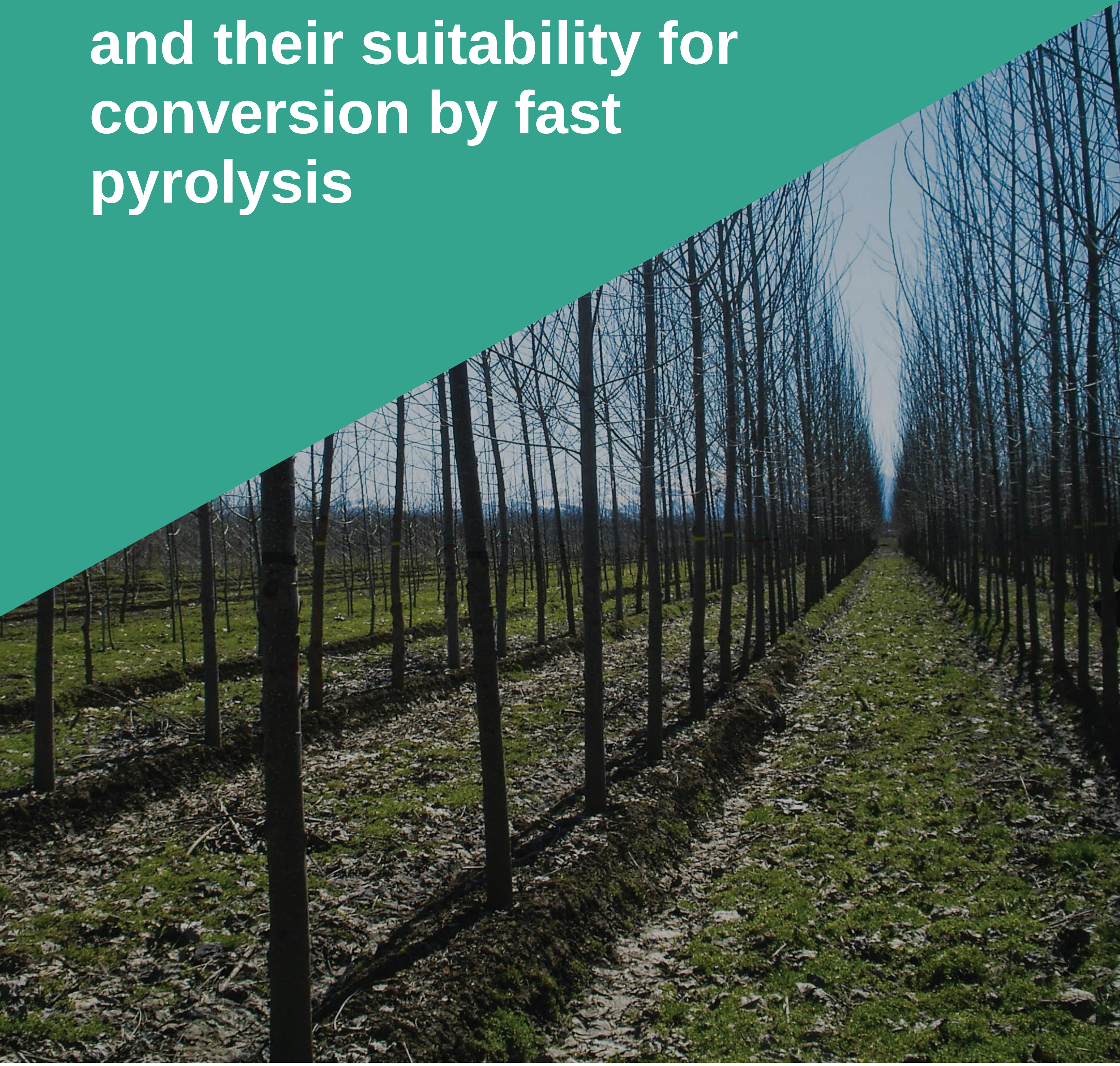
Chemical composition of ten biomass feedstocks and their suitability for conversion by fast pyrolysis



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BIO4 PRODUCTS
Creating sustainable resources for process industry

Authors

A. Kozlo (CAPAX), B. Tambuyser (CAPAX), H. Heeres (BTG), B. Van de Beld (BTG)

Editing

A. Kozlo (CAPAX), J. Ling (Greenovate! Europe)

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Executive summary

Within the Bio4Products project, CAPAX is responsible for the collection and preparation of various primary and secondary feedstocks for the production of large quantities of pyrolysis oil to enable fractionation on pilot scale.

As part of this activity a range of biomass feedstocks were investigated to determine their chemical composition. Besides the dry matter and ash content, the presence of minerals like potassium, calcium, chlorine and organic compounds (nitrogen) were determined. Furthermore, the ash melting behaviour was evaluated to get information about the slagging tendency during thermo-chemical conversion. The effect of the biomass resource in relation to its performance in the complete processing chain was also evaluated.

This report contains additional analytical data concerning the chemical fuel properties of the selected biomass feedstocks together with summarised data from earlier reports. With this combined data the effect of the biomass feedstock in relation to its performance in fast pyrolysis and following FPBO fractionation is evaluated. Subsequently a (final) feedstock selection was performed applying 10 performance parameters to indicate the two most suitable feedstocks for pilot (fast pyrolysis) processing. Ultimately, sunflower (seed husks) and poplar slabs were found to be the best scoring feedstocks.

