AEBIOM

WOOD FUELS HANDBOOK

PRODUCTION | QUALITY REQUIREMENTS | TRADING

Biomass Trade Centres

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Supported by

eaci

Intelligent Energy Europe

EIE/07/054

Publisher
AIEL - Italian Agriforestry Energy Association
Agripolis - Viale dell'Università 14
I-35020 Legnaro (Pd) - Italy
www.aiel.cia.it

Graphic design
Marco Dalla Vedova

Print
Litocenter Srl - Limena (Pd)

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INTRODUCTION

Biomass is already the most important Renewable Energy Source in Europe with a huge potential for further expansion. The future development of Biomass should follow some basic principles such as high conversion efficiency, competitiveness and sustainability. The experience proves that the use of biomass to produce heat complies in an optimal way with these principles.

Biomass for heat can be used in small scale units for individual houses, in heat contracting projects, in district heating and in the industry. In any case the supply of high quality biomass be it firewood, wood chips or refined wood is of essential importance for the rapid growth of this market. To guarantee the availability of high quality feed stock for the consumers new structures for trading are necessary. The concept of biomass trade centers offers the opportunity to match on a local or regional level the supply and demand of firewood, woodchips and other forms of wood to the benefit of the consumers and the producer. Transparent rules about the quality of the feedstock and its specification are needed to gain the confidence of the consumers to this new local energy carriers.

The presented handbook on biomass trade centers offers all the information needed to develop this promising new energy market. AEBIOM thanks all participants of the project and hopes that this publication encourages many farmers, forest owners and decision makers on the community level to promote locally grown biomass as the energy carrier for a sustainable heat supply of the future. The realization of such a concept creates new jobs, avoids greenhouse gas emissions, lowers the cost of heating and improves the security of the supply of energy.

Heinz Kopetz
Chairman of AEBIOM
European Biomass Association

FOREWORD

This Handbook is one of the main deliverables of the Biomass Trade Centres project, which is supported by the European Agency for Innovation and Competitiveness (EACI) in the frame of the Intelligent Energy Europe programme.
This publication is aimed at improving the professionalism of the log woods and wood chips supply chain on a regional scale by supporting the implementation on the market of European Technical Specification CEN/TS 14961 and enabling, at the same time, a better match between supply and demand.
Producers are asked to supply wood fuels according to qualitative classification of solid biofuels, therefore suitable to heating appliance requirements. In order to encourage the installation of new modern wood heating systems, it is essential that the supply of log woods and wood chips meet the confidence of costumers and investors in the local availability of wood fuels of proper quality.
Wood heating system manufactures, particularly those who produce small to medium scale devices, need that the wood fuels available on the market meet the quality standards to which the heating appliances developed by themselves have been tested and certified (efficiency and emission factor).
As successful experience - at European level - has clearly demonstrated, the creation of Biomass Logistic&Trade Centres (BL&TC) makes it possible to set up a professional wood fuel spot market, thus providing customers with a costumer-friendly service and ensuring the delivery and quality standards of wood fuels.
A market more transparent in terms of prices and trading conditions will enhance a steady growth of the biomass sector.

Legnaro (Padova, Italy), January 2009

Valter Francescato, Eliseo Antonini
project coordinators

1. UNITS OF MEASUREMENT

1.1 Volume

The **solid cubic meter** (m^3) is used with reference to the volume that is entirely occupied by wood. This unit of measurement is commonly used for timber.
The stere, which refers to the volume occupied by wood as well as by air space, void space being considered as filled space, is instead typically used for wood fuels.
The **stacked cubic meter** (stacked m^3) is the unit of measurement used for neatly-stacked log woods.
The **bulk cubic meter** (bulk m^3) is the unit of measurement used for log woods and, more typically, wood chips.
The volume of wood fuels, whether densified or not, varies according to the shape, size and arrangement of the single pieces of wood. The steric volume, i.e. the ratio between filled and void volume, depends on these factors.

1.2 Weight

The units of weight used for wood fuels are the kilogram and the metric ton.

Listed below are the units of measurement for volume and weight that are commonly used in the marketing of wood fuels.

Units of measurement			
Ton	Kilogram	Stacked cubic meter	Bulk cubic meter
t	kg	stacked m^3	bulk m^3
log woods chips pellets and briquettes		log woods	chips log woods

1.3 Weight/volume ratios

Three different units of measurement can be used to express the weight/volume ratio of wood fuels:

Specific gravity: it is an adimensional value resulting from the ratio between the weight and volume of water (at 4°C) and of woody substance. It refers to the weight of the woody substance in the oven-dry state – mainly cellulose, hemicellulose and lignin – which make up the cell walls. The specific gravity of such substance is 1.5 and this same value applies to all the different species.

Mass density: It refers to the ratio between the weight and volume of the wood body (porous body) made up of a set of substances and voids (vascular cavities) variously filled with air and/or water. It is expressed in units of g/cm^3 or kg/m^3.
Mass density is frequently referred to as apparent specific gravity or even, and erroneously, merely as specific gravity.
As for wood pellets, mass density relates to the weight of one single piece of wood, which must be over 1.15 g/cm^3; in the case in point, when released in a container full of water, the piece of wood sinks rapidly.

Bulk density: It is used for piles of wood fuels (log woods and wood chips) that create voids among the wood pieces which may be bigger or smaller depending on the size and shape of the latter.
It is expressed in either kg/stacked m^3 or kg/bulk m^3, depending on whether the pile is stacked or bulk.

1.4 Volume terminology

In order to make uniform and comparable any references to the units of measurement used in the wood energy field, the following definitions are provided, which correspond to those in use in some European countries (table 1.4).

Table 1.4 Volume terminology in six languages

ENGLISH	Symbol	GERMAN	Symbol
Solid cubic meter	Solid m^3	Festmeter	Fm
Bulk cubic meter	Bulk m^3	Schüttraummeter	Srm
Stacked cubic meter	Stacked m^3	Schichtraummeter	rm
ITALIAN	**Symbol**	**SLOVENIAN**	**Symbol**
Metro cubo	m^3	Kubični meter	m^3
Metro stero riversato	msr	Prostrni meter	prm
Metro stero accatastato	msa	Nasut kubični meter	Nm^3
FRENCH	**Symbol**	**POLISH**	**Symbol**
Mètre cube de bois plein	m^3	metr sześcienny	m^3
Mètre cube apparent plaquette	MAP	metr nasypowy	mn
Stère	stère	metr przestrzenny	mp

1.5 Mass density of the main forestry species

Table 1.5.1 CONIFERS – mean values with moisture content (M) 13%[1]

SPECIES	kg/m^3	SPECIES	kg/m^3
Norway spruce	450	Cypress	600
Silver fir	470	Stone pine	620
Arolla pine	500	Larch	660
Douglas-fir	510	Maritime pine	680
Scots pine	550	Yew	700
Black pine	560	Aleppo pine	810

Table 1.5.2 BROADLEAVED – mean values with moisture content (M) 13%[1]

SPECIES	kg/m^3	SPECIES	kg/m^3
Willows	450	Hackberry	720
White poplar	480	Ash	720
Black poplar	500	Manna ash	720
Speckled alder	520	Laburnum	730
Italian alder	550	Field maple	740
Black Alder	560	Beech	750
Chestnut	580	Sessile oak	760
Cherry	600	Black locust	760
Elm	620	Peduncolate oak	770
Elder	620	Rowans	770
Birch	650	Common hornbeam	800
Lime	650	Hophornbeam	820
Hazel	670	Turkey oak	900
Sycamore Maple	670	Olive	920
Planes	670	Holm oak	940
Walnut	700	Cornel	980

Table 1.5.3 Mean mass density of oven-dry wood (ÖNORM* B 3012)

	Species (oven-dry wood, M=0)	kg/m^3
Conifers	Black Pine	560
	Larch	550
	Scots Pine	510
	Douglas-fir	470
	Norway Spruce	430
	Silver Fir	410
	Arolla pine	400
Broadleaved	Common hornbeam	750
	Turkey Oak	740
	Black locust	730
	Beech	680
	Oak	670
	Ash	670
	Elm	640
	Birch	640
	Maple	590
	Hazel	560
	Lime	520
	Willow	520
	Alder	490
	Aspen	450
	Poplar	410

* ÖNORM: Austrian Standards Institute - Österreichisches Normungsinstitut

1.6 Bulk density of the main solid biofuels[2]

Table 1.6

Wood fuels	M %	Specie	Bulk density (kg/bulked m^3)
Log woods (33 cm piled)	15	Beech	445*
		Spruce and fir	304*
Wood chips	30	Beech	328
		Spruce and fir	223
Conifers' bark	15		180
Saw dusts			160
Shavings			90
Pellets	8		620-650
Agriculture biomass			
Bales	15	Miscanthus	140
Hog biomass		Miscanthus	110
Grain		Triticale	750

* kg/stacked m^3

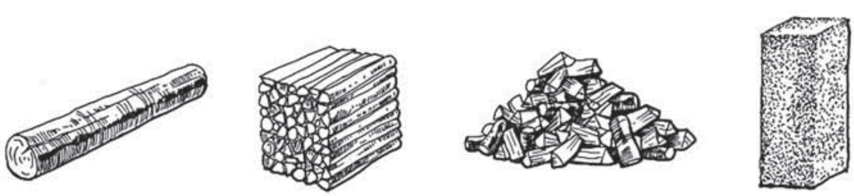
1.7 Roundwood/log woods/wood chips conversion rates

Table 1.7.1 provides the indicative conversion factors for the most common wood energy assortments mentioned in the annex to Austrian standards ÖNORM M7132 and M7133[3].

Table 1.7.1 Roundwood/log woods/wood chips conversion rates

Assortments	Round-wood	One-meter log woods	Chopped log woods		Wood chips	
			stacked	bulked	fine (G30)	medium (G50)
	m^3	stacked m^3	stacked m^3	bulk m^3	bulk m^3	
1 m^3 roundwood	1	1.4	1.2	2.0	2.5	3.0
1 stacked m^3 one-meter log woods	0.7	1	0.8	1.4	(1.75)	(2.1)
1 stacked m^3 chopped log woods	0.85	1.2	1	1.7		
1 bulk m^3 chopped log woods	0.5	0.7	0.6	1		
1 bulk m^3 forest chips fine (G30)	0.4	(0.55)			1	1.2
1 bulk m^3 forest chips medium (G50)	0.33	(0.5)			0.8	1

Note: 1 ton of wood chips G30 with M 35% corresponds to around 4 bulk m^3 of spruce wood chips and 3 bulk m^3 of beech wood chips.



1 m^3 roundwood ≈ 1.4 stacked m^3 one-meter log woods ≈ 2 bulk m^3 chopped log woods ≈ 3 bulk m^3 forest chips medium (G50)

Conversion factors for the main primary lumber manufacturing by-products[3]

1 stacked m^3 of bundle slabs	= 0.65 m^3	of roundwood
1 bulk m^3 of saw wood chips G50	= 0.33 m^3	
1 bulk m^3 of fine saw-dusts (≤5mm)	= 0.33 m^3	
1 bulk m^3 of shavings	= 0.20 m^3	
1 bulk m^3 of bark	= 0.30 m^3	

Table 1.7.2 Conversion factors for log woods (with bark)[2]

Species	Roundwood (m^3)	Round long-wood (stacked m^3)	One-meter log woods (stacked m^3)	Chopped log woods 33 cm (stacked m^3)	Chopped log woods 33 cm (bulk m^3)
Ref. to 1 m^3 roundwood with bark					
Beech	1.00	1.70	1.98	1.61	2.38
Spruce		1.55	1.80	1.55	2.52
Ref. to 1 stacked m^3 round long-wood					
Beech	0.59	1.00	1.17	0.95	1.40
Spruce	0.65		1.16	1.00	1.63
Ref. to 1 stacked m^3 one-meter log woods stacked					
Beech	0.50	0.86	1.00	0.81	1.20
Spruce	0.56	0.86		0.86	1.40
Ref. to 1 stacked m^3 chopped log woods 33 cm stacked					
Beech	0.62	1.05	1.23	1.00	1.48
Spruce	0.64	1.00	1.16		1.62
Ref. to 1 bulk m^3 chopped log woods 33 cm bulk					
Beech	0.42	0.71	0.83	0.68	1.00
Spruce	0.40	0.62	0.72	0.62	

Table 1.7.3 Mass and bulk density of main tree species[2]

Moisture M %	Beech			Oak			Spruce			Pine		
	m^3	Fw stacked m^3	Cw bulk m^3	m^3	Fw stacked m^3	Cw bulk m^3	m^3	Fw stacked m^3	Cw bulk m^3	m^3	Fw stacked m^3	Cw bulk m^3
Mass and bulk density in kg*												
0	680	422	280	660	410	272	430	277	177	490	316	202
10	704	437	290	687	427	283	457	295	188	514	332	212
15	716	445	295	702	436	289	**472**	304	**194**	527	340	217
20	730	453	300	724	450	298	488	315	201	541	349	223
30	798	495	328	828	514	341	541	349	223	615	397	253
40	930	578	383	966	600	397	631	407	260	718	463	295
50	1117	694	454	1159	720	477	758	489	312	861	556	354

The equivalence 1 m^3 roundwood=2.43 bulk m^3 (volumetric index=0.41 m^3/ bulk m^3) of wood chips has been used. Initials: Fw=chopped log woods (33 cm, stacked), Cw=wood chips.

* Within the moisture range (M) 0-23%, the values have been calculated based on dry woody mass listed in table 1.5.3. The mass and bulk densities (with water) calculated have been corrected using the following swelling factors: beech 21.8%, oak 13.9%, spruce 13.5%, pine, 13.8%, assuming a linear variation of volume within the moisture range considered.

Example 1.7.1 – Analytical calculation of bulk density within the moisture range M 0-23%

With reference to the note (*) of table 1.7.3 and for a better understanding of mass and bulk density calculation within the moisture range M 0-23%, an example of how to calculate the bulk density of spruce chips at M 15% has been provided below.

Starting parameters

Dry mass density (table 1.5.3) = 430 kg/m^3

Swelling factor = 13.5% (chap. 2.4)

Volumetric index = 0.41 m^3/bulk m^3

Moisture (M) 15% → moisture d.b. (u) = 17.65% (chap. 2.5)

Calculation of mass density at M 15%

Mv_{15} = 430 kg/m^3 x [1+(17.65:100)] = 430 x 1.1765 = 506 kg/m^3

Calculation of volumetric correction factor (swelling)

Fcv = 1+ [(13.5:100):30] x 17.65 = 1.07

Calculation of corrected mass density (with water)

$Mv_{15\ corr}$ = Mv_{15} : Fv = 506 : 1.07 = **472** kg/m^3

Calculation of spruce chips bulk density at M 15%

Spruce bulk density = 472 kg/m^3/2.43 = **194** kg/bulk m^3

Example 1.7.2 – Measurement of chips bulk density through sampling

a) Use a bucket of known volume (e.g. 13 l) and a pair of scales.

b) Take a representative sample from the truck container, e.g. 3 buckets from a 40 m^3 container (ref. CEN/TS 14778-1), and fill in the bucket without compacting the chips

c) Weigh the samples and divide their mean value (kg) by the known volume (l) – e.g. (3.25 kg x1000 l) : 13 l = 250 kg/msr

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

Table 2.1.1 Conversion factors of thermal energy units

	kJ	kcal*	kWh	toe
1 kJ	1	0.239	0.278×10^{-3}	23.88×10^{-9}
1 kcal(*)	4.1868	1	1.163×10^{-3}	0.1×10^{-6}
1 kWh	3,600	860	1	86×10^{-6}
1 toe	41.87×10^{6}	10×10^{6}	11.63×10^{3}	1

* The calorie is a pre-SI unit of energy.

