

## 04-01: Ligno-cellulose – Properties and processes

Wood – ligno-cellulose – is the most abundant biomass and, globally, the most important biofuel. Much of the wood-fuels used are, however, used in in-appropriate processes and causing lung diseases among poor people not only in Africa but also in Asia because of the emission of soot and heavy hydrocarbons. To some extent these problems have given wood-firing a bad reputation also in industrialised countries where the technology for environmentally-friendly is available.

Two major reasons that wood, throughout history, has been the most important fuel for mankind are

- It is easily available in large amounts (see sections 01-00-03, 02-00-02a and others)
- It has the capacity to reach very high combustion temperatures

The high temperatures attainable in wood-firing were, throughout history, the basis for the production of glass, building brick, cement, bronze, iron ... all the types of materials found in, for example, the Versailles castle. This is often forgotten and many people today tend to regard wood as a fuel that can only be used for low-temperature applications such as steam-raising.

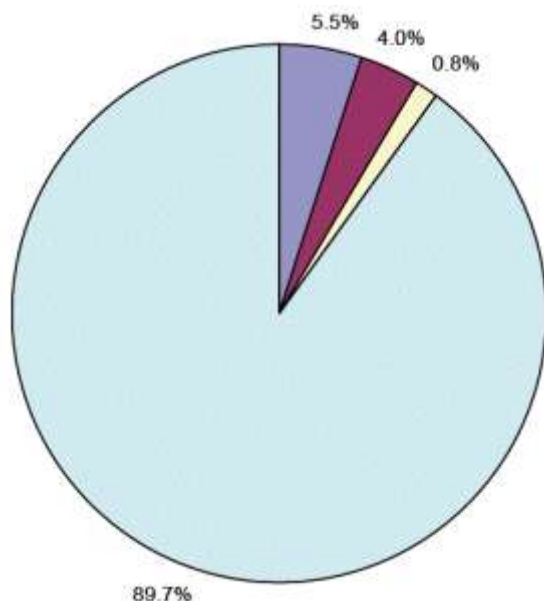
Comparing the attainable temperatures in combustion with air and the flue gas volumes produced per energy unit under ideal conditions yields the following values for wood and selected competitive fossil fuels. These two values are crucial for an over-all quality judgment of a fuel.

Fuel	Flame temperature (°C)	Gas/Energy unit (m <sup>3</sup> /MJ)
Propane	1935	0.285
Light fuel oil	1845	0.300
Dry wood	1805	0.300
Coal (dry)	1805	0.305
Charcoal	1780	0.310
Wood (10 % moisture)	1630	0.335

**Table 04-01 1:** Combustion properties of some fuels

The values in this table will explain why wood and charcoal have both been used for high-temperature processes throughout history. Generally, the temperatures attainable in wood combustion are higher than those attainable from solid herbaceous biomass, though, of course, specific liquid biofuels such as olive or rape-seed oil will be competitive.

The general properties of wood make it an excellent fuel and the main use of wood in the federal European energy system is via combustion applications to provide heat and – to a minor extent – electricity.



**Figure 04-01 1:** Shares of renewables in the EU27 energy system 2008.

From Eurostat “*Statistics in focus*” 56/2010

[http://epp.eurostat.ec.europa.eu/cache/ITY\\_OFFPUB/KS-SF-10-056/EN/KS-SF-10-056-EN.PDF](http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-10-056/EN/KS-SF-10-056-EN.PDF)

5.5 % renewable energy for heating

4.0 % electricity from renewable sources

0.8 % transport energy from renewable sources

Remaining 89.7 % is energy based on non-renewables

Looking closer at the use of renewables for heat production reveals that 611.2 TWh of heat was produced using wood as a fuel within EU27 in 2008, 90.2 TWh of heat was produced from “biomass”, 12.6 TWh were produced using solar heating systems, 12.6 TWh were produced from biogas, 8.6 TWh were produced using geothermal systems and 6.4 TWh were produced from liquid biofuel.

For heat production from renewables in the federation, wood combustion is thus completely dominant, providing in 2008 more than 80 % of the total (611 of 742 TWh) heat produced from renewables.

Also compared to the total consumption of renewable energy in the federation (1 459.6 TWh in 2008), wood fuels are one major source totalling about 42 %.

The total amount of electricity consumed in the federation during 2008 was 3 356.5 TWh and out of that 16.7 % or 560.5 TWh originated from renewables. Hydroelectricity was dominant (60% or 336 TWh) followed by wind power (21 % or 118 TWh) and biomass (17 % or 95 TWh).

To conclude, in 2008 wood fuel was the dominant renewable energy source within the federation supplying 611 TWh of energy, followed by hydroelectricity at 336 TWh, wind power (118 TWh) and then followed by electricity and heat from “biomass”, 95+90 TWh.

Obviously, these statistics are a few years old and wind power and biogas have both increased significantly – but the major role of wood fuels in the expansion of the renewable energy system is clearly seen.

