- *Wood is usually paid for per tonne.*
- *Harvesters record production in terms of m^3 over bark.*
- *Chip volume is expressed in m^3 loose volume.*
- *The amount of energy in wood chips is the most important factor and is depends largely on moisture content.*

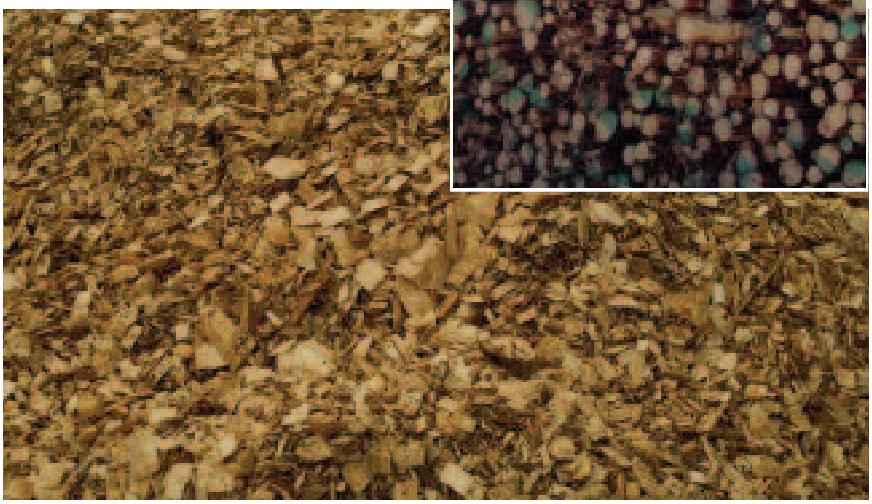
Units, conversion factors and formulae for wood for energy

Pieter D. Kofman[1]

Introduction

The production of energy from wood biomass is becoming increasingly important in Ireland. However, there is considerable confusion about the various units used in the sector. The forest owner is usually paid by the tonne for the wood removed, while a harvester records its production volume in solid cubic metres (over bark). Once the wood fibre is chipped, the volume of chips is expressed in cubic metres (loose volume). What is most important is the *amount of energy* that is contained in those chips. This depends mostly on moisture content. Most people know how much oil, gas, electricity or peat they use to heat their home, but what is the wood equivalent?

This COFORD Connects note explains the conversion factors commonly used in the Irish wood biomass sector.



Wood is usually paid for per tonne, whereas chips are sold according to volume, measured in m^3 loose volume.

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Units

The most commonly used unit for the measurement of wood biomass is the cubic metre solid volume ($m^{3\ s}$). In Ireland, this usually includes bark (expressed as over bark volume). By measuring the mid-diameter and the length of a piece of timber, the volume of a log can be calculated in cubic metres (m^3). An approximation of this volume can be found by using the formula:

$$(0{,}25*\pi*D^2*L) = V\ m^{3\ s}$$

where D is the diameter in m (over bark), L is the length in m and V is the volume. π can be approximated by dividing $^{22}/_{7}$, in which case the formula can be expressed as:

$$(0.7857*D^2*L) = V\ m^{3\ s}$$

When logs are stacked there is air space between them; by measuring the length, height and width of the stack the m^3 stacked volume ($m^{3\ st}$) can be calculated. This amount of wood can then be converted to solid volume ($m^{3\ s}$) by assessing:

1. the quality of the stacking,
2. the length of the logs,
3. the straightness of the logs,
4. the quality of the delimbing.

For conifer pulpwood, a factor of 0.60 is normally used to calculate the amount of solid timber present in a stack of roundwood. However, this factor can vary between 0.48 and 0.65. Using the lower factor implies the presence of crooked and/or long, poorly delimbed or badly stacked logs; while the higher factor implies logs that are short, well delimbed, straight, and neatly stacked.

After wood is chipped, it is then measured in cubic metres loose volume ($m^{3\ lv}$). The air space between the particles increases substantially, so the conversion factor becomes much lower. The factor used depends mostly on the size and quality of the chips produced. The smaller the chips and the lower the quality, the lower the conversion factor - the conversion factor for normal forest chip varies from 0.35 to 0.37. A factor of 0.36 has been used in the calculations.

Pulpwood is often sold by the tonne, which is easy to measure on a weighbridge. However, the weight of logs is highly dependent on moisture content. Wood that has been standing at the roadside for several weeks in spring or summer can lose between 10 and 20% of its original moisture content. Conversion factors are used to convert tonnes to m^3 solid volume. The factor used for such calculations depends not only on moisture content, but also on tree species, site type and silviculture.

