Project No.        BYE/03/G31

Title             Biomass Energy for Heating and Hot Water Supply in Belarus

Wood Energy Brochure

First Draft, 23 December 2004

Date               December 2004

Prepared for       UNDP/GEF
Biomass Energy for Heating and Hot Water Supply in Belarus (BYE/03/G31)

Wood Energy Brochure

Colophon

Authors:

John Vos
BTG Biomass Technology Group BV
c/o University of Twente
P.O. Box 217
7500 AE Enschede
The Netherlands
Tel. +31-53-4861186
Fax +31-53-4861180
www.btgworld.com
office@btgworld.com
# TABLE OF CONTENTS

1  BELARUS ENERGY POLICY 5

2  WOOD AS ENERGY SOURCE 6
   2.1  CONSUMPTION OF ENERGY WOOD 6
   2.2  PHYSICAL CHARACTERISATION OF WOOD FUELS 7
      2.2.1  Fuelwood 7
      2.2.2  Wood Chips 7
      2.2.3  Bark 8
      2.2.4  Sawdust and Shavings 9
      2.2.5  Wood Briquettes and Wood Pellets 9
      2.2.6  Recycled Wood 10

3  PROPERTIES OF WOOD AS A FUEL 11
   3.1  GENERAL ASPECTS 11
   3.2  DEFINITIONS FOR WOOD FUEL PROPERTIES 12
      3.2.1  Proximate analysis 12
      3.2.2  Ultimate analysis 13
      3.2.3  Calorific value (kJ/kg) 13
      3.2.4  Ash composition (wt% ash) 15
      3.2.5  Biomass analysis (mg/kg dry) 15
      3.2.6  Biochemical composition (wt%) 15
   3.3  AVERAGE PROPERTIES OF WOOD FUELS 15

4  PRODUCTION OF FOREST CHIPS 18
   4.1  PRODUCTION OF FOREST CHIPS 18
      4.1.1  Thinning in Immature Softwood Stands 18
      4.1.2  Clearing of Forest Residues 18
   4.2  HARVESTING OF FOREST CHIPS 19
      4.2.1  Felling for Chipping 19
      4.2.2  Comminution 20
      4.2.3  Off-Road Hauling 23
      4.2.4  Storage in the Forest 23
      4.2.5  Road Transport 24

5  PURCHASE AND SALE OF FIREWOOD AND FOREST CHIPS 25
   5.1  PURCHASE AND SALE OF FIREWOOD 25
   5.2  PURCHASE AND SALE OF WOOD CHIPS 27

6  CHIPPING AND SUSTAINABLE FORESTRY 29
   6.1  PLANT NUTRIENTS 29
   6.2  HUMUS CONTENT 31
   6.3  SUSTAINABLE UTILISATION 31
1 BELARUS ENERGY POLICY

(to be written)
WOOD AS AN ENERGY SOURCE

Wood is an important energy source all over the world. Energy wood is available in the form of e.g. forest chips, wood processing residues, wood pellets, and in some countries it is produced to a limited extent in short rotation forestry. In Austria every year more than 3,000,000 solid m\(^3\) of wood (or close to 20% of the annual wood harvest) is used directly as energy wood, mainly in private households. In the light of the Government’s aim to increase the energy supply from biomass by 75% between 2002 and 2010, Austria’s energy wood supply should increase to at least 5,000,000 solid m\(^3\).

2.1 Consumption of Energy Wood

In 2001 the Austrian energy supply was based on oil (42.4%), gas (22.8%), renewables (22.6%) and coal (12.1%). Renewable energy sources thus play a prominent role in the energy supply. In 2001 total energy consumption reached 1291 PJ. Renewables contributed approx. 293 PJ, with 11.7% of total energy supply originating from hydropower and 11.0% from other sources, mainly solid biomass. The biomass is used in different forms and for different applications.

Wood chips result from first and second thinnings in forest stands, from harvesting overmature and partly dying forest plantations, from harvesting in climate and insect damaged stands, from the harvesting of nurse trees (species that are planted at the same time of the primary tree species in order to protect them against e.g. frost and weeds), and from tops by clear-cutting (timber harvesting of the whole stand at the end of the rotation). Wood chips have been gaining importance over the last two decades.

Fuelwood is obtained primarily in hardwood stands by thinning and by clear-cutting in the form of tops, branches and but ends. Earlier, fuelwood was the most important source of energy, but around 1900, wood as a source of energy was substituted by coal and later by oil. As a result of fossil fuel prices returning to traditional price levels in the mid-nineties, there has been a recognisable drop in the household use of woodlogs in Austria in the last decade.

Wood waste consisting of bark, sawdust, shavings, demolition wood etc. is used primarily in the industry’s own boiler furnaces. A portion is used for the production of wood pellets and briquettes.

Picture: Industrial wood processing waste
2.2 Physical Characterisation of Wood Fuels

In Austria, wood from forestry and from wood industry is used in the form of firewood, wood chips, bark, shavings, briquettes, pellets, and demolition wood for firing in, e.g., wood stoves, wood pellet-fired boilers, district heating plants, and cogeneration (CHP) plants. The technologies used at these plants stipulate various requirements in respect of the physical properties of the wood i.e. size, size distribution, moisture content, ash content, and pollutants (stones, soil, and sand).

Physical characterisation of wood fuels is important when choosing fuels for various boiler systems and technologies. In addition, information on the physical properties of the wood fuels can be used when drafting contracts for future deliveries, specifying the fuel in relation to certain types of boiler systems, and the drafting of quality descriptions of the wood fuel. Knowledge of these properties in relation to various types of wood fuels thus contributes to a promotion of an environmentally and economically optimal application of the fuel.

2.2.1 Fuelwood

Fuelwood is split, round or chopped wood from delimbed stems, cut-off root ends, and tops and branches of hardwood or softwood. Ready-to-use firewood is normally split to 15-35 cm. Chunks of 6-8 cm thickness are most suitable for the majority of wood-log stoves. Firewood consists of wood and bark.

The moisture content in fresh spruce is approx. 55-60% of the total weight and approx. 45% in fresh beech. After drying during the summer season, the moisture content is reduced to approx. 15% of the total weight - depending on weather, stacking and covering - which is the recommended moisture content for use in wood-log stoves. The ash content is often below 2% of the dry matter.

