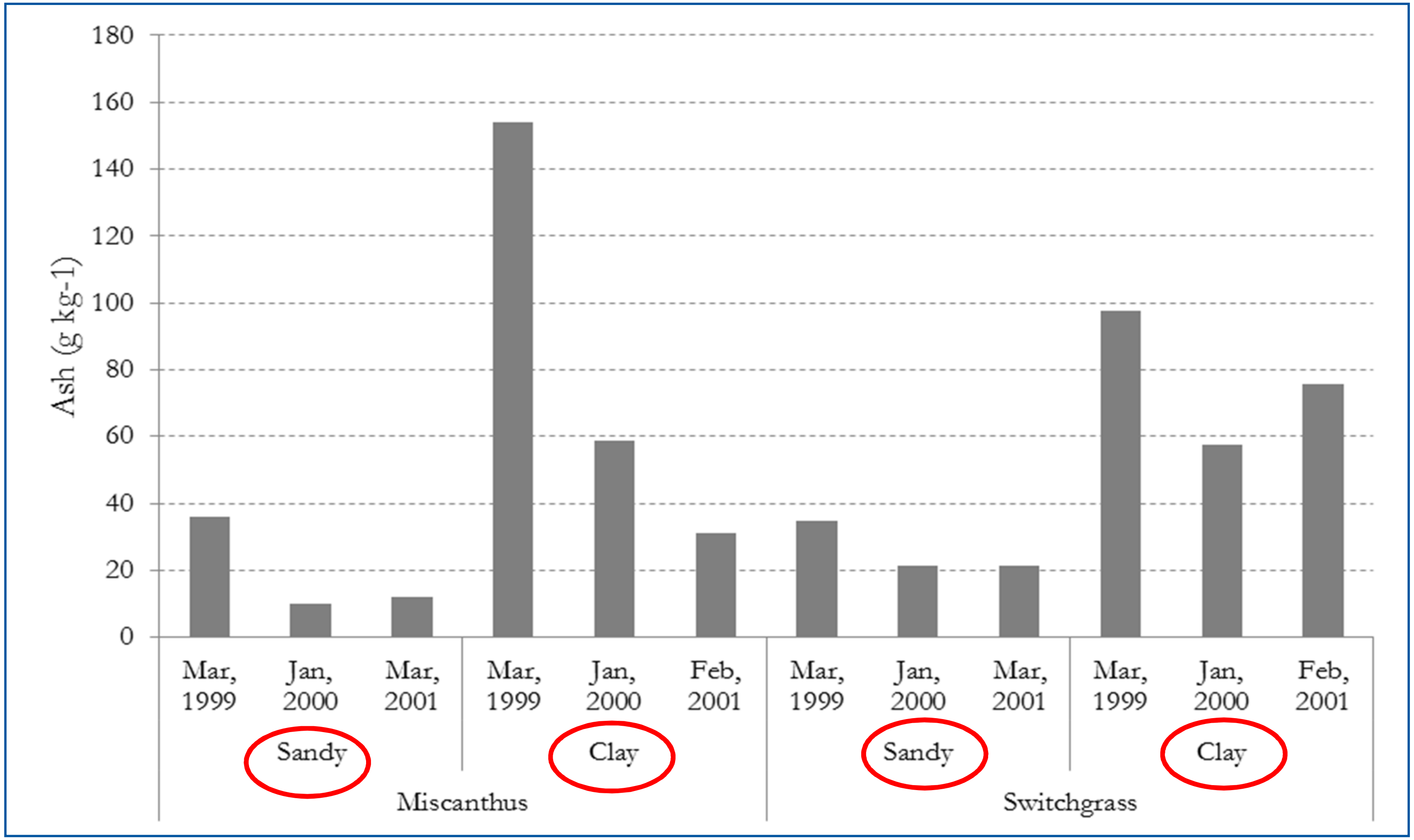
Crop choice and crop breeding

	Type	Plant	Ash content (%DM)
C4	Perennial	Prairie cordgrass *(spartina pectinata)*	1.6
	Perennial	Switchgrass *(Panicum virgatum)*	1.7
	Perennial	Big bluesterm *(Andropogin gerardii)*	1.8
	Perennial	Prairie sandrees *(Calanovilfa longifolis)*	1.9
	Perennial	Miscanthus *(Miscanthus sinensis)*	2.0
C3	Perennial	Reed Canary Grass *(Phalaris arundinacea)*	6.3
	Perennial	Phragmites *(Phragmites communis)*	7.5
	Annual	Wheat straw	11.1

Source: Samson and Mehdi, 1998

Characteristic	Cool season (C3)	Warm season (C4)
Initial molecule formed during photosynthesis	3 carbon	4 carbon
Growth period	Temperate and cold climates or yearlong	Mediterranean and warm climates/seasons
Light requirements	Lower	Higher
Temperature requirements	Lower (18-24 ^{o}C optimum)	Higher (32-35 ^{o}C optimum)
Water requirements	Higher	Lower