Most common conversions

1 kWh	= 860 kcal	= 3,600 kJ (3,6 MJ)
1 MJ	= 239 kcal	= 0.278 kWh
1 kcal	= 4.19 kJ	= 0.00116 kWh
1 toe	= 41.87 GJ	= 11.63 MWh

The **ton of oil equivalent (toe)** is a conventional unit of measurement used for statistical-comparative purposes. It corresponds to the amount of energy released by burning one ton of crude oil.

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)

Table 2.2.1 Equivalences among the most used thermal energy units

	kWh	MWh	GWh	TWh	TJ	PJ	toe
1 kWh	1	$1x10^{-3}$	$1x10^{-6}$	$1x10^{-9}$	$3{,}6x10^{-6}$	$3{,}6x10^{-9}$	$86x10^{-6}$
1 MWh	$1x10^{3}$	1	$1x10^{-3}$	$1x10^{-6}$	$3{,}6x10^{-3}$	$3{,}6x10^{-6}$	$86x10^{-3}$
1 GWh	$1x10^{6}$	$1x10^{3}$	1	$1x10^{-3}$	3,6	$3{,}6x10^{-3}$	86
1 TWh	$1x10^{9}$	$1x10^{6}$	$1x10^{3}$	1	$3{,}6x10^{3}$	3,6	$86x10^{3}$
1 TJ	$278x10^{3}$	278	$278x10^{-3}$	$278x10^{-6}$	1	$1x10^{-3}$	23.9
1 PJ	$278x10^{6}$	$278x10^{3}$	278	$278x10^{-3}$	$1x10^{3}$	1	$23.9x10^{3}$
1 ton	$11.6x10^{3}$	11.6	$11.6x10^{-3}$	$11.6x10^{-6}$	$41.87x10^{-3}$	$41.87x10^{-6}$	1

Thermal power (Q) is the ratio between the thermal energy that is produced and the time spent to produce it. It expresses the amount of final heat transmitted to a thermal vector.

Unit of power $$Watt = \frac{Joule}{second}$$

Gross boiler capacity (Q_B) indicates the power released by a fuel at firebox.
Nominal thermal capacity (Q_N) expresses the maximum amount of thermal energy per unit of time continuously produced by a boiler through combustion.
Boiler efficiency (η_k) expresses the ratio between the useful thermal power (Q) and the capacity at firebox (Q_B).

The boiler capacity is usually expressed in kW, although kcals are still used, improperly, as a unit to measure it. In order to convert kcals into Watts, the SI unit of energy, the following equation is used:

1 kcal	=	1.163 W		1 kW	=	860 kcal

A 100,000 kcal boiler has a capacity of 116,280 W [= 116 kW]

Example 2.2.1 – Calculation of heat supply by boiler
A boiler with a capacity of 100 kW operating at full load for 1,000 hours produces an amount of gross heat of 100 kW x 1,000 h = 100,000 kWh = 100 MWh

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%. As illustrated by the figure 2.3.2, water loss inside wood is not uniform.

Figure 2.3.1
Three-dimensional structure of conifers' wood[1]

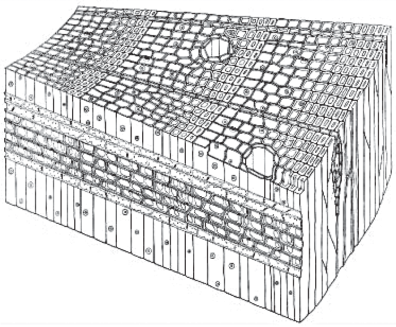
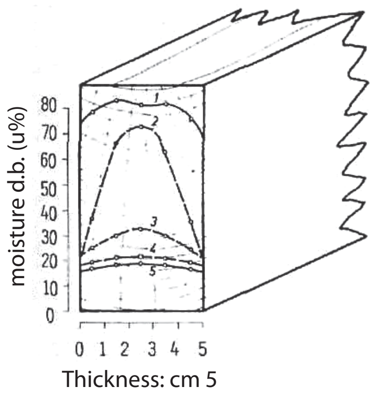


Figure 2.3.2 Development in radial sense, moisture on d.b. (u) into a piece of beech board

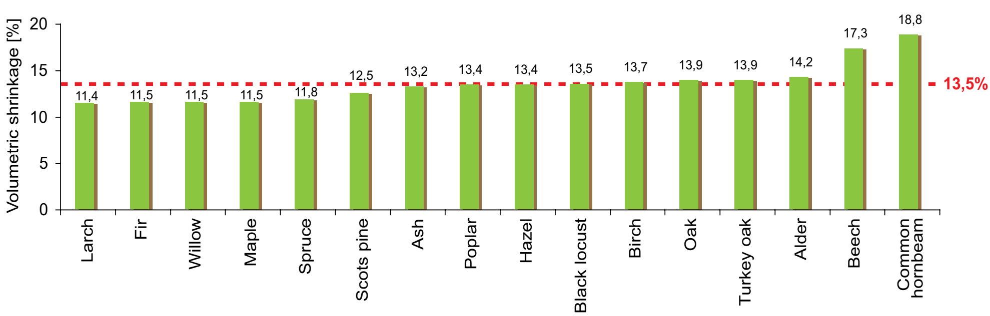
LEGEND
1. after 6 weeks
2. after 6 months
3. intermediate period 2-4
4. after 1 year
5. after 1.5 year[4]



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 (β_v) 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 (α_v)*.
The shrinkage of the single pieces in a log woods stack or wood chips pile entails an overall decrease in the volume of the pile that is almost always lower than that of the single pieces[5].

Figure 2.4.1 Volumetric shrinkage in some tree species[3]



* Shrinkage and swelling are linked by the following formulas: $\beta_v = (100x\alpha_v):(100+\alpha_v)$; $\alpha_v = (100x\beta_v):(100-\beta_v)$

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 (tables 1.7.3 and 2.9.1, example 1.7.1).

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.

$$u = \frac{Ww\text{-}W0}{W0} \times 100$$

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.

$$M = \frac{Ww\text{-}W0}{Ww} \times 100$$

Wherein:

Ww = wet weight of wood

W0 = oven-dry weight of wood

Conversion formulas

The following two formulas are used to calculate u from M and vice verse.

$$u = \frac{100xM}{100\text{-}M} \qquad M = \frac{100xu}{100+u}$$

M %	15	20	25	30	35	40	45	50	60
u %	18	25	33	43	54	67	82	100	150

u %	15	20	30	40	50	65	80	100	150
M %	13	16	23	28	33	39	44	50	60

Assuming that the mass of newly-chopped fresh wood is made up half by water and half by wood substance, wood has a moisture on w.b. (M) of 50% and a moisture on d.b. (u) of 100%.

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 (table 2.6.1).

Table 2.6.1 Chemical composition of solid biomass[2]

	C	H	O	N	K	S	Cl
	wt% (d.b.)						
Spruce (with bark)	49.8	6.3	43.2	0.13	0.13	0.015	0.005
Beech (with bark)	47.9	6.2	43.3	0.22	0.22	0.015	0.006
Poplar SRC	47.5	6.2	44.1	0.42	0.35	0.031	0.004
Willow SRC	47.1	6.1	44.2	0.54	0.26	0.045	0.004
Bark (coniferous trees)	51.4	5.7	38.7	0.48	0.24	0.085	0.019
Typical values for virgin wood materials Coniferous wood *	47-54	5.6-7.0	40-44	<0.1-0.5		<0.01-0.05	<0.01-0.03
Typical values for virgin wood materials Deciduous wood *	48-52	5.9-6.5	41-45	<0.1-0.5		<0.01-0.05	<0.01-0.03
Typical values for virgin bark materials*	51-56	5.9-6.5	36-43	0.3-1.2		0.02-0.20	<0.01-0.05
Typical values for virgin wood materials Logging residues*	50-53	5.9-6.3	40-44	0.3-0.8		0.01-0.08	<0.01-0.04
Typical values for virgin wood materials Short rotation coppice*	47-51	5.8-6.7	40-46	0.2-0.8		0.02-0.10	<0.01-0.05
Miscanthus	47.5	6.2	41.7	0.73	0.70	0.150	0.220
Wheat straw	45.6	5.8	42.4	0.48	1.00	0.082	0.190
Triticale (grains)	43.5	6.4	46.4	1.68	0.60	0.110	0.070
Rape cake	51.5	7.4	30.1	4.97	1.60	0.550	0.019
For comparison, fossil fuels							
Coal	72.5	5.6	11.0	1.30	-	0.940	< 0,1
Lignite	65.9	4.6	23.0	0.70	-	0.390	< 0,1
Heating oil	85-86	11-13	1-4	-	-	-	-
Natural gas	75	25	-	-	-	-	-

* CEN/TS 14961:2005 Solid biofuels - Fuel specifications and classes – Annex C

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 SO_2 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** (NCV_0) 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 NCV_0 (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 NCV_0 of wood fuels is on average 9% higher than that of herbaceous plants.

Table 2.7.1 Calorific value, ash content and ash-melting point of various biomass fuels[2, 6, 7, 20]

	NCV_0 MJ/kg	Ash (wt% d.b.)	Ash-melting point (°C)
Typical values for virgin wood materials Coniferous wood	19.2 (18.8-19.8)	0.3 (0.2-0.5)	
Typical values for virgin wood materials Deciduous wood	19 (18.5-19.2)	0.3 (0.2-0.5)	
Typical values for virgin bark materials	20 (19-21)	4-5 (2-10)	
Typical values for virgin wood materials Logging residues	19-20	1.5-2	
Typical values for virgin wood materials Short rotation coppice (SRC) (Willow and Poplar)	18.6-19.2	2	
Spruce (with bark)	18.8	0.6	1,426
Beech (with bark)	18.4	0.5	1,340
Poplar (SRC)	18.5	1.8	1,335
Willow (SRC)	18.4	2.0	1,283
Bark (coniferous trees)	19.2	3.8	1,440
Vine wood (chips)	19.8	3.4	1,450
Miscanthus	17.6	3.9	973
Wheat straw	17.2	5.7	998
Triticale (grains)	16.9	2.1	730
Rape cake	21.2	6.2	-

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/m^3.

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/m^3.

* Ca and Mg usually increase ash fusion temperature.

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 (table 2.7.2).

Table 2.7.2 Chemical composition of various biomass ashes[6, 9, 10]

Elements	m.u.	Bark	Wood chips	Saw dust	Straw
pH	in $CaCl_2$	12.7	12.8	12.5	11.2
C_{org}	wt% d.b.	0.8	1.3	5.9	5.2
CO_2		4	7.2	12.5	1
P_2O_5		1.7	3.6	2.5	2.7
K_2O		5.1	6.7	7.1	11.5
CaO		42.2	44.7	35.5	7.4
MgO		6.5	4.8	5.7	3.8
Na_2O		0.8	0.6	0.5	0.3
Al_2O_3		7.1	4.6	2.3	1.2
SiO_2		26.0	25.0	25.0	54.0
SO_3		0.6	1.9	2.4	1.2
Fe_2O_3		3.5	2.3	3.7	1
MnO		1.5	1.7	2.6	0.1
Cu	$mg/kg_{d.b.}$	87.8	126.8	177.8	23.2
Zn		618.6	375.7	1429.8	234.6
Co		23.9	15.3	16.7	1.5
Mo		4.8	1.7	3.4	7.1
As		11.4	8.2	7.8	5.4
Ni		94.1	61.5	71.9	3.9
Cr		132.6	54.1	137.2	12.3
Pb		25.3	25.4	35.6	7.7
Cd		3.9	4.8	16.8	0.7
V		58.4	42.0	26.7	5.5

2.8 Analytical calculation of calorific value

In order to calculate the net calorific value (MJ/kg) of wood with given moisture content (M) the following formula is used[2]:

$$NCV_M = \frac{NCV_0 x(100\text{-}M)\text{-}2{,}44xM}{100}$$

Figure 2.8.1 **Net calorific value (NCV_0=19 MJ/kg) as a function of dry and wet basis moisture (M and u)[5]**

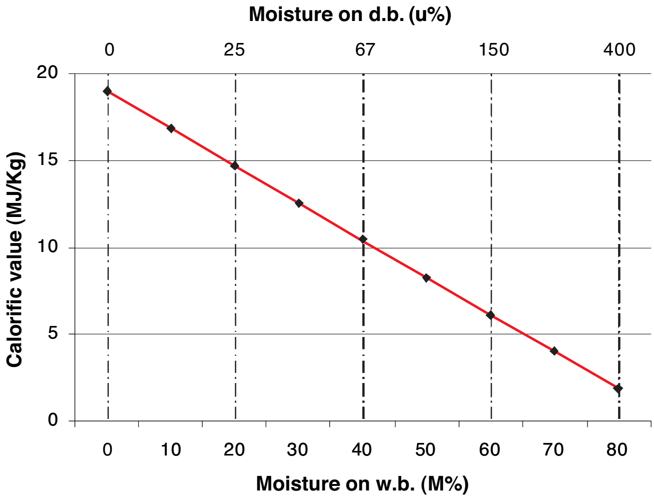
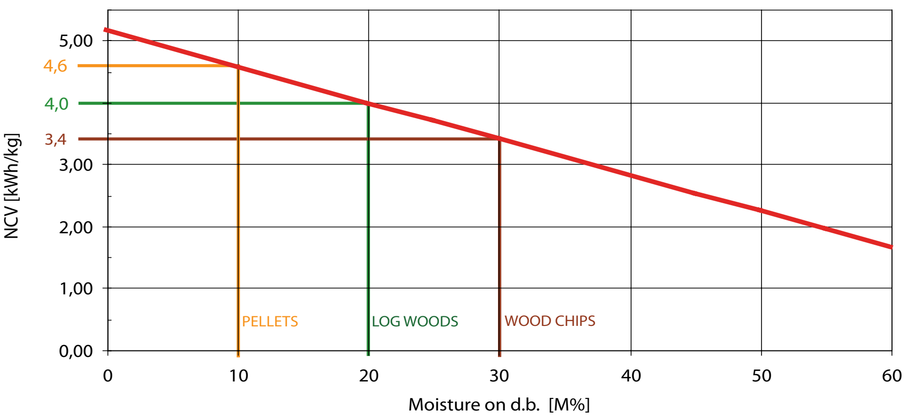


Figure 2.8.2 **Net calorific value (NCV_o = 5.14 kWh/kg) as a function of moisture (M)**



During seasoning, the 10% decrease in moisture entails an approximate 0.6 kWh/kg (2.16 MJ/kg) increase in energy content.

