S2Biom

Delivery of sustainable supply of non-food biomass to support
a "resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

Explanatory note accompanying the database for standardized biomass characterization (and minimal biomass quality requirement for each biomass conversion technology) (D2.4)

1 November 2016

About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

Project coordinator

Scientific coordinator

Project partners

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1. Introduction

The database for standardized biomass characterization (D2.4) is intended to be used to determine, if certain biomass types can be used as feedstocks for specific conversion technologies. This is done in matching tool (Bio2Match) that was developed in the S2Biom project (see D4.5 'Bio2Match: A Tool for Matching Biomass and Conversion Technologies').

There is a need for explanations and disclaimers about how the database was designed, how the data was collected and how representative the data is. Therefore, general statements and explanations and a few specific explanations have been added in this explanatory note.

2. Database description

The database (D2.4) gives a list of characteristics of different biomass categories which have been compiled mostly in a random order. An example of the type of data in the database is given in Figure 1.

	Origin								
	Category – Level 1			2.2 Agricultural residues					
	Category – Level 2			2.2.1 Straw/ stubbles					
	Category – Level 3			2.2.1.1 Rice straw	2.2.1.2 Cereal (wheat) straw	2.2.1.3 Oil seed rape straw	2.2.1.4 Maize stover	2.2.1.5 Sugarbeet tops/leaves	2.2.1.6 Sunflower straw/stalks
8	Dimensions Length	mm	Typical						
			Minimum						
			Maximum						
9	Dimensions Diameter	mm	Typical						
			Minimum						
			Maximum						
10	Dimensions Height	mm	Typical						
			Minimum						
			Maximum						
11	Net calorific value, dry	MJ/kg	Typical	14.47	15.95	17.67	17.04		
			Minimum	13.66	14.49	17.50	16.35		
			Maximum	15.27	17.4	17.99	17.73		
12	Net calorific value as received	MJ/kg	Typical						16
			Minimum						
			Maximum						
13	Gross Calorific value	MJ/kg	Typical	15.52	17.15	19.33	18.325		
			Minimum	15.09	15.7		17.65		
			Maximum	15.95	18.6		19		
14	Ash content	w-% dry	Typical	18.5	6.5	4	5.58	10%	10
			Minimum	12.4	1.1	2.86	3.7	5	
			Maximum	22.1	13.5	5.14	9.7	23	
15	Ash melting behavior (DT) oxidating conditions	°C	Typical	992	892	1267	1277	0	1000
			Minimum	823	780	920			800
			Maximum	1240	1080	1380			1270

Figure 1. Example of part of the content of the database.

2.1 Biomass categories

The purpose of the database is to be able to match biomass with conversion technologies. Most data have been included, especially for the biomass types that represent large available quantities.

Some characteristics can be highly variable. The biomass characteristics database has been compiled using many different sources and aims to give as much as possible a representative view of different biomass types.

Still, one has to consider that biomass can be highly variable and the characteristics of the biomass material are determined by:

- The plant and wood species itself;
- The soil;
- The harvesting time and climate;
- The part of the plant or wood (i.e. leaf or stem) that is considered;
- The type of fertilization (if applicable)

The characteristics can also be influenced by the chosen harvesting, collection and storage and other pretreatment/drying method and also by (soil) contamination. We have tried to exclude these effects as much as possible, but some effect may be unavoidable and can for example be reflected in a higher ash content. In Chapter 3 a small explanation is given to explain how variation occurs.

If the database is applied for setting up a specific chain, then preferably real measured biomass characteristics should be used when available. If you have your own composition data on a certain biomass type the matching method should work well. But do remember that you have to stay critical about the data you find. Especially with respect to characteristics that are highly variable such as ash, Cl, and Na and with biomass types that change over time (fresh straw vs weathered straw or fresh grass versus winter harvested grass). The database therefore has to be used with great caution. The data given here are only an indication of what characteristics to expect.

The moment of harvest can make such a large difference that for some types of biomass we should distinguish two sub-types. Such as early and late harvest for Miscanthus, switchgrass and Reed Canary grass. Early harvested grasses can be used for biogas but are useless for thermal conversion because of high alkali content. For late harvested grasses it is the other way round.

2.2 Biogas production

Biogas production is generally expressed as biogas yield in m^3/kg Volatile Solids (VS). The volatile solids content is generally 75 to 90% of dry matter (DM) content for straw type material. The biogas yield for most biomass types depends on the composition (ash, cellulose, hemicellulose, lignin, fat, protein, etc.). For straw type material we used the estimate by Seadi, et al. (2008) of 0.15 to 0.5 m^3 biogas per kg VS. This results in a wide range or values, but it does reflect the wide range that may be expected for this variable material.

3. Clarification of data collection issues for biomass categories

The two main types of biomass that can be distinguished are herbaceous biomass and woody biomass. Within these types many different biomass categories were identified in WP1 of the S2Biom project (see Annex I). Classification of raw material compiles with EN ISO 17225-1:2014 standard categories. For some of these categories it was difficult to find representative data (Alakangas et al. 2016).