Minimum soil temperature to start growing	4 – 7 ^{o}C	16-18 ^{o}C
Frost sensitivity	Lower	Higher
Yield potential	Lower	Higher
Ash content	Higher	Lower
Examples	Wheatgrass, sorghum, reed canary grass, weeping grass and phragmites	Sugar cane, maize, *Miscanthus*, switchgrass Kangaroo grass, red grass and wire grass,

Clay soil 3x more ash than sandy soil



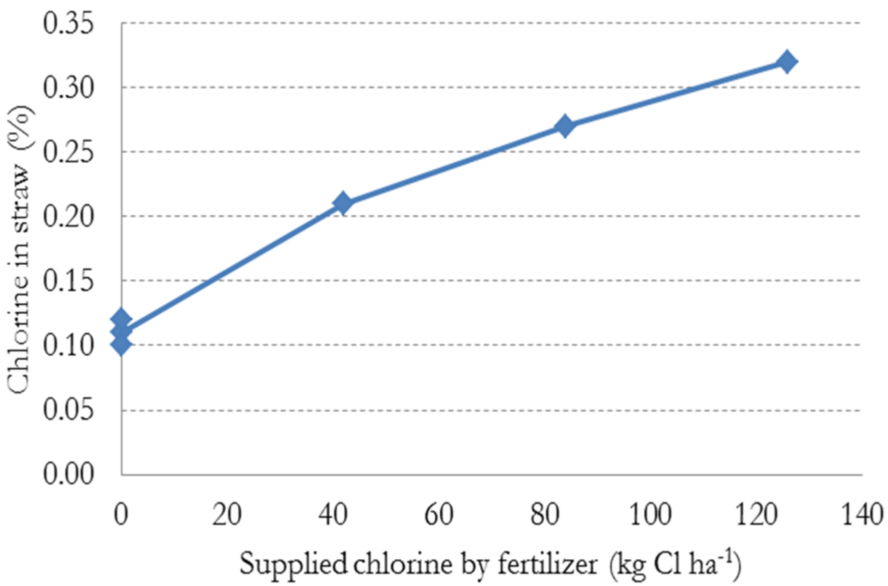
Bakker and Elbersen, 2004

Use of fertilizer:

K and Cl concentration in reed canary grass fertilized with different K salts

	KCl		K_2SO_4		Ash	
	August	Spring	August	Spring	August	Spring
K (% DM)	1.13	0.26	1.20	0.25	1.12	0.25
Cl (% DM)	0.71	0.09	0.38	0.08	0.36	0.08

Source: 1Landström et al. (1996)



Chlorine in straw as a function of Cl supply to the field

Source: Sander, 1997

Harvest / field

Plant Fraction:

Relation Leaf/stem

- N = 2.5
- Ca = 2.9
- Mg = 2.4
- P = 1.8

Cl and K depend on harvest time

- L/S=2.1 (August)
- L/S= 0.9 (spring)