Keywords: Feedstock, selection, pre-treatment, chemical fuel properties, fast pyrolysis, fractionation

Contents

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List of Abbreviations

Abbreviation	Description
FPBO	Fast Pyrolysis Bio-Oil
RD	Research Data
wt%	Weight percent
PL	Pyrolytic Lignin
PS	Pyrolytic Sugar
LHV	Lower Heating Value
DB	Data Base
MC	Moisture Content
AC	Ash Content
ICP	Inductively Coupled Plasma Analysis
MPP	Mini Pyrolysis Plant
PP	Pilot Plant (pyrolysis)
RED	Renewable Energy Directive
Extr.	Extractives (from FPBO)
PL	Pyrolytic Lignin
PS	Pyrolytic Sugar

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1 Introduction

The overall objective of Bio4Products is to demonstrate the thermal fractionation of four different biomass resources, and to demonstrate the use of the fractions in four different applications supported by the techno-economic and environmental assessment of the whole value chain as illustrated in Figure 1.

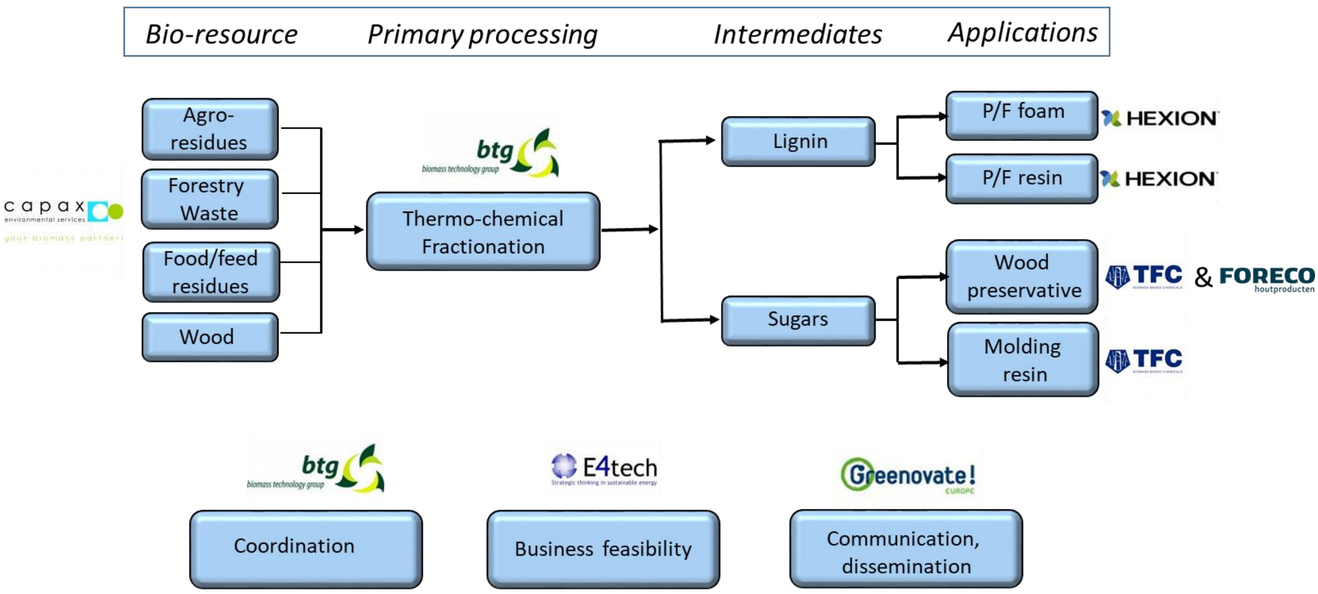

Figure 1: Schematic representation of the 4x4 Bio4Products concept

Bio4Products will demonstrate the production of phenolic foams, phenolic resins, wood preservation products, and moulding resins, using renewable alternatives to substitute fossil resources. Concrete resources which will be replaced with renewable alternatives include phenol, creosote and foundry resins.

The thermo-chemical fractionation used is a combination of biomass (fast) pyrolysis followed by pyrolysis oil fractionation. Pyrolysis is the thermal decomposition of a material under inert conditions. Biomass pyrolysis results in the formation of solid, liquid and gaseous products. When it is desired to maximise the liquid product, fast pyrolysis is applied. Typically, temperatures around 500°C are used, and in order to maximise the liquid production rapid condensation of the vapour stream is required. For clean woody biomass (e.g. pine wood) up to 70 wt% of a liquid product can be obtained. About 15 wt% of the biomass is converted into charcoal and the remaining 15 wt% to non-condensable gases. The obtained liquid is polar, acidic, contains water, and is a mixture of cracked components derived from the cellulose, hemicelluloses, and lignin components of the f

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eedstock. The liquid can be easily separated in a pyrolytic sugar, pyrolytic lignin and a pyrolytic extractives phase. Subsequently, these intermediate processing streams can be used as renewable alternatives for a wide variety of end products. The pyrolysis oil fractionation will be scaled up in the project from a 12 kg/h bench-scale unit to a 3 t/d pilot plant.