The project team sometimes had trouble to find the required data, so they focused on the main characteristics that determine suitability for conversion options.

In the sections below issues are described that refer to the data collection process for some of the specific biomass categories.

3.1 Herbaceous biomass

Herbaceous biomass is from plants that have a non-woody stem and which die back at the end of the growing season or non-wood. This biomass includes most agricultural crops and grasses. Such as straw (see EN ISO 17225-1:2014). Also relatively young and essentially not woody parts of trees exhibit similar characteristics.

In general herbaceous biomass will have higher nutrient contents and lower lignin contents. Herbaceous biomass is variable in composition depending on the time of year and on the type of tissue. Composition can also be strongly influenced by availability of minerals in the soil. The references for the data on perennials biomass and short rotation coppice (SRC) are given in Annex II.

211 - Energy grasses, annual & perennial crops
Perennial biomass grasses like switchgrass, *Miscanthus* (*giganteus*), reed canary grass (*Phalaris arundinacea*), Giant Reed (*Arundo Donax*) and reed (*Phragmites australis*) differ in their characteristics depending on harvest time. Data on characteristics are generally taken in fall or after a killing frost in winter or early spring. In fall K, Cl, Na and ash content will be higher than in winter. The differences are due to loss of leaves (having a higher ash content than the stalk) during winter and leaching out components that are easily dissolved in water such as Cl, K and Na. This explains the large differences in K and Cl contents reported for these types of biomass. Therefore, it would be logical to present fall and winter/spring harvested data separately. This is difficult as most data sources of biomass composition do not clearly define the time of harvest. We therefore present here average data here and include a caution that fall harvested sample will have higher K, Cl and ash contents and lower ash melting points than average. While winter/spring harvested samples

should have lower K, Cl and ash contents and a higher ash melting point. A large difference in biogas yield may also be expected as green material will have a higher yield than dry material harvested in winter. Also ash melting behavior is different; herbaceous biomass has lower deformation temperature (DT) than woody biomass (Alakangas et al. 2016).

Contamination

Some datasets are clearly based on samples with high (soil/sand) contamination, which generally increases ash and can also change the Deformation Temperature (DT, or FT ash melting point, flow temperature).

3.2 Woody biomass

Woody biomass is a very large category of biomass which is essentially dead plant material containing thick cell walls with a high lignin content. Wood has very good characteristics for thermal conversion mainly due to the very low ash, K, Na and Cl contents. Below some remarks are made on difficulties that were encountered and assumptions that needed to be made regarding several woody biomass types.

12 - Primary forestry residues

Especially for broadleaf trees, but also for conifers, the moisture content decreases with the dimension of the stem (see UNECE FAO 2010, text and different figures for stem and pulpwood). Since branches and roots and trees from thinnings do not include a stem of high diameter, it was suggested to use the values from pulpwood for residues, stumps and stem wood from thinning. Only for stem wood final cuttings the values presented in UNECE FAO 2010 for stem wood were used.

4111 & 4112 - Sawdust (conifers and non-conifers)

For lignin-cellulose-hemicellulose content the same was assumed as stem wood from final fellings.

412 - Residues from industries

It was difficult to find representative data on ash, DT, lignin-cellulose-hemicellulose, N, Cl. These residues might include also some chemicals (e.g. glue) so then it is not possible to use virgin wood values. E.g. residues from plywood industry, furniture industry. If these residues do not include any chemicals e.g. sawdust, cutter chips, shavings than values of stem wood could be used. If residues include chemicals e.g. lacquer, glue, paint usually N, K, Na and ash contents are higher. In these cases, it is also recommended to make an analysis on heavy metals (see Alakangas et al. 2016).

4121 - Residues industries producing semi-finished wood based panels

It was assumed that the industry fully utilizes the wood and that these residues are cut-offs from panel boards. However, it was not possible to find reliable data on panel boards. Therefore, particle board values were used instead. Usually these residues are blended with other recycled wood, which properties differ quite a lot.

4122 - Residues from further wood processing

This category is understood as being non-panel industry using wood, so probably mostly furniture. Therefore, it was assumed that these residues are cut-offs of wood rather than glued parts, so the values of conifer stem wood were assumed.

4132 - Black liquor

Black liquor has a dry matter content of usually 80w-%, so moisture is then around 20w-% (Alakangas et al. 2016). The dry matter content increases, when the recovery boiler size increases. Most important is the lignin in black liquor and chemical recovery back to pulp process. It should be regarded that the weight and the volume in the data base only express the weight of the wood (forest fresh) and the corresponding dry matter of the included wood. This should be kept in mind when the properties are "applied" on the values in the cost supply database to draw the right conclusions and put the right values there.