2.2.2 Wood Chips

Wood chips are comminuted pieces of wood in lengths of 5-50 mm in the fibre direction, longer twigs (slivers), and a fine fraction (fines). Whole-tree chips are chipped from whole trees including branches in the first thinning of forest stands. Wood chips are also produced from top ends and other residues in clear-cuttings. Sawmill wood chips are a by-product of the sawing of logs.

The required type of wood chips depends on the type of heating system. A system for the quality description of wood chips based on size classification is specified in the Austrian norm Önorm M7133, as follows:

<table>
<thead>
<tr>
<th>Wood chip class</th>
<th>Permissible mass share and range for particle size (sieve analysis)</th>
<th>Permissible extreme values for particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>max. 20 %</td>
<td>60-100 %</td>
</tr>
<tr>
<td>G 30</td>
<td>&gt; 16 mm</td>
<td>16-2.8 mm</td>
</tr>
<tr>
<td>G 50</td>
<td>&gt; 31,5 mm</td>
<td>31.5-5.6 mm</td>
</tr>
</tbody>
</table>
G 100  > 63 mm  63-11.2 mm  11.2-1 mm  < 1 mm  10 cm²  25 cm

<table>
<thead>
<tr>
<th>Wood chip class</th>
<th>Values</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content classes (m.c. on wet basis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W 20</td>
<td>&lt; 20 %</td>
<td>&quot;air-dry&quot;</td>
</tr>
<tr>
<td>W 30</td>
<td>20-30 %</td>
<td>&quot;long shelf life&quot;</td>
</tr>
<tr>
<td>W 35</td>
<td>30-35 %</td>
<td>&quot;limited shelf life&quot;</td>
</tr>
<tr>
<td>W 40</td>
<td>35-40 %</td>
<td>&quot;damp&quot;</td>
</tr>
<tr>
<td>W 50</td>
<td>40-50 %</td>
<td>&quot;freshly harvested&quot;</td>
</tr>
<tr>
<td>Bulk density classes (values for water-free condition)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 160</td>
<td>&lt; 160 kg/m³</td>
<td>&quot;low bulk density&quot;</td>
</tr>
<tr>
<td>S 200</td>
<td>160-250 kg/m³</td>
<td>&quot;medium bulk density&quot;</td>
</tr>
<tr>
<td>S 250</td>
<td>&gt; 250 kg/m³</td>
<td>&quot;high bulk density&quot;</td>
</tr>
<tr>
<td>Ash content classes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 1</td>
<td>&lt; 1 %</td>
<td>&quot;small ash content&quot;</td>
</tr>
<tr>
<td>A 2</td>
<td>1-5 %</td>
<td>&quot;increased ash content&quot;</td>
</tr>
</tbody>
</table>

The Önorm M7133 quality description is based on three types of wood chips, i.e., G30, G50 and G100. Note that the names refer to the size-grading only and not to the quality. A CEN working group (CEN TC 335) is drafting a European standard for the classification of solid biofuels. The purpose of the working group is to standardise measuring methods and to arrive at common quality descriptions.

The moisture content in whole-tree chips depends on the production method. The moisture content of wood chips produced from green trees is approx. 50-60% of total weight, but after summer drying of the trees for 3-6 months, the moisture content is reduced to approx. 35-45% of the total weight. Chip-fired boilers with stoker for detached houses etc. can manage wood chips with a moisture content between 20 and 50% of the total weight, while district heating plants normally accept wood chips with a moisture content of 30-55%. District heating plants with flue gas condensation normally want wood chips with a high moisture content in order to utilise the condensation heat.

Wood chips may be polluted with stones, soil, and sand which increase the ash content. The ash content in whole trees depends on the wood species and the quantity of needles, branches, and stemwood. The natural ash content in needles may exceed 5% of the dry matter weight, in branches and bark approx. 3%, and in stemwood approx. 0.6%. Wood fuel for small boilers and district heating plants has an ash content of 1-2% of the dry matter weight.

2.2.3 Bark

Bark for energy production is produced by peeling of bark at softwood sawmills and by the cutting of slabs at hardwood sawmills. Strictly speaking, comminuted bark cannot be regarded as wood chips, but size analyses of bark - based on wood chip standard - show that bark has a very heterogeneous size distribution with a large proportion of fines. Bark is very moist, approx. 55-60 % of the total weight, and single firing with bark normally takes place in special boilers because of problems with the high moisture content. Bark is the outermost layer of the tree, where pollutants are often found in the form of soil, sand, and to a certain extent lead from cartridges.
2.2.4 Sawdust and Shavings

Sawdust and shavings that are produced by planing, milling etc. are a by-product or residue from wood industries. Sawdust and shavings are between 1 and 5 mm in diameter and length. The moisture content in sawdust varies with the material that has been sawed, originating from wood industries that manufacture rafters and windows etc., and may have a moisture content of 6-10% of the dry matter weight, but 45-65% of the total weight if the wood was green, recently harvested.

Shavings are very dry with a moisture content between 5 and 15% of the total weight. Therefore, they are normally used for the production of wood pellets and wood briquettes. They contain few pollutants, since it is normally stemwood that is used, and the ash content is therefore less than 0.5% of dry weight.

2.2.5 Wood Briquettes and Wood Pellets

Wood briquettes are square or cylindrical fuels in lengths of 10-30 cm and a diameter/width of 6-12 cm. Wood pellets are cylindrical in lengths of 5-40 mm and a diameter of 8-12 mm. Briquettes and pellets consist of dry, comminuted wood, primarily consisting of shavings and sawdust compressed at high pressure. The size distribution is very uniform which makes the fuel easy to handle. Pellets from the same consignment will be of the same diameter. Moreover the moisture content is low, approx. 8-10 % of the total weight. Slagging problems are very limited when burning briquettes and pellets, and the amount of ash is low, approx. 0.5-1% of the dry matter weight.
2.2.6 **Recycled Wood**

Recycled wood refers to “waste wood” of such item of timber that has been utilised for some specific purpose (e.g. construction) and after the utilisation phase has become waste. Such waste wood consists of, for example, demolition wood used in constructions and repair operations, including old kitchen cupboards and loading pallets etc. Impregnated wood, instead, is classified as hazardous waste. The "waste" of the wood processing industry, such as sawdust, shavings, etc., is not waste wood as such but rather by-products of the industry. Neither is the "waste" of timber harvesting, for example forest residue, included in the concept of waste wood.