Tree species, site type and silviculture largely determine the basic density of wood. This is defined as the amount of dry matter present in a solid cubic metre of timber at 0% moisture content. Slow growing Sitka spruce will have an average basic density of 420 kg/$m^{3\ s}$, while fast grown Sitka spruce has an average basic density of only 350 kg/$m^{3\ s}$. For broadleaves like oak and beech, the basic density is much higher. The ForestEnergy programme showed that the basic density of energy chips varies greatly, but the average is 380 kg/$m^{3\ s}$. This figure includes bark and branch material.

Bulk density is the weight of a cubic metre of loose volume (lv) of chips. This varies with the moisture content of the chips. If an average basic density of 380 kg/$m^{3\ s}$ is assumed, then the bulk density of Sitka spruce chips can vary from 206 kg/$m^{3\ lv}$ at 30% moisture content to 320 kg/$m^{3\ lv}$ at 55% moisture content.

The energy content of wood fibre is expressed in GJ[2] or in MWh[3,4]. All wood has roughly the same gross calorific value per tonne dry matter. This is 19.2 GJ/tonne for conifers and 19.0 GJ/tonne for broadleaves[5].

The net energy content of wood fuel depends greatly on its moisture content. For conifers, the net calorific value per tonne can be calculated using the formula:

$$NCV= 19.2-(0.2164*MC)= x\ GJ/tonne$$

Moisture content (MC) is expressed as a percentage (e.g. 45%) and not as a proportion (e.g. 0.45).

Conversions - wood

If the basic density of wood fibre is known, then all the other units can be calculated from that and conversion factors as detailed above.

As an example, the calculations are illustrated for Sitka spruce with a basic density of 380 kg/$m^{3\ s}$ and starting moisture content levels of 30 and 55% in Figures 1 and 2.

[2] *GJ: Giga Joules.*
[3] *MWh: Mega Watt hours.*
[4] *To convert from GJ to MWh, divide the amount of Giga Joules by 3.6.*
[5] *Coniferous wood contains resins which add to its calorific value.*

Solid volume

1 $m^{3\ s}$ = 2.63 $m^{3\ lv}$ (loose volume) chips

1 $m^{3\ s}$ = 6.91 GJ

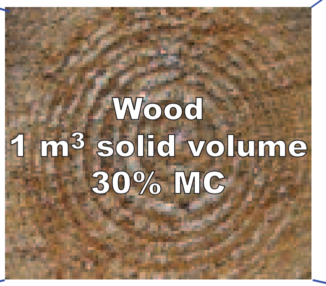
1 $m^{3\ lv}$ = 6.91/2.63 = 2,63 GJ/$m^{3\ lv}$

Loose volume

1 $m^{3\ s}$ = 2.63 $m^{3\ lv}$ chips = 543 kg

1 $m^{3\ lv}$ = 543/2.63 = 206 kg

1000/206 = 4.85 $m^{3\ lv}$/ton



Energy content at 30% MC = 19.2 – (0.2164*30) = 12.71 GJ/ton

1 ton = (1000/543) =1.84 $m^{3\ s}$

1 $m^{3\ s}$= 12.71/1.84 = 6.91 GJ/$m^{3\ s}$

Dry matter content = 380 kg dry matter

Total weight is (380/((100-30)/100)) = 543 kg

1000/571 = 1.84 $m^{3\ s}$/ton

Figure 1: Conversion chips at 30% moisture content.

Solid volume

1 $m^{3\ s}$ = 1/0.36 = 2.63 $m^{3\ lv}$ (loose volume) chips

1 $m^{3\ s}$ = (7.3/1.18) = 6.19 GJ/$m^{3\ s}$

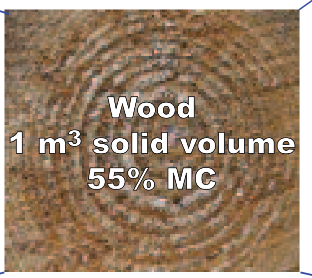
1 $m^{3\ lv}$ = 6.19/2.63 = 2.35 GJ/$m^{3\ lv}$

Loose volume

2.63 $m^{3\ lv}$ chips = 844 kg

1 $m^{3\ lv}$ = 844/2.63 = 320 kg

1000/320 = 3.12 $m^{3\ lv}$/ton



Energy content at 55 % MC = 19.2 – (0.2164*55)=7.3 GJ/ton

1 ton = (1000/844) = 1.18 $m^{3\ s}$

1 $m^{3\ s}$ = 7.3/1.18= 6.19 GJ/$m^{3\ s}$

Dry matter content = 380 kg dry matter

Total weight is (380/((100-55)/100)) = 844 kg/$m^{3\ s}$

1000/844=1.18 $m^{3\ s}$/ton

Figure 2: Conversion chips at 55% moisture content.