The fundamental reason for the dominant role played by wood fuels is the simplicity inherent with their use and the reasons for that must be sought in the fundamental composition and properties of wood.

### **04-01-01: Overview of wood biomass composition**

#### **04-01-01a: The anatomy of a tree and its effect on composition**

A tree is not composed only from ligno-cellulose but consists of a stem, branches and foliage.

For the production of fuel biomass, the prime-quality stem wood should not be considered in the first instance as is pointed out in section 02-01-02c.

As a very rough estimate, one may say that the above-ground biomass of a full-grown conifer tree will consist of about  $73 \pm 10$  % stem wood,  $10 \pm 5$  % branches,  $5 \pm 3$  % bark and a similar amount ( $5 \pm 3$  %) of needles.

For broadleaf trees, the amount of useful stem wood is typically about 5-10 % lower since many hardwood tree species exhibit forked stems. You will find more details about these distributions in section 02-01-03, where the wood-fuel resources are discussed in more detail.

The proportions of the different parts of the tree are of course variable not only with the individuals and the tree species but also with the age of the tree, the season and within the different fractions. Young trees and/or thin branches will obviously have a higher proportion of bark to stem-wood than a section of a thick stem, the foliage of most broadleaf trees will be less during winter than during summer etc.

In the growing tree, the main transport of minerals and nutrients – i.e. components that make up the intrinsic ash – occurs in the outer layers of the stem wood and in the inner layer of the bark. The mineral and the nutrients are then transported further through the branches and twigs to the green parts, needles and leaves, where the photosynthesis take place.

It then becomes obvious that the outer fraction of the stem wood, the inner part of the bark and the foliage will exhibit higher intrinsic ash contents than, for example, the central parts of the stem. This applies also to thin branches and twigs. Not only the ash content will be higher but the same thing applies to the main nutrients, nitrogen being of major concern in thermal utilisation since it may contribute to the formation of nitrogen oxides.

#### **04-01-01b: The anatomy of a tree, organic components and heating value**

A tree is not composed only from ligno-cellulose but consists of a stem, branches and foliage.

Products of the photosynthesis, as discussed in chapter 01-00, are basically composed of carbohydrate polymers (cellulose and hemicellulose), phenolic polymers (lignin) and other substances, such as resins, fats and fatty acids, commonly known as extractives.

For conifer trees, the content of lignin is typically approaching 30 % by dry weight while for most broadleaf trees it will be lower, about 20-25 %. As a very rough rule-of-thumb one may assume the cellulose content to be about constant, 40 %, which gives as a result that the total content of hemicellulose and extractives is typically lower in hardwoods than in softwood.

Since the lower heating value of lignin is about 25-26 MJ/kg while cellulose and hemicellulose both have heating values in the range 16-18 MJ/kg, the higher lignin content with softwoods will result in a higher total heating value.

The extractives – terpenes and other volatile hydrocarbons acting as herbicides and insecticides to protect the tree from fungi and from insects, will typically constitute only less than 5 % of the total weight. Hence, in spite of their high heating value (35±2 MJ/kg) they will only contribute to a small extent to the heating value.

The physical structure of a tree cell is that the tall macro-molecules in cellulose and hemicellulose are “glued” together with lignin, forming a porous, honeycomb structure of cell walls. The mechanical strength of this structure is partly determined by the amount of “glue”, i.e. lignin, and those parts of the tree where the need of mechanical strength are the highest like the inner part of thick branches or the lowest part of the stem, will consequently have higher lignin contents and higher heating values than other parts.

It is generally believed that lignin is the binder in pellets and the high lignin content with woody biomass makes it easy to produce durable pellets without any additives, i.e. from pure stem wood like saw-dust.

The mechanical strength with wood is a good thing from a transportation point of view since it prevents the formation of too much fine fraction from attrition during transport – but on the other hand it increases the specific need of energy to chip or mill the material to the particle size desired for the energy extraction, be it combustion, gasification, co-firing or any other process. A high mechanical strength is also required from upgraded fuels like pellets; they may not disintegrate into too much fine fraction during transport. Again, the high lignin content with wood makes the production of pellets that can meet these criteria feasible.

The same thing – the high lignin content – also makes woody biomass unsuitable for biochemical treatment. You will find in section 04-03-02 that lignin is assumed almost indigestible in the most common anaerobic digesters.

The relatively high lignin content is thus a key factor distinguishing woody (ligno-cellulosic) biomass from herbaceous biomass and making the woody biomass more apt than crops for thermochemical energy-releasing processes like combustion.

#### **04-01-01c: The growth rate of a tree and the inorganic components**

The necessary influx of nutrients and minerals to a growing tree is determined by its growth rate. The growth rate is typically described as the fractional increase in organic mass per time unit and may thus be expressed as % weight increase per year – or any other suitable time period.

It then becomes obvious that young trees grow faster than mature trees and hence a young tree will generally have higher intrinsic ash content than a mature tree.