Table 2.8.1 Net calorific value (NCV_0 = 18.5 MJ/kg) as a function of moisture (M)

M (%)	MWh/t	GJ/t	M (%)	MWh/t	GJ/t
15	4.27	15.36	38	2.93	10.54
16	4.21	15.15	39	2.87	10.33
17	4.15	14.94	40	2.81	10.12
18	4.10	14.73	41	2.76	9.91
19	4.04	14.52	42	2.70	9.71
20	3.98	14.31	43	2.64	9.50
21	3.92	14.10	44	2.58	9.29
22	3.86	13.89	45	2.52	9.08
23	3.80	13.68	46	2.47	8.87
24	3.75	13.47	47	2.41	8.66
25	3.69	13.27	48	2.35	8.45
26	3.63	13.06	49	2.29	8.24
27	3.57	12.85	50	2.23	8.03
28	3.51	12.64	51	2.17	7.82
29	3.45	12.43	52	2.12	7.61
30	3.40	12.22	53	2.06	7.40
31	3.34	12.01	54	2.00	7.19
32	3.28	11.80	55	1.94	6.98
33	3.22	11.59	56	1.88	6.77
34	3.16	11.38	57	1.82	6.56
35	3.11	11.17	58	1.77	6.35
36	3.05	10.96	59	1.71	6.15
37	2.99	10.75	60	1.65	5.94

For practical purposes the following average values are used for wood fuels:

NCV_0 = 18.5 MJ/kg = 5.14 kWh/kg	OVEN-DRY WOOD	(M 0%)
NCV_{10} = 16.9 MJ/kg = 4.6 kWh/kg	PELLETS	(M 10%)
NCV_{20} = 14.4 MJ/kg = 4 kWh/kg	WOOD LOGS	(M 20%)
NCV_{30} = 12.2 MJ/kg = 3.4 kWh/kg	WOOD CHIPS	(M 30%)

In order to convert MJ into kWh and vice verse the conversion factor to be used is 3.6.

Example – conversion MJ-kWh
18.5 MJ : 3.6 = 5.14 kWh
4 kWh x 3.6 = 14.4 MJ
1 kWh/kg = 1 MWh/t

2.9 Energy density

It expresses the ratio between the fuel energy content and the volume occupied by the fuel.

Table 2.9.1 Energy density at different moisture content in various wood fuels[2]

Wood fuels	Quantity	Moisture	Mass	NCV	Energy density*		
		M%	kg	MJ/kg	MJ	kWh	liter of oil
Stacked log woods							
Beech 33 cm	1 stacked m^3	15	445	15.3	6,797	1,888	189
Beech 33 cm	1 stacked m^3	30	495	12.1	6,018	1,672	167
Spruce 33 cm	1 stacked m^3	15	304	15.6	4,753	1,320	132
Spruce 33 cm	1 stacked m^3	30	349	12.4	4,339	1,205	121
Wood chips							
Beech	1 bulk m^3	15	295	15.3	4,505	1,251	125
Beech	1 bulk m^3	30	328	12.1	3,987	1,107	111
Spruce	1 bulk m^3	15	194	15.6	3,032	842	84
Spruce	1 bulk m^3	30	223	12.4	2,768	769	77
Wood pellets	1 bulk m^3	8	650	17.1	11,115	3,088	309

* In the range M 0-23% the relative correction factors have been applied.

2.10 Energy equivalences[3]

Fuels	Net calorific value (mean values)	
	MJ	kWh
Heating oil extra light	36.17 MJ/l (42.5 MJ/kg)	10 kWh/l (11.80 kWh/kg)
Heating oil light	38.60 MJ/l (41.5 MJ/kg)	10.70 kWh/l (11.50 kWh/kg)
Natural Gas**	36.00 MJ/m^3	10.00 kWh/m^3
LPG***	24.55 MJ/l (46.30 MJ/kg)	6.82 kWh/l (12.87 kWh/kg)
Coal	27.60 MJ/kg	7.67 kWh/kg
Coke 40/60	29.50 MJ/kg	8.20 kWh/kg
Lignite (briquettes)	20.20 MJ/kg	5.60 kWh/kg
1 kWh electricity	3.60 MJ	1 kWh
1 kg wood (M = 20%)	14.40 MJ/kg	4.00 kWh/kg

** 1 kg = 5.8 l (20 °C, 216 bar)
*** 1m^3 LPG = 4 l = 2 kg

1 kg heating oil ≈ 3 kg wood
1 l heating oil ≈ 2.5 kg wood

For approximate calculation the following correspondences can be used, which do not take into account the boiler efficiency.

1.000 liter heating oil ≈	5-6 bulk m^3 broad-leaved log woods
	7-8 bulk m^3 conifers log woods
	10-15 bulk m^3 wood chips
	2.1 t pellets

Example 2.9.1 – Calculation of the wood chips requirements of a boiler

The wood chips requirements of a boiler may be calculated based on previous fossil fuel consumption.

a) Calculation of thermal charge based on previous heating oil demand (average of last three years)

- heating oil consumption: 23,530 l/year
- NCV of oil: 10 kWh/l
- plant efficiency η_k: 85%

kWh supplied: (23,530 x 10) x 0.85 = 200,000 kWh/year

b) Calculation of wood chips consumption

- heat to be supplied: 200,000 kWh/year
- NCV of wood chips (M 30%): 3.4 kWh/kg
- plant efficiency η_k: 80%

Wood chips requirements: 200,000/3.4/0.80 = 73,530 kg (≈ 75 t)

c) Approx. calculation of boiler capacity (1500 operating hours)

Q (kW) = 200,000 kWh/1,500 h/0.80 ≈ 160 kW

For the calculation of wood chips requirement in small-medium size plants, the following empiric formulas may be used:

Boiler capacity in kW x 2.5 = wood chips requirement in bulk m^3/year (softwood P45, M30)
Boiler capacity in kW x 2.0 = wood chips requirement in bulk m^3/year (hardwood P45, M30)

3. LOG WOODS AND WOOD CHIPS PRODUCTION

3.1 Working phases and working systems

With reference to forest harvesting operations, it is possible to differentiate between the following working phases:

- felling: cutting a tree from its stump so that the tree falls to the ground;
- processing: delimbing (removing branches from the trunk and topping it) and cross-cutting (cutting the trunk to predetermined lengths);
- bridling: transporting wood from felling site to extraction routes;
- hauling: transporting wood along extraction routes to the landing site;
- debarking: partially or completely removing the bark from a log;
- transporting: moving wood using forest roads and public roads;
- transforming: reducing wood for fuel destination (cutting, splitting, chipping).

The importance of chipping operation has been growing in the last few years. This is due to the fact that chipping makes it possible to exploit and make the most of woody biomass otherwise unused.

There are two main working systems in forest harvesting operations:

- Short Wood System - SWS: processing is completed on the falling site in the forest and commercial logs are hauled;
- Full Tree System - FTS: after felling the whole tree is hauled and processing is performed either on the forest road or on the landing site.

Although in Italy SWS is the most predominantly used system, the FTS system is becoming more and more common, particularly in the Alpine area, especially when yarding with cable cranes: with this method, forest residues (branches and tops) are collected either at the roadside or at the landing site, ready to be chipped.

3.2 Machines and equipment

A review of the most important machines and equipment involved in forest harvesting operations, with reference to the Italian context, is presented in table 3.2.1. For each datum the range of the most frequent values is indicated, leaving extreme values out. Hourly cost, when specified, includes the operator's wage. All prices are exclusive of VAT.

Table 3.2.1

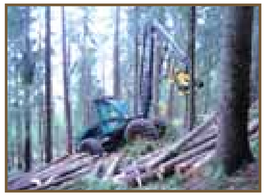
Chainsaw
purchase cost: 500-900 €
productivity in high forest:
1-1.2 solid m^3/h (thinning)
2-2.5 solid m^3/h (main felling)
productivity in coppice:
0.4-0.7 stacked m^3/h (average cond.)
0.8-1.8 stacked m^3/h (good cond.)
fuel consumption per hour:
0.6-1 l (petrol and oil mixture)
hourly cost: ≈ 18-20 €


Tractor and winch
tractor purchase cost: 45,000-60,000 €
winch purchase cost: 3000-4200 €
productivity in high forest: 2.5-6 solid m^3/h
productivity in coppice: 3-7 stacked m^3/h
fuel consumption per hour: 4-9 l
hourly cost: ≈ 45-50 € (2 operators)


Tractor and trailer
tractor purchase cost: 45,000-60,000 €
trailer purchase cost: 8,000-25,000 €
loading capacity: 5-15 t
productivity: 5-12 solid m^3/h
(depending on hauling distance)
fuel consumption per hour: 5-10 l
hourly cost: ≈ 40-50 €


Cable crane with mobile tower yarder
light
purchase cost: 40000-120,000 €
max traction power: 2,000 daN
productivity: 3-6 solid m^3/h
fuel hourly consumption: 5-6 l
hourly cost: ≈ 25-40 €
medium
purchase cost: 100,000-220,000 €
max traction power: 5000 daN
productivity: 3-12 solid m^3/h
fuel consumption per hour: 6-10 l
hourly cost: ≈ 40-80 €


Harvester
purchase cost: 300,000-370,000 €
max cutting diameter: 65-70 cm
max delimbing diameter: 45-60 cm
max negotiable slope: 35% (wheels)
60% (tracks)
(with optimal soil bearing capacity)
productivity in high forest: 8-20 solid m^3/h
fuel consumption per hour: 11-16 l
hourly cost: ≈ 90-120 €

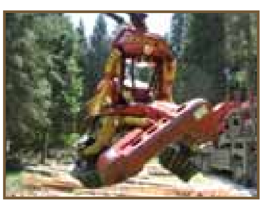
Forwarder
purchase cost: 180,000 – 270,000 €
loading capacity: 10 - 14 t
max negotiable slope: 30 - 35%
logs length: up to 6 m
productivity: 12-20 solid m^3/h
(depending on hauling distance)
fuel consumption per hour: 7-11 l
hourly cost: ≈ 65 - 80 €


Hybrid harvester
purchase cost: 240,000 €
max cutting diameter: 55 cm
max delimbing diameter: 50 cm
max negotiable slope: 45-50%
productivity: 10-15 solid m^3/h
fuel consumption per hour: 10-12 l
hourly cost: ≈ 80 €


Skidder
purchase cost: 120,000 – 150,000 €
skidding capacity: up to 3 t
max negotiable slope: 20%
productivity: 8 - 12 solid m^3/h
(depending on hauling distance)
fuel consumption per hour: 6-10 l
hourly cost: ≈ 55 - 65 €


Tractor-mounted processor
tractor purchase cost: 30,000 €
processor purchase cost: 45,000 €
max cutting diameter: 48 cm
max delimbing diameter: 40 cm
productivity: 10-15 solid m^3/h
fuel consumption per hour: 4-5 l
hourly cost: ≈ 35 €


Excavator-based processor
excavator purchase cost: 170,000 €
processor purchase cost: 60,000 €
max cutting diameter: 65 cm
max delimbing diameter: 60 cm
productivity: 15-40 solid m^3/h
fuel consumption per hour: 15 - 17 l
hourly cost: ≈ 85 €




Chipper
small power
purchase cost: 3,500-35,000 €
working diameter: max 20 cm
productivity: 2-3 t/h
fuel consumption per hour: 5-8 l
medium power
purchase cost: 15,000-75,000 €
working diameter: max 30 cm
productivity: 4-7 t/h
fuel consumption per hour: 10-14 l
high power
purchase cost: 31,000-250,000 €
working diameter: > 30 cm
productivity: 13-20 t/h
fuel consumption per hour: 34-38 l
hourly cost: ≈ 150-190 €




Saw wood
purchase cost: 600-2,000 €
working diameter: 14-25 cm
Split wood
purchase cost: 1,500-14,000 €
working log length: 0.3-4 m
Combined (saw-split wood)
purchase cost: 7,000-70,000 €
working diameter: 25-60 cm
working log length: 2-6 m
hourly cost: ≈ 70-150 €


Truck and trailer (log transport)
truck purchase cost: 110,000-150,000 €
trailer purchase cost: 20,000-30,000 €
loading capacity: 18-20 t
fuel consumption: 2.5-3.5 km/l
hourly cost: ≈ 60-75 €


Truck and trailer (wood chips transport)
truck purchase cost: 100,000-115,000 €
trailer purchase cost: 45,000 €
loading capacity: 20-22 t (85-90 bulk m^3)
fuel consumption: 2.5-3.5 km/l
hourly cost: ≈ 65-70 €
with clamshell bucket loader
purchase cost: 205,000 €
loading capacity: 81 bulk m^3
hourly cost: ≈ 70-75 €


The machines that are most specifically involved in the wood-energy supply chain are employed for log woods and wood chips production.

Machines for log woods production

After its first working by chainsaw, wood is transported to a working place, where it is reduced to a form compatible with fuel destination.

The raw material undergoes three different phases:

- **selection**: the material is divided into assortments depending on its destination (chimney or oven). Division is usually done by hand;
- **cutting off**: shortening the wood to lengths from 25 to 100 cm, by cutting logs orthogonally to fibres;
- **splitting**: reducing the width by breaking the log by a mechanical force applied parallel to the fibres.

Depending on the operation, machines for log woods production can be distinguished into:

- **saw wood**: if based on band saw, they can process diameters bigger than 40 cm and have low cutting loss; if based on disc saw, they can only process smaller diameters and have higher cutting loss;
- **split wood**: they are equipped with either a wedge or a screw breaking device. The ones with wedge device for domestic use have either 2 or 4 sides, they work keeping the log vertical and can exert up to 15 t of splitting power, while for industrial use the log is kept horizontal and pushed against a wedge, or a grate, up to 16 sides with a power up to 40 – 60 t. The ones with screw are equipped with a threaded cone which spins into the wood so as to split it; they are faster than the former, but less precise; for safety reasons, the best solution is to install the device on a boom (of a tractor, for example);
- **combined** (saw-split wood): there are mobile models, but most of them are stationary machines which combine the two operations, allowing an elevated process automation and a higher productivity, working both on logs and on big branches. They are endowed with electric or spark-ignition engine (up to 55 kW), can work logs up to 6 m long and 60 cm of diameter and can produce more than 12 t/h of material.

Processing hardwood requires more power than processing softwood and all types of wood can more easily be split when fresh rather than seasoned.

Chippers

A chipper is a machine that is especially built to reduce wood to chips and can either be stationary or mounted on a carriage, on a trailer, on a truck or on the rear three point hitch of a tractor. It can be equipped with its own engine or activated by the tractor power take off. Depending on the chipping unit, it is possible to differentiate between:

- **disc chippers**: the chipping unit consists of a heavy flywheel on which are radially mounted from two to four knives. The material comes into contact with the disc at an angle of 30 to 40 degrees to the plane of the disc and the rotating knives, acting against an anvil at the end of the inffed spout, cut progressive slices from the wood that breaks up into chips whilst being cut. Chip size is usually between 0.3 and 4.5 cm and can be modified by an adjustable bed knife;
- **drum chippers**: bigger and more powerful than disc chippers, these chippers can easily work both logs and harvesting residues. The chipping unit consists of a steel cylinder with up to 12 knives installed in tangential position; chip size is more heterogeneous, with lengths up to 6.5 cm. Knives must be replaced every 50–100 t (working with hardwood) or 200–300 t (with softwood);
- **feed screw chippers**: chipping is provided by a big worm of decreasing section with sharp edges that rotates on a horizontal axis. These machines, which are not particularly widespread, can mostly process full trees or logs and produce bigger chips (up to 8 cm) compared to disc and drum chippers.