In Bio4Products the four end products were selected because of their high added-value and proven technical suitability (at least TRL 5). The potential to develop additional new innovative products from the renewable intermediates is very high. With the current development trajectory, these renewable intermediates will be produced in large quantities enabling the further development of innovative products.

The production process is flexible with respect to feedstock properties. In theory, all kinds of lignocellulosic bio-resources can be used. To demonstrate this flexibility, four bio-resources from different backgrounds are used as feedstock in Bio4Products; residues from agriculture (e.g. straw), wood debarking, forest residues and food/feed industry (e.g. sunflower husks).

In this way Bio4Products approach essentially demonstrates 4x4=16 value chains simultaneously. By depolymerisation of the biomass components, followed by separation of the functional groups, the chemical functionalities of the biomass are retained. The processing steps are of a thermo-chemical and physical nature, with high conversion rates and yields. By-products are used within the process to enable the production of value-added streams with minimal external resources, while avoiding the generation of waste streams.

1.1 Goal and purpose

This report provides an overview of all collected data concerning the chemical fuel properties of the selected biomass feedstocks and evaluates the effect of the biomass resource in relation to its performance in the complete processing chain. With this data evaluations were made concerning the performance of the feedstock in processing (fast pyrolysis and fractionation), including for instance the ease of processing (in pyrolysis), obtained yields of FPBO, the quality of the FPBO's, the suitability in fractionation and yield and quality of individual fractions. Using the outcome of this (first) evaluation combined with other performance parameters such as; availability, being none-food, feedstocks cost, RED criteria, etc. two feedstocks were selected for pilot plant testing.

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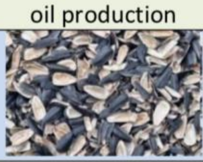
2 Biomass feedstock selection

In order to maximise the replicability and the potential impact of the Bio4Products concept, it essential that the processes are feedstock flexible. Therefore, Bio4Product's aim was to make a first selection of feedstocks originating from four lignocellulosic biomass feedstock categories being: a) agricultural residues; b) food/feed processing residues; c) forestry residues from wood debarking activities (e.g. sawmill residues); and d) forestry residues from forestry harvesting activities (see Table 1).This concept was put in place in order to be able to unravel the key chemical functionalities of the biomass, and in this way produce three different intermediate process streams which are used as the raw material for four green products. It is important that the composition of the intermediate process streams should hardly be affected by the original feedstock, and only the ratio in which the fractions are produced varies. In this first selection process the aim was to select and prepare at least five of the biomasses mentioned in medium quantities (~c.a. 200 kg) to be processed in the MPP (mini pyrolysis plant) at BTG Biomass Technology Group.

Table 1: Four lignocellulosic biomass categories used within the primary selection of feedstocks

	Lignocellulosic biomass residues (non-food)			
	Agricultural	*Food/Feed processing*	*Forestry*	
	Straw	Sunflower husks	Bark	Forest residues
Description	Residue from grain production	Residue from sunflower oil production	Residue from debarking of wood	Harvest residues left in forest
				
Current use / disposal route	none / energy / animal bedding (depends on region)	None/Energy	None / Energy	None
Availability in the EU [Kt/y]	121.000	More than 7.000	More than 12.000	59.000

Ultimately, within this primary selection of biomass feedstocks, a total of 10 feedstocks were selected for initial screening (Table 2). Feedstock properties are always somewhat variable due to a number of different factors such as seasonal climate variations, soil conditions, etc. and even how the feedstock is being handled. As a result, at this point, only the two most important criteria were used in the selection process, being: i) availability of the feedstock and ii) suitability of the feedstock for the BTG fast pyrolysis process. Moreover, the evaluation criteria have been set out to be within the EU level. Apart from these parameters playing a major role, the focus was directed to lignocellulosic residual biomass products that have i) sufficient technical suitability, ii) are logistically

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and iii) geographically conveniently positioned from a strategical point of view and iv) are sustainably sourced, where maximised food/feed chain avoidance can be reached.

Table 2: Primary selection of (10) feedstocks

Feedstock category	Chosen Feedstock	Origin
Agricultural	Hemp shives	The residual shives from the production of hemp ropes and textiles;
	Flax shives	Side stream residue from fibre treatment for linen production;
	Flax pellets	Side stream residue from fibre treatment for linen production;
	Wheat straw	Straw residues coming from cereal production;
Food/feed processing	Olive kernels	Ground olive stones. Comes from oil pressing residue activities;
	Sunflower husk	Scrap from sunflower seed processing (flour and oil pressing);
Forestry	Poplar wood slabs	Residue from sawmill activities;
	Softwood	Sieved out dust from animal bedding wood shavings originating from sawmill activities. The base material is stem wood;
	Hardwood (poplar)	Forestry residue, branches/slash of the tree;
	Phytoremediated poplar wood	Poplar wood coming from phytoremediation of heavy metal polluted land – SRC (short rotation coppice) chips from whole tree;

In summary, for the first selection process the partners have chosen to work with: i) flax (shives and pellets), ii) wheat straw and iii) hemp shives within the agricultural lignocellulosic biomass residue category. In the food/feed processing biomass residue category, i) sunflower husks and ii) olive kernels were picked. Within the forestry biomass category, i) residues of softwood shavings, ii) hardwood (poplar) forestry chips, iii) poplar wood slabs, and iv) phytoremediated poplar wood were selected.