Conversions - fossil fuels

The energy content of wood biomass varies greatly depending on its moisture content. In Table 1 the energy content, tonnes, m^3 solid wood and m^3 loose volume are shown for a typical volume of fossil fuels such as oil, natural gas, coal, peat briquettes, electricity and for wood pellets.

It is important to note that not every boiler can handle every moisture content. Therefore, values are shown for a dry fuel boiler (25 or 30% moisture content) for a medium moisture content boiler (45% moisture content) and for a wet fuel boiler (55% moisture content).

By multiplying the figures from Table 1 by actual fossil fuel consumption, one can calculate the amount of wood fuel needed to replace that amount of fossil fuel.

Table 1: The amount of wood fuel needed to replace a standard amount of fossil fuel dependent on the moisture content the boiler is capable of handling.

Fuel		Wood pellets	Wood chips 25%	Wood chips 30%	Wood chips 45%	Wood chips 55%
	Energy content GJ/ton	17.46 GJ	13.64 GJ	12.57 GJ	9.35 GJ	7.21 GJ
	Energy content MWh/ton	4.85 MWh	3.79 MWh	3.49 MWh	2.59 MWh	2.00 MWh
Oil (1,000 litres)	36 GJ/10 MWh	2.06 ton	2.64 ton	2.86 ton	3.85 ton	4.99 ton
			5.20 m$^{3\,s}$	5.26 m$^{3\,s}$	5.58 m$^{3\,s}$	5.89 m$^{3\,s}$
		3.16 m$^{3\,lv}$	13.67 m$^{3\,lv}$	13.83 m$^{3\,lv}$	14.67 m$^{3\,lv}$	15.49 m$^{3\,lv}$
Natural gas (1,000 m^3)	39 GJ/10.83 MWh	2.24 ton	2.86 ton	3.10 ton	4.17 ton	5.41 ton
			5.63 m$^{3\,s}$	5.70 m$^{3\,s}$	6.05 m$^{3\,s}$	6.38 m$^{3\,s}$
		3.45 m$^{3\,lv}$	14.81 m$^{3\,lv}$	15.00 m$^{3\,lv}$	15.90 m$^{3\,lv}$	16.87 m$^{3\,lv}$
Coal, anthracite (1 ton)	27 GJ/7.5 MWh	1.55 t	1.98 ton	2.14 ton	2.89 ton	3.74 ton
			3.90 m$^{3\,s}$	3.93 m$^{3\,s}$	4.19 m$^{3\,s}$	4.41 m$^{3\,s}$
		2.38 m$^{3\,lv}$	10.25 m$^{3\,lv}$	10.35 m$^{3\,lv}$	11.02 m$^{3\,lv}$	11.59 m$^{3\,lv}$
Peat briquettes (1 ton)	17.7 GJ/4.91 MWh	1.01 ton	1.29 ton	1.41 ton	1.89 ton	2.45 ton
			2.54 m$^{3\,s}$	2.59 m$^{3\,lv}$	2.74 m$^{3\,s}$	2.89 m$^{3\,s}$
		1.56 m$^{3\,lv}$	6.68 m$^{3\,lv}$	6.81 m$^{3\,lv}$	7.20 m$^{3\,lv}$	7.60 m$^{3\,lv}$
Electricity (1,000 kWh)	3.6 GJ/1 MWh	0.21 ton	0.26 ton	0.29 ton	0.38 ton	0.50 ton
			0.52 m$^{3\,s}$	0.53 m$^{3\,s}$	0.56 m$^{3\,s}$	0.59 m$^{3\,s}$
		0.31 m$^{3\,lv}$	1.36 m$^{3\,lv}$	1.39 m$^{3\,lv}$	1.47 m$^{3\,lv}$	1.55 m$^{3\,lv}$
Wood pellets (1 ton)	17.46 GJ/4.85 MWh	1 ton	1.28 ton	1.39 ton	1.87 ton	2.42 ton
			2.52 m$^{3\,s}$	2.55 m$^{3\,s}$	2.71 m$^{3\,s}$	2.85 m$^{3\,s}$
		1.54 m$^{3\,lv}$	6.63 m$^{3\,lv}$	6.70 m$^{3\,lv}$	7.12 m$^{3\,lv}$	7.49 m$^{3\,lv}$

For information and a free on-line advisory service on the wood energy supply chain, the quality of wood fuels and internal handling visit ***www.woodenergy.ie***