Basic density and bulk density of wood

The reported values in the cost supply database e.g. in the board industry in terms of weight and volume only contain the "part" that originates from wood and does not include chemicals. For the part that is wood the average was used of the values for coniferous and non-coniferous reported for pulp and fuel wood e.g. for average BD UNECE / FAO present 448 kg/m³ solid for pulp and fuel wood logs 449 kg/m³ solid for saw/veneer logs so 448 kg/m³ solid is the overall average. Thus: the real full weight and the real full chemical properties differ by single sub category and inside the board total by the board type. The weight of the categories from forestry is in all cases expressed in tonnes of dry matter. So, e.g. the real the transport weight is different. Bulk density is a mass of a portion (i.e. a large quantity of particulate material) of a solid fuel divided by the volume of the container which is filled by that portion under specific conditions. Bulk density is an import property for handling equipment e.g. for conveyors and silos.

51 & 52 – Used wood/Waste wood

The values of volumes and weight for the used are ‘as received’ (moisture is taken into account). So this is different when compared to the forestry and SRF (short rotation forestry) categories.

Secondary forestry residues

For the secondary forestry residues all weight values are oven dry tons (ODT) and they relate to the volume values (see Table 1). These weights are not values as delivered. But tonnes absolute dry as provided by EFI and additional information was given by VTT. So the moisture content should still be added to calculate actual weight to be transported.

Table 2. Conversion factors and approach used to determine the supply potentials in volume and weight units for secondary forest residues (UNECE FAO Timber section, 2010).

Final level subcategories		**kg d.m. of lignocellulose biomass per m³**	**Moisture content assumed under this conversion**	**Source/ Comment**
ID	Name	In: m Out: kg d.m.	In % of dry matter	
4111	Sawdust from sawmills from conifers	442.1	16.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4112	Sawdust from sawmills from non-conifers	571.9	18.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4113	Sawmill residues: excluding sawdust, conifers	442.1	16.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4114	Sawmill residues: excluding sawdust, non-conifers	571.9	18.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4121	Residues from industries producing semi -finished wood based panels	448	a) 52.3	UNECE /FAO (2010) Value for round wood pulp, fuel wood logs c/nc Referring to the wood volume and moisture based of the Round wood product.
4122	Residues from further wood processing	b) 509	c) 6 to 18.9	Estimates are determined per sector and then summed up. Conversion factors based on own calculations considering wood product properties and product share per sector utilizing data from Germany in Mantau & Bilitevski (2010) and wood and wood product properties from UNECE/FAO (2010).
4131	Bark residues from pulp and paper industry	373	a) 52.3	UNECE /FAO (2010) Value for bark
4132	Black liquor	448	a) 52.3	UNECE /FAO (2010); Value for round wood pulp, fuel wood logs c/nc

a) calculation based on round wood input units
b) average of conversion factor used per sector: construction 477.4, furniture 574.2, packaging 465.4 and other 520.9
c) different by wood product

4. Clarifications on relevant biomass characteristics

In this chapter we discuss the main biomass features in terms of its importance, how and why they vary in different biomass types and what caution should be taken while interpreting the data.

4.1 Moisture content

Moisture content is generally a negative feature because it does not confer value. The risk of spoilage, biomass loss and self-ignition increases with a higher moisture content. For herbaceous biomass efficient storage and transport is not possible if moisture is above 15% moisture (on wet basis). For wood this value is 23% for small scale use. In Nordic countries, when outdoor storage of logging residues and thinning wood is the prevailing method, the storage moisture is higher, usually about 35 to 45 w-% on wet basis. During storage moisture content decrease.

At the same time moisture content is a feature which can easily be manipulated, though often at an extra cost. At harvest, moisture content will typically vary between 50% for wood to 80% for leafy herbaceous material. As moisture content is variable in the growing plant and also changes quickly after harvest the given numbers in the database should be seen as just an indication.

There are boiler technologies (1–10 MW_{th}) which can burn very wet woody biomass such as sawdust (50% moisture) with low emissions and high efficiency.

4.2 Ash

Ash is the mass of inorganic residue remaining after combustion of a fuel under specified conditions, typically expressed as a percentage of the mass of dry matter in fuel. Ash content of biomass is generally defined as the remaining material after combustion at 550 or 800 °C. Ash consists mainly of silica and other oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, P_2O_5, SO_3. Ash is an important quality feature of biomass because it generally does not confer value. Ash has to be transported (and needs to be disposed of) which causes extra costs. Furthermore, part of the minerals such as K and P have a value for the plant growth and therefore for the farmer and should preferably remain on the field.

The composition of the ash differs according to plant tissue and plant type. But it is also influenced by soil type, available elements in the soil, fertilization used and time of the year. For example, plants on a sandy soil will have less ash than plants on a clay soil (mainly due to more silica uptake). Although plants only need some elements for plant growth, plants only have limited capability for selective uptake of those elements which are essential for their growth (Kirbey, 2012). Biomass can easily be contaminated by soil (on the outside of the plants) which can dramatically increase ash content of biomass samples so called extraneous ash. In the database we have tried to only include the ash content of biomass itself without contamination. Still, always be aware that many biomass ash data are at least partly determined by the contamination after harvest. The composition of ash is also very relevant as this determines its melting point. Ash content for wood without bark is usually less than 0.5%. Bark and especially stumps can have higher ash content.