Waste wood that is comminuted before burning varies very much in size. Demolition wood is often relatively dry with a moisture content of approx. 10-20% of the total weight. The burning of demolition wood and other industrial wood waste may be problematic, since the wood may be polluted with residues from paint, glue, wood preservatives, metal, rubber, and plastic material depending on the previous use.

**Picture @@@: Sawdust pellets**

**Picture @@@: Unselected waste wood**
3 PROPERTIES OF WOOD AS A FUEL

3.1 General aspects

There are several characteristics affecting the properties of wood as a fuel. These include such as heating value, chemical composition (e.g. content of such elements as chlorine Cl, carbon C, hydrogen H, nitrogen N and sulphur S), moisture content, density, hardness, the amount of volatile matters, the amount of solid carbon, ash content and composition, the melting behaviour of ash, the slagging behaviour of ash, the amount of impurities, dust and fungi spores. Wood fuel chips, for instance, are often made of various tree species with various proportions of wood, bark, foliage, twigs (branches), buds and even cones. This causes variation in the fuel properties.

The main components of wood cells are cellulose, hemicellulose and lignin, forming some 99% of the weight of the wood material. Cellulose and hemicellulose are formed by long chains of carbohydrates (such as glucose), whereas lignin is a complicated component of polymeric phenolics. Lignin has a close relationship with hemicellulose, as it acts as a glue fixing the bunches of cellulose chains and planting tissues together. Thus it gives mechanical strength to the plant. Lignin is rich in carbon and hydrogen, which are the main heat producing elements. Hence lignin has a higher heating value than carbohydrates. Wood and bark also contain so-called extractives, such as terpenes, fats and phenols. Many of them are soluble in organic solvents (hexane, acetone, ethanol) and in hot water. The amount of wood extractives is relatively small when compared to the amount of extractives from bark and foliage.

Approximately one half of fresh, just fallen tree is water. The other half consists of dry matter of wood, approx. 85% of which consists of volatile matters, 14.5% of solid carbon and 0.5% of ash (see Figure @@@). In water-free wood, the total content of the carbon element is about 50%. When wood is combusted, its components will change into steam of water (H₂O), carbon dioxide (CO₂), nitrogen oxides (NOₓ), sulphur oxide (SO₂) and ash. Wood has practically no sulphur at all, as its share in wood is 0.05% at the highest.

Figure @@@: Average chemical contents of wood fuels

<table>
<thead>
<tr>
<th></th>
<th>SOLID</th>
<th>VOLATILE MATERIALS</th>
<th>BARK</th>
<th>ca. 60 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBON (C)</td>
<td>84-88%*</td>
<td></td>
<td>SAWDUST</td>
<td>ca. 55 %</td>
</tr>
<tr>
<td>11.4-15.6%*</td>
<td>Carbon (C)</td>
<td>ca. 35.5% → CO, CO₂,</td>
<td>FOREST</td>
<td></td>
</tr>
<tr>
<td>→ CO₂</td>
<td>Hydrogen (H)</td>
<td>6.0 - 6.5% → H₂O</td>
<td></td>
<td>ca. 40 %</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>38 - 42%</td>
<td></td>
<td>CHOPPED</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>0.1 - 0.5% → NOₓ</td>
<td></td>
<td>FIREWOOD</td>
<td>ca. 25 %</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>max. 0.05% → SO₂</td>
<td></td>
<td>BRIQUETTES</td>
<td>ca. 5 %</td>
</tr>
</tbody>
</table>

* Share % of dry matter weight
The nitrogen content of wood is in average about 0.75%, varying somewhat from one tree species to another. The wood chips, for instance, made from so-called nitrogen-fixing trees, such as alder (*Ainus sp.*), contain more than twice as much nitrogen as chips made of coniferous trees like pine (*Pinus sp.*) and spruce (*Picea sp.*). The bark of wood also contains more nitrogen than wood material.

The heating properties of different fuels depend on the proportions of the elements they contain. Carbon and hydrogen increase the so-called heating value, whereas high share of oxygen on wood decreases it. Compared to many other fuels, wood has a fairly low carbon content (some 50% of dry weight) and high oxygen content (some 40%), which leads to a fairly low heating value per dry weight. Dry wood and bark also have quite low ash contents, as one solid cubic metre of wood fuels produces in average only 3-5 kg of clean ash. In practice, however, there is often some sand and unburned carbon in the ash.

The combustibles of solid fuels can be shared into two groups: volatile matters and components combusting as solid carbon. The share of volatile matters in wood is typically high, whereas the share of solid carbon is low. Eighty percent of wood energy actually originates from the combustion of volatile matters or gases and twenty percent from the combustion of solid carbon (glowing embers). Due to the large amounts of volatile matters, wood burns with long flames and therefore needs a lot of space for combusting. The bark of wood is similar to peat when combustion properties are considered.

### 3.2 Definitions for wood fuel properties

In this section some terminology as well as methods of analysing the different properties of wood fuels are described.

#### 3.2.1 Proximate analysis

In the so-called proximate analysis of wood fuels, such properties as solid carbon, volatile materials and moisture contents are defined in the following ways.

**Ash**

Ash content expressed in weight% of dry base (dry) and of as received (ar) material. Through the moisture content the different types of ash contents are related to each other:

\[
\text{Ash content (wt% dry)} = \text{ash content (wt% ar)} \times \frac{100}{(100 - \text{moisture content (wt%)})}
\]

**Moisture content**

Moisture content in weight% of wet base (as received). It is important to note that there can be a large difference in the moisture contents of the material between the time it is actually available and the time it is analysed. Also, the moisture content can be lowered by natural drying during storage.

**Volatiles and fixed carbon**

The amount of volatile materials is determined by standardised methods. The amount of volatiles is expressed in weight% of dry material, as received material (ar) or dry and ash
free material (daf). The amount of fixed (solid) carbon is calculated according to the
following formulas as the remaining part:

\[
\begin{align*}
dry \quad \text{fixed C} &= 100 - \text{ash (dry)} - \text{volatiles (dry)} \\
daf \quad \text{fixed C} &= 100 - \text{volatiles (daf)} \\
ar \quad \text{fixed C} &= 100 - \text{ash (ar)} - \text{water content} - \text{volatiles (ar)}
\end{align*}
\]

### 3.2.2 Ultimate analysis

In ultimate analysis, the share of different elements of dry material is defined in the
following manner: Carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S),
chlorine (Cl), fluorine (F) and bromine (Br) content in weight % of dry material (wt% dry),
dry and ash free material (wt% daf) and on as received material (wt% ar).

\[
\begin{align*}
dry \quad C + H + O + N + S + Cl + F + Br + \text{ash} &= 100 \\
daf \quad C + H + O + N + S + Cl + F + Br &= 100 \\
ar \quad C + H + O + N + S + Cl + F + Br + \text{ash} + \text{water content} &= 100
\end{align*}
\]

In many cases the oxygen content is not measured but calculated as the difference
between 100 and the measured components. When the oxygen content is measured, the
total sum can exceed 100% due to experimental errors in the analysis. For each
component it is indicated whether it has been measured or calculated.