With short rotation coppice such as willow plantations for energy (refer to section 03-01-03) – where the trees are harvested only at a few years of age – this may result in a fuel with a very high ash content.

Depending on the harvesting technology chips from such plantations will usually also contain very high fractions of bark, again contributing to a high ash content.

In case the plantation is fertilized using digestate from waste digestion and the digestate content of heavy metals is high, the high mineral content with the fuel may also lead to an undesired high content of heavy metals.

With forest fuels extracted as side products from mature trees and from un-fertilized forest land, the problems mentioned in this paragraph are most often negligible.

#### **04-01-01d: The composition of trees and crops**

Food and fodder crops like cereals or other primary agricultural products differ from ligno-cellulose in many aspects but one obvious aspect is the ultimate aim of the plantation: Food and fodder are aimed for eating while wood is not. Food and fodder crops will therefore be grown to contain high proportions of digestible sugars, fats and proteins and this will be reflected in the composition.

Due mainly to the higher content of proteins inherent in agricultural residues from food and fodder production, fuels from these fractions will contain significantly higher proportions of nitrogen, chlorine, sulphur and other elements that may cause harmful emissions and may also be corrosive in the energy extraction process. The chlorine content in straw may for example well exceed 0.5 %, dry basis.

In contrast, the contents of chlorine and sulphur in pure ligno-cellulose are typically both far below 0.1 % by weight while the nitrogen content in stem wood is typically below 1 %.

### **04-01-02: Fuel properties affecting the supply chain**

The total supply chain (please refer to section 03-00-02 for a general overview and to chapter 03-01 for more specific aspects and descriptions for wood fuels) may consist of up to eight different unit operations, namely:

**Harvesting:** The operations and machinery required will become different depending on the origin of the biomass. Rather than the harvesting operation being influenced by the biomass properties *per se*, the opposite is true, namely that the harvesting operation will have a strong influence on the fuel quality. You may want to refer to section 03-00-02a as well as to chapter 03-01.

**(Road) Transport**, re-loading operations included: Road transport is often a significant part of the total cost for woody biomass (see chapter 05-01) and this is mainly influenced by the bulk energy density (see sections 03-00-02b and 03-01-07).

**Drying:** In case drying is necessary – it will not be for example in the case of dry demolition wood or cutter shavings from planing mills – the time necessary becomes a function of particle size, moisture content and of how the drying is organised; forced drying, mechanical de-watering or natural drying (refer to 03-00-02c). During extended drying periods there may also be a certain amount of biological deterioration (refer to 03-00-02e) depending on the fuel assortment.

**Comminution:** As pointed out in section 03-00-02d, comminution is almost unavoidable in biomass supply since most solid biomass is collected and/or harvested in particle sizes too big for the energy release processes. The mechanical strength of woody biomass makes comminution an energy intensive process and it becomes important not only to choose the correct type of machinery (see 03-00-02d for an overview) but also not to run the process too far, i.e. to strive for too small particles.

**Storage (03-00-02e):** Even though woody biomass is less susceptible to biological deterioration than most biomasses. As you will understand from the properties listed in 04-03-02, wood is not a very suitable substrate for biochemical digestion but it will still be attacked by mould and rot fungi consuming first cellulose and hemicellulose but finally also the lignin itself. Moisture content and particle size are two major factors determining the rate of deterioration. Depending on storage conditions and handling standards there may also be a risk for auto-ignition.

**Homogenization:** The need for homogenization just prior to feeding into the boiler, gasifier, pyrolysis reactor or whatever process is used is more depending on the reactor than on the fuel itself.

**Compaction** – density increase to reduce transport costs, to homogenize the material and/or to improve conveying properties: As already mentioned (04-01-01b), the high lignin content in woody biomass makes it very suitable for pelletizing or briquetting.

**Conveying** (see 03-00-02h): Wood chips – the most common type of wood fuel for medium-to-large scale applications are irregular in shape, they have a relatively low density and their outer surface is rough. Altogether this yields a high internal friction between particles which means that to provide an even mass flow of material to the final reactor a significant amount of energy must be input in the conveying process to overcome the internal friction. For wood chips, this necessary energy input may be as high as 2 % of the power represented by the fuel

flow so that a 100 MWth plant may require up to 2 MWel only for the fuel conveying. With pellets, the conveying power rarely exceeds 0.5 % of the power represented by the fuel.

**Quality control:** Obviously, the quality control and the quality aspects considered must be adapted to the fuel assortment.

#### **04-01-02a: Woody fuel properties with respect to harvesting**

Harvesting and collection operations will have a strong influence on the final ash content (i.e. intrinsic ash + extrinsic ash) in the fuel.

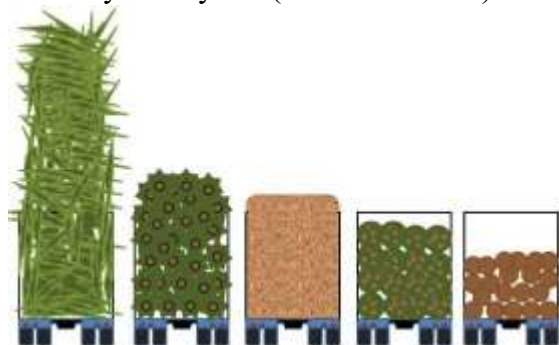
The wood properties *per se*, though, will only have a minor influence on the harvesting procedure.