Plant Fraction:

Element	Plant Fraction	Miscanthus (Lewandowsky and Kicherer, 1997) [a]			Reed Canary grass (Landström et al., 1996) [b]						Switchgrass (Elbersen et al., 2001) [c]		
					August			spring					
		Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
N	Stem	1.61	0.15	10	0.62	0.05	21	0.70	0.04	26	2.65	0.27	31
	Leaf	5.45	0.44	10	2.32	0.07	21	1.86	0.07		6.48	0.49	31
	Ratio L/S	**3.4**			**3.7**			**2.7**			**2.5**		
K	Stem	6.25	0.49	10	0.90	0.07	21	0.24	0.03	26	3.49	0.32	31
	Leaf	3.50	0.52	10	1.59	0.07	21	0.35	0.05	26	2.14	0.21	31
	Ratio L/S	**0.6**			**1.8**			**1.5**			**0.6**		
Ca	Stem	0.73	0.05	10	0.10	0.01	21	0.12	0.01	22	2.41	0.23	31
	Leaf	2.96	0.18	10	0.69	0.03	21	0.35	0.02	22	11.44	0.56	31
	Ratio L/S	**4.1**			**6.9**			**2.9**			**4.8**		
Cl	Stem	0.88	0.10	10	0.52	0.03	21	0.11	0.02	22			
	Leaf	0.56	0.08	10	1.07	0.07	21	0.10	0.02	22			
	Ratio L/S	**0.6**			**2.1**			**0.9**					
Mg	Stem				0.06	0.01	21	0.04	0.00	22	0.68	0.05	31
	Leaf				0.26	0.02	21	0.10	0.01	22	1.65	0.17	31
	Ratio L/S				**4.3**			**2.5**			**2.4**		
P	Stem				0.11	0.01	21	0.08	0.01	26	0.35	0.03	31
	Leaf				0.25	0.01	21	0.20	0.01	26	0.63	0.04	31
	Ratio L/S				**2.3**			**2.5**			**1.8**		
Ash	Stem				4.21	0.23	21	3.42	0.20	26			
	Leaf				8.51	0.31	21	6.60	0.34	26			
	Ratio L/S				**2.0**			**1.9**					

Refine out the leaves, use the stems

A pre-treatment system separates out the high ash and nutrients containing parts of the biomass (mainly leaves) comprising <1/3 of the biomass but containing > 2/3 of the ash and nutrients.

The remaining (>2/3) biomass used as biofuel.

Harvesting

Natural Leaching

Strip Harvest

Delayed harvest =
to winter/spring

	Switchgrass	Reed Canary grass	Miscanthus	Verge grass
K	-84%	-75%	-83%	-84%
Cl		-84%	-94%	-89%