2.1 Biomass pre-treatment

Pre-treatment of lignocellulosic biomass plays an important role in the fast pyrolysis process. It can for instance have a large influence on the yield and quality of the end product. By pre-treating biomass, the structure is modified to an extent where, for instance, a suitable feedstock contains smaller quantities of undesirable components that could interfere in fast pyrolysis processing (e.g. sand, particle size, water). Depending on the type and nature of biomass, different pre-treatment mechanisms can be used. There are always limitations to each feedstock and how it can be pre-treated.

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2.1.1 Biomass specifications for fast pyrolysis

In fast pyrolysis, it is important that the biomass particle size is not too small or too large. Small particles can result in dust in the FPBO product, whereas large particles will mean a longer residence time of the particle in the reactor, resulting in the production of more char and/or gaseous products. Preferably the biomass particle size should be in the range of 1-10 mm. Also, the moisture content of the biomass is very important and shouldn't be higher than 6 wt%, to ensure a homogeneous 1-phase FPBO.

In order to achieve the BTG feedstock requirements, the majority of biomass feedstocks selected need to be pre-treated. The pre-treatment steps can include chipping, grinding, milling, drying, sieving and potentially pelletising for logistical and handling reasons. All these techniques are based on proven technologies. Some feedstocks could need a more specific and potentially more intense pre-treatment step(s) in relation to their nature and origin, while other feedstocks could already be refined close to some of the requirements because they are the result of an industrial process e.g. flax shives (size is ± 20 mm, 10-12 wt% MC). Other feedstocks are far from matching the requirements, e.g. forestry residues directly coming from the forest (branches). Chipping, grinding, sieving and drying is therefore necessary. Standard forestry chips are up to 120 mm and have an average moisture content of 45 wt%.

The BTG process requires a moisture content below 6 wt%. This can only be guaranteed when pre-drying is done on site. All the selected feedstocks are hygroscopic by nature. For specific feedstocks, moisture content can be guaranteed around 8-10 wt%. It needs to be noted that when feedstocks have to be refined to these specifications off site, the additional costs will be high.

Because of this it is advisable that a FPBO plant has its own pre-treatment capacity for preparing the targeted biomass feedstocks.

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Table 3: A guideline of moisture content range shown for each selected feedstock.

Category	Feedstock	Typical MC range, %[1]
Agricultural	Hemp shives	10-20
	Flax shives	9.6-14.0
	Flax pellets	5-12
	Wheat straw	15-25
Food/feed processing	Olive kernels	12-18
	Sunflower husk	12-20
Forestry	Poplar wood slabs	40-50
	Softwood dust	20-40
	Hardwood (poplar)	40-50
	Phytoremediated poplar wood	40-50

[1] Values on wet basis, %

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3 Composition of biomass feedstocks

3.1.1 Physical characteristics and chemical composition

In fast pyrolysis, different biomass feed specifications are required when compared to established biomass conversion technologies. For instance, the physical characteristics and composition of lignocellulosic biomass (ash, water, etc.) are more important parameters than a small difference in the lignin/cellulose/hemi-cellulose ratio. On the other hand, in biomass conversion processes such as for pulp and paper and bio-ethanol production, a high hemicellulose and cellulose content is preferred, while a high water and/or high mineral content is of less importance.

A study of the technical feedstock characteristics was performed for all 10 feedstocks. At least three references within the feedstock analyses were compared by using the Phyllis database (https://phyllis.nl/), CAPAX's own confidential database and their network sources. These values are presented in average as RD (Research Data). This data was combined and compared with the feedstock analysis performed in collaboration with BTG on the delivered biomass feedstock samples. The data obtained for the 10 feedstocks is given in Table 3.

From Table 3 it can be seen that, amongst others, elemental analysis (CHN) was performed on the samples. This analysis is very important to calculate the lower heating value (LHV) of the biomass and to determine the amount of nitrogen in the samples. Also the moisture content (MC) of the feedstocks was measured before and after drying. The ash content of the biomasses together with the ash melting point was also determined. A high ash content (AC) can have a large influence on the yield of FPBO produced, due to the fact that some minerals might have a negative catalytic effect during pyrolysis processing. In cases where the ash melting point is too low, slagging might occur in e.g. the (char) combustor, which is of course highly undesirable as it blocks the system. The combined data (CHN, MC, AC) is also required for preparing the mass- and energy-balances of the process.