#### **04-01-02b: Woody fuel properties with respect to transport**

Long-distance transport of woody biomass tends to become relatively expensive due to the low energy density of the fuel.

The capacity of the carrier – be it a trailer, a truck or a railroad car – may be either volume limited or weight limited. The weight limits in the federal states are different and can be found at [1]. As can be seen, the majority of states allow total weights about 40-44 tonnes, some only 35-38 and some up to 60. The federal directive 2002/7/EC outlines some of these limits, referring further for those interested in details.

However, for a simple estimate, let us assume a road trailer using the two recommended containers 100 m<sup>3</sup> (13.6 m) and 57.5 m<sup>3</sup> (7.82 m) and with a maximum weight of 44 tonnes. Assuming the empty truck to have a total weight about 25 % of the maximum weight, so that the payload capacity is 75 % of maximum weight, we find that the weight per volume ratio becomes 33 tonnes/157.5 m<sup>3</sup> or 210 kg/m<sup>3</sup>. With a smaller carrier, using only one of the containers, for example, one will have to assume that the weight load capacity decreases so that maybe only 2/3 (instead of 75 %) of the maximum weight and be utilised for payload.



**Figure 04-01 2 (from 03-01-07):** Weight- and volume limitations in transport

Using the limiting number from the example above –  $210 \text{ kg/m}^3$  – one finds that the transport of anything that has a lower bulk density than this value (saw dust, cutter shavings, brash...) will hit the volume limitation while transport of anything with a higher bulk density (round wood, pellets, briquettes...) will hit the weight limit. Wood chips with moisture content around 30-40 % and with a normal size distribution produced by a chipper or a crusher will end up with a bulk density about  $200\text{-}300 \text{ kg/m}^3$ .

With railroad transport one may roughly assume that the limiting bulk density is about double.

#### **04-01-02c: Woody fuel properties with respect to drying**

With respect to the primary moisture content in wood-fuels one should distinguish between four major assortments:

**Saw-mill and pulp/paper-mill bark:** To protect the timber from dry-cracking, saw-mill timber is often water soaked through spray arrangements prior to sawing. Though pulp- and paper mills do not necessarily soak the timber it will be stored outdoors and also in these cases will the bark be very wet. After de-barking, the wet bark is available as fuel, in the saw-mill application often to produce steam for the driers, in the pulp-mill often used to replace heavy fuel oil in the lime kilns and in the paper-mill to provide process steam for the drying. The very high moisture contents (up to 60-65 %) in combination with the limited requirements on the moisture content set by the combustion temperatures in the applications (about 40 %) makes mechanical de-watering often the most economical alternative.

**Brash:** Branches, treetops and thin trees from felling or thinning operations. When harvested, this fraction will have the moisture content of the living tree, strongly depending on season. During spring and early summer the moisture content may be as high as 55 or even 60 %, during winter as low as 40 % or even less. The most cost-effective method to achieve a reduction in moisture content down to about 40 % (obviously depending on climate) or less is by open-air drying in covered windrows as shown in figure 03-01 16, text section 03-01-07.

**Joinery and wood-processing industry residues:** This fraction may basically be of two kinds, namely wet material produced at early stages in the processing chain and dry materials produced at the later stages. In both cases, the material will be present in the form of small bits-and-pieces, from cut-offs to adjust the length of sawn goods down to grinding dust, and it will exclusively be stem-wood. Another part of this assortment may be reject chips from the pulp industry, reject (stained) wood from joineries and alike. The wet and the dry material should be collected and kept separate. Typically, the “wet” material in this assortment will have moisture contents less than 50 % and will be useful as a fuel without any drying at all. Keeping the wet and the dry materials separate throughout the supply chain finally gives the opportunity to homogenize the material by mixing just prior to feeding into the energy releasing process, thus saving the cost for drying.



**Waste and demolition wood:** The main part of this wood will have been used indoors while some of it – like used pallets or formwork timber – may have been exposed to outdoor conditions. Just like the previous assortment it is important to keep wet and dry material separate so as to avoid drying processes.

#### **04-01-02d: Woody fuel properties with respect to comminution**

While pure ligno-cellulose will typically have low ash content, this is not true for the “real” fuel fractions. Felling residues as well as stumps from up-rooting may not only contain significant amounts of soil but may also contain stones – all depending on the handling during harvesting.

The most common types of machinery used in the first stages of wood fuel processing are chippers and crushers (see also 03-00-02d), sometimes shredders.