4.3 Ash melting behaviour

The ash melting behaviour is important because it is an indication of the risk of ash sintering and boiler fouling in thermal conversion. Ashing temperature for biomass is typically 550°C. The following temperatures are usually measured: ash shrinkage starting temperature (SST), ash deformation temperature (DT), ash flow temperature (FT), ash hemisphere temperature (HT) in oxidating conditions. These ash melting temperatures are determined by the ash composition. Having said that, it is still difficult to predict the exact value of the ash melting temperatures even when the ash composition is known. In general, high K and Na values lower the ash melting temperatures while high Ca and Mg values increase the ash melting temperature. Indicators have been developed which predict ash melting behaviour based on ash composition. Ash melting behaviour for biomass is measured according to standard methods like the CEN/TS 15370-1:2006. New international standard (ISO 21404) for solid biomass is under development and new ashing temperature is proposed to be 710°C ± 10°C. If ashing is done at 550°C carbonates in Ca-rich solid biofuels, especially Calcium carbonate, will mainly contribute to SST since decomposition of Calcium carbonates occur from approx. 600°C. It may be more difficult to determine DT due to strong shrinkage of test pieces. If there is any doubt of incomplete ashing, ashing shall be continued at 710°C until complete ashing is obtained (Alakangas et al. 2016).

4.4 Chlorine (Cl)

Chlorine is an essential micronutrient for higher plants. However, the average concentration in plant shoots for adequate growth is just 100 mg per kg of dry matter (0.01% of dry matter) (Kirbey, 2012). In practice the content can exceed 1% (DM) in plants. For example, when chlorine containing fertilizer (KCl fertilizer) is used or when the biomass is produced on salt-containing soils or in areas near the sea. Reporting “typical” Cl contents for biomass types is therefore difficult. Chloride content depends on management and soil and hardly on the type of plant or variety. Chlorine is important for thermal conversion, but many data-sets on composition do not include chlorine as this is not a relevant issue for agronomic analysis. Chlorine content together with Na and K content is important to know especially for fluidised boiler combustion.

Chlorine increases the chance of corrosion and harmful emissions in thermal combustion and is also unwanted in many chemical biomass treatments. Fortunately, chlorine is easily flushed out of biomass when the biomass is weathered as is the case with winter-harvested reed, *Miscanthus*, switchgrass, *Arundo donax*, and reed canary grass or old (grey) straw. Weathering can reduce the chlorine content by 90%. The negative effect of chlorine in combustion can be partially undone if the S/Cl ratio is above 4, which is however, seldom the case in plants. For woody biomass higher Cl- contents can be found in forest residues, which include needles or leaves (Alakangas et al. 2016).

4.5 Sulphur (S)

Sulphur is also an essential plant element that is needed for plant growth. The average concentration in plant shoots for adequate growth is 1,000 mg per kg of dry matter (0.1% of dry matter). Plants will generally contain not much over this amount. Wood and similar material will have even lower contents. For woody biomass the S-content is usually < 0,05%.

Sulphur can reduce the corroding effects of chlorine in combustion. For combustion a higher S/Cl ratio is positive, preferably above 4, which will seldom occur though. Therefore, we use Cl-% instead of S/Cl for Bio2Match as indicator for corrosion. S/Cl is mainly useful when you're talking about coal or peat co-combustion.

4.6 Potassium (K)

Potassium is an essential plant mineral found in high amounts in living plant tissue. The average concentration in plant shoots for adequate growth is 10,000 mg per kg of dry matter (1% of dry matter). The variability of potassium in living tissue is not very high. A potassium content of 2% or higher is not often found. The potassium content of leafy biomass can have a value of €5 to €10 per ton of dry matter. The potassium content may be much lower than 1% in dead and weathered tissues such as wood and winter harvested reed, *Miscanthus*, switchgrass, *Arundo donax*, and reed canary grass or old (grey) straw. Potassium is easily leached out of the tissue. Potassium is the main mineral causing sintering and boiler fouling in thermal conversion. Potassium content can be high in industrial wood residues including e.g. glue.

4.7 Sodium (Na)

Sodium is a non-essential element in most plants (Kirbey, 2012). There is therefore in general no minimum amount needed in plants. Sodium behaves similarly to potassium and it can replace the function of potassium in plants to some extent. In practice plants can have very variable amounts of sodium in their tissues (as with chlorine). Contents can vary from close to 0% to more than 1%. The reported sodium contents in the database are therefore only indicative and depend more of the soil sodium content than on the type of plant. This is because the sodium content is strongly related to the amount of sodium in the soil. It is also easily leached out of plant tissues and it also increases the risk of sintering and boiler fouling in thermal conversion. Sodium content can be high in industrial wood residues including e.g. glue. It is important to know the reactive K+Na content especially for fluidised bed combustion (Alakangas et al. 2016).

4.7 Calcium (Ca)

Calcium is an essential plant element. The average concentration in plant shoots for adequate growth is 5,000 mg per kg of dry matter (0.5 % of dry matter). In living plant tissue the variability of calcium is lower than for sodium. Calcium is not easily removed from plant tissues (unlike potassium or sodium). Calcium is generally positively correlated to the ash melting behaviour.