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Table 4: Chemical analysis of delivered feedstocks[(1-8)]

	Softwood dust		Olive stones		Hemp shives[2]		Flax shives		Flax pellets		Sunflower seed husk		Poplar slabs		Poplar forestry		Wheat straw		Phytorem. wood	
Type[1]	A		C		B		B		B		C		A		A		B		A	
	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB	BTG	DB
C (wt.%)[3] H (wt.%)[3] N (wt.%)[3]	49.2 6.2 0.3	51.1 5.5 0.1	52.5 6.5 0.6	48.8 6.6 1.6	47.5 6.0 0.5	42.4 5.6 0.4	47.4 6.0 0.4	50.0 6.1 0.6	48.3 6.0 0.4	50.0 6.0 0.6	47.3 6.0 0.7	47.4 6.7 1.4	47.6 5.7 -[4]	47.5 6.2 0.4	49.1 5.9 -[4]	49.0 6.1 0.4	45.8 5.8 0.4	46.0 6.0 0.5	47.3 5.9 0.5	48.0 6.2 0.2
Moisture[5] AR (wt.%) AD (wt.%)	 15.3 5.6	 10 -	 13.2 5.6	 12 -	 11.2 4.1	 7.9 -	 10.5 3.1	 10.5 -	 11.1 4.2	 9.9 -	 17.3 2.7	 12.5 -	 42.9[6] 4.5	 60 -	 30.0[6] 3.1	 46 -	 20.0[6] 5.5	 10 -	 >40 3.7	 53 -
LHV (MJ/kg)[7]	18.2	18.4	20.0	18.9	17.5	14.8	17.4	18.7	17.9	18.6	17.4	18.5	17.2	17.9	18.1	18.3	16.8	17.6	17.1	18,0
Ash cont. (wt.%)	0.4	0.7	0.7	3.3	2.9	3.4	2.3	1.8	2.7	3.0	2.7	4.0	2.5	3.8	2.5	2.0	5.4	10	1.7	2.4
Ash MP[8] IT(°C) ST(°C) HT(°C) FT(°C)	NM[9]	 1550	NM[9]		NM[9]	 1377	 1190 1198 1212 1249		 1100 1190 1210 1244		NM[9]		 1196 1208 1225 1234		 1148 1216 1235 1255		 1018 1058 1074 1090	 915	NM[9]	

[1]:A: Forestry, B: Agricultural, C: Food/Feed processing, BTG: Analysed by BTG, DB: from data base CAPAX. [2]: Will be discontinued due to low availability. [3]: On dry base. [4]: N < 0.2 wt.%. [5]: Moisture content; AR: water content analysis on biomass as received, AD: water content of biomass after drying. [6]: strong variation in moisture content observed. [7]: LHV calculated on dry base. [8]: Ash MP: ash melting point according to D1857; IT: initial deformation temperature, ST: softening temperature, HT: hemispherical temperature, FT: fluid temperature.[9]: NM = No melting.

The chemical analysis of the feedstock residues showed that wheat straw contained the highest amount of ash (based on research (RD) – 10 wt%, based on sample analysis – 5.4 wt%) (Table 4). The ash content of the other feedstocks in the agricultural category were typically in the range of 1.8-3.4 wt% (for analysis and RD). The lowest ash content of all feedstocks was obtained with the softwood dust: by analysis it was 0.4 wt%, while the average value from the different data sources was 0.7 wt%. The ash content of the poplar related feedstocks ranged between 2.0 and 3.8 wt% depending on their origin. Compared to the other forestry feedstocks, a relatively high amount of ash was found in poplar wood slabs (3.8 wt% RD, 2.5 wt% based on analysis). This feedstock contains a lot of bark which often holds sand. In the food and feed processing category sunflower husks were found to have the highest ash content compared to the olive kernels (4.0 wt% RD and 2.7 wt% based on analysis).

In Table 4, the biomass composition in terms of the fraction of the three main building blocks (lignin, cellulose and hemicellulose) is given. This data can be compared to the yield of PL and PS produced after fractionation of the produced FPBO's.

Table 5: Composition of the organic content of the selected feedstocks(9-13)

Feedstock		Lignin content[1]	Hemi-cellulose[1]	Cellulose[1]
Agricultural residues	Flax shives Wheat straw	23% 17%	25% 38%	44% 27%
Food/feed processing residues	Olive kernels Sunflower husks	48% 17%	24% 35%	24% 48%
Forestry residues	Softwood Hardwood (poplar) Poplar wood slabs Phytoremediated poplar (SRC)	28% 22% n/a 24%	27% 17% n/a 21%	43% 48% n/a 48%

[1] Average data from at least 3 data sources

3.1.2 ICP analysis of feedstocks

The amount and type of minerals present in the biomass feedstock can have a large effect on the yield of pyrolysis products (liquid, char, gas). A high quantity of minerals in the biomass feedstock can ultimately cause ash to accumulate in the pyrolysis unit, resulting in system blockage and a bad quality FPBO. The type of minerals present in the biomass feedstock is also very important. Certain types of minerals have a low melting point which can result in severe slagging, for instance in the char combustor. Also certain kinds of minerals can have a catalytic effect in pyrolysis, meaning that the yield of liquid product might go down, while on the other hand more gas and/or char will be produced.

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ICP analysis was performed for all ten biomass feedstocks. In ICP analysis a whole range of metals and elements such as Cl, P and S can be measured. In Table 5, the ICP results for the 10 different feedstocks are given. From the table it can be observed that there are mutual differences in element concentrations between the 10 different feedstocks.

When looking at the agricultural residues, the wheat straw gives the highest values for Cl, Mg, Pb, Si and Zn. The high(er) chlorine is often an indication of the presence of low melting salts. The detected amount of Si, is maily due to the presence of some residual soil (sand) on/in the biomass. Striking is the relatively high amount of Zn in the wheatstraw. This could be species related and/or due to the soil it was cultivated on.