Compared to other solid fuels, biomass contains relatively much hydrogen and oxygen, as
is illustrated in Figure @@

**Figure @@:** Chemical composition of various solid fuels

![Chemical composition of various solid fuels](source: Handbook of Biomass Combustion and Co-firing)

### 3.2.3 Calorific value (kJ/kg)

The calorific value is expressed either as Higher Heating Value (HHV) or Lower Heating
Value (LHV). The heating value, lower or higher, can be expressed per the dry fuel unit
(normally kg or m\(^3\)) or per the fuel unit including the moisture. In addition to the moisture
content of fuel the moisture is born in the combustion of hydrogen. The state of moisture makes the difference between higher and lower heating value. The HHV is calculated with assumption that moisture is condensed to water and LHV with assumption that moisture is in form of saturated steam.

HHV  Higher heating value
  Calorific value
  Combustion heat
LHV  Lower heating value
  Effective heating value

Calorimetric heating value is used when the existing water after the combustion is in liquid form. Effective thermal value, \( H_i \), is used when the existing water after the combustion is in the form of steam. This is the most common thermal value in technical combustion processes as the exhaust gas seldom is cooled to a level that makes the steam condense into water.

The unit of the thermal value is usually MJ/kg or kJ/kg (table @@@).

<table>
<thead>
<tr>
<th>Fuel</th>
<th>( H_i ) (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (dry)</td>
<td>18.5-21.0</td>
</tr>
<tr>
<td>Peat (dry)</td>
<td>20.0-21.0</td>
</tr>
<tr>
<td>Carbon</td>
<td>23.3-24.9</td>
</tr>
<tr>
<td>Oil</td>
<td>40.0-42.3</td>
</tr>
</tbody>
</table>

The calculation of the calorific value normally results in a value for the HHV. By using the ash content, the fraction of moisture in the material and the fraction of hydrogen (from the ultimate analysis) the different HHV's and LHV's can be calculated in the following ways: \( w \) = moisture fraction (as received); \( a \) = ash fraction (dry); \( H \) = mass fraction of hydrogen in sample (dry).

\[
\begin{align*}
\text{HHV}_{\text{ar}} &= \text{HHV}_{\text{dry}} \times (1-w/100) \\
\text{HHV}_{\text{dry}} &= \text{HHV}_{\text{daf}} \times (1-a/100) \\
\text{LHV}_{\text{dry}} &= \text{HHV}_{\text{dry}} - 2.442 \times 8.396 \times H/100 \\
\text{LHV}_{\text{ar}} &= \text{LHV}_{\text{dry}} \times (1-w/100) - 2.442 \times w/100 \\
\text{LHV}_{\text{ar}} &= \text{HHV}_{\text{dry}} - 2.442 \left\{ 8.396 \times H/100 \times (1-w/100) + w/100 \right\}
\end{align*}
\]

Figure … illustrates the relationship between the several heating values

Figure@@: Relationship between several heating value definitions
3.2.4 **Ash composition (wt% ash)**

A large amount of data on the ash composition is available. In general, these data are expressed as weight% of oxides. The selected oxides are not representatives for the actual chemical form of the components. Lead (Pb), cadmium (Cd), copper (Cu), mercury (Hg), manganese (Mn) and chromium (Cr) are expressed in mg/kg ash.

3.2.5 **Biomass analysis (mg/kg dry)**

The metal content of biomass is expressed in mg/kg of dry (original) material. For each element it is shown whether it is measured or whether the value is below the detection limit.

3.2.6 **Biochemical composition (wt%)**

The biochemical composition of materials is expressed in weight % of dry material (cellulose, hemicellulose, lignin, fats, proteins).

3.3 **Average properties of wood fuels**

This section will discuss most important fuel properties such as:

- Moisture content
- Density
- Heating value
- Particle size distribution
- Ash content and properties
- Chemical composition
- Amount of volatiles
- Results of proximate and ultimate analysis.

Emphasis is on the properties of wood chips.

*Moisture content* influences significantly the lower heating value since vaporising water requires energy. The moisture content of fresh wood fuel varies from 50 to 60 percent of the weight of the total mass of chips, for instance. In general, the moisture content of wood fuels varies usually from 20 to 65 percent and is influenced, among other things, by the climatic conditions, the time of year, tree species, the part of stem in question and by storage phase. The effect of moisture content on the heating value of wood is clearly defined in Figure @@@@.
Figure @@@. The effect of moisture content on the heating value of wood.

**Explanation**: lower and higher heating values (LHV & HHV) of barkless wood as a function of the moisture content in percentage of total weight. Red line: LHV. Blue line: HHV.

Thus it is obvious that the acquisition of energy per m³ of wood fuel increases as the dry matter content per m³ increases and the moisture content decreases. The dry matter content of the chip measure varies considerably. This is influenced by the basic density and the solid volume content of chips. Basic density (kg/m³) indicates the relationship of dry mass to solid volume measure, or how much dry wood weighs per a solid measure of wood.

The *solid volume content of chips* indicates the relationship between the masses of so-called bulk measure and solid measure, that is, how many solid m³ one bulk m³ will yield. The solid volume content of chips is influenced mostly by the technical specifications of the chipper, such as particle size distribution, blowing power and loading method. The drying time of chips and the compacting that occurs during long-distance transport, however, have no decisive effect on the solid volume content value. Solid volume content (the portion of solid measure) is needed for converting bulk measure into solid measure. The *bulk density* of Austrian beech (40% mc db) is some 327 kg/loose m³, for Austrian spruce 221 kg/loose m³.

The *particle size* and moisture content of direct wood fuels or forest fuels are often very heterogeneous. The particle size varies from sawdust, needle and bark material to sticks of wood and branch pieces. The size of the wood particles is influenced both by the original raw material being chipped and by the chipper types. The more stemwood the raw material contains, the more even the particle size distribution will be. The condition of chipper knives as well as the aperture size of the screen in the chipper also influence the particle size. Chips produced with crushers have typically coarser particles compared to the chips produced with chippers.