According to the required power, three categories can be identified:

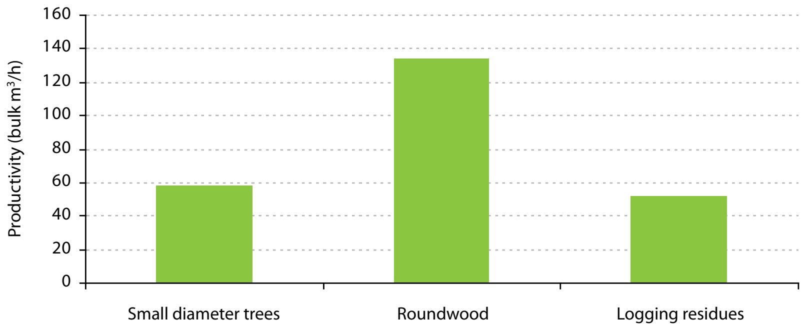
- **small power**: usually installed on the rear three point hitch of a tractor or on a trailer, these chippers are powered by the tractor power take off or by an independent engine (~50 kW). They can only process small diameters (20 cm max) and can produce no more than 20 t/day;
- **medium power**: trailer-mounted, usually with independent engine (50-110 kW), they can chip diameters up to 30 cm and produce up to 50 t/day;
- **high power**: installed on trailers or on trucks, these chippers are sometimes activated by the truck's engine, but normally they are provided with an autonomous engine (>130 kW); they can chip big diameters (>30 cm) and easily produce more than 60 t/day.

The **sieve** is an important tool which makes possible the selection of chips during the expulsion phase, thus refining the material but at the same time lowering productivity.

When chipping is performed in a place different from the final plant, chips are transported either by truck or truck and trailer, rarely by articulated vehicle, set up with large cases in light alloy; a clamshell bucket loader can be installed on the truck and trailer to make possible an autonomous loading of the chips.

Austrian studies show that the productivity (bulk m³) of a high-power chipper varies according to the kind of material to be chipped[19]; average productivity values (graph 3.2.1) include waiting times for the truck and trailer to unload the chips. These times have been calculated to account for about 20% of total time.

Graph 3.2.1



3.3 Wood-energy supply chain and its costs

As an example, three charts of possible wood-energy supply chains for chip boilers (with fixed or mobile grate) situated in mountainous area have been provided below. Calculations have been done from the point of view of the forest enterprise that manages the supply chain.*

1. Thinning in coniferous stand adopting the FTS working system. Chip destination: chip boiler with fixed-bed combustion (M 30%, P45; ref. table 4.4.1). Price ex thermal power station 18-20 €/bulk m^3 (=80-90 €/t).

Working phase	Equipment	Productivity (bulk m^3/h)	Cost (€/bulk m^3)
Felling	2 chainsaws	35	0.5
Full tree skidding	2 tractors and winch	17	5.9
Mechanized processing at the landing site	processor on tractor	24.3	1.4
Loading logs on the truck and trailer	truck and trailer	121.5	0.6
Transporting logs to the biomass trade centre (back&forth 90 km)	truck and trailer	36.5	2
Unloading logs from the truck and trailer	truck and trailer	145.8	0.5
Natural seasoning	—	—	0.3
Chipping logs	high power chipper	100	1.4
Delivery of chips (back&forth 90 km)	truck and trailer	24.4**	2.0
TOTAL			14.6

Standing tree value is to be added to the total (from 0 to 5 €/bulk m^3 for thinning operations)
** Seasoned chips (M 30%)

2. Main felling in coniferous stand adopting the FTS working system. Chip destination: chip boiler with moving grate (M 55%, P63; ref. table 4.4.1). Price ex thermal power station 10-13 €/bulk m^3 (= 29-38 €/t). Harvesting residues let on the forest road are available at no cost, since all harvesting costs are charged on industrial timber.

Working phase	Equipment	Productivity (bulk m^3/h)	Cost (€/bulk m^3)
Chipping harvesting residues	high power chipper	55	2.6
Delivery of chips (back&forth 90 km)	truck and trailer	22.1***	2.4
TOTAL			5.0

*** Fresh chips (M 55%)

* The following equivalences have been employed: 1 solid m^3=2.43 bulk m^3 of chips (volume coefficient=0.41 solid m^3/bulk m^3); 1 bulk m^3=223 kg (M 30%); 1 bulk m^3=347 kg (M 55%).

3. Thinning in coniferous stand adopting the FTS working system.

Chip destination: chip boiler with moving grate (M 55%, P63; ref. table 4.4.1). Price ex thermal power station 10-13 €/bulk m^3 (= 29-38 €/t). The results are in agreement with indications found in the reviewed literature, according to which harvesting chances with fresh chips (from softwood or hardwood) as the only product, to be employed in boilers with moving grate, can hardly be economically feasible. The production of this kind of chips must be integrative, and not exclusive, of the harvesting chance.

Working phase	Equipment	Productivity (bulk m^3/h)	Cost (€/bulk m^3)
Felling	2 chainsaws	35	0.5
Full tree skidding	2 tractors and winch	17	5.9
Chipping full trees	high power chipper	60	2.4
Delivery of chips (back&forth 90 km)	truck and trailer	22.1*	2.4
TOTAL			11.2

Standing tree value is to be added to the total (from 0 to 5 €/bulk m^3 for thinning operations)
* Fresh chips (M 55%)

4. QUALITY REQUIREMENTS AND REFERENCE STANDARDS

The European Committee for Standardization, CEN (TC335) is currently preparing 30 technical specifications for solid biofuels. CEN/TC 335 is the technical committee developing the draft standard to describe all forms of solid biofuels within Europe, including wood chips, wood pellets and briquettes, logs, sawdust and straw bales.

The two most important technical specifications being developed deal with classification and specification (CEN/TS 14961) and quality assurance for solid biofuels (CEN/TS 15234). The classification of solid biofuels is based on their origin and source. Here is the list of more important technical specifications prepared by CEN 335:

1. CEN/TS 14588:2003 Solid biofuels - Terminology, definitions and descriptions
2. CEN/TS 14961:2005 Solid biofuels - Fuel specifications and classes
3. CEN/TS 15234:2006 Solid biofuels - Fuel quality assurance
4. CEN/TS 14774-1:2004 Solid biofuels - Methods for determination of moisture content - Oven dry method - Part 1: Total moisture - Reference method
5. CEN/TS 14774-2:2004 Solid biofuels - Methods for the determination of moisture content - Oven dry method - Part 2: Total moisture - Simplified method
6. CEN/TS 14774-3:2004 Solid biofuels - Methods for the determination of moisture content - Oven dry method - Part 3: Moisture in general analysis sample
7. CEN/TS 14778-1:2005 Solid biofuels - Sampling - Part 1: Methods for sampling
8. CEN/TS 14918:2005 Solid Biofuels - Method for the determination of calorific value
9. CEN/TS 15103:2005 Solid biofuels - Methods for the determination of bulk density
10. CEN/TS 15296:2006 Solid Biofuels - Calculation of analyses to different bases

Qualitative classification of solid biofuels is defined at European level by Technical Specification CEN/TS 14961 (*Solid biofuels, fuel specification and classes*, 2005).

4.1 Technical Specifications for log woods and wood chips

European Specification CEN/TS 14961:2005 provides regulatory information to be taken into account when drawing up any supply contracts and the relative Declarations of Quality for the biofuels supplied (Annexes A1 and A2). Reproduced below is the normative section of the specifications for log woods and wood chips.

Table 4.1.1

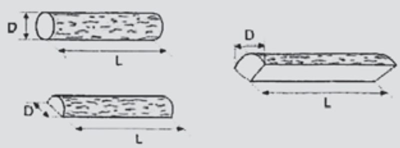
	Origin: According to table 1 of TS	Woody biomass (1.1.2.1, 1.1.2.2, 1.1.2.3)
	Traded Form	LOG WOODS
NORMATIVE	**Dimensions** Length (L) Thickness (D) (maximum diameter of a single chop)	
	P200– P200 P250 P330 P500 P1000 P1000+	L < 200 and D < 20 (ignition wood) L = 200 ± 20 and 40 ≤ D ≤ 150 mm L = 250 ± 20 and 40 ≤ D ≤ 150 mm L = 330 ± 20 and 40 ≤ D ≤ 160 mm L = 500 ± 40 and 60 ≤ D ≤ 250 mm L = 1000 ± 50 and 60 ≤ D ≤ 350 mm L > 1000 (actual value has to be stated)
	Moisture (M) M20 ≤ 20% M30 ≤ 30% M40 ≤ 40% M65 ≤ 65%	 Oven-ready log Seasoned in the storage Seasoned in the forest Fresh, after cut in the forest
	Wood To be stated if coniferous or deciduous wood or mixture of these is used	

Table 4.1.2

	Origin: According to table 1 of TS		Woody biomass (1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.6, 1.2.1.1, 1.2.1.2, 1.2.1.4)	
	Traded Form		WOOD CHIPS	
NORMATIVE	**Dimensions**			
		Main fraction > 80% of weight	Fine fraction <5%	Coarse fraction <1%
	P 16	3.15 mm ≤ P ≤ 16 mm	< 1 mm	> 45 mm, all < 85 mm
	P 45	3.15 mm ≤ P ≤ 45 mm	< 1 mm	> 63 mm
	P 63	3.15 mm ≤ P ≤ 63 mm	< 1 mm	> 100 mm
	P 100	3.15 mm ≤ P ≤ 100 mm	< 1 mm	> 200 mm
	Moisture (M)			
	M20	≤ 20% Dried		
	M30	≤ 30% Suitable for storage		
	M40	≤ 40% Limited for storage		
	M55	≤ 55%		
	M65	≤ 65%		
	Ash (% on d.b.)			
	A0.7	≤ 0.7%		
	A1.5	≤ 1.5%		
	A3.0	≤ 3.0%		
	A6.0	≤ 6.0%		
	A10	≤ 10.0%		

4.2 Instruments for a quick determination of moisture

Although the gravimetric method (see CEN/TS 14774-1) is the only recognized reference method for an exact determination of wood moisture*, today technology offers a series of portable practical tools for a rapid determination of the latter. Such tools prove particularly useful in the implementation of contracts for supply by weight (see chapter 5.2).
The accuracy of results is of course dependent on both the representativeness of the sample and the carefulness with which measuring has been carried out. Special care must be taken in the initial setting of tools and correction factors.
Meters available on the market can be divided into contact and pin type meters.

Log woods and long-wood
For log woods and small diameter long-wood it is possible to use pin type meters that measure the electrical resistance (conductance) between two electrodes (nails). Between electrical resistance and wood moisture content there is a correlation that is maximum in the hygroscopic field (M 0-23%). Measurement is made solely within the space between the two electrodes at their insertion depth (up to about 5 cm).
The most recent specific models can determine the moisture of the sample within a M 10-60% (u 11-150%) range with a 0.1% resolution (www.humimeter.com).

Wood chips

The instruments used for wood chips are contact instruments that measure the dielectric constant (electrostatic charge). The higher the moisture content is, the higher the dielectric constant will be. In the last few years some dielectric hygrometers have been developed specifically for wood chips, sawdust, wood shavings, bark and pellets, and which meet Specification CEN/TS 14961 (www.schaller-gmbh.at). Such instruments can measure wood chips belonging to size classes P16 and P45, with a maximum moisture of 60%. First the material is weighed so as to identify the correct calibration curve for the instrument. Once this has been done, wood chips are poured into a container in which they cross a weak electromagnetic field that is influenced by the moisture of the wood. In a few seconds it is possible to read the measurement of the moisture of the sample on the display.

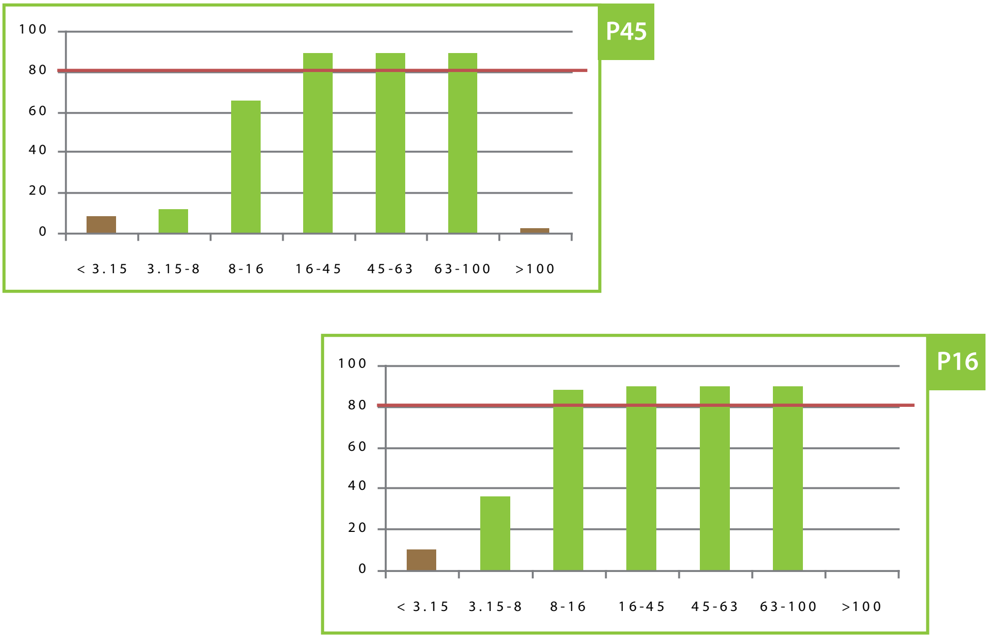
* The gravimetric method is applied in the laboratory and consists in weighing a sample before and after complete drying in a boiler at 103 °C. It takes 24 hours to do this.

4.3 Determination of wood chips dimensions

Size class is determined in the laboratory using special vibrating sieves arranged in series that meet the requirements set by Standard CEN/TS 14961.

Figure 4.3.1 Device for wood chips size determination (AIEL 2006)

Figure 4.3.2 Example of size classification in two wood chips samples P45 and P16



4.4 Qualitative characteristics required by boilers

The main characteristics of wood fuels required by boilers are: dimensions, moisture and ash contents. Table 4.4.1 gives an indicative overview of the characteristics required of fuels by log woods and wood chips boilers.

Table 4.4.1

Types of boiler	Capacity kWt	Grate	Feeding system	Dimensions (P)	Moisture (M)	Ash (A)
Wood log boiler	< 100	fixed	manual	P330-1000	M20	-
Wood chips boiler	< 150	fixed	screw	P16-45	M20-M30	A1.5
	(30)150 -1000	fixed/ partially moving	screw	P16-45	M20-M40	A1.5-3.0
	>1000	moving	hydraulic piston	P16-100	M30-M55	A3.0-10.0

The size required for **wood log boilers** with manual loading depends on the size of the fuel-loading opening; certain models with a 100 kW capacity and a larger opening for charging log woods can be loaded with pieces up to 1 m long.
Wood log boilers require the use of class M20, otherwise combustion does not occur completely inasmuch as the energy required to evaporate water causes the temperature in the combustion chamber to drop below the minimum level required to sustain combustion. The use of log woods with moisture higher than M20 causes a considerable increase in the emission factor.

Fixed-grate **wood chips boilers** require very homogeneous material (P16 and P45) because of the small-sized grate and because of the fact that oversize pieces might block the screw conveyor. On the contrary, boiler with a higher capacity and in which it is possible to install hydraulic piston feeders, are much more flexible.
The moisture of wood chips in fixed-grate boilers must not be above 30% (M30); indeed, they have little thermal inertia inasmuch as the volume of the combustion chamber, and that of the water, in the heat exchanger are limited. Thus, the introduc-

tion of highly moist material would lower the temperature of combustion excessively. Moreover, too high moisture might compromise the starting phase since these boilers are provided with an automatic (electric) ignition device. The moisture of wood chips should be as homogeneous as possible; indeed, the more heterogeneous it is, the higher capital expenditure will be for technology capable of managing even the most complex combustion process that may result from it. Moving-grate boilers can burn fresh wood chips; however, the higher moisture in wood chips is, the more the energetic conversion process will lose in efficiency. Indeed, part of the energy must be 'spent' to evaporate water from wood. Moreover, the use of low-quality wood chips (e.g. wood chips solely obtained from conifer logging residues and mainly made of needles) increases maintenance costs (fusion slags, exchanger cleaning) and produces a considerable drop in generator performance with a consequent increase in final energy costs[14].