4.7 Magnesium (Mg)

Magnesium is also an essential plant element. The average concentration in plant shoots for adequate growth is 2,000 mg per kg of dry matter (0.2 % of dry matter). In living plant tissue, the variability of magnesium is lower than the variability of sodium. Just like calcium, magnesium is also not easily removed from plant tissues (unlike potassium or sodium). Magnesium is generally positively correlated to the ash melting behaviour.

4.8 Silicon (Si)

Silicon is not an important plant element for most plants. Therefore, no minimum silica content of plants can be given. All plants grown in soil will contain some silicon in their tissues. However, the silicon concentration in the shoots varies considerably among plant species, ranging from 1 to 100 mg silicon per g dry mass (Broadly et al., 2012). Rice for example accumulates more than 10% silica in the leaves. Some plants such as grasses accumulate more silicon than others. Silica content is also related to transpiration and will mostly accumulate in the leaves. It is also observed that in grasses, ash content (mostly silica), is higher in clay than in sandy soil. Silica (SiO_2) is generally the most important element contributing to ash content of plants where it can dilute the ash temperature lowering effects of potassium and sodium.

4.8 Nitrogen (N)

Nitrogen is the most important essential mineral in plants. The average concentration in plant shoots for adequate growth is 15,000 mg per kg of dry matter (1.5% of dry matter). The nitrogen content can be as high as 5%. The nitrogen content of woody biomass is usually 0.2%. Industrial wood residues including glue can have high N-content. If this is the case the value for other purposes than non-food uses are likely to fetch a higher price. Nitrogen, which is mostly found in proteins, is generally high in seeds and young tissue. In older and mature tissue, nitrogen levels can be reduced considerably, mainly due to active translocation. Nitrogen does not flush out easily like with chlorine or potassium. In combustion it is less of a problem than chlorine or potassium but it may increase the risk of NOx emissions requiring costly emission controls.

4.9 Phosphorus (P)

Phosphorus is an essential element for plants. The average concentration in plant shoots for adequate growth is 2,000 mg per kg of dry matter (0.2 % of dry matter). In general, the phosphorus content will not be much above this. Phosphorus is not easily removed from plants, though content of phosphorus can be reduced in maturing tissue. The effect of phosphorus is less pronounced than for chlorine or potassium. Phosphorus does however have a cost and is becoming a scarce resource. Combustion can make phosphorus unavailable for recycling.

4.10 Energy content of biomass

The energy content of biomass is expressed in net calorific (or lower heating value, LHV) or gross calorific (or higher heating value, HHV). In gross calorific value the condensation heat of water is included. The HHV will therefore always be higher than the LHV especially, if the biomass contains water. The HHV (MJ/kg) of biomass is measure by a weighed portion of the analysis sample of the solid biofuel is burned in high-pressure oxygen in a bomb calorimeter under specified conditions. The gross calorific value is calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the fuse(s) and for thermal effects from side reactions such as the formation of nitric acid. Furthermore, a correction is applied to account for the difference in energy between the aqueous sulphuric acid formed in the bomb reaction and gaseous sulphur dioxide, i.e. the required reaction product of sulphur in the solid biofuel. (EN ISO 17225-1:2014, Alakangas et al. 2016):

The net calorific value at a constant pressure for a dry sample (dry basis, in dry matter) is derived from the corresponding gross calorific value at a constant volume according to Equation (1)

$$q_{p,\mathrm{net,\,d}} = q_{V,\mathrm{gr,d}} - 212{,}2 \times w(\mathrm{H})_\mathrm{d} - 0{,}8 \times \left[w(\mathrm{O})_\mathrm{d} + w(\mathrm{N})_\mathrm{d} \right] \quad (1)$$

where

$q_{p,\mathrm{net,\,d}}$	is the net calorific value for dry matter at a constant pressure in joules per gram(J/g) or kilojoules per kilogram (kJ/kg);
$q_{V,\mathrm{gr,\,d}}$	is the gross calorific value for dry matter in joules per gram(J/g) or kilojoules per kilogram (kJ/kg);
$w(\mathrm{H})_\mathrm{d}$	is the hydrogen content, in percentage by mass, of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance);
$w(\mathrm{O})_\mathrm{d}$	is the oxygen content, in percentage by mass, of the moisture-free biofuel;
$w(\mathrm{N})_\mathrm{d}$	is the nitrogen content, in percentage by mass, of the moisture-free biofuel.

For the calculation of the net calorific value as received using Equation (2), the result from Equation (1) in in joules per gram(J/g) or kilojoules per kilogram (kJ/kg), shall be divided by 1 000 to get the result in megajoules per kilogram (MJ/kg).

NOTE $\left[w(\mathrm{O})_\mathrm{d} + w(\mathrm{N})_\mathrm{d} \right]$ can be derived by subtracting from 100 (w-%) the percentages of ash, carbon, hydrogen and sulphur.