The *calorific heating value* of wood chips does not vary a great deal from one tree species to another (18.7-21.9 MJ/ kg), but it is slightly higher in coniferous species than in broad-leaved or deciduous tree species.
The structural elements (ultimate analysis) of the organic portion of wood are carbon (45-50%), oxygen (40-45%), hydrogen (4.5-6%) and nitrogen (0.3-3.5%). The ash composition of tree species is usually less than a few percent (0.3% in spruce or birch without bark, 1.6% in birch bark and 3.4% in spruce bark).

The distinct advantage of woody biomass over fossil fuels is the small amount of sulphur. The ultimate analysis of some tree species show that carbon and hydrogen contents are rather uniform among species. Bark has a higher percentage of carbon and hydrogen than wood. This is most visibly the case with birch and alder. In the proximate analysis the amount of volatiles is 65-95%, fixed carbon 17-25% and ash content 0.08 - 2.3%.

Many sources present details on the properties of wood fuels. The most comprehensive database of wood fuel properties, Phyllis, is maintained by ECN, the energy research centre of the Netherlands, and can be accessed via URL: [http://www.ecn.nl/phyllis/](http://www.ecn.nl/phyllis/)

Moisture content, heating values, bulk density and energy density of various woodfuels are presented in Table @@@.

Table @@@: Physical characteristics of selected woodfuels

<table>
<thead>
<tr>
<th>woody material</th>
<th>moisture content [wt% wb]</th>
<th>HHV [(kWh/kg (db.))]</th>
<th>LHV [(kWh/kg (d.b.))]</th>
<th>Bulk density [kg (wb)/m³]</th>
<th>Energy density [kWh/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood pellets</td>
<td>10.0</td>
<td>5.5</td>
<td>4.6</td>
<td>600</td>
<td>2,756</td>
</tr>
<tr>
<td>wood chips (hardwood, pre-dried)</td>
<td>30.0</td>
<td>5.5</td>
<td>3.4</td>
<td>320</td>
<td>1,094</td>
</tr>
<tr>
<td>wood chips (hardwood)</td>
<td>50.0</td>
<td>5.5</td>
<td>2.2</td>
<td>450</td>
<td>1,009</td>
</tr>
<tr>
<td>wood chips (softwood, pre-dried)</td>
<td>30.0</td>
<td>5.5</td>
<td>3.4</td>
<td>250</td>
<td>855</td>
</tr>
<tr>
<td>wood chips (softwood)</td>
<td>50.0</td>
<td>5.5</td>
<td>2.2</td>
<td>350</td>
<td>785</td>
</tr>
<tr>
<td>Bark</td>
<td>50.0</td>
<td>5.5</td>
<td>2.3</td>
<td>320</td>
<td>727</td>
</tr>
<tr>
<td>Sawdust</td>
<td>50.0</td>
<td>5.5</td>
<td>2.2</td>
<td>240</td>
<td>538</td>
</tr>
</tbody>
</table>

Abbreviations: HHV = higher heating value, LHV = lower heating value, db = dry basis, wb= wet basis.
Source: Handbook of Biomass Combustion and Co-firing
4 PRODUCTION OF FOREST CHIPS

4.1 Production of forest chips

The utilisation of forest chips for fuel is of great importance to forestry, since the production and sale of forest chips enable the necessary stand care and also the conversion of stands from one species to another.

The production of forest chips mainly takes place in connection with two different tasks:

- Thinning in immature softwood stands.
- Clearing of logging residues.

Quantitatively, the proportion of chips arising from thinning dominates, but the proportion of arising from logging residues is growing.

4.1.1 Thinning in Immature Softwood Stands

Thinning in immature stands is made in order to encourage the growth and thus increase the total yield of useful material from the trees that remain in the stand. Additional benefits of thinning are improved health of the stands and higher recreational value for the visiting public.

In establishing a softwood stand, a stock of 3,500-5,000 trees is planted per ha. First thinning is normally performed when the trees are approx. 8 m high. 25-50% of the trees are removed, thereby reducing the number of stems to 2,000-2,500 trees per ha. When the trees in the stand are approx. 10 m high, a second thinning is performed, often a selective thinning, thereby reducing the number of stems to approx. 1,000-1,500 trees per ha.

The trees from first thinning are so small that it is difficult to sell them as merchantable timber, and chipping is therefore a widely used practice. In periods when the price of pulp is low, trees from second thinning are also chipped.

The sale of forest chips is a prerequisite of carrying out early thinnings at a low price or without any costs for the owner of the forest. Without the market outlets, thinnings would most often be postponed until the trees have attained a size where a balance can be achieved between the cost of thinning and the income from the sale of the product. Thinning in due time is a prerequisite of the production of high quality commercial timber. In other words, it is not possible to maintain a production of high quality commercial timber without at the same time producing (and selling) wood fuel.

4.1.2 Clearing of Forest Residues

After clear-cutting of stands, large amounts of forest residues are left in the area, primarily tops from trees that have been harvested, but also branches and logs that have been cut off due to rot. Under Austrian legislation it is necessary to clear the cultivation area for residues. Often residues are gathered and arranged in long rows. The rows can be used as skid rows along which vehicles can move later on in the life of the stand, but it
takes at least 5-10 years for the rows to rot away so as to enable vehicles to pass along them.

Research has proven that tops from clear-cuttings can be profitably chipped and used for fuel. Thus chipping contributes to the benefit of the harvesting, and often makes the clearing of the area unnecessary, since chipping removes a large proportion of the residues.

4.2 Harvesting of Forest Chips

The production of forest chips can be divided into several stages:

- Felling for chipping,
- Comminution,
- Off-road hauling,
- Storage in the forest, and
- Road transport.

4.2.1 Felling for Chipping

Felling for chipping is made in a way that ensures that the wood chips produced are as dry as possible. The moisture content of the trees is lowest from January-March, and the felling of trees for chipping should therefore take place in the first three months of the year. This may also limit the risk of stump infection by the decay fungus *Heterobasidion annosum* which can subsequently spread from the roots of the stumps to the remaining trees in the stand. The trees that have been felled are left in the area for the summer. This is done in order to achieve drying of the trees to a certain extent and in order to enable needles and small branches to detach before chipping. The moisture content in wood chips is thus reduced from 50-55% to approx. 35-45%, and the majority of the nutrients in the trees - actually contained in the needles and small branches – remains in the area.