When comparing the results of the food/feed residues, it can be observed that in general higher concentrations of (almost all) elements were found in the sunflower husks. Again this could also be species related and/or due to soil composition and perhaps due to residual soil material still attached to the biomass. Obviously, olive kernels contain less residual soil as they are covered by the olive flesh, and after picking are likely washed (the whole olive) before the pressing process.

The four forestry residues have also been analysed by ICP. What stands out here are the, in general, low concentrations of heavy metals in the phytoremediated wood compared to the other biomass residues and especially compared to the poplar forestry feedstock, which is very similar in nature. The amount of e.g. Hg, Mn, Pb and especially Zn is much lower for the phytroremediated poplar. It is known from literature (J. Janssens, 2015)[14] that heavy metals do not accumulate in the wood of trees growing on polluted soil but rather end up in the leaves and young twigs. The uptake of heavy metals also depends on many parameters such as: i) type of heavy metal; ii) plants that are used; iii) soil conditions; iv) pH; and v) climate. Because of these parameters it can take decades to clean up a soil via phytoremediation. Short Rotation Coppice of Poplar (SRC poplar) can be used as a phytormediation technique. These trees are harvested every 2–5 years. As a result the heavy metal concentrations can be lower compared to in older trees (15-20 years) that come from land that is not considered to be polluted by heavy metals. It is important to understand that phytoremediation is a slow, less efficient and cheap remediation method compared to more conventional remediation techniques. This technique is useful for very large areas of land where the cleanup time is not so important. From an environmental and economical point of view phytoremediation can be the best option in these scenarios.

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Element	Agricultural residues HS	FS	FP	WS	Food/feed res. OK	SF	Forestry residues PS	SD	PRW	PF
Al	13	574	392	236	31	39	361	47	106	657
Ca	3326	3326	2328	3357	730	3301	3245	971	4053	13505
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cl	2400	1450	802	4550	487	2000	1050	2450	3450	845
Co	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
Cu	4	9	11	6	2	34	4	1	<1	13
Fe	<1	3	<1	<1	<1	<1	<1	1	<1	<1
Hg	40	369	370	221	28	306	361	74	210	689
K	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
Mg	7027	2465	4873	13140	1788	6398	1642	449	2557	4380
Mn	509	452	418	610	123	1634	413	157	348	1267
Na	17	19	27	26	3	11	12	104	21	37
Ni	47	170	110	154	34	10	67	46	96	164
P	2	4	4	4	1	16	4	1	<1	8
Pb	412	471	524	789	56	621	299	42	319	879
S	<1	<1	<1	<1	1	<1	<1	1	1	6
Si	398	314	364	1161	98	1280	260	70	279	681
Zn	59	538	1773	8371	31	506	955	68	526	4415

Table 5: ICP-analysis of the selected feedstocks

Each data point represents an average in mg/kg (inclusive chlorine). All samples were quantified using a calibration line. HS – Hemp Shives; FS – Flax shives; FP – Flax pellets; WS – Wheat straw; OK – Olive kernels; SF – Sunflower husk; PS – Poplar slabs; SD – Softwood dust; PRW – Phytoremediated poplar wood; PF – Poplar forestry residues (hardwood).

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4 Pyrolysis of the biomass feedstocks

4.1.1 Effect on Fast Pyrolysis Bio-Oil yield and quality

The 10 different biomass feedstocks were processed in the Mini Pyrolysis Plant (MPP) reactor at BTG at an average feed rate of about 3.5 kg/h, and at a reactor temperature close to 500 °C. The type of biomass processed, the yields of pyrolysis oil (FPBO) produced and the following associated analytical data are given in Table 6. With the exception of the wheat straw FPBO, the given data do not show any large deviant results, though there are some differences in obtained FPBO yield between the feeds. Softwood dust gave the highest yield of FPBO. The lowest water content was obtained with the softwood dust and flax shives oil. The difference in water content is related to the biomass feed applied and initial water content. The difference between, for example the flax shives oil and the flax pellet oil could be related to the difference in size, shape and density of the feed particle, as the starting moisture content was almost equal. Fluctuations in the water content result in a variation in the CHN-results. The lowest yield and highest water content were obtained with the wheat straw. Processing this feed gave some complications due to the high amount of dust present. Furthermore, the highest ash-content, viscosity, carbonyl content and carbon residue were observed for the softwood FPBO. The high value for the latter two is a strong indication of a higher fraction of pyrolytic sugar present in the oil. The FPBO produced from the olive stone feed gave the highest value for the TAN and the lowest pH.

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Table 5: Results of the pyrolysis tests