The net calorific value as received

The net calorific value (at constant pressure) on as received (the moist biofuel) can be calculated on the net calorific value of the dry basis according to Equation (2).

$$q_{p,\mathrm{net,ar}} = q_{p,\mathrm{net,d}} \times \left(\frac{100 - M_\mathrm{ar}}{100}\right) - 0{,}024\,43 \times M_\mathrm{ar} \quad (2)$$

where

$q_{p,\mathrm{net,ar}}$	is the net calorific value (at constant pressure) as received in megajoules per kilogram (MJ/kg);
$q_{p,\mathrm{net,d}}$	is the net calorific value (at constant pressure) in dry matter in megajoules per kilogram (MJ/kg);
M_ar	is the moisture content as received [w-%];
0,024 43	is the correction factor of the enthalpy of vaporization (constant pressure) for water (moisture) at 25 °C (in megajoules per kilogram (MJ/kg) per 1 w-% of moisture).

The energy content of biomass is therefore mostly dependent on net calorific value on dry basis, moisture and ash content. The dry and ash free energy content of different biomass types are generally only marginally different and mostly determined by the lignin and oil content, which have a higher energy content than cellulose/hemicellulose and starch.

4.11 Bulk density and particle size distribution of biomass

The bulk density (BD) of biomass is expressed as kg/m^3 as received. It is a function of plant characteristics and harvesting or collection method. It is an important characteristic because it determines to a large extent the ease of handling and the cost of handling and transport. Bulk density for wood chips and hog fuel is measured in a 50 litre container according to EN ISO 17828:2016 (Alakangas et al. 2016).

Particle size distribution is important property to evaluate flowability and conversion behaviour. E.g. gasification requires more homogenous particle size distribution of biomass than grate combustion. Particle size distribution is analysed by screening method. For small combustion of wood pellets is important to know amount fine particles (< 3.15 mm), because fine particles cause problems in storage and combustion.

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EN ISO 16968, Solid Biofuels — Determination of minor elements — As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, V and Zn

EN ISO 18125, Solid biofuels — Determination of calorific value (under preparation)

EN ISO 18122, Solid biofuels — Determination of ash content

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B. WEB-LINKs

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https://en.wikipedia.org/wiki/Plant_physiology
www.prs-systeem.nl
http://retirees.uwaterloo.ca
www.phytocare.nl
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www.hoogstamboomgaard.be
www.bodemacademie.nl
www.plantaardig.com
www.groen.net
www.sanfiero.nl
www.cartage.org.lb
http://gardener.wikia.com

www.hbci.com
www.knowledgebank.irri.org

Annex I. Final biomass categories from S2Biom-WP1

Table I1. Subcategories of first level category 1 “Forestry”

Second level subcategories		Third level subcategories		Final level subcategories	
ID	Name	ID	Name	ID	Name
11	Production from forests	111	Stemwood from final fellings &thinnings	1111	Stemwood from final fellings originating from nonconifer trees
				1112	Stemwood from final fellings originating from conifer trees
				1113	Stemwood from thinnings originating from nonconifer trees
				1114	Stemwood from thinnings originating from conifer trees
12	Primary residues from forests	121	Logging[1] residues from final fellings &thinnings	1211	Logging residues from final fellings from nonconifer trees
				1212	Logging residues from final fellings from conifer trees
				1213	Logging residues from thinnings from nonconifer trees
				1214	Logging residues from thinnings from conifer trees
		122	Stumps from final fellings &thinnings	1221	Stumps from final fellings originating from nonconifer trees
				1222	Stumps from final fellings originating from conifer trees
				~~1223~~	~~Stumps from thinnings originating from nonconifer trees~~
				~~1224~~	~~Stumps from thinnings originating from conifer trees~~

[1] In the sense of “Standard” logging residues, thus excluding stamps, on second level 121 and 122 are both “logging residues.

Table I2. Subcategories of second level category “21 Primary production of lignocellulosic biomass crops

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
211	Energy grasses, annual & perennial crops	2111	Sweet and biomass sorghum (Annual grasses)
		2112	Miscanthus (Perennial grass)
		2113	Switchgrass (Perennial grass)
		2114	Giant reed (Perennial grass)
		2115	Cardoon (Perennial crop)
		2116	Reed Canary Grass (Perennial grass)
212	Short rotation coppice	2121	SRC Willow
		2122	SRC Poplar
		2123	Other SRC

Table I3. Subcategories of second level category “22 Agricultural residues”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
221	Straw/stubbles	2211	Rice straw
		2212	Cereals straw
		2213	Oil seed rape straw
		2214	Maize stover
		2215	Sugarbeet leaves
		2216	Sunflower straw
222	Woody prunning & orchards residues	2221	Residues from vineyards
		2222	Residues from fruit tree plantations (apples, pears and soft fruit)
		2223	Residues from olives tree plantations
		2224	Residues from citrus tree plantations
		2225	Residues from nuts plantations

Table I4. Subcategories of second level category “23 Grasland”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
231	Grassland	2311	Unused grassland cuttings (abandoned grassland, managed grasslands not used for feed)