Felling is performed by chain saw or by a feller-buncher. The feller-buncher is a special machine equipped with a crane mounted saw felling head. During thinning, the feller-buncher requires a track in order to travel in the stand. The establishing of skid rows normally takes place by manual chain saw felling. The material is dried over the summer and chipped one season before selective thinning takes place.
During the establishing of skid rows and during felling, it must be remembered that the chipper has limited movability on soft areas, when passing ditches or operating on steep slopes. Also chippers have large turning radii and require much space for entering skid rows. The feller-buncher dumps the trees in rows, butt ends in the same direction, enabling the chipper to easily take them by the crane and feed them into the chipper, while the machine simultaneously travels slowly forward.

During clear-cutting of old spruce stands, the felling is normally performed with chain saw or by means of harvesting machinery. During harvesting by a one grip harvester, the tops can be placed in the same direction in rows, after the processing of commercial timber, thereby making the chipping operation easier. Harvesting should also be planned, so that the greatest possible amount of tops are placed in the rows. It is of great importance not to drive over the tops during the haulage of the commercial timber products, since it would result in an increased amount of broken material and an increase in the sand content.

4.2.2 Comminution

The thinning and clear-cutting of forest stands yields a wide range of woody materials, including branches, tops, stems and bark with very different shapes and particle sizes. Comminution (particle size reduction) is commonly applied to produce more homogeneous material that is suitable for use as woodfuel. Comminution is usually carried out by chipping or chunking (when sharp cutting edges are used to cleave or shear the biomass into engineered particles), or by employing a blunt impacting tool to crush or shred the material, producing particles of indistinct geometry and often termed hogging or shredding:

- Cutting
- Chipping
- Chunking
- Impact
- Shredding/hogging
- Hammermilling

Various forms of comminution system are commercially available for use by the forest industry and can easily be adapted for biofuel production. Selection of comminution equipment should fit into the overall handling and delivery system, and relates very much to end product specifications. Most commonly used are chippers.
A chipper consists of a self-propelled (or tractor-mounted) basic machine with cabin, chipper and crane equipment mounted at the front part of the machine. At the rear end of the basic machine, a high-tipping container is mounted. There are both specialised machines designed for the purpose of chipping only and also large agricultural tractors equipped with a chipper and high-tipping trailer. Figure shows various chipper configurations whereas Table summarises the characteristics of various classes of chippers.

Table: Characteristics of various sizes of chippers

<table>
<thead>
<tr>
<th>Size</th>
<th>Productivity (m³ bulk/hr)</th>
<th>Diameter of the material (cm)</th>
<th>Fuel-feeding system</th>
<th>Power cons. (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-scale</td>
<td>3-25</td>
<td>8-35</td>
<td>manual, crane</td>
<td>20-100</td>
</tr>
<tr>
<td>medium-scale</td>
<td>25-40</td>
<td>35-40</td>
<td>crane</td>
<td>60-200</td>
</tr>
<tr>
<td>large-scale</td>
<td>40-100</td>
<td>40-55</td>
<td>crane</td>
<td>200-500</td>
</tr>
</tbody>
</table>

Source: Handbook of Biomass Combustion and Cofiring

Figure: Various chipper configurations

Fig: **Trailer mounted chipper** with auxiliary power source rather than being connected to a tractor power-take-off (pto).

Fig: **Tractor-mounted chipper** powered from the tractor power-take-off (pto).

Fig: **Self-propelled chipper** is a purpose-built forest vehicle with front-mounted grapple to feed the chipper unit mounted on the front or the side of the vehicle, and with a rear-mounted chip bin.

Fig: **Forwarder-mounted chipper** is a large, self-propelled comminution unit with integral power source and chip bin, mounted on a forwarder chassis.
Commonly used types of chippers include disc chippers and drum chippers. They differ only in their way of chipping. All chippers are equipped with a fan to blow the chips out of the chipper housing through the chute into the container.

**Disc chippers**

Disc chippers consist of a heavy rotating disc with a diameter of about 600 to 1,000 mm and 2-4 knives. The chip size can be modified by adjusting the knives and the anvil. Disc chippers produce fairly uniform chips, as the cutting angle in relation to the fibre direction of the tree remains unchanged regardless of the thickness of the stem.

**Drum chippers**

Drum chippers consist of a rotating drum with a diameter of about 450 to 600 mm in which the knives are embedded in 2-4 longitudinal grooves in the curved surface. As in the disc chipper, the knives pass a fixed anvil and the chip size is modified in the same way. As a result of the circular movement of the drum chipper, the cutting angle in relation to the fibre direction of the tree changes with the diameter of the stem. Consequently, the chips produced are less uniform than those produced by a disc chipper.

---

Source: Sims, 2002

Fig (e): **Heavy-duty trailer-mounted chipper** with integral power source mounted on a heavy-duty chassis and trailed by truck or forest vehicle.

Fig (f): **Truck-mounted chipper** with auxiliary power source and grapple, mounted on a truck chassis.

Fig (g): **Truck-mounted chunker** with integral power source and grapple, mounted on a truck chassis, and used in conjunction with an elevator for loading the chunks that are too heavy to blow.
The disc chipper principle ensures that the wood chips are produced to a rather uniform size, since the entrance angle in relation to the fibre direction of the tree is the same irrespective of the thickness of the tree. The drum chipper circular movements cause the knife entrance angle in relation to the tree fibre direction to change with the tree diameter. It therefore produces wood chips of a more non-uniform size than a disc chipper.

In the production of forest wood chips, there are various approaches to lower chipping costs. As far as chipping material from early thinnings is concerned (stems with a diameter less than 15-20 cm and tops), wood harvesting and chipping in a one-process step is more promising because of lower costs. When utilising forest residues (branches, tops from clearfellings) the use of a large-scale central chipper at the combustion plant or central storage facility seems advisable.

**Picture**: Truck-mounted chipper at work

### 4.2.3 Off-Road Hauling

As the chipper is a very expensive machine, the work should to a high extent be arranged so as to comply with the requirements of the machine. It is usual to have a tractor with high-tipping trailer or a specialised forwarder following the chipper, thereby enabling it to continue chipping while the forwarder carries the wood chips to the roadside.

### 4.2.4 Storage in the Forest

The storage of wood chips forms an important part of the distribution of the fuel from forest to heating plant. It is necessary to store wood chips for several reasons:

- The consumption of wood chips varies heavily with the time of the year.
- There are periods when harvesting of wood chips is not possible.
- During the summer more wood chips are produced than consumed.