	FPBO1 Softwood dust	FPBO2 Olive stones	FPBO3 Hemp Shives[5]	FPBO4 Flax shives	FPBO5 Flax pellets	FPBO6 Sunflower husks	FPBO7 Poplar slabs	FPBO8 Poplar forestry	FPBO9 Wheat straw	FPBO10 Phyto-remediated
FPBO yield (wt.%)	68	57	61	62	57	56	61	58	45	57
C(wt.%) H (wt.%) N (wt.%)	44.9 7.6 0.3	40.2 8.4 0.4	40.3 8.1 0.5	43.6 7.9 0.4	42.8 7.8 0.5	40.8 8.1 0.9	42.6 7.2 0.2	42.8 7.4 0.3	34.4 8.9 0.6	44.4 7.8 0.4
H_2O (wt.%)	19.8	30.8	29.5	22.8	27.5	28.9	24.5	26.9	38.4	23.9
Solids content (wt.%)	0.10	0.07	-	0.08	0.07	0.15	0.37	0.00	0.21	0.41
Ash content (wt.%)	0.22	0.05	-	0.03	0.03	0.08	0.00	0.00	0.03	0.14
TCN (mg BuO/g)[1]	190.4	105.0	-	146.5	122.3	114.4	101.3	84.1	160.2	113.2
pH	3.2	2.4	-	2.6	3.2	3.0	2.7	3.0	3.4	3.2
TAN (mg KOH/g)[2]	56.7	111.0	-	98.4	84.4	100.6	80.7	77.7	72.3	77.5
CR (wt.%)[3]	21.7	13.7	-	18.9	16.2	15.7	17.8	18.2	11.4	18.0
Density (kg/l)	1.2	1.1	-	1.1	1.1	1.1	1.2	1.1	1.1	1.1
Kinematic viscocity at 40 °C (cSt)	33.8	11.9	-	25.9	14.9	15.0	23.6	24.9	5.4	27.8
LHV (MJ/kg)[4]	17.2	15.6	15.7	16.9	16.2	15.6	15.5	15.7	13.2	17.1

[1]: TCN = Total Carbonyl Number, calculated in mg butanone/g sample. [2]: TAN = Total Acid Number, calculated in mg KOH/g sample. [3]: CR = Carbon Residue. [4]: Calculated from CHN- and water content data.[5]: Will be discontinued due to low availability.

4.1.2 Feedstock effect on pyrolysis products and fractions

The produced FPBO's were subsequently extracted and an overview of the yield of obtained pyrolysis products including the obtained liquid fractions (of the FPBO) is given in Figure 2. The FPBO produced from the hemp shives was not further extracted. The processing of the hemp shives feedstock was discontinued due to the lack of availability. In general, no large difficulties were observed during the extractions. Some of the pyrolysis oils were a bit more difficult to extract then others due to phase separation and/or a high oil viscosity. For the overall biomass chain, limited differences were observed for the pyrolytic lignin, whereas the pyrolytic sugars yield is significantly higher for softwood compared to the others and lower for the wheat straw. The pyrolytic lignin produced were send to partner Hexion for chemical reactivity analysis. From this analysis no large differences were observed concerning the chemical reactivity.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

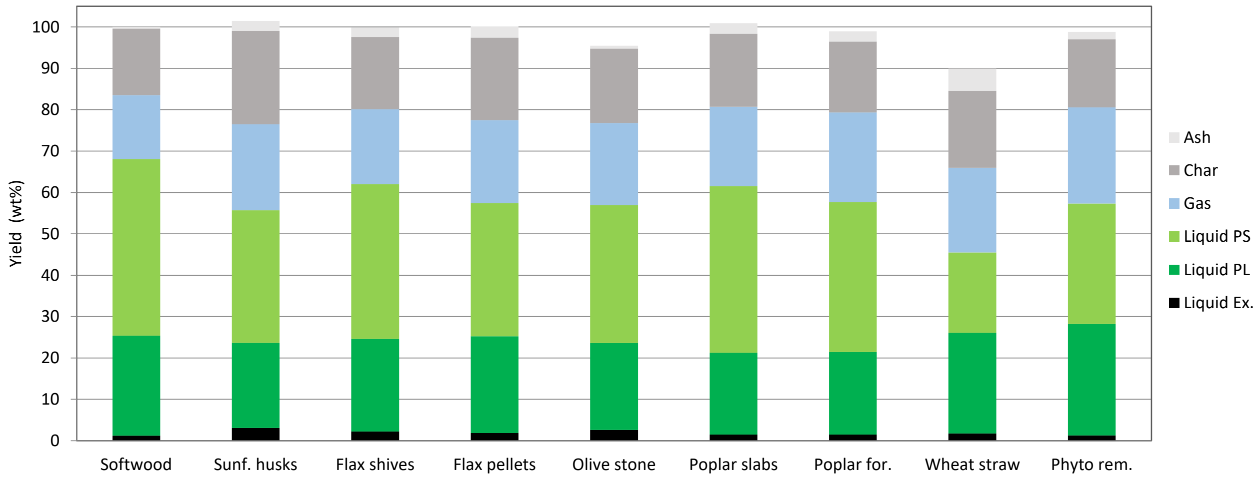

Figure 2: Yield of pyrolysis products

The yield of liquid fractions relative to the biomass input was also determined and is given in Table 6.

Table 6: Obtained fractions relative to biomass input

No.	Type[1]	Biomass	FPBO yield (wt%)	Extr. yield BM (wt%)	PL yield BM (wt%)	PS yield BM (wt%)
1	A	Softwood dust	68	1.2	21.2	45.6
2	C	Olive stones	57	2.6	19.5	34.9
3	B	Flax shives	62	2.2	20.0	39.8
4	B	Flax pellets	57	1.8	20.9	34.3
5	C	Sunflower	56	3.0	17.8	35.2
6	A	Poplar slabs	61	1.5	16.4	43.1
7	A	Poplar forestry	58	1.5	16.4	40.1
8	B	Wheat straw	45	1.7	20.7	22.6
9	A	PhytoR. Poplar	57	1.3	23.5	32.2

[1]: A: Forestry, B: Agricultural, C: Food/Feed processing. [2]: Extr. = Extractives.