- In case of a clean material – free of stones, metallic components, plastic strings and alike – chippers are usually preferred.
- If there is a risk for stones or other large chunks of hard materials, for example chunks of concrete, nails and screws or similar contaminants in demolition wood or the same types of contaminants in formwork timber or worn-out pallets, crushers would be preferred.
- In case of baled or bundled material, so that plastic strings or nets are present in fuel, shredders are recommended.

In all three cases, the total energy requirement for the fractioning is determined by four major factors:

- The design and make of the machinery. There are no general models available to predict theoretically the total need of fractioning energy but experience shows that different makes of machinery will exhibit large variations in specific energy consumption ranging from order of magnitude 5 kWh/tonne and up to and exceeding 100 kWh/tonne.
- The ratio of feed particle size to exit particle size, i.e. the ratio of reduction. The larger the reduction in size, relative to the feed particle size, the larger the energy consumption. The relationship is not linear but the specific energy consumption tends to increase faster as the reduction ratio increases.
- The moisture content of the feed. The mechanical properties of wood are strongly depending on moisture content so that dry wood tends to be very hard while wet wood is very tensile. Depending on the type of fragmentation, cutting in a chipper, shearing and tearing in a shredder and compression/crushing in a crusher, there will be optimum moisture contents to be found for each application.
- The composition of the fuel assortment. While dry bark is a very brittle material, dry hardwood is extremely resistant to mechanical wear...

In co-firing applications – wood powder combustion together with coal powder – it is advantageous to mill the wood together and in the same mill as the coal. To facilitate this, the wood fuel must be pre-treated and either introduced into the mill in the form of wood pellets or undergo a low-temperature pyrolysis (“torrefaction”) before it is introduced into the mill. If this pre-treatment is not done, then the wood must be milled separately from the coal, thus affecting the capital and operational costs for the co-firing.

#### 04-01-02e: Woody fuel properties with respect to storage

While pure ligno-cellulose, stem-wood, is quite resistant to microbiological attack and especially so if the moisture content is low, wood fuels are *never* neither biologically nor chemically inert. You may want to refer back to 03-00-03 and to 03-00-03a for a reminder.

Due to the large volumes of wood fuels to supply reasonably-sized energy plants (some 50 – 500 MWth), wood fuels will typically be stored outdoors. Pellets and briquettes, though, have to be stored under a rain-protecting roof.



**Figure 04-01 3a:** Outdoor storage of saw-dust for fuel at a pulp-mill



**Figure 04-01 3b:** Outdoor storage of chips from felling residues at an energy plant

You will notice how the upper picture shows how the saw-dust piles are partly snow-covered and how the lower picture shows one of the chips stacks (in the background) to be covered by plastic while the front one is not.

It is important to realize that a pile of comminuted material, the size of which is indicated in table 03-01 4 in text section 03-01-07, is not very sensitive to rain and that the moisture content inside the stack (i.e. further than about 0.5 m from the surface) is only to a minor extent affected by the outside weather.

Climate, though, will have an effect so that storage in large (i.e. high) piles in warmer climates will lead to higher temperatures inside the pile and increase the risk of auto-ignition. The limiting heights mentioned in table 03-01 4 are for Swedish (i.e. boreal) climate conditions and they should be adjusted downwards for warmer climates.

The biological – and chemical – activity inside the pile of fuel are of course affected by the material as such, by the moisture content and by the air throughflow, i.e. the permeability of the pile. The chemical activity is also radically increased by the presence of catalysts – iron, nickel, chromium and other metals – so that the risk for auto-ignition increases. This means that the discipline and the cleanliness in the fuel storage area is of utmost importance. Fallen-off tooth from front-loader or an excavator ladles, dropped hand tools or any other object made from high-alloy steel – or indeed any metallic object at all – covered by wood chips may act as an ignition point.

As a rule of thumb, different fuel assortments should be stored separately. If dry bark and wet bark are available as fuel fractions, they should be stored in separate piles. If dry stem-wood and wet stem-wood are available they should be stored in separate piles. If wet felling residues (> 45 % moisture) and “dry” felling residues (< 40 % moisture) are available, they should be stored separately. There is one major exception: Carpentry dry saw dust may be mixed with carpentry dry cutter shavings and stored in the same pile.

With an inappropriate planning of the storage, e.g. mixing fractions with each other, the losses of combustible material may become as high as 5 %/month while a proper planning and management of the fuel store may bring them down to well below 2, even down to about 1 % per month or some fuel fractions.

It is obvious that a wildfire started by carelessness – for example an adjustable spanner that has accidentally been dropped and not retrieved in a pile of chips – will radically increase the losses of combustible material.

#### **04-01-02f: Woody fuel properties with respect to compaction**

As already mentioned in section 04-01-01b, the high lignin content in woody biomass renders it very suitable for pellet production. Wood pellets, shown at about natural size in the picture, is an upgraded fuel made from clean stem wood without additives. Many European federal standards concerning biofuel have been updated during the period 2000-2016 and the standards for wood pellets are among them. Since standards are a commercial product they cannot be included in a handbook like this but readers are referred to download the pellet-standards report from the PelletAtlas project

(<https://ec.europa.eu/energy/intelligent/projects/en/projects/pelletslas>) or to download the

“Summary of Woodfuel standards” from the Woodheat Solutions project

(<http://ec.europa.eu/energy/intelligent/projects/en/projects/whs>). At this site there is also a report named “Introduction to woodfuel standards” that may be of interest for those not too familiar with woody biomass for energy. You will notice that there is also a “Pellet Handbook” among the PelletAtlas project documents.