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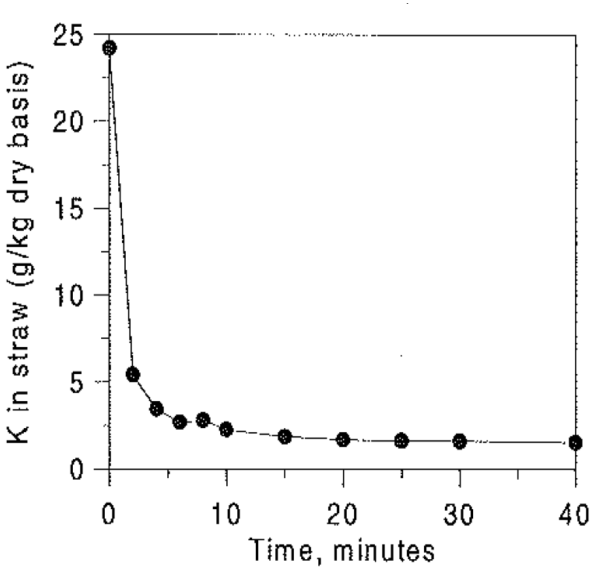
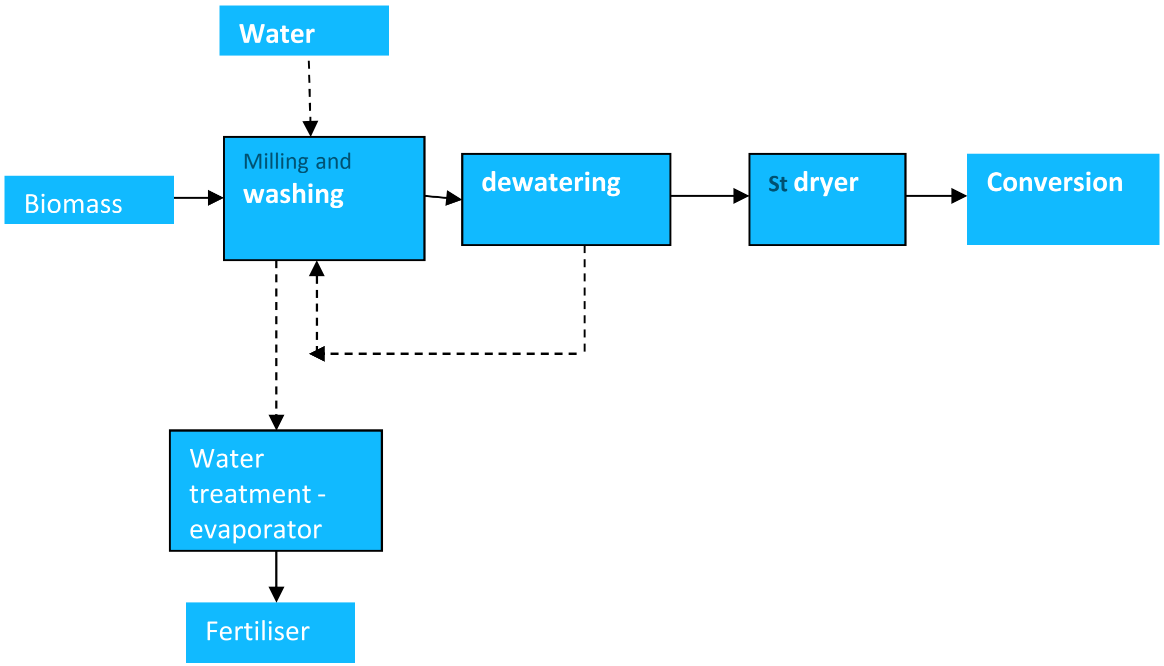
Pre-processing

Pre-Processing: leaching

Industrial/field leaching





Leaching increases ash quality of grass!