Wood chips should preferably be produced as the need for it arises at the heating plant. However, storage cannot be avoided, as the forests have to meet larger demands for wood
chips in cold periods and be capable of delivering wood chips even if stand conditions make working there impossible. Normally it is specified in the contract of supply, how large quantities of wood chips the forest entrepreneur should store during the heating season (normally 10-20% of the heating plant’s annual consumption).

The storage site should be carefully selected. The wood chip pile should first and foremost be placed close to an all-weather road that is capable of carrying trucks throughout the year. The road should be dry, since the pile would otherwise be splattered when vehicles pass. The pile should be located higher than the road, as water would otherwise percolate from the road into the wood chip pile. The ground under the pile should be level and free of stumps, large stones or residues. Wood chip piles should be made as large as possible, since it minimises the loss at the bottom of the pile. However, wood chip piles must not be higher than 7-8 metres, due to the risk of spontaneous combustion in piles.

Chips for storing should be as dry as possible and of the best possible quality. If the wood chips are to be stored for more than two weeks, the pile should be covered with tarpaulins. A certain drying takes place in the central part of a wood chip pile that has been covered with tarpaulins. The evaporated water condenses in the outer wood chip layers, which thereby become equally wetter. If wood chips are stored with a view to reducing the moisture content, it should be stored under roof. Experiments have shown that storage under roof for 4-6 months may result in a reduction of the moisture content from approx. 45% to 25-30%. In the case of outdoor storage without tarpaulins, the wood chip moisture content will increase, whereas the overall moisture content of chips stored under tarpaulins remains constant.

4.2.5 Road Transport

Road transport of forest chips is normally performed by means of container trucks which with a container on the tractor and one on the trailer can transport approx. 80 m³ of bulk volume at a time. If delivered at the time of chipping, at least two containers, but preferably more, should be placed in the forest. The containers are filled as the chips are produced, and the truck carries the wood chips to the heating plant or storage site concurrently. During loading from storage, it is normal to use a wheel loader for filling the containers. With an output of 30-50 m³ per hour, a chipper can fill up two containers in 2-3 hours.
5 PURCHASE AND SALE OF FIREWOOD AND FOREST CHIPS

In Austria, there are many different wood fuels, e.g. firewood, wood chips, wood pellets and briquettes, bark, sawdust and shavings. In this chapter the most common methods for the purchase and sale of firewood and forest chips are described.

5.1 Purchase and sale of firewood

Standard firewood is paid by the volume. There are many different volume indications for wood, but they all refer to two principally different units:

- One cubic metre stacked volume including air equals the content of a cube (with six equal sides) of 1 by 1 by 1 meter, exterior measure.
- One cubic metre solid volume equals the amount of solid wood containing exactly 1 m³, e.g., a solid block of wood with length, height, and width being 1 m.

In Austria firewood is sold primarily by the stacked cubic metre (a m³ of sawn, split and stacked wood, a m³ stacked volume of whole-tree wood, or a loose volume cubic metre). A m³ stacked volume of sawn, split, and stacked wood contains the most wood of the three units, but the volume of wood depends on the density of the stack and the size of the pieces. The larger the pieces are, the more wood is in the m³ stacked volume.

Figure @@@ illustrates the properties of different wood stacks whereas Table @@@ presents average conversion factors between bulk, stacked and solid cubic meters for chopped firewood.

**Figure @@@:** Properties of different wood stacks

**Table @@@:** Average conversion factors of chopped firewood

<table>
<thead>
<tr>
<th></th>
<th>bulk m³</th>
<th>stacked m³</th>
<th>solid m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 bulk (or loose) m³</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>1 stacked m³</td>
<td>1.68</td>
<td>1</td>
<td>0.67</td>
</tr>
<tr>
<td>1 solid m³</td>
<td>2.5</td>
<td>1.49</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Wood Fuels Basic Information Pack
A m³ stacked volume of whole-tree is wood that is stacked in the forest after harvesting and shortening. It is often cut into two-meter pieces, but softwood also in lengths of one and three meters. It is typically wood that is delivered for the purpose of do-it-yourself cutting/splitting. There may be a lot of air in such a stack. If the pieces are long or crooked and perhaps stacked by crane, the wood content is small. A stack consisting of short pieces of large diameters contains more wood than if it consists of long, thin pieces.

A m³ loose volume consists of wood that is not stacked, but just loaded into a cube with sides of 1 meter each. This gives space for a lot of air, because the pieces are placed just anyhow. It is estimated that a loose volume m³ of firewood contains a solid mass amounting to between half and two thirds of a m³ of sawn, split, and stacked wood.

When fixing the value of a stacked m³ of firewood, regard should be taken to the degree of processing of the firewood, the tree species, and the solid mass or solid mass percentage.

The degree of processing describes whether the firewood is cut in appropriate lengths and split. All Austrian tree species have more or less the same calorific value per kg dry matter, but with large variations in dry weight per volume unit.

Solid mass or solid mass percentage indicates the amount of solid mass of wood in a m³ stacked volume of firewood. If the solid mass factor for example is 0.65, then the solid mass percentage is 65, and both designate that one stacked m³ of firewood contains 0.65 cubic metre of solid wood or 65% wood. The remaining part is air.

The solid mass varies a lot and the care with which the firewood has been stacked plays an important role. The tree species and lengths of the firewood pieces also affect the solid mass, as illustrated by Table @@@.

<table>
<thead>
<tr>
<th>Firewood length (in meter)</th>
<th>Solid mass in beech fuelwood</th>
<th>Solid mass in spruce fuelwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>1.00</td>
<td>0.65</td>
<td>0.75</td>
</tr>
<tr>
<td>2.00</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>3.00</td>
<td>0.55</td>
<td>0.65</td>
</tr>
</tbody>
</table>


The wood content for the same solid mass figure is the same in a stacked m³ of firewood irrespective of the moisture content. Thus, when purchasing and selling firewood, the moisture content is normally not taken into consideration. However, it is a prerequisite of firing with firewood in a wood stove that the firewood is dry. This means that the moisture content in percentage of the total weight should be below 20%.
5.2 Purchase and sale of wood chips

The sale of wood chips for firing requires a measurement of the wood chips for the purpose of fixing the price. However the price must depend on the quality and calorific value of the wood chips. The concept of calorific value was discussed in Chapter 3.