**Figure 04-01 4:** Wood pellets, about natural size

The production of high-quality wood pellets requires access to clean stem-wood of a suitable particle size distribution and moisture content, a pellet mill and a cooling tower or cooling section.

Even if the pellet production is integrated in a saw mill and the saw-dust is used for pellet production, there will usually be a need of an additional milling, usually via a hammer mill. It may also be necessary to adjust the moisture content so that it is 10-15 % just prior to the

pellet mill. Inside the mill, the particles are pressed through holes in a circular matrix at a pressure about 700 bar. The lignin then becomes plastic and the pellets are cut off from the outside of the rotating matrix. The energy requirement depends on the mill status but is about 100-300 kJ/kg of pellets.

The same technology can be used to pelletize some crops – but the quality of the pellets is strongly dependant on the lignin content, so wood is basically the best material to be pelletized.



**Figure 04-01 5:** A worn-out pellet press matrix on a rainy day

In contrast to wood pellets, briquettes are a low-quality product produced only at about 150 bar pressure and with much less mechanical durability. The picture below shows wood briquettes at about 25 % of their natural size.



**Figure 04-01 6:** Wood briquettes, about 1/4 of natural size

Briquettes can be made from mixtures of saw-dust and cutter shavings and like pellets they will have moisture contents at about 10-15 %. Again, it is the high lignin content or the stem-wood that makes the process feasible and low-lignin raw material cannot be briquetted without additive, as wood can.

### **04-01-03: Overview of fuel properties as from different sources**

#### **04-01-03a: Woody fuel properties from felling operations**

The quality of wood fuels from felling sites is mainly determined by the skill of the personnel and less of the site or the species treated at the site.

With un-skilled personnel the total ash content may be as high as above 10 % by weight, the fraction of foliage may be high and there may even be stones and similar objects present in the fuel fraction delivered.

It must be accepted that fuel from felling sites will contain bark together with some amounts of foliage mixed with the stem wood and that the moisture content may be variable.

The process to extract the energy must be apt to handle such, sometimes quite large, quality variations with high, or at least acceptable, environmental performance.

#### **04-01-03b: Woody fuel properties from thinning operations and SRC**

Thinning operations as well as short rotation energy forestry will produce a fuel fraction dominated by juvenile wood. As pointed out in the section about the tree growth-rate, 04-01-01c, this will result in relatively high moisture content at the harvesting and also in relatively high intrinsic ash content.

Depending on the use of fertilizer (in the case of SRC or MRC) the fuel may also be contaminated by high contents of heavy metals.

#### **04-01-03c: Woody fuel properties from plantations, parks and gardening**

Just like with fuel from thinning operations and SRC/MRC, park or garden clippings and prunings will consist of relatively thin material and hence constitute a fuel fraction with relatively high bark fraction.

As a consequence of that, the ash content may be high.

In case of stumps from up-rooting, e.g. from the re-generation of a fruit-tree plantation or alike, there may also be large amounts of soil, sand and even stones in the fuel fraction – mainly depending on the skill of the personnel.

#### **04-01-03d: Woody fuel properties from paper and pulp industry**

In this category, two separate solid-fuel fractions are easily distinguishable:

- The wet bark from the de-barking operation. This will typically be heavily contaminated by soil and sand and is therefore not suitable for chipping or milling. This fraction will commonly be de-watered through mechanical pressing, shredded and used as an internal fuel on-site, either in the lime kilns or to produce process heat (steam).
- Reject – stained or dis-coloured chips that would affect the pulp or paper quality. This will be pure stem wood, the “normal” moisture content being the same as that of the pulpwood chips, some 35-50 %. The colouring of the chips have no influence at all on their fuel properties so this a high-quality, pure stem-wood fuel.

The third category of biofuels found in this industry sector is the internal process fuels like black liquor and such. These fuels are left out of this handbook entirely.

#### **04-01-03e: Woody fuel properties from timber processing industry**

This category includes the first saw-mills, bringing in the fresh log, debarking and delivering sawn planks and boards – dried or wet, planed or unplanned – and all the way through to the joineries finally producing furniture or pre-fab building elements and everything in between.

Except for the very first stage, the primary saw-mill, the fuel fraction produced will consist of more or less pure stem wood at fairly low moisture content.

Much of the by-products from the manufacturing stages will lend itself excellent to the production of pellets for sale to the household sector or to large-scale co-firing, pulverized-fuel firing plants (you may want to re-read the last paragraph in 04-01-02d). However some care must be taken to keep an eye on the metal content in the raw material since the wear of cutter and saw blades will generate contamination from high-alloy steel. With grinding dust, the wear of the sand paper will also lead to relatively high ash contents in the fuel fraction.

