

We are very pleased to have been given access to the main output of the EU-funded Biomass Trade Centres project, the Wood Fuels Handbook, which has been an invaluable guide for many in the industry for the past decade. Over the next few newsletters, we'll be reproducing sections of the key chapters of this comprehensive resource. This second section is on the energy content of biomass.

Thanks are due to the principal authors, Valter Fancescato and Eliseo Antonini of the Italian Agroforestry Energy Association, and Luca Zuccola Bergomi of the University of Padua.

2. ENERGY CONTENT

2.1 Units of measurement for thermal energy

Fuel has a certain amount of energy named **primary energy** that is converted through combustion into **final energy** to be used for any wished-for purposes (e.g. heating, hot water for sanitary purposes and process heat).

The SI (International System of Units) units of measurement to be used are the Joule (J), the Watt-hour (Wh) and multiples of these units.

The units that are most commonly used are:

MJ/kg	MJ/ms	kWh/kg	kWh/ms	MWh/t
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2.2 Energy and power

Thermal energy is that form of energy that is associated with molecular agitation. It can be considered as the sum of all the kinetic energy possessed by the single molecules. Thermal energy is not synonymous with heat, the latter indicating the amount of thermal energy transferred/exchanged from one system to another.

Units of energy

1 Joule =	1 Newton x 1 meter =	1 Watt x second (Ws)
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2.3 Water in wood

Wood is not typically found in the oven-dry state, but it has a moisture which may vary from 60 to 15% depending on the duration of open-air seasoning. Wood is a **porous and hygroscopic** material and, due to its chemico-histological structure, it has two different types of porosity:

- The **macroporosity** created by the cavities of the conductive vessels and by parenchymal cells containing **free (or imbibition) water**;
- the **microporosity** of the actual wood substance (mainly cellulose, hemicellulose and lignin), which always contains a certain amount of **bound (or saturation) water**.

Wood begins to lose water from the moment the tree is cut down. First, imbibition water evaporates from the outermost (sapwood) and, later, innermost (*duramen*) parts of the trunk. At a certain point in time, all free water in seasoned wood evaporates, while saturation water reaches a dynamic balance with the outward moisture, reaching a value below 20%.

2.4 Volume shrinkage and swelling

During log woods and wood chips seasoning, and up to a moisture content (M) of 23% ($u < 30\%$, **fibre saturation point**) no shrinkage in the volume of the single pieces and piles occurs. Up to this point, wood has only lost its free (or imbibition) water. Later, when wood begins to lose its bound (or saturation) water as well, there occurs shrinkage (βv) in volume that, although it may vary depending on the wood species, is usually of 13% (figure 2.4.1). Contrariwise, if saturation water increases, wood will swell (αv)*.

The shrinkage of the single pieces in a log woods stack or wood chips pile entails an over- all decrease in the volume of the pile that is almost always lower than that of the single pieces.

From an applicative point of view, any variations in volume (shrinkage and swelling) registered within a 0 to 23% interval (hygroscopic field) must be taken into account for a correct calculation of the mass density, whether steric (with water) or not, and of the energy density of fuels.

2.5 Moisture content

Wood moisture is expressed as a percent and is calculated using these two formulas:

Moisture on dry basis → u (%)

It expresses the mass of water present in relation to the mass of oven-dry wood.

$$u = \frac{W_w - W_0}{W_0} \times 100$$

Moisture on wet basis → M (%)

It expresses the mass of water present in relation to the mass of fresh wood. This measure is used in the marketing of wood fuels.

$$M = \frac{W_w - W_0}{W_w} \times 100$$

Wherein: W_w = wet weight of wood and W_0 = oven-dry weight of wood

2.6 Biomass chemical composition

Vegetal biomass mainly consists of carbon (C), oxygen (O) and hydrogen (H). Carbon is the solid biofuel component through whose oxidation the fuel energy content is released. Besides, further energy is supplied by hydrogen to the oxidation process which, added to the

energy produced by carbon, determines the **net calorific value** of the fuel. Oxygen, on the contrary, solely sustains the progression of the oxidation process.

Effects of the chemical composition of solid biofuels on combustion and emissions

The elements that bear a direct effect on the level of harmful emissions produced by combustion are: sulphur (S), nitrogen (N), chlorine (C) and ash contents. The following rule generally applies to the above-mentioned elements: the higher their content in the fuel, the greater their presence in the emissions into the atmosphere.