Table I5. Subcategories of “3 Other Land use”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
311	Biomass from other areas under landscape maintenance	3111	Grassy biomass from landscape maintenance (recreational and nature protection areas, dykes)
		3112	Woody biomass from landscape maintenance (landscape elements)
312	Biomass from road side verges	3121	Grassy biomass from road side verges
		3122	Woody biomass from road side verges

Table I6. Subcategories of second level category 41 “Secondary residues from wood industries”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
411	Saw mill residues	4111	Sawdust from sawmills from conifers
		4112	Sawdust from sawmills from nonconifers
		4113	Sawmill residues: excluding sawdust, conifers
		4114	Sawmill residues: excluding sawdust, nonconifers
412	Other wood processing industry residues	4121	Residues from industries producing semi -finished wood based panels
		4122	Residues from further wood processing
413	Secondary residues from pulp and paper industry	4131	Bark residues from pulp and paper industry
		4132	Black liquor

Table I7. Subcategories of “42 Secondary residues of industry utilising agricultural products

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
421	By-products and residues from food and fruit processing industry	4211	Olive-stones
		4212	Other by-products and residues from food and fruit processing industry
422	Other industry by-products utilising agricultural products	4221	Cotton_acorn
		4222	Other industry by-products utilising agricultural products

Table I8. Subcategories of “Waste”

Second =Third level subcategories		Final level subcategories	
ID	Name	ID	Name
51/511	Biodegradable municipal waste	5111	Biowaste as part of integrally collected municipal waste: Biodegradable waste of not separately collected municipal waste (excluding textile and paper)
		5112	Separately collected biowaste: Biodegradable waste of separately collected municipal waste (excluding textile and paper)
52/521	Post consumer wood	5211	Hazardous post consumer wood
		5212	Non hazardous post consumer wood

Annex II. Other sources perennials biomass and SRC

B. WEB-LINKs

Phyllis2, database for biomass and waste, https://www.ecn.nl/phyllis2*, Energy research Centre of the Netherlands.*

Reed canary grass

https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#reed canary grass
https://www.ecn.nl/phyllis2/Biomass/View/2062
https://www.ecn.nl/phyllis2/Biomass/View/1994
https://www.ecn.nl/phyllis2/Biomass/View/2061
https://www.ecn.nl/phyllis2/Biomass/View/1975
https://www.ecn.nl/phyllis2/Biomass/View/2124
https://www.ecn.nl/phyllis2/Biomass/View/3093
https://www.ecn.nl/phyllis2/Biomass/View/1909
https://www.ecn.nl/phyllis2/Biomass/View/3165
https://www.ecn.nl/phyllis2/Biomass/View/3475
https://www.ecn.nl/phyllis2/Biomass/View/3091
https://www.ecn.nl/phyllis2/Biomass/View/3092
https://www.ecn.nl/phyllis2/Biomass/View/3089
https://www.ecn.nl/phyllis2/Biomass/View/1820
https://www.ecn.nl/phyllis2/Biomass/View/3090
https://www.ecn.nl/phyllis2/Biomass/View/2407
https://www.ecn.nl/phyllis2/Biomass/View/2368
https://www.ecn.nl/phyllis2/Biomass/View/2062

Cellulose, hemicellulose, lignin
https://www.ecn.nl/phyllis2/Biomass/View/2381
https://www.ecn.nl/phyllis2/Biomass/View/2257
https://www.ecn.nl/phyllis2/Biomass/View/2406

Miscanthus
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#miscanthus

https://www.ecn.nl/phyllis2/Biomass/View/594
https://www.ecn.nl/phyllis2/Biomass/View/590
https://www.ecn.nl/phyllis2/Biomass/View/593
https://www.ecn.nl/phyllis2/Biomass/View/589
https://www.ecn.nl/phyllis2/Biomass/View/576
https://www.ecn.nl/phyllis2/Biomass/View/583
https://www.ecn.nl/phyllis2/Biomass/View/573
https://www.ecn.nl/phyllis2/Biomass/View/581
https://www.ecn.nl/phyllis2/Biomass/View/568
https://www.ecn.nl/phyllis2/Biomass/View/578
https://www.ecn.nl/phyllis2/Biomass/View/571
https://www.ecn.nl/phyllis2/Biomass/View/572
https://www.ecn.nl/phyllis2/Biomass/View/575
https://www.ecn.nl/phyllis2/Biomass/View/582
https://www.ecn.nl/phyllis2/Biomass/View/584

https://www.ecn.nl/phyllis2/Biomass/View/585
https://www.ecn.nl/phyllis2/Biomass/View/586
https://www.ecn.nl/phyllis2/Biomass/View/587
https://www.ecn.nl/phyllis2/Biomass/View/588
https://www.ecn.nl/phyllis2/Biomass/View/595
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https://www.ecn.nl/phyllis2/Biomass/View/577
https://www.ecn.nl/phyllis2/Biomass/View/591
https://www.ecn.nl/phyllis2/Biomass/View/596
https://www.ecn.nl/phyllis2/Biomass/View/597
https://www.ecn.nl/phyllis2/Biomass/View/580