#### **04-01-03f: Woody fuel properties from waste fractions**

The fuel quality from these raw materials is mainly depending on the primary use and the age of the raw material. Railway sleepers, for example, may be creosote impregnated and should be handled with care and may be combusted and utilized only in dedicated waste combustion plants while and un-painted, pure redwood, IKEA bookshelf is pure stem-wood and certainly may be subject to the waste directive regulations – or not – depending on the law in the individual state. Regardless of origin, a large fraction of this material will be dry.

The main contaminants affecting the usability of these fractions are three:

- Paint. The composition of paints way well contain such concentrations of heavy metals, or other metals, as to make the fuel fraction fall irrevocably within the waste directive.
- Impregnating agents including anti-rot agents. Exactly the same thing as with the paints apply also to these substances.

- Solid contaminants like concrete, nails, screws and alike. Using a crusher followed by a magnetic separator and a density separator (such as an air-screener) it is possible to separate these contaminants from the fuel fraction. This does not guarantee the cleanness of the fuel but in combination with a quality control on reception of the raw material it may, while this is of course subject to state law and to supervising environmental authorities, be sufficient to classify the resulting fuel fraction as biofuel.

The use of this fraction for energy purposes is thus, to a great extent, depending on state law and on the guarantees one may offer with respect to the handling and raw material.

#### **04-01-04: Overview of process options for wood biomass**

As pointed out in chapter 04-00, the main processes that can be used from the production of useful energy from any type of biomass are the following five:

Three thermal process routes

- Combustion for direct generation of heat and electricity in CHP-plants or co-firing in industrial processes,
- Thermal gasification for subsequent combustion of the gas (“product gas”) in CHP-plants, in industrial processes, or for further chemical processing of the product gas
- Pyrolysis for subsequent combustion of the solid, liquid and/or gaseous product fuel in CHP-plants, in industrial processes or further chemical processing of the pyrolysis product. The pyrolysis can be high-temperature (about 700 °C) or low-temperature (about 300 °C, “torrefaction”), yielding different ratios of solid residue (“char”), liquid residue (“pyrolysis oil”) and gaseous residue (“pyrolysis gas”)

There are also two different biochemical process routes

- Fermentation for subsequent combustion of the liquid fuel (alcohol, mainly ethanol) in IC-engines or as an additional fuel in CHP-plants, in industrial processes or as raw material for subsequent synthesis to a new product
- Anaerobic digestion for subsequent combustion of the gas (“biogas”) in IC-engines or as an additional fuel in CHP-plants, in industrial processes or as raw material for subsequent synthesis to a new product

In order to choose the appropriate process technology for the resource, it is important for bioenergy system planners to have a good understanding of how the characteristics of the woody biomass may affect the different processes.

#### **04-01-04a: Wood fuel use and behaviour in direct combustion processes**

As pointed out in the introductory section to this chapter, combustion of wood for various purposes has been a major process throughout history. The basic reason is that wood lends itself excellent to this process.

The low ash contents in combination with the relatively high ash melting temperatures (see the “ash appendix”) yields combustion of pure stem-wood a simple and versatile process.



The combustion technology for wood-firing is also well-proven and mature for scales extending from individual household heating (a few kW) up to several hundred MW.

Co-combustion with coal has also been well proven up to some 10-15 % of the power.

With modern combustion technology, wood can replace fossil fuel in many industrial high-temperature processes.

#### **04-01-04b: Wood fuel use and behaviour in thermal gasification processes**

The same properties that are behind the fact that wood combustion was the dominant source for renewable energy in the federation in 2008, and still is, also make it an excellent fuel for thermal gasification.

A major advantage of woody biomass as a feedstock or gasification, rather than crop biomass, are the relatively low chlorine, nitrogen and sulphur contents. These being low in ligno-cellulose mean that the product gas will contain less hydrochloric acid, less ammonia and less hydrogen sulphide than the corresponding gas from gasification of herbaceous biomass. This will reduce the risk of corrosion damage downstream the gasifier and will also make product gas clean-up simpler and cheaper.

However, even if the content of ash, chlorine, nitrogen and sulphur are much lower in pure ligno-cellulose (stem wood) than in herbaceous biomass, they are still not low enough to allow a thermal gasifier to feed its product gas straight into a modern gas turbine without an intermediate gas clean-up.

Most thermal gasifiers installed today are neither used for combined-cycle applications, i.e. for gas turbines, nor for the production of high-quality synthesis gas or subsequent processing, but are directly connected to boilers for gas-firing. In such applications, the use of gasification provides no significant advantages to direct combustion of the solid wood.

An interesting application, though, is the use of thermal wood gasification prior to high-temperature process furnaces such as glass- or steel making furnaces. The advantage would be that the control system for the burners and for the furnace would become simpler than if wood-powder firing was employed in the furnace and it would also be simpler to distribute the product (fuel) gas to a large amount of burners than to have individual solid-fuel feeders to the burners. The technology has been demonstrated in full scale for glass melting but at current prices for fossil fuels it is not economically viable.