4.5 Wood seasoning processes

Self-heating

During storage, fresh lignocellulosic biomass gets warmer due to the respiration processes of still-living parenchymal cells. Such processes stop on reaching 40°C. The further increase in the temperature of the wood mass can be ascribed to the metabolism of fungi and bacteria. While fungi can survive up to a temperature of about 60°C, the activity of thermophilic bacteria begins at 75 to 80°C. Under special circumstances, wood mass warming can even reach a temperature of about 100°C; the reasons for this further increase in temperature have, however, not yet been explained. Over 100°C there begin some thermochemical transformation processes that can lead, although this only happens very rarely, to spontaneous combustion phenomena. Such phenomena generally occur with very fine wood material (fine sawdust) and bark.

Under optimum conditions for the growth of bacteria and fungi (e.g. M 40%), the wood already starts warming after a few seconds. On the contrary, microorganisms are not activated under conditions of permanent low temperatures (winter), unless they have previously been activated (figures 4.5.1 e 4.5.2).

Figure 4.5.1 Temperature trends inside a wood chips pile at different moisture content. The higher the moisture level is, the quicker the pile will warm up[2]

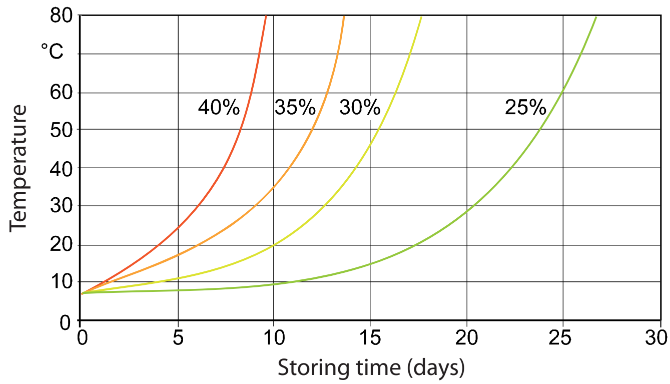
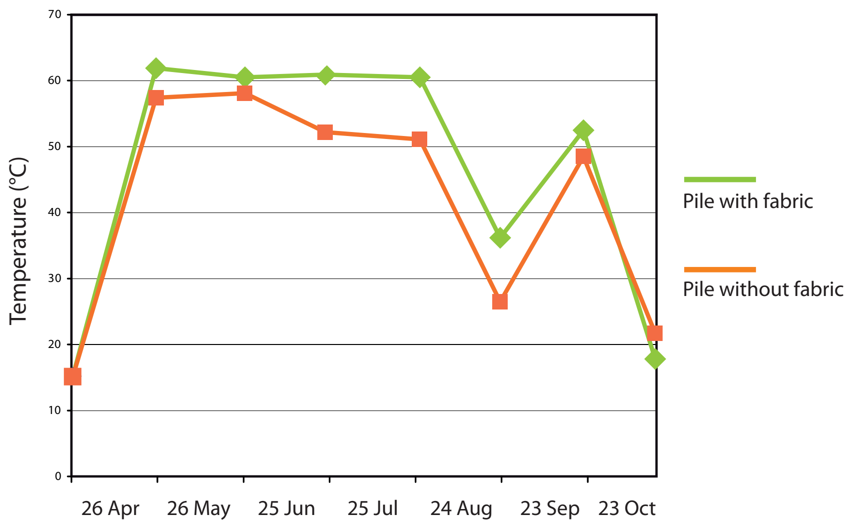


Figure 4.5.2 Development of temperature (from April to November) in two wood chips piles, covered and not covered by a breathable fabric (TOPTEX)[12]



Loss of wood substance

Due to an intensification of the metabolic activities of fungi and bacteria, there occurs the decomposition of the wood substance and, consequently, there is a loss of fuel organic mass. In order to minimize such losses, biological activity must be kept as much as possible under control. Below is a list of measures to take, particularly for wood chips and bark which, among fuels, are most frequently affected by such problems.

- Store material with the least possible moisture and keep it out of the rain;
- Favour natural ventilation: it quickens the loss of heat and water;
- Remember that a rough and regular size of the material encourages internal ventilation;
- Use adequately sharp cutting tools (regular size);
- Reduce to a minimum the presence of needles and leaves, which are easily attacked by microorganisms;
- Minimize the duration of storage;
- Choose an ideal height for the pile.

It is not always possible to adopt all the above-mentioned tactics; therefore, a certain loss of wood substance must be taken into account. Some indicative values are provided in table 4.5.1[2].

Table 4.5.1

Material/Storage type	Annual loss (wt% d.b.)
Forest wood chips, fresh, uncovered	20 up to >35
Forest wood chips fine, seasoned, covered	2-4
Forest wood chips coarse (7-15 cm), fresh, covered	4
Bark, fresh, uncovered	15-22
Log woods (beech, spruce) after 2 years, covered	2.5
Log woods (beech, spruce) after 2 years, uncovered	5-6
Logs (spruce, fir) fresh, uncovered	1-3
Young whole trees (poplar, willow) fresh, uncovered	6-15

The loss of dry substance can, partly at least, be balanced by the decrease in moisture in the material at storage site; this entails an increase in net calorific value (with reference to a mass of 1 kg inclusive of water). Even when resorting to drying (with warmed air), an approximate 4% overall loss of dry substance is to be estimated. When resorting, for a given period of time, to forced ventilation (with unwarmed air), which makes possible the self-heating of the mass, the loss is redoubled up to 7-8%[2].

4.6 Log woods seasoning

Log woods starts to lose water in winter, but it is in March that there is the highest loss of water (about 10%). In particularly hot summers (e.g. in summer 2003, figure 4.6.1) fresh wood chopped in December and stored under cover can reach, as early as June, a moisture of 20% (M20), being thus suitable to be commercialized as 'oven-ready log'. In the case of damp summers (e.g. summer 2003, figure 4.6.1), however, detectable differences are minimal and the value M 20% is reached but one month later. Starting from May, spruce wood dries more quickly than beech wood, although the latter at first appears to be drier than the former because of both its initially lower moisture and the quicker loss of water. In any case, it takes both species more or less the same period of time to reach M20.

In April the amount of water evaporated from wood is maximum, with peaks of about 90 l/stacked m^3/month. Starting from September, wood regains moisture from air and rain; it is estimated that from October to December wood regains 5 l/stacked m^3/month (figure 4.6.2).

Figure 4.6.1 Drying process in split and stacked log woods, outdoor-seasoned and under cover[4]

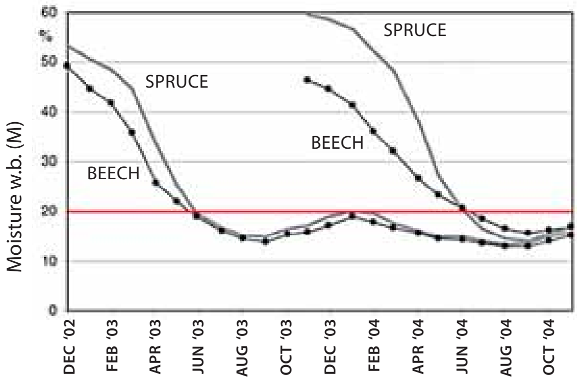
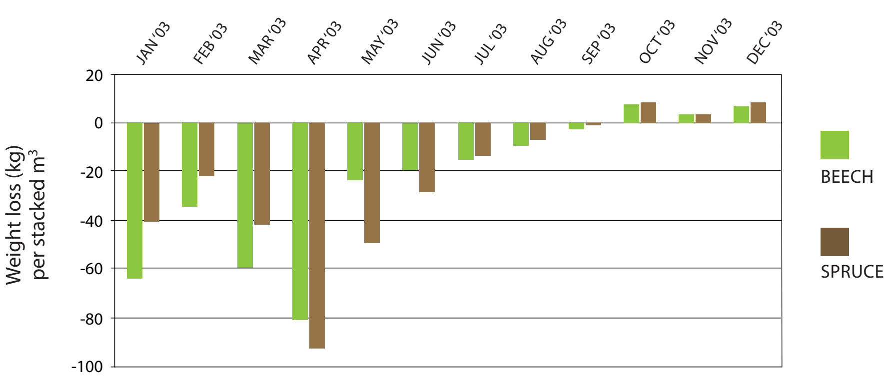


Figure 4.6.2 Monthly dry rate of freshly one-meter split and stacked firewood, outdoor-seasoned and under cover[4]



Log woods stored under cover dries somewhat more quickly during the early winter months; this advantage of covered wood is compensated for by uncovered wood during the summer months. The presence of a woodshed, particularly in very rainy places,

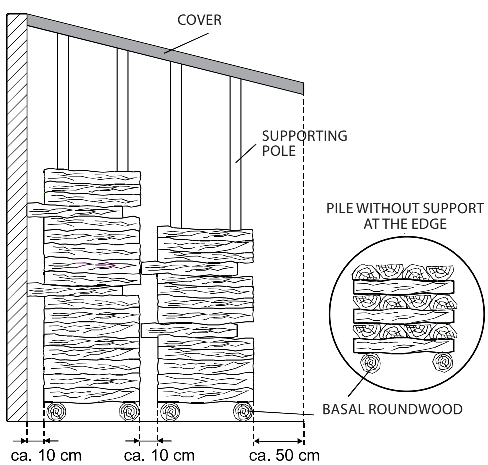
is, however, advisable since it contributes to limit moisture regain during the following autumn-winter period. Provided that the structure is adequately ventilated (slotted walls), storage under cover is the most recommended.
Compared to split log woods, non-split log woods reaches M20 two months later. Thus, in order to reach M20 with a higher degree of certainty and in order to retain such moisture until autumn, it is advisable to chop low-quality roundwood with a diameter larger than 10 cm before seasoning.

Prescriptions for log woods storage

During wood processing and log woods stack preparation it is important to avoid, as much as possible, 'dirtying' the log woods. The processing yard must be provided with a firm and stable flooring (either cement or asphalt).
Log woods can be seasoned either in open yards or under ventilated cover, but in any case they must be protected from soil moisture and rain.
Main prescriptions for log woods storage:

- The ground (flooring) must be kept dry; if possible, the passage of air must be favoured by lifting up the stack from the ground with wood supports (beams, logs);
- It is preferable to store the wood in places that are open to the air and sun (e.g. at the edge of the wood, in the yard);
- There must be at least a 10 cm distance between the single stacks and between the stacks and the walls of the storage structure (figure 4.6.3);
- The exterior walls of the structure must be kept open (slotted);
- Whenever possible, it is advisable to store the log woods for daily use in the boiler room so as to have it preheated.

Figure 4.6.3 Example of arrangement and spacing of under-roof log woods[2]



Containers for log woods storage, seasoning and transportation

Different types of containers for split log woods storage, seasoning and transportation are available on the market. Among the most interesting, also from an economic point of view, are containers made of a basal wood pallet to which a square-mesh wire netting is applied that serves as a wall; the upper part is covered by a second pallet which is insulated from the outside by nylon. Such structure is 2 m high and can contain 2 bulk m^3 of split log woods; this is put in directly from the log processor conveyer (figure 4.6.1).

Figure 4.6.1

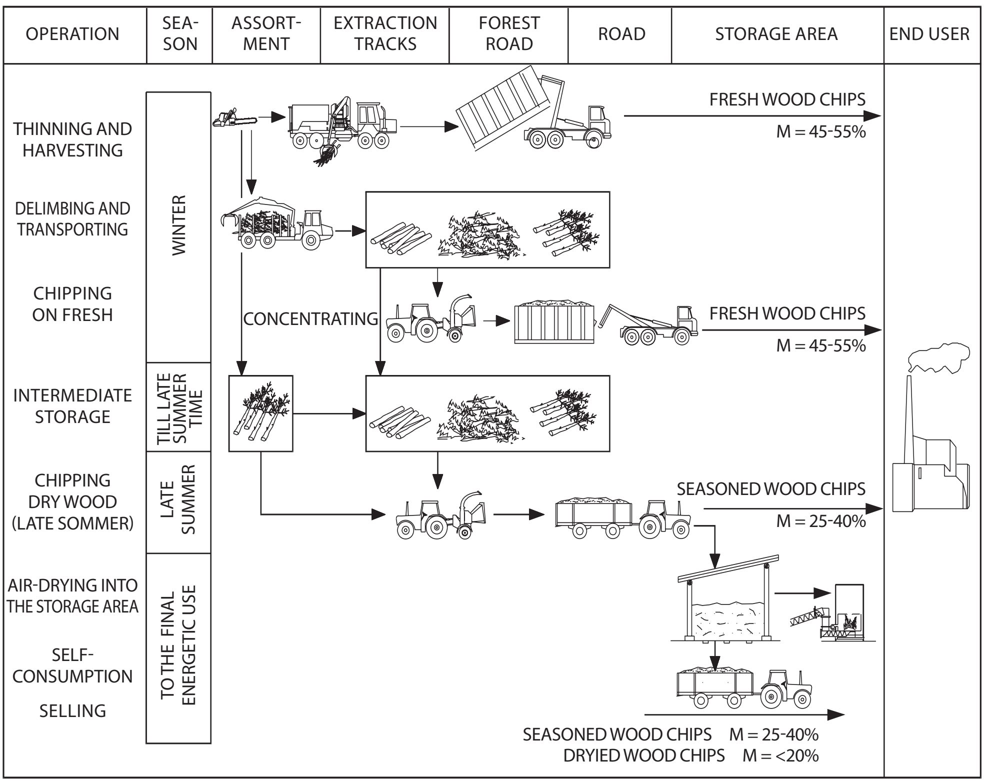

Another functional and low-cost possibility is to reuse the metal structure installed on a wood pallet as a support for 1 m^3 plastic containers for the storage of liquids (figure 4.6.2)

Figure 4.6.2

4.7 Wood chips seasoning

In order to produce wood chips of a suitable quality so that they can be used in low to medium power (fixed-grate) boilers, the following wood raw material is used: branchless conifer trunks, conifer and broad-leaf slash and slabs, broad-leaf trunks (with or without branches) and broad-leaf logging residues, possibly with a 5 cm minimum diameter in order to limit ash contents, whose percentage is higher in bark than in wood.

Figure 4.7.1 Logistic, timing and destination of forest wood chips[2]



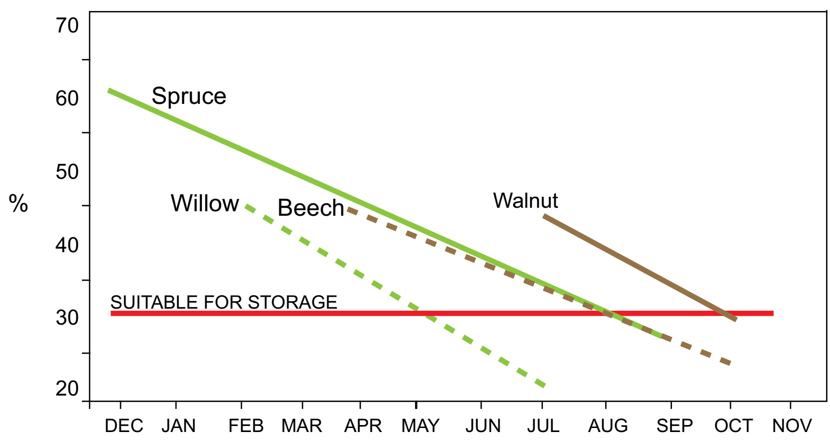
This material needs to go through a seasoning phase, with an intermediate storage in a banking ground outside the wood before it is chipped in the late summer/autumn (figure 4.7.1). Seasoning must take place during summer, when the free energy supply from the sun and the wind, which favours the natural drying of the wood, is maximum. The loss of moisture in broad-leaves during seasoning generally varies from 40 to 50%. If cut in May, with leaves still attached, plants accelerate the natural drying of wood. The same applies to conifers (spruce and fir) that are cut during the period that goes from late autumn to December, and which are later laid out at the banking ground.