Nitrogen content in wood biofuels is relatively low, whereas it is much higher in cereal - particularly if we thereby include reproductive organs (grains) as well – and above all in oilseed rapes (rapeseed cake); this bears a direct impact on the formation of nitrogen oxides (NO_x) which, during combustion, become gasiform and do not remain in the ashes. **Potassium** (K), which is mainly to be found in agricultural biofuels, lowers the melting point of the ashes, thus favouring the formation of slags in the grate that are the cause of considerable problems for the combustion process. Moreover potassium, which, as a consequence of combustion, is released in the shape of fine particles, is one of the elements that abound in particulates.

Sulphur (S) content in solid biofuels is much lower compared to that in carbonaceous fossil fuels; sulphur generally remains for the most part in the ashes (40 to 90%), while volatile SO₂ is formed from the remainder.

Unlike for example cereal straws and Miscanthus, which have a decidedly higher **chlorine** (Cl) content, wood fuels are characterised by a rather low chlorine content. Cl takes part in the formation of compounds like HCl and dioxins/furans. Despite the most part of Cl will be bound in the fly-ash (40-95%), the rest goes forming HCl, enhanced by condensing processes, which together with other compounds, causes corrosive effects on metal internal parts of boilers and chimneys.

2.7 Calorific value and ashes

The calorific value of a fuel expresses the amount of energy released during the complete combustion of a mass unit of a fuel.

The moisture content of wood changes the calorific value of the latter by lowering it. Indeed, part of the energy released during the combustion process is spent in water evaporation and is consequently not available for any wished-for thermal use.

Water evaporation involves the 'consumption' of 2.44 MJ per kilo of water. It is thereby possible to distinguish between the following:

Net calorific value (NCV): The water released is treated as a vapour, i.e. the thermal energy required to vaporize the water (latent heat of vaporization of water at 25°C) has been subtracted.

Gross calorific value (GCV): The water in the combustion products is treated as liquid. When not specified, 'calorific value' is to be intended as net calorific value.

The **oven-dry calorific value (NCV₀)** of wood of different wood species varies within a very narrow interval, from 18.5 to 19 MJ/Kg. In conifers it is 2% higher than in broad-leaved. This difference is due especially to the higher lignin content - and partly also to the higher resin, wax and oil content - present in conifers. Compared to cellulose (17.2-17.5 MJ/kg) and hemicellulose (16 MJ/kg), lignin has a higher NCV₀ (26-27 MJ/kg). Some variability in the

anhydrous calorific value is also due to the slight variability in hydrogen (H) content and to the comparatively much wider variability in ash contents.

However, when taking into account agricultural biofuels as well, the oven-dry calorific value varies within a 16.5 to 19 MJ/Kg interval. The NCV0 of wood fuels is on average 9% higher than that of herbaceous plants

Ash content and melting point

Among solid biofuels, wood without bark is the one with the lowest ash content, whereas agricultural biofuels typically have high ash content.

During combustion, there occur, on the bed of embers, some physical modifications in the ashes; with the rise in temperature, they soften until the complete fusion of the particles is reached. Using fuels with low ash fusion temperatures increases the risk of **ash slagging** being formed on the grate. Fusion slags disturb the combustion process by altering primary air flows and favouring the overheating of the grate as well as corrosive phenomena.

It is however possible to handle and solve the problems related to the formation of slags by intervening, for example, on cooling the grate and fume recirculation, and by inserting mechanical systems of automatic cleaning (self-cleaning screens) or, in the case of cereal, by using calcium additives.*

Wood and bark have a relatively high melting point (1,300-1,400°C) and thus do not have any criticalities. On the contrary, the melting point of herbaceous plants is below 1,000°C and, consequently, slags can easily be created during combustion. In the case of cereal (grains), the melting point is lower than 750°C and is, thus, particularly critical (table 2.7.1).

For the reasons listed above, agricultural biofuels have higher criticalities as compared to wood, and are only to be used in specific combustion devices.

Ashes characterization and utilization

Ash can be divided into two categories:

Bottom ash

It is a considerable portion of the ash that gathers under the boiler grate and it is channelled into a storage tank. It has a mass density of 1.3 t/m³.

Fly ash

It is the ash that derives from flue gas cleaning and can further be divided into:

- cyclone light ash;
- fine particles from electrostatic and bag filters.

It has a mass density of 0.8-0.9 t/m³.

Ash chemical composition

The components that most affect the environment (lead, cadmium and zinc) are those that are most volatile and predominantly gather in fine ash.



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