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5 Final selection of biomass feedstocks

5.1.1 Performance scoring based on data

The final selection process is a follow up to the first selection process and was performed to identify the two most suitable feedstocks to be further processed in the project at pilot-scale (fast pyrolysis). In this selection process, the feedstocks from the first selection were evaluated by using multiple performance parameters. In total 10 different parameters were applied, including:

- (ease of) handling of the biomass in pyrolysis,
- yield of FPBO products and the performance in subsequent FPBO fractionation
- biomass availability (current and future)
- biomass feedstock cost(s)
- sustainability criteria related to RED
- other sustainable issues such as indirect land use change; cascading use, carbon debt, etc.

For each feedstock, a value between 0-5 was given per parameter. Subsequently these values were added up to obtain a total score. The higher the total score the more suitable the feedstock will be. In Table 7, the results of this process are given. It can be seen that sunflower (seed) husks and poplar slabs gave the highest total, respectively 42 and 41 points. Therefore, these two feedstocks were selected for further pilot plant processing in this project. Although wheat straw was not one of the best scoring feedstocks, mainly due to difficulties in MPP processing and following fractionation, it was decided to also process it as a third feedstock in view of a multi feedstock scenario (and having residual feeds from each of the three categories: forestry, agriculture and food/feed processing). Also, it is thought that only with some small adjustments a large improvement in the quality of FPBO (one phase) produced form wheat straw can be obtained. The selected feedstocks will be prepared (up to specs) and supplied in quantities of two ton each by CAPAX to BTG.

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Table 7: Feedstock selection criteria

No.	Biomass	Type[1]	Availability	Price	Expected future availability	Prim/Sec[4]	RED[5]	OSS[6]	MPP processing (preference)	FPBO yield	Ease of Frac.	Chem. Reactivity[3]	Total
1	Softwood dust	A	3	3	3	3	3	4	5	5	5	4	38
2	Olive stones	C	3	3	3	5	5	5[7]	5	3	4	4	40
3	Flax shives	B	3	2	4	5	5	4	5	3	5	4	40
4	Flax pellets	B	3	2	4	5	4	4	5	3	5	4	39
5	Sunflower husks	C	4	3	3	5	5	5[7]	5	3	5	4	42
6	Poplar slabs	A	3	5	3	5	3	4	5	4	5	4	41
7	Poplar forestry	A	3	3	3	3	3	4	5	3	5	4	36
8	Wheat straw	B	5	2	3	3	4	4	3	2	2	4	32
9	Hemp shives	B	0[2]	0[2]	3	0	5	4	5	4	0[2]	0[2]	21
10	Phytoremediated poplar	A	2	4	3	3	2	4	4	3	5	4	34

[1]:A: Forestry, B: Agricultural, C: Food/Feed processing. [2]: zero = No go. [3]: Based on PL (Hexion) testing. [4]: Primary feedstock = 3, secondary feedstock = 5. [5]: RED (Renewable Energy Directive): GHG emission + biodiversity + maintaining carbon stock. [6]: OSS = Other Sustainable Issues: Indirect land use change + cascading use + carbon dept. [7]: A low ILUC feedstock (D5.1, p85).

6 Conclusions

The chemical fuel properties of 10 selected biomass feedstocks originating from four different sources (Agricultural, Food/feed processing, Bark, Forestry residues) are given. The standard analysis such as CHN, moisture- and ash-content, ash melting behaviour were performed at BTG and were compared to reference data obtained from at least three different databases. Furthermore, ICP analysis was performed on all 10 feedstocks by an external laboratory, to identify the ash composition. All the analytical data was used to prepare mass- and energy-balances, to indicate possible difficulties/limitations and used to explain/clarify certain effects observed in processing (fast pyrolysis, FPBO fractionation). The 10 selected biomass feedstocks were pyrolysed in a bench-scale fast pyrolysis unit (MPP unit). The FPBO yields were determined and analysis of the FPBO was performed, subsequently the FPBO's were fractionated, the yield of individual fractions was determined and fractions were analysed. With all this collected and combined data the effect of the biomass feedstock in relation to its performance in fast pyrolysis and subsequent FPBO fractionation could be evaluated. Subsequently a second feedstock selection was performed, using the outcome of this first evaluation combined with additional performance parameters such as; availability, costs, RED criteria, etc.

Ultimately, **sunflower (seed husks) and poplar slabs showed to be the best scoring feedstocks**. Therefore these two feedstocks were selected for further pilot plant processing in this project. Although wheat straw was not one of the best scoring feedstocks (mainly due to difficulties in MPP processing and following fractionation) it was decided to also process it as a third feedstock in view of a multi feedstock scenario. All selected feedstock will be prepared and supplied in amounts of two ton by CAPAX to BTG for processing in the PP unit.

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WWW.BIO4PRODUCTS.EU
@BIO4PRODUCTS

COORDINATOR
Bert van de Beld
vandebeld@btgworld.com

COMMUNICATION AND DISSEMINATION
James Ling
j.ling@greenovate-europe.eu

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