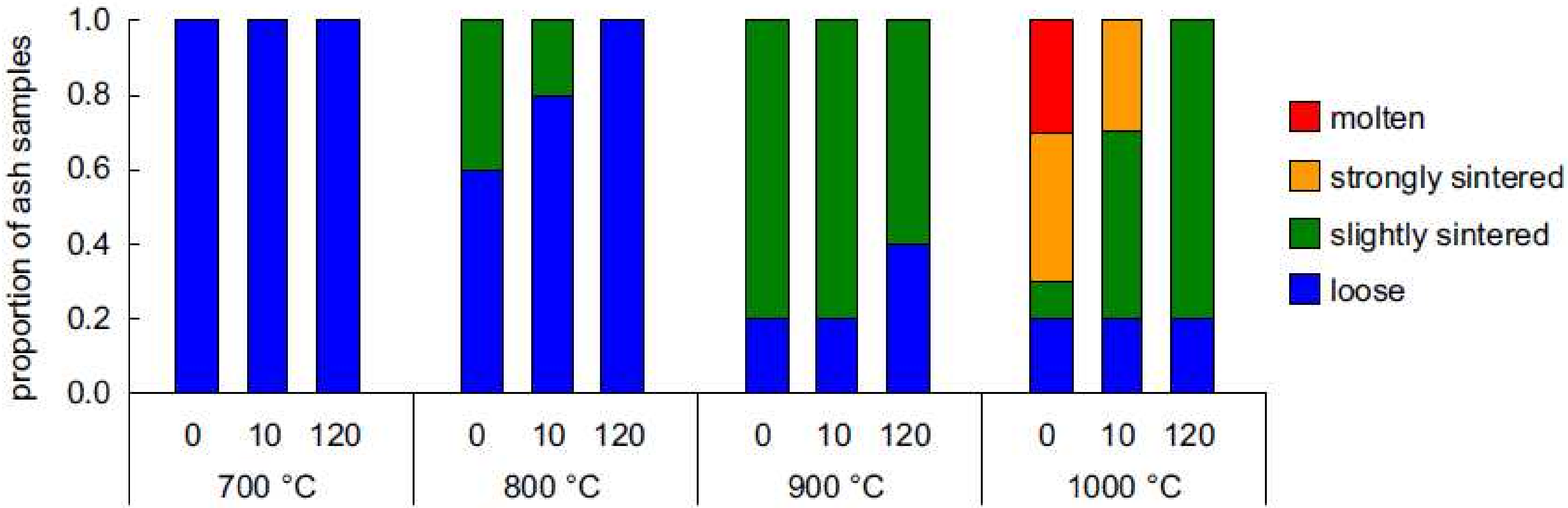


Fig. 3 – Proportion of ash samples that fall into each of four ash fusion classes after heating low-temperature ash to four different temperatures. Biomass leaching treatments – 0: unleached control, 10: leaching for 10 min, 100: leaching for 120 min.

Tonn et al. 2012.

Table 1: Results from chemical analysis and combustion tests before and after extrusion and rinsing for three verge grass samples collected in the fall and winter from three different locations.

		De Wieden		Weerribben		Baarle-Nassau	
Component	unit[1]	before	after	before	after	before	after
HHV[2]	kJ/kg daf[4]	19571	20308	20246	20317	20375	20363
LHV[3]	kJ/kg daf	18143	18918	18919	19081	18999	19078
Moisture	wt% fresh	68.8	60.7	66	53.6	71	63.4
Ash	wt%	6.8	5.8	9.4	14.8	9.6	9.3
Aggl. Temp	°C	870	no	>825	no	825	no
Fuel flow	g/hr	985	1100	990	670	1055	820
Ash flow	g/hr	53	58	20	34	51	39
Volatile matter	wt%	73.3	76.1	71.3	68.9	70.6	72.9
N	wt%	1.47	1.51	1.32	1.06	2.51	1.67
S	wt%	0.190	0.131	0.150	0.088	0.260	0.131
Cl	wt%	0.314	0.077	0.278	0.015	0.678	0,021
Ca	mg/kg	6611	5290	4055	2890	5901	4515
K	mg/kg	5157	1405	3261	465	20707	1255
Na	mg/kg	1669	425	902	195	342	125
P	mg/kg	1386	730	692	240	3072	480
Si	mg/kg	11315	14130	6736	7230	2556	3765

Elbersen et al 2004

What is needed?

- Examine cost vs benefits of up-stream options for upgrading herbaceous biomass for thermal conversion
- Compare up-stream to down-stream measures
- Development of standards for “good” herbaceous biomass (pellets)
  - Herbaceous biomass will still not reach current “wood standards” (ash, N)
  - But can be much better than generally thought (ash melting, Cl, etc)
- What is the value of “good” herbaceous biomass compared to wood pellets? (€130,- per ton)
  - -10% to -30%?

End

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References:

- Diana Amparo Cardona Zea. 2011. Methods to improve biomass quality for thermal conversion. Internship report Wageningen UR.
- DBI “Pellets for Power Ukraine” project

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