Leaving chopped log woods in a shady environment inside the wood does not determine a considerable loss of moisture in wood. Consequently, the material should always be seasoned in a sufficiently sunny, and possibly much ventilated, place[3].

When taken to a sunny banking ground outside the wood, wood as such (figure 4.7.2), from the moment it is cut, reaches in the late summer a moisture below 30% and is thus ready to be chipped[3].

The M 30% value is defined as **suitable for storage**; below this limit wood chips are classified as fit for storage without any biological stability problems (ÖNORM M 7133).

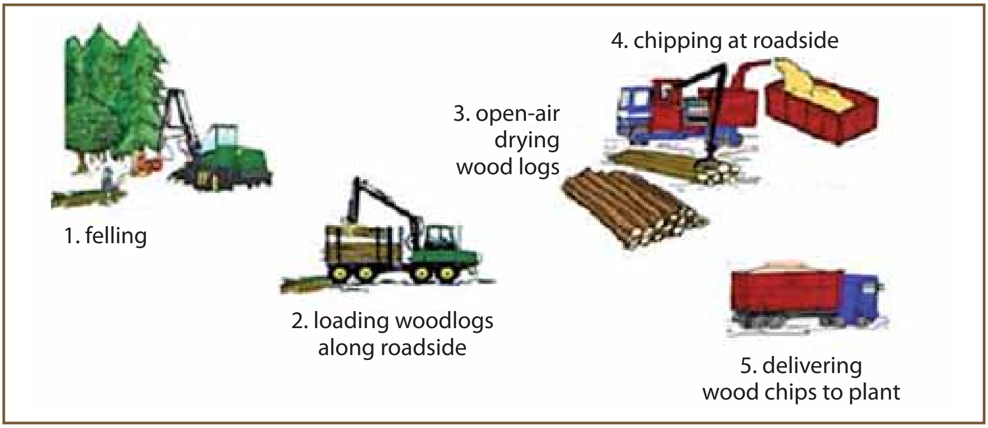
Figure 4.7.2 Drying process in various tree species[3]



The seasoning of material as such can be done on the verge of a road, provided that the banking ground is exposed to the sun and is of adequate size; otherwise, the material needs to be transported to a logistic area where it is chipped and stored under cover (figure 4.7.3).

When seasoning is done at a logistic and trade centre, it is a good rule to 'split' the biggest trunks (Ø>35-40 cm) using special wood-splitter pincers (figure 4.7.4), so as to accelerate the water loss of the trunks.

Figure 4.7.3 Production of forest wood chips after seasoning raw material either on landing site or at a biomass trade centre[13]



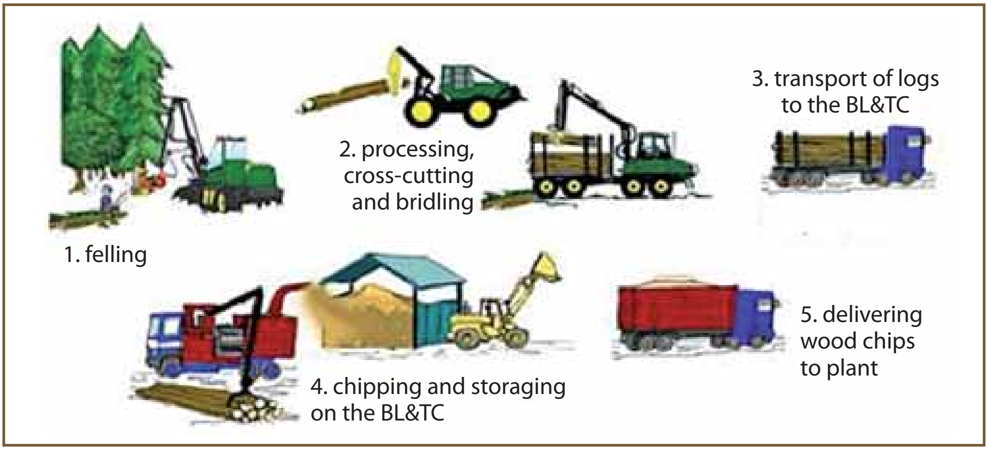
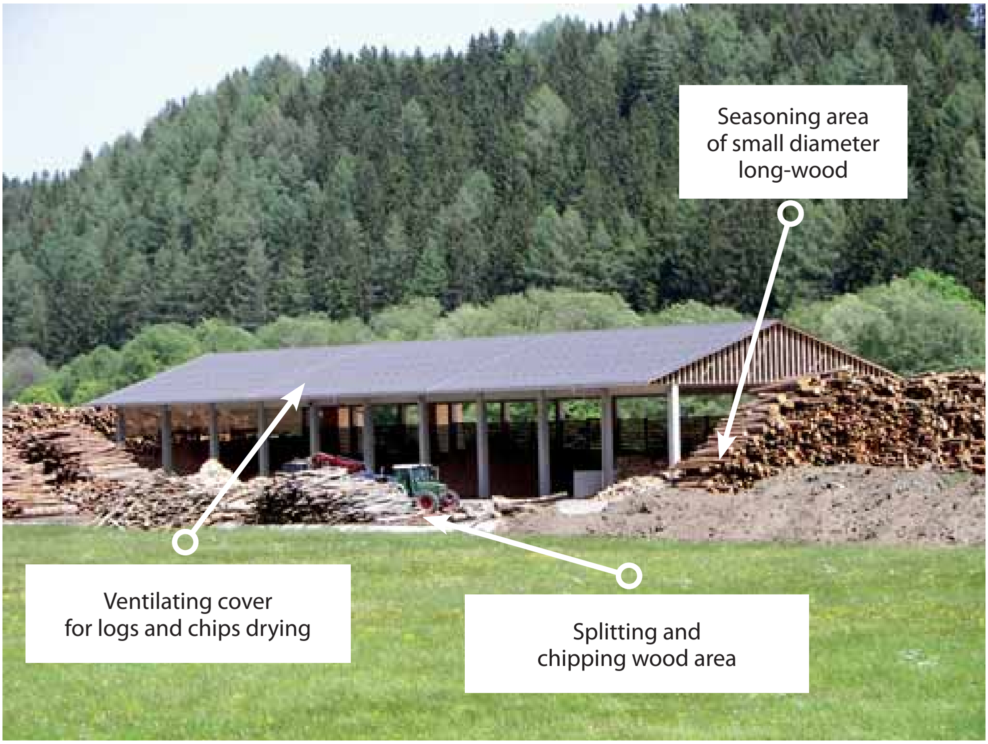


Figure 4.7.4

4.8 Biomass Logistic&Trade Centre (BL&TC)

BL&TC is a physical location that is pinpointed on the basis of forestry and productive characteristics of the supply area (supply) and of the localization and typology of the purchasers (demand). It is provided with first storage and seasoning areas for wood as such and with a cover for the storage and seasoning of wood chips and log woods. (figure 4.8.1). BL&TC is an infrastructure that is fundamental for the production and professional marketing of wood fuels as such, and which makes it possible to make available on the market products that meet technical specifications.

Figure 4.8.1 BL&TC Pölstal (Styria-Austria)



Covers for wood chips storing and seasoning

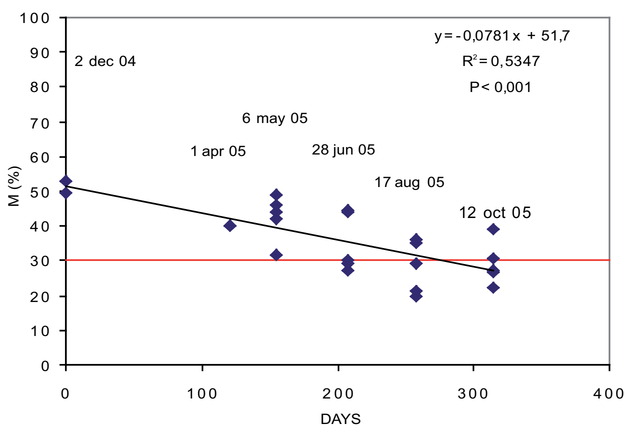
The best way to store and season wood chips is to lay them on a waterproof surface (cement and/or asphalt) protected by a cover located in a sunny and ventilated site. The architectural structure of the cover (figure 4.8.2) should maximize the ventilation of the stored material and make wood chips turnaround and handling operations easier.

Figure 4.8.2 Examples of architectural structure in two BL&TC, in Austria (Pölstal, Styria) and in Italy (Deutschnofen, Bozen)

Protective fabric cover for wood chips

Protective fabric specific for wood chips is available on the market (www.tencate.com); it has proved effective both for the seasoning of fresh wood chips and for the storage of M<30 wood chips (figure 4.8.3).

Figure 4.8.3 Plane wood cut in December and freshly chipped reaches M30 after 9 months[15]



The fabric is breathable and makes it possible to keep away water-saturated air during the mass self-heating phase. Wood chips must be laid on a waterproof surface and the pile must be made conical in shape so as to favour the flow of rainwater on the fabric surface (figure 4.8.4).

Figure 4.8.4 Wood chips pile covered with fabric

4.9 Drying systems

Drying prompted by the heat of fermentation processes

The heat that originates from the demolition processes of the wood substance present in wood chips piles creates convective motion; as a consequence of this, cool air is drawn from underneath and sideways. Therefore, ventilated flooring works particularly well if used in storage covers. As for wood chips of medium-fine size, self-heating has a considerable effect on the drying of wood chips if combined with forced-ventilation systems. Water-saturated air originating from the self-heating heat of the mass is kept away and, as a result, the mass cools down.

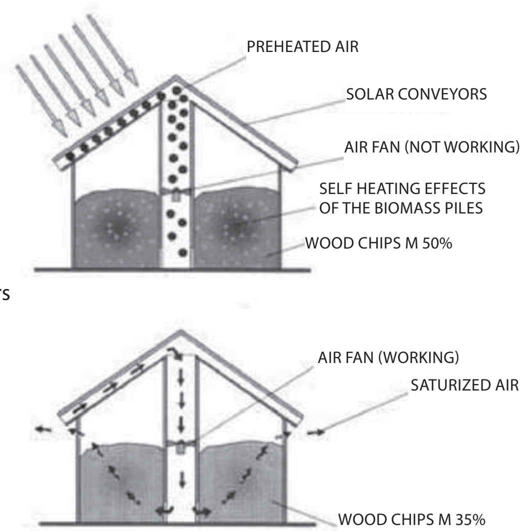
In structures where forced air circulation systems are used, ventilation cycles are regulated by the differences in temperature. A 5 to 10°C internal-external ΔT is enough to favour the natural circulation of air and, consequently, reduce the amount of energy that is necessary to force the circulation of air.

Forced ventilation using air preheated by solar energy

Whatever technical (external) measure is taken to increase, no matter how slightly, air temperature inside the mass of wood chips, air circulation is created and wood drying is consequently facilitated.

If covers are predominantly to be used to season wood chips, their construction might be planned in such a way that they are provided with forced ventilation systems with preheated air placed in special under roof air space. The air that is preheated by the sun is then blown into a ventilation chimney and forced from underneath into wood chips piles by a ventilator (figures 4.9.1 and 4.9.2). Thanks to these systems it is possible to reduce the moisture content of 150 bulk m^3 of wood chips approximately from M 50% to M 30% in one week (in spring/summer).

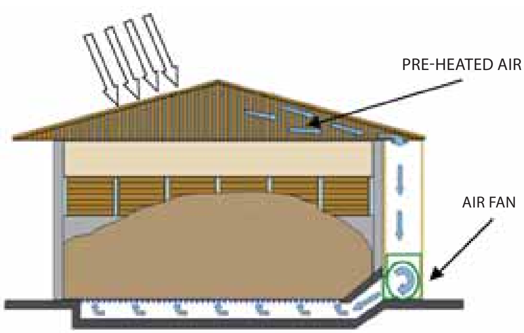
Figure 4.9.1 Diagram of the principle of a pulsating solar biomass drying process[6]



STEP 1
- warming up outside air by solar conveyors
- self heating effects of the biomass piles

STEP 2
- preheated air is blown by the air fan through the biomass piles
- the water from the biomass is carried out by the air

Figure 4.9.2 Pre-heated and forced ventilation system used at BL&TC Pölstal (Styria-Austria)



Over night, when the relative humidity of the air is higher, it is advisable to suspend forced ventilation in order for wood chips not to absorb humidity.
For the design rating of the necessary air capacity, reference can be made to the surface covered by the pile. This quantity is expressed in terms of air speed, which, with reference to wood chips, varies within a range that goes from 180 to 540 m^3/h (=0.05 to 0.15 m/s) per m^2 of surface covered by the pile.
These quantities can as well be expressed in volumetric terms (ventilation rate). It is estimated that approximately 40 m^3/h of air per m^3 of (solid) wood to be dried are necessary for wood chips. In order to accelerate the drying process, it is standard practice to increase the ventilation rate up to 150 $m^3/(h\ m^3)$[2].

Forced ventilation systems for log woods

Log woods is dried in a greenhouse provided with a forced ventilation system that considerably reduces the seasoning period. In 15 days it is possible to take 200 steres of fresh log woods to M20. The ventilator absorbs approximately 1 kW and facilitates the circulation of the air which is heated primarily by the sun, although in winter a wood chips/pellet boiler is also used to supplement the action of the sun. An automatic change of the internal saturated air is made possible through the activation of roof openings. The structure (figure 4.9.3) costs approx. € 150,000 and log woods production costs increase by approximately 15 €/stere; however, the burden is offset by the smaller amount of space required and by the possibility of marketing M20 log woods eight and a half months in advance.

Figure 4.9.3 **Greenhouses for drying log woods at the Biomassehof Allgäu (Bayern - DE)**

Hot air drying

The drying effect is considerably improved by using air heated by a generator. Working temperature may vary from 20 to 100°C. Again, the air is introduced into the log woods/ wood chips pile through a ventilator.

The overall heat necessary for drying is approximately 3 to 4 MJ per kg of water, 2.5 MJ/kg of which are needed for the preheating and evaporation of water. Alongside with embedded systems for heat production, it is worth taking advantage of low-cost (or free) heat co-produced with, and retrieved from, co-generation plants (either biogas or wood chips plants); this thermal energy, which, more often than not, is completely dissipated during the summer, can therefore be exploited to dry either wood chips or log woods.

Simplified drying devices

The suggested structures for wood chips and log woods drying are simplified structures (either fixed or mobile) with double basal flooring through whose holes hot air is introduced. The heat distribution system consists of a series of rigid piping easily installed in the dryer which can be obtained either from a moving container or from a farm trailer (figures 4.9.4 and 4.9.5).

Today, alongside with simplified dryers, more advanced devices are available on the market in order to exploit biogas plant waste-heat (figure 4.9.6).