Cellulose, hemicellulose, lignin
https://www.ecn.nl/phyllis2/Biomass/View/2532
https://www.ecn.nl/phyllis2/Biomass/View/1040

Switchgrass

https://www.ecn.nl/phyllis2/Biomass/View/701
https://www.ecn.nl/phyllis2/Biomass/View/2426
https://www.ecn.nl/phyllis2/Biomass/View/2436
https://www.ecn.nl/phyllis2/Biomass/View/1843
https://www.ecn.nl/phyllis2/Biomass/View/621
https://www.ecn.nl/phyllis2/Biomass/View/2441
https://www.ecn.nl/phyllis2/Biomass/View/2428
https://www.ecn.nl/phyllis2/Biomass/View/2442
https://www.ecn.nl/phyllis2/Biomass/View/1842
https://www.ecn.nl/phyllis2/Biomass/View/2429
https://www.ecn.nl/phyllis2/Biomass/View/2437
https://www.ecn.nl/phyllis2/Biomass/View/2427
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https://www.ecn.nl/phyllis2/Biomass/View/2432
https://www.ecn.nl/phyllis2/Biomass/View/2032
https://www.ecn.nl/phyllis2/Biomass/View/620
https://www.ecn.nl/phyllis2/Biomass/View/2258

Arundo donax
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#arundo donax

https://www.ecn.nl/phyllis2/Biomass/View/988

https://www.ecn.nl/phyllis2/Biomass/View/1992

Cellulose, hemicellulose, lignin (foliage, internode, node)
https://www.ecn.nl/phyllis2/Biomass/View/2618
https://www.ecn.nl/phyllis2/Biomass/View/2619
https://www.ecn.nl/phyllis2/Biomass/View/2617

Cynara cardunculus
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#cynara

https://www.ecn.nl/phyllis2/Biomass/View/2295
https://www.ecn.nl/phyllis2/Biomass/View/1787
https://www.ecn.nl/phyllis2/Biomass/View/3508
https://www.ecn.nl/phyllis2/Biomass/View/2812
https://www.ecn.nl/phyllis2/Biomass/View/3128

Sorghum bicolor
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#sorghum

https://www.ecn.nl/phyllis2/Biomass/View/2792
(Sweet sorghum)
https://www.ecn.nl/phyllis2/Biomass/View/558
https://www.ecn.nl/phyllis2/Biomass/View/561
https://www.ecn.nl/phyllis2/Biomass/View/560
https://www.ecn.nl/phyllis2/Biomass/View/562
https://www.ecn.nl/phyllis2/Biomass/View/3166
https://www.ecn.nl/phyllis2/Biomass/View/564
https://www.ecn.nl/phyllis2/Biomass/View/1822

Cellulose, hemicellulose, lignin (*Sorghum bicolor and 1 sweet sorghum#1758*)
https://www.ecn.nl/phyllis2/Biomass/View/2682
https://www.ecn.nl/phyllis2/Biomass/View/2681
https://www.ecn.nl/phyllis2/Biomass/View/2685
https://www.ecn.nl/phyllis2/Biomass/View/2680
https://www.ecn.nl/phyllis2/Biomass/View/2684
https://www.ecn.nl/phyllis2/Biomass/View/2683
https://www.ecn.nl/phyllis2/Biomass/View/1758

SRC
Willow
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#willow

https://www.ecn.nl/phyllis2/Biomass/View/1306
https://www.ecn.nl/phyllis2/Biomass/View/851
https://www.ecn.nl/phyllis2/Biomass/View/1307
https://www.ecn.nl/phyllis2/Biomass/View/719
https://www.ecn.nl/phyllis2/Biomass/View/867
https://www.ecn.nl/phyllis2/Biomass/View/869
https://www.ecn.nl/phyllis2/Biomass/View/870
https://www.ecn.nl/phyllis2/Biomass/View/947
https://www.ecn.nl/phyllis2/Biomass/View/852
https://www.ecn.nl/phyllis2/Biomass/View/2715
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Biochemical composition
https://www.ecn.nl/phyllis2/Biomass/View/2543

Poplar
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https://www.ecn.nl/phyllis2/Biomass/View/809
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https://www.ecn.nl/phyllis2/Biomass/View/830
https://www.ecn.nl/phyllis2/Biomass/View/293
https://www.ecn.nl/phyllis2/Biomass/View/287
https://www.ecn.nl/phyllis2/Biomass/View/1828
https://www.ecn.nl/phyllis2/Biomass/View/2285
https://www.ecn.nl/phyllis2/Biomass/View/700
https://www.ecn.nl/phyllis2/Biomass/View/1930
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https://www.ecn.nl/phyllis2/Biomass/View/289
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https://www.ecn.nl/phyllis2/Biomass/View/831
https://www.ecn.nl/phyllis2/Biomass/View/1683
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Eucalyptus
https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#eucalyptus

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