#### **04-01-04c: Wood fuel use and behaviour in pyrolysis processes**

Throughout history, auto-thermal wood high-temperature pyrolysis to produce charcoal for forgery as well as for blast furnaces has been used.

Low-temperature auto-thermal pyrolysis to produce tar is also a widespread process known since ancient times.

Charring – i.e. high temperature pyrolysis to render charcoal as the prime product – will basically have the characteristics shown in this simple example:

- Assume a dry wood particle, 1 kg, to have heat content about 20 MJ and further assume that the necessary energy to run the process is supplied from an external source so that all the original energy in the wood (20 MJ) is distributed between the products.
- Through a complete pyrolysis at 700 °C, most wood species will lose about 70 % of their weight and the charcoal finally produced will have a heating value about 30-35 MJ/kg.
- Hence the final products after a complete pyrolysis will become
  - 1: 0.3 kg of charcoal at about 33 MJ/kg, i.e. 10 MJ or half the original energy (20 MJ with the 1 kg original, dry, wood) will remain in the charcoal
  - 2: The remaining half of the original energy, 10 MJ, will then be found in the 0.7 kg of liquid (pyrolysis oil) and gaseous (pyrolysis gas) products.

To make the pyrolysis process autothermal parts of the energy otherwise present in the products is used by internal or external combustion so as to maintain the desired process temperature.

In modern low-temperature pyrolysis (“torrefaction”) the process temperature is only about 250-350 °C so that the pyrolysis is not complete and that part of the pyrolysis oil is retained in the solid product.

The net result of this is that a larger fraction of the original energy – up to almost 80 % - is found in the solid product and that the solid also gains hydrophobic properties. The heating value of the solid product is similar to that of charcoal, 30-35 MJ/kg. Like charcoal, the solid product is also very brittle and easy to grind.

Torrefied wood is therefore competing with pellets as the simplest fuel to be used in case of co-firing wood with coal in pulverized-fuel fired applications such as large-scale power stations.

#### **04-01-04d: Wood fuel use and behaviour in biochemical processes**

As pointed out in several places throughout this chapter, ligno-cellulose is not very suitable for biochemical processes like fermentation and/or digestion.

There are several ongoing research and development projects aiming to pre-treatment methods so as to make the cellulose and hemicellulose bound in the lignin available to microorganisms and thus make biochemical treatment of ligno-cellulose feasible, but so far the economy and the high lignin content are effectively preventing the success.

### **04-01-05: Planning for the use of wood fuels**

The most important aspect when planning for a supply chain and for the use of wood fuels for energy is to be aware that any mistakes in the supply chain are likely to impair the high fuel quality inherent in ligno-cellulose.

- Pure ligno-cellulose, as compared to other solid biofuels, has a high heating value, low ash content, relatively low contents of environmentally problematic and corrosive components like nitrogen, chlorine and sulphur and a high ash melting temperature.
- On top of this it can be found as a by-product from a multitude of industrial sectors, small scale like saw dust and cutter shavings from local furniture manufacturers and large scale like reject pulp chips from pulp-mills.
- Pure ligno-cellulose lends itself excellent to upgrading into a uniform, high-grade and high energy-density fuel (wood pellets) without the need for any additives or complicated pre-treatment.
- With a proper planning for the necessary intermediate storages, one can make use of the resistance to microbial attacks inherent in the pure ligno-cellulose and hence keep the inevitable mass losses under strict control.

The technologies and the processes to make full use of these qualities in applications to heat water or superheat steam to the same pressures and temperatures as are attainable in coal-firing are already mature, well-proven and commercially available.

But there are also new developments emerging:

- It has been shown that co-milling and co firing with coal, either adding wood pellets or adding torrefied wood to the coal prior to the coal mills is a versatile process, at least as long as the fraction of wood-borne energy is up to 15 % of the total fuel energy.
- Finally, it has been proven in a full-scale test that gasified wood can be used to replace propane firing in glass-melting applications.

Making full use of these qualities, of the process solutions commercially available and of the current knowledge requires that all stages of the fuel supply chain are optimized and that each and every person involved in the fuel supply chain is properly educated.

Hence, the main responsibility of the planner is to see to the qualifications and the expertise of the stakeholders and the entrepreneurs throughout the supply chain and to see to that the equipment bought for the processes involved is appropriate.

Residual or “waste” fractions of ligno-cellulosic fuels will have higher ash contents, variable moisture contents and may also contain inorganic and other contaminants originating from the original use of the material. Examples are paint or impregnating agents. Such contaminants may render the fuel fraction to irrevocably to fall under the waste directive – but even so, an in-mix of relatively high-quality ligno-cellulose into a sorted fraction of MSW may contribute to stabilise the combustion process and improve the environmental performance of the incinerator.

## REFERENCES

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