Figure 4.9.4 Container: it costs approx. 50,000 € and it can store 22 bulk m^3; the remaining space is occupied by the fan system and by the steering panel. Drying time: ca 5 days to reach M20[16]

Photo: Energie Pflanzen 6/2006

Figure 4.9.5 Farm trailer: it costs approx. 1,500 – 2,000 €. The hot air comes from the biogas plant through a heat exchanger: the two flexible pipes bring the hot air (80°C) into a flat-bottomed (10 cm thickness) of the lorry which is filled with wood chips. During the drying process, wood chips do not need to keep turning and after two-three days they are ready to be delivered (M30)[17]

Photo: Energie Planzen 6/2007

Figure 4.9.6 Horizontal drum dryers suitable for drying both log woods and wood chips (www.s-und-ue.de)[18]

5. ENERGY COSTS, TRENDS AND COMPARISONS

Market price for fuels, whether wood or fossil fuels, is expressed in different units of measurement (ponderal and volumetric) and is characterized by considerably different calorific values. All this makes it difficult to make an instant comparison. The parameter that makes it possible to compare the price of fuels is primary energy costs (€/MWh), i.e. the cost of the energy contained in fuels before they are converted into final energy.
Table 5.1 shows a comparison between energy costs for various fuels (December 2008). Their relation to wood chips is calculated based on three different primary energy costs: 20 and 25 €/MWh. The prices are related to the Italian market.

Table 5.1 Primary energy costs based on wood chips costs (VAT excluded)

	MWh	Price €	Energy Price €/MWh	Ratio
1 t wood chips (M30, P45)	3.40	**68**	**20.00**	1.00
1 t wood chips (M40, P45)	2.81	**56**	**20.00**	1.00
1 t log woods (M20, P330)	3.98	130	32.66	1.63
1 t pellet (M10) loose	4.70	150	31.91	1.60
1 t pellet (M10) sack 15 kg	4.70	180	38.30	1.91
100 mc natural gas "served"	1.00	70	70.00	3.50
1 t heating oil (greenhouse)	11.7	448	38.39	1.92
1 t heating oil (domestic use)	11.7	863	73.95	3.70
1000 l LPG (own tank)	6.82	1020	149.56	7.48

	MWh	Price €	Energy Price €/MWh	Ratio
1 t wood chips (M30, P45)	3.40	**85**	**25.00**	1.00
1 t wood chips (M40, P45)	2.81	**70**	**25.00**	1.00
1 t log woods (M20, P330)	3.98	130	32.66	1.31
1 t pellet (M10) loose	4.70	150	31.91	1.28
1 t pellet (M10) sack 15 kg	4.70	180	38.30	1.53
100 mc natural gas "served"	1.00	70	70.00	2.80
1 t heating oil (greenhouse)	11.7	448	38.39	1.54
1 t heating oil (domestic use)	11.7	863	73.95	2.96
1000 l LPG (own tank)	6.82	1020	149.56	5.98

5.1 Final energy costs

An important aspect of any economic evaluation is the calculation of final energy costs, thereby including investment and related expenses for plant operating.

The production costs of six different energy generation systems with 100 kW boilers and the same annual operating rate (1300 hours) have been calculated by way of illustration. At a rough estimate, (in North Italy) a building of about 100 m^2 inhabited by three people has an annual consumption of approximately 10-15 MWh. Such heat can indicatively serve a building composed of six flats (table and chart 5.1.1).

Assumptions made (e.g. choice of interest rate, investment duration, average yearly production of the generator etc.) and values used refer to average conditions.

Table 5.1.1 Cost categories and their values (December 2008, Italy)

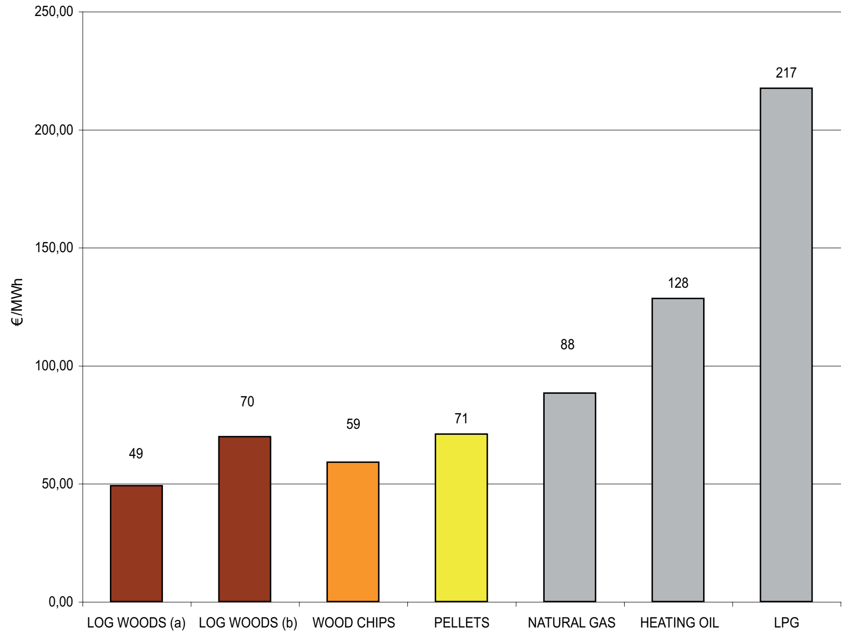
COST CATEGORIES	UNIT	LOG WOOD (a)	LOG WOOD (b)	WOOD CHIPS	PELLETS	NATURAL GAS	HEATING OIL	LPG
Interest rate	%	5	5	5	5	5	5	5
Investments duration (years)	y	20	20	20	20	20	20	20
Boiler capacity	kW	100	100	100	100	100	100	100
Annual running (hours)	h	1,300	1,300	1,300	1,300	1,300	1,300	1,300
Primary energy production	MWh/y	130	130	130	130	130	130	130
Season global efficiency	%	75%	75%	79,0%	84%	90%	85%	90%
Final energy output*	MWh/y	97.50	97.50	102.70	109.20	117.00	110.50	117.00
Investment costs (VAT incl.)	€	45,000	45,000	65,000	40,000	13,000	18,000	13,000
Amortisation	€/y	1,361	1,361	1,966	1,210	393	544	393
Annual fuel demand	u.m.*	32.7	32.7	38.2	28.3	13,542	13,000	19,062
Cost/price of fuels**	€/u.m.	77	130	88	216	0.72	1.04	1.22
Cost of annual fuel consumption (a)	€/y	2,944	4,971	3,365	6,104	9,750	13,463	24,863
Cost of electricity (b)	€/y	50	50	200	100	30	30	30
Operational cost (O=a+b)	€/y	2,994	5,021	3,565	6,204	9,780	13,493	24,893
Cleaning cost (c)	€/y	130	130	130	130	60	60	60
Maintenance charges (d)	€/y	300	300	400	200	95	95	95
Running cost (E=c+d)	€/y	430	430	530	330	155	155	155
Annual COSTS (R+O+E)	€/y	4,785	6,812	6,060	7,744	10,328	14,192	25,441
FINAL ENERGY COSTS	€/MWh	49.08	69.87	59.01	70.92	88.27	128.44	217.44

* Calorific values used: log woods M20, 3.98 MWh/t, wood chips M30, 3.4 MWh/t, pellets M10 4.6 MWh/t, natural gas, 9.6 kWh/m^3, heating oil 10 kWh/l, LPG, 6.82 kWh/l

** Prices (VAT included; for wood fuels VAT is 10%, except for pellets which is 20%)

Initials – Log woods (a): self-produced, desired size; Log woods (b): bought on the local market (P500); Wood chips: M30 P45.

Graph 5.1.1 Energy systems and related energy costs



Initials – Log woods (a): self-produced, desired size; Log woods (b): bought on the local market (P500); Wood chips: M30 P45.

5.2 Log woods and wood chips sale

Log woods and wood chips are sold either by the weight (€/t) or by steric volume (€/stacked m^3 e €/bulk m^3). Professional producers shall provide the buyer with relevant information on the fuel physico-energetic characteristics, so as to make possible an objective economic evaluation of the ponderal or volumetric price proposed; therefore, the application of European Technical Specifications in wood fuel trading is particularly important. The presence of professional producers on the market makes it possible to develop practical and transparent purchase and sales systems which not only gain consumer confidence, but also favour the development of the market.

Log woods

Regulatory information to be specified for the sale of log woods is provided in table 4.1.1. At the most advanced logistic and trade centres (e.g. www.holzbrennstoffe.de, www.ofen-holz.at) oven-ready log woods (M20) is sold by steric volume; besides moisture class, composition and dimensions are also specified. An example of how to draw up a price list for the professional sale of log woods is provided in annex A4.


In the still common event that only log woods composition, and not moisture as well, is specified, it is forever preferable to purchase by volume rather than by weight; this is due to the lower degree of uncertainty with which it is possible to determine energy costs, particularly when purchasing non-seasoned material[5].
Nowadays, stacked log woods is frequently sold by pallets of 1x1x1.8 m with composition specified. For occasional users, chopped log woods is available as oven-ready (M20) in boxes or netted bags and is sold by the weight (6-17 kg) with wood species indicated.

Example 5.2.1 – Calculation of log woods energy price

Supposing we want to buy a certain amount of log woods to supply a modern boiler for the whole season, we would like to find the price of energy in order to compare different offers.
The wood fuel producer sets the following prices for one-meter logs (P1000) of two different species:

Beech 62 €/stacked m^3
Spruce 46 €/stacked m^3

1) to calculate the log woods weight (M20, P1000) for the two species, tables 1.7.2 and 1.7.3 are used

Beech → 453 x 0,81 = 367 kg/stacked m^3
Spruce → 315 x 0,86 = 271 kg/stacked m^3

2) energy cost (M20) with NCV_{20} = 4 kWh/t

Beech → 62:[(367x4):1.000] = **42,2 €/MWh** (11,7 €/GJ)
Spruce → 46:[(271x4):1.000] = **42,4 €/MWh** (11,8 €/GJ)

At the prices proposed and with log woods to be used for a modern boiler, the two products are energetically equivalent.

Wood chips

In the Centre-North of Europe, and in the case wood chips are sold directly from sawmill, the composition is generally known; thus selling by volume, even when moisture is not specifically indicated, makes it possible to determine energy cost with sufficient precision.

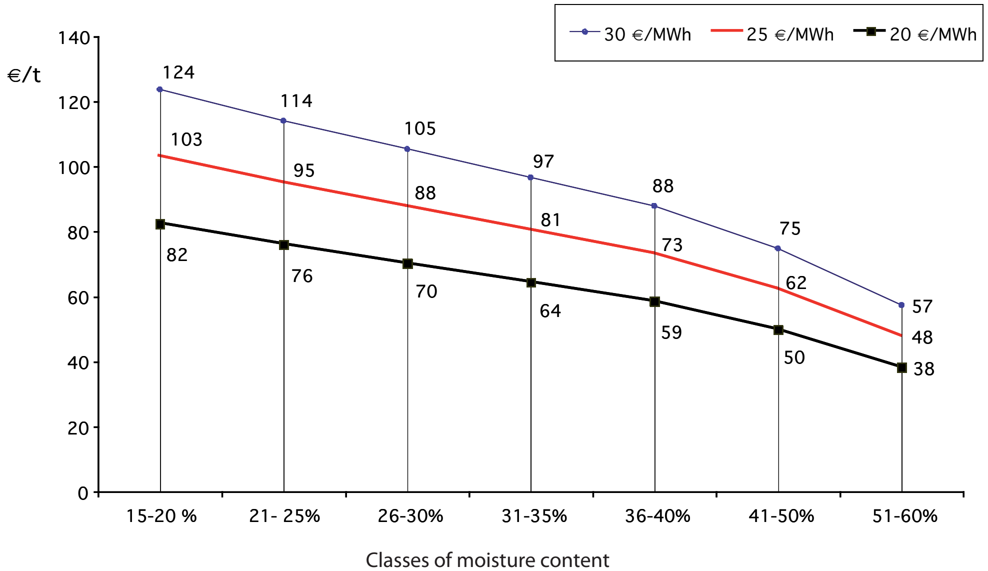
On the contrary, in the Centre-South of Europe, and in the case of producers working on mixed forest stands, it is virtually impossible to know the composition of wood chips; in this case it thus seems preferable to purchase and sell wood chips by the weight, measuring their moisture. As a matter of fact, it is sufficient to know the weight and moisture: though great the difference in composition might be, the variation in energy content is very slight because, as has already been pointed out, the NCV0 of wood is almost the same in all the different species[14].

Generally, usual practice is that the parties haggle over a target price for wood chips with a minimum moisture on which basis the price of primary energy is calculated. At this point, a table is created in which wood chips are priced based on their moisture class, while the price of energy remains constant (table 5.4.1).

Table 5.2.1 Wood chips price related to moisture classes at the energy price of 25 €/MWh

Moisture content (Classes)	M (%)	€/t	
		VAT excl.	VAT incl.
M 20	≤ 20	103	114
M 25	≤ 25	95	105
M 30	≤ 30	88	97
M 35	≤ 35	81	89
M 40	≤ 40	73	81
M 50	≤ 50	62	69
M 60	≤ 60	48	53

Graph 5.2.1 Variation in price of wood chips according to three different energy prices



A draft of a contract for the sale of wood chips with energy content is provided in annex A1.

5.3 Energy consumption and CO_2 emissions

In order to adopt sustainable energy systems it is both useful and proper to possess comparative evaluations on the non-renewable energy consumption that is necessary to feed, with energy and raw materials, the entire process of final energy production (productive chain). Energy analysis* encompasses all the non-renewable energy that is consumed along the chain: extraction, processing, storage, fuel energetic conversion, including the energy cost of the machinery and tools used for the single phases.

Table 5.3.1 shows energy consumption expressed as a percent of non-renewable energy consumed to produce useful thermal energy (CER**).

Energy consumption for the production and final use of the fuel entails the emission into the atmosphere of a certain amount of carbon dioxide (CO_2) and other types of greenhouse gases that are expressed in aggregated form with the equivalent CO_2 parameter.

* This analysis has been carried out using the GEMIS database (Global Emission Model for Integrated Systems version 4.42, Öko-Institut e.V. Darmstadt (Germany) www.oeko.de).

** CER (Cumulated Energy Requirement) measures the total amount of (primary) energy recourses that is necessary to supply a unit of final thermal energy.

The values listed in table 5.3.1 make it possible to calculate the reduction of CO_2 emissions that can be obtained by using wood fuels instead of fossil fuels.

Table 5.3.1 Energetic consumption and CO_2 emissions

Heating system	CER %	CO_2 kg/MWh	CO_2 eq. kg/MWh
Log woods (10 kW)	3.69	9.76	19.27
Forestry wood chips (50 kW)	7.81	21.12	26.04
Forestry wood chips (1 MW)	8.61	21.13	23.95
Wood chips poplar SRC (50 kW)	10.44	27.39	40.16
Pellet (10 kW)	10.20	26.70	29.38
Pellet (50 kW)	11.08	28.95	31.91
Heating oil (10 kW)	17.33	315.82	318.91
Heating oil (1 MW)	19.04	321.88	325.43
LPG (10 kW)	15.03	272.51	276.49
Natural gas (10 kW)	14.63	226.81	251.15
Natural gas (1 MW)	17.72	233.96	257.72

Example 5.5.1 – Estimation of CO_2 and CO_2 eq. reduction

Illustrated below is the procedure to follow in order to estimate the amount of CO_2 that can be saved by converting a natural gas boiler into a wood chips one. In the following example reference is made to a 500 kW wood chips district heating plant.

1) Calculation of the final amount of energy as annual output of the plant:
   2-year thermal output registered: (556+603)/2 = 580 MWh/year (average)
2) Calculation of the annual CO_2 and CO_2 eq. emissions using natural gas: (table 5.3.1)
   Natural gas: (580 x 233.96): 1000 = 135.7 t CO_2
   Natural gas: (580 x 257.72): 1000 = 149.5 t CO_2 eq.
3) Calculation of the annual CO_2 and CO_2 eq. emissions using wood chips: (table 5.3.1)
   Forestry wood chips: (580 x 21.13): 1000 = 12.3 t CO_2
   Forestry wood chips: (580 x 23.95): 1000 = 13.9 t CO_2 eq.
4) Calculation of avoided CO_2 and CO2 eq. emissions using wood chips instead of natural gas to produce heat
   135.7 – 12.3 = 123.4 t CO_2/year
   149.5 – 13.9 = 135.6 t CO_2 eq./year

Supposing that the plant has a lifetime of 20 years, an avoided emission of 2468 t CO_2 can be calculated.

A car driver who covers an average of 25,000 km a year emits approx. 3.5 to 4 t of CO_2; in this case, therefore, the plant can replace about 30 cars covering all together 830,000 km/year.

5) Calculation of monetary value of carbon dioxide saving

Nowadays, on the international market (BlueNext - EUA), one ton of CO_2 is quoted around 15 € (December 2008)

123.4 x 15 = 1,851 €/year

ANNEXES

A1. Contract draft for the sale of wood chips with energy content

(see CEN/TS 14961:2005)

Parties

This contract is set down by and between the following parties:

the Supplier *Cooperativa Agroforestale - Viale Università 14*
32021 Agordo (BL) VAT 01237780265 hereinafter referred to as **FO**
and the Buyer
Wood chips district heating Ltd. hereinafter referred to as **TE**

Art. 1. Subject matter

The subject matter of this contract shall be the delivery by FO to TE of wood chips obtained by chopping virgin wood. The wood chips shall serve as a fuel for the provision of the district heating that is property of TE.

Art. 2. Delivery time

FO commits to delivering each load of fuel within 6 working days of receipt of a written request sent by TE either by fax or by e-mail. TE shall also notify FO of the entity of the load to be delivered expressed in tons.

Art. 3. Annual requirements

The quantity of wood chips to be delivered during the period of validity of this contract is equal to the quantity of wood chips that will actually be consumed by the plant during the heating season. On the basis of energy calculations it is estimated that this quantity will be 500 tons (with reference moisture (M) of 30%).

Art. 4. Fuel biomass origin

The wood chips delivered shall be the product of mechanical processing of virgin wood, as is stated in technical specification CEN/TS 14961.

Wood chips shall be obtained from the chopping of: branchless conifer or broad-leaf trunks, leafless broad-leaf trunks with branches attached, broad-leaf logging residues (either leafless or with dry leaves), slash and slabs and other primary conversion waste products from which it is possible to obtain high-quality wood chips.

Art. 5. Dimensions

As concerns wood chips dimensions, reference is made to the technical specifications CEN/TS 14961. The wood chips delivered shall belong to class P45.

Wood chips dimension classes in compliance with technical specification CEN/TS 14961

Dimension classes (mm)	Composition of particle size (%)		
	Main amount >80% of wt.	Fine particle <5%	Coarse particle <1%
P16	$3.15 \leq P \leq 16$	<1 mm	> 45 mm all < 85 mm
P45	$3.15 \leq P \leq 45$	<1 mm	> 63 mm
P63	$3.15 \leq P \leq 63$	<1 mm	>100 mm
P100	$3.15 \leq P \leq 100$	<1 mm	>200 mm

Art. 6. Purity

The wood chips delivered shall not contain extraneous matter such as nails, wires and bolts, nor any other metal object.

Art. 7. Moisture and load weight

Moisture (M) and load weight shall be determined by FO.

Art. 8. Invoicing terms and conditions

Invoicing of the wood chips delivered is made with reference to their energy content that is to their NCV_M expressed in MWh/t, calculated, on the basis of the weight (t) and moisture (M) of the load, according to the following formula:

$$NCV_M = \frac{NCV_0 \text{ x } (100\text{-}M)\text{-}2{,}44 \text{x} M}{100} \text{ x } 0{,}278$$

For each delivery, FO shall issue to TE a quality declaration for wood chips (see A2).

Art. 9. Delivery price ex heating plants

TE shall pay to FO the target price for wood chips equal to 85.00 €/t (+ VAT at 10%) at M30, ex plant (24.15 €/MWh). Price varies according to the moisture of the wood chips delivered. Moisture in the wood chips delivered shall never exceed 35%.

The following table shows the variation in price according to 4 classes of moisture.

Energy price:	€/MWh 24,15	€/t	
Moisture classes content		VAT excl.	VAT incl.
M 20	15-20 %	€ 95	€ 104.5
M 25	21- 25%	€ 90	€ 99.0
M 30	26-30%	€ 85	€ 93.5
M 35	31-35%	€ 75	€ 82.5

Art. 11. Payment

Payment shall be made by TE within thirty days end of month from date of issue of invoice. In the event of failure to pay within agreed terms, FO reserves the right to suspend supply service and claim interest on delayed payment in accordance with current rules.

Art. 12. Non-conforming supplies

Any loads of non-conforming wood chips supplied shall not be paid for by TE.

Art. 13. Term of validity

The term of this contract shall commence on the date it is signed by the parties and shall continue in full force and effect for a period of three years.

In the event the operativeness of the plant ceases or is highly damaged as a consequence of the revocation of the necessary licences or decisions issued by the relevant authorities or any other reasons not ascribable to the parties, TE has the right to permanently terminate this contract within 6 months.

Art. 14. Special provisions

1. In the event of any dispute or claim arising out of, or in connection with this contract, including, but not limited to, any question regarding its validity, interpretation and correct execution, the parties agree that such disputes or claims shall be finally settled by arbitration administered by Court of ....

2. This contract shall be in full force and effect from and after the date it is signed by both parties
3. This contract is made in two copies, with each party keeping one copy.
4. Any changes in the terms and conditions of this contract shall be notified to the other party in writing.
5. Any third party taking over either of the parties shall be assigned the rights and obligations arising out of this contract.
6. The parties agree to share equally the costs of drawing up this contract, with each party paying 50% of the total cost.

Place, date stamp and signature of FO's legal representative	Place, date stamp and signature of TE's legal representative

A2. Example of a fuel quality declaration for wood chips

(see CEN/TS 15234:2006)

Applicant: Cheap-Wood Chips District heating Ltd.

FUEL QUALITY DECLARATION FOR WOOD CHIPS BASED ON CEN/TS14961	
Supplier	SOLID WOOD-FUELS Cooperative P.O. Box 110 CB 10 1HL – SAFFRON WALDEN Essex (UK) Tel +44.01799 5165689 Fax +44.01799 5165690 Contact persons: Mr. Peter Wood E-mail: Delivering@solid.wood-fuels.co.uk Contract number: N. 0015/a
Raw material	Coniferous logs, slabs and trimmings (1.1.2.2; 1.2.1.2)
Origin	Uttlesford, District of Essex
Amount of delivery	10 t (see attached weighing receipt)
Properties	
Particle size	P45
Moisture (M)	M30
Ash content (wt% d.b.)	A3.0
Bulk density (kg/bulk m^3)	230
Calorific value (MJ/kg)	12.2
Energy density (MJ/bulk m^3)	2806

Place and date Signature of assigned person

A3. Limit values for the concentration of heavy metals in biomass ashes used in agricultural land in Austria[9, 10]

Metals	Limit value mg/kg_{db}	Spreading amount g/ha/year	
		Arable land	Meadow-pasture
Zinc (Zn)	1.500	1.500	1.125
Copper (Cu)	250	250	190
Chromium (Cr)	250	250	190
Lead (Pb)	100	100	75
Vanadium (V)	100	100	75
Cobalt (Co)	100	100	75
Nickel (Ni)	100	100	75
Molybdenum (Mo)	20	20	15
Arsenic (As)	20	20	15
Cadmium (Cd)	8	8	6
PCDD/F (dioxin)	100 ng TE/kg_{db}	100 µg/ha	75 µg/ha

PCDD/F – polychlorinated dibenzodioxins/furan
TE: Toxicity equivalent

A4. Example of a price list for professional log woods trading

The prices listed below are indicative only.

PRICE LIST 2007/08

Valid until 31st July 2008

Ex store, VAT included.

SPRUCE and BEECH LOG WOODS – OVEN-READY (M20)

→ Prices per stacked and bulk m^3, 1 stacked m^3 ~ 1.4 bulk m^3

→ NCV_{20} = 4 kWh/kg

→ ~ 450 kg Beech ~ 300 kg Spruce M20 = 1 stacked m^3 P330 (L=33 cm)

Beech (with a quota of other hardwood species) 1 stacked m^3 = 450 kg 1 bulk m^3 = 320 kg	Length (L)	Up to 7 bulk m^3	Up to 5 stacked m^3	More than 5 stacked m^3 5% discount
	100 cm (P1000)	-	79.00 €	75.05 €
	50 cm (P500)	-	84.00 €	79.80 €
	33 cm (P330)	59.70 €	84.00 €	79.80 €
	25 cm (P250)	63.30 €	89.00 €	84.55 €
Spruce (with a quota of other hardwood species) 1 stacked m^3 = 300 kg 1 bulk m^3 = 215 kg	Length (L)	Up to 7 bulk m^3	Up to 5 stacked m^3	More than 5 stacked m^3 5% discount
	100 cm (P1000)	-	69.00 €	65.55 €
	50 cm (P500)	-	74.00 €	70.30 €
	33 cm (P330)	53.00 €	74.00 €	70.30 €
	25 cm (P250)	56.60 €	79.00 €	75.05 €

A5. Abbreviations and symbols

m^3: solid cubic meter

Stacked m^3: stacked cubic meter

Bulk m^3: bulk cubic meter

u: moisture on dry basis [%]

M: moisture on wet basis [%]

Mv: solid density, [volumic mass] [kg/m^3]

Ms: stacked and bulk density [kg/msa, kg/msr]

Ww: wet weight [kg, t]

W0: dry weight [kg, t]

d.b.: dry basis [kg, t]

w.b.: wet basis [kg, t]

GCV: gross calorific value [MJ/kg, kWh/kg]

NCV_M: net calorific value [MJ/kg, kWh/kg]

toe: ton of oil equivalent

Q: thermal boiler capacity [kW]

Q_B: gross boiler capacity [kW]

Q_N: nominal thermal capacity [kW]

η_k: efficiency [%]

β_v: volume shrinkage [%]

α_v: volume swelling [%]

SRC: Short Rotation Coppices

A6. International System of units

10^n	Prefix	Symbol	Long scale	Decimal
10^{15}	peta	P	Billiard	1 000 000 000 000 000
10^{12}	tera	T	Billion	1 000 000 000 000
10^9	giga	G	Milliard	1 000 000 000
10^6	mega	M	Million	1 000 000
10^3	kilo	k	Thousand	1 000
10^2	hecto	h	Hundred	100
10	deca	da	Ten	10
10^{-1}	deci	d	Tenth	0.1
10^{-2}	centi	c	Hundredth	0.01
10^{-3}	milli	m	Thousandth	0.001
10^{-6}	micro	µ	Millionth	0.000 001

REFERENCES

1 GIORDANO G., 1988 - *Tecnologia del legno*. UTET, Milano.

2 HARTMANN H. (Hrsg.), 2007 - *Handbuch Bioenergie-Kleinanlagen* (2. Auflage). Sonderpublikation des Bundesministeriums für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL) und der Fachagentur Nachwachsende Rohstoffe (FNR), Gülzow (DE) 224 S., ISBN 3-00-011041-0.

3 JONAS A., HANEDER H., FURTNER K., 2005 - *Energie aus Holz*. Landwirtschaftskammer Niederösterreich St. Pölten (AT).

4 HÖLDRICH A., HARTMANN H., DECKER T., REISINGER K., SOMMER W., SCHARDT M., WITTKOPFT S., OHRNER G., 2006 - *Rationelle Scheitholzbereitstellungsverfahren*. Technologie- und Förderzentrum (TFZ) Straubing (DE).

5 HELLRIGL B., 2006 - *Elementi di xiloenergetica. Definizioni, formule e tabelle*. Ed. AIEL, Legnaro (PD).

6 LOO VAN S., KOPPEJAN J., 2003 - *Handbook of Biomass Combustion and Co-Firing*. Ed. Twente University Press (NL).

7 FRANCESCATO V., ANTONINI E., PANIZ A., GRIGOLATO S., 2007 - *Vitis Energetica, valorizzazione energetica dei sarmenti di vite in provincia di Gorizia*. Informatore Agrario n° 10.

8 OBERNBERGER I., 1995 - *Logistik der Aschenaufbereitung und Aschenverwertung*. Bundesministerium für Ernährung, Landwirtschaft und Forsten, Bonn (DE)

9 BUNDESMINISTERIUM FÜR LAND- UND FORSTWIRTSCHAFT, 1997 - *Der sachgerechte Einsatz von Pflanzenaschen im Wald*. Wien (AT)

10 BUNDESMINISTERIUM FÜR LAND- UND FORSTWIRTSCHAFT, 1998 - *Der sachgerechte Einsatz von Pflanzenaschen im Acker- und Grünland*. Wien (AT)

11 AA.VV. Progetto BIOCEN, 2004 - *Gestione e valorizzazione delle ceneri di combustione nella filiera legno-energia*. Regione Lombardia

12 BURGER F., 2005 - *Wood Chip Drying Pilot Study "Wadlhausen"*. Bayerische Landesanstalt für Wald und Forstwirtschaft, Freising (DE).

13 ITEBE, 2004 - *Produire de la plaquette forestière pour l'énergie*. Bonne pratique n°1 du bois déchiqueté. Lons Le Saunier (FR).

14 FRANCESCATO V., ANTONINI E., MEZZALIRA G., 2004 - *L'energia del legno. Nozioni, concetti e numeri di base*. Regione Piemonte.

15 FRANCESCATO V., PANIZ A., ANTONINI E., CORREALE S.F., AGOSTINETTO L., 2007 - *Stagionatura e caratterizzazione qualitativa del cippato di legno*. Rivista Tecnica AGRIFORENERGY n° 2. Ed. AIEL, Legnaro (PD).

16 FLORIAN G., 2006 - *Nicht länger das Aschenputtel der Holzbranche*. Energie Pflanzen n°6. Das Fachmazin für nachwachsende Rohstoffe und erneuerbare Energien. Scheeßel-Hetzwege (DE).

17 DANY C., 2007 - *Allgäuer Hackschnitzel*. Energie Pflanzen n°6. Das Fachmazin für nachwachsende Rohstoffe und erneuerbare Energien. Scheeßel-Hetzwege (DE).

18 BIERNATH D., 2006 - *Brennholztrocknung mit der Biogasanlage*. Energie Pflanzen n°2. Das Fachmazin für nachwachsende Rohstoffe und erneuerbare Energien. Scheeßel-Hetzwege (DE).

19 STAMPFER K., KANZIAN C., 2006 - *Current state and development possibilities of wood chip supply chains in Austria*. Croatian Journal of Forest Engineering 27 (2): pp 135-144.

20 CEN/TS 14961, 2005 - *Technical specification - Solid biofuels - Fuel specification and classes*.

Printed in April 2009

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