The quality of the wood chips depends on the size distribution, moisture content and on impurities (soil, stone etc.). The quality of wood chips is often associated with its handling and burning properties. Thus a poor wood chip quality is often tantamount to difficult handling, i.e. disadvantageous properties of the chips as to angle of friction, angle of slide, and its propensity to bridging. The wood chip quality may also have an important influence on the combustion efficiency and on the content of harmful substances in smoke/flue gas and ash.

For most chip-fired heating and CHP plants by far, the payment of forest chips is based on the energy content of the wood chips determined as the lower heating value (LHV) per tonne total weight. In a few cases, there may be consignments that are paid per m³ of wood chips. For forest chips, the general formulae for calculating the LHV can be simplified to:

For forest chips consisting of primarily pine, spruce and birch wood:

\[ \text{LHV} = 19.2 - 0.2164 \times F \text{ (GJ per tonne total weight)} \]

For mixed wood chips of various origin consisting primarily of hardwood of unknown mixture:

\[ \text{LHV} = 19.0 - 0.2144 \times F \text{ (GJ per tonne total weight)} \]

where F is the moisture content of the chips in % of the total weight of the wood chips.

The calculation of the value of a truckload of wood chips requires knowledge of the weight of the load and the moisture content. The weight of the load is determined by a weighing bridge as the gross weight of the loaded vehicle minus the weight of the vehicle itself. The difference shows the total weight of the load, i.e. the content of dry matter + water of the load.

Box @@: Determining moisture content

In practice, the moisture content of the load is determined by taking representative samples totalling 5-10 litres with a bucket at 3-5 places in the pile after unloading. Then the samples are mixed thoroughly, and one sample of approx. 3 litres is taken for the determination of the average moisture content in the load. The moisture content is normally expressed in percentages of the total weight in the following way:

- The sample is weighed after sampling.
- The sample is dried in a drying cabinet at 105°C to constant weight. In practice, the drying of three litres of wood chips distributed in a tray in a ventilated drying cabinet to constant weight takes 16 hours.
- The difference in weight between the fresh sample and the dried sample expressed in percentage shows the moisture content in percentage (F) of the total weight

Water content = (fresh weight minus kiln-dry weight) divided by fresh weight times 100%
The calorific value of the load in GJ per tonne total weight is determined by using one of the two above-mentioned formulae for the lower heating value LHV. Then the weight of the load in tonne total is multiplied with the number of GJ per tonne and with the price agreed per GJ (e.g. EUR 7.70 per GJ).

Calculation example for pine chips:
- Moisture content in wood chips: 55% of total weight
- Weight of load: 15 tonnes
- Energy price (at sawmill gate): EUR 7.70/GJ
- Wood chip lower heating value LHV: 19.2 GJ/tonne - (0.2164 × 55) = 7.30 GJ/tonne
- Wood chip energy content: 15 tonnes × 7.30 GJ/tonne = 109.50 GJ
- Wood chip price: EUR 7.70/GJ × 109.50 GJ = EUR 843.15

The above method, which has been in use in Denmark since 1980, is simple and easy to use in practice, and there have only been minor problems in practical use. The method can be simplified if it has to do with a large number of truckloads from the same supplier. If so, the number of wood chip samples for the determination of the moisture content in the loads can be reduced. Deviations from the official sampling method can be agreed by the parties upon entering into the contract. It can also be agreed who is to take the samples.
CHIPPING AND SUSTAINABLE FORESTRY

It is clearly advantageous to the environment to use wood fuels, but at the same time chipping involves an increased use of the forest ecosystem compared to conventional timber harvesting, since a greater part of the biomass is thereby removed. This use may perhaps affect the stability and growth of forests in a long term, thereby creating the need for fertilisation.

An increased utilisation of the forest ecosystem by chipping of thinning trees and logging residues may have consequences connected with the following two aspects, in particular:

- Chipping increases the removal of plant nutrients from the area, since a major proportion of the nutrient-rich parts (needles, branches, and bark) are removed.
- A great proportion of organic material is removed, which may reduce the humus content of the soil and thereby its capability to support wood production.

In order to avoid these effects, it is necessary to balance the utilisation with the yielding capacity of the soil or, e.g. to return the wood chip ash to the forest in order to compensate for the loss of nutrients.

6.1 Plant Nutrients

Historically, the exhaustion of the forests is well-known. In certain German forest areas, a considerable soil depletion can still be demonstrated due to the utilisation of limbwood, branches, and leaves for fuel and animal feed in the 19th century.

The major part of the nutrients is bound in the active parts of the tree (needles and bark) that make out a rather small proportion of the biomass. An exception is calcium of which the wood also contains a considerable amount. Thus the removal of nutrients by chipping depends to a high extent on the parts of biomass that are removed. The maximal removal occurs by whole-tree harvesting of green chips (chips with needles and branches). This increases the yield but by this increase in yield, between 50% and 75% of the nitrogen, phosphorus, potassium and calcium amount are removed.

The predominant part of the harvesting of forestry chips is obtained by thinnings in immature stands. In practice, the thinning trees are felled during the winter and hence dry at the place of felling for four to six months. By this method, the following is achieved:

- Evaporation of approx. 50% of the moisture content of the trees.
- Shedding of needles and a number of thin branches before the trees are fed into the chipper.

This practice reduces the amount of plant nutrients removed compared to the chipping of green trees.

The removal of nutrients during the entire rotation should be viewed in relation to the capability of the area to supplement these nutrients by the weathering of soil minerals or in the form of fallout. On very nutrient-poor soil, conventional logging of stems removes more nutrients than is applied, thereby exhausting the soil little by little resulting in a state of nutrient deficiency. However, on the basis of the present knowledge, it is not possible
to point out these areas. In sea-bordering countries, stands close to the coast will be less exposed, since these areas are currently supplied with nutrients in sea salt being carried over the country by storms.

A range of experiments has been undertaken in the Nordic countries with the purpose of clarifying the consequences of increased removal of biofuels from the forest. A test-series included sixteen localities with ten stands of Scotch Pine and six stands with Norway Spruce. Ten years after green chipping of the first-thinnings the increment was assessed. The results varied from locality to locality, with an average decrease in growth of 6% and 5% was found in the Norway Spruce and Scotch Pine, respectively. Drilling tests show that the reduction in growth begins approximately 4 years after the green chipping and still remains after 10 years. The growth reduction in the Nordic test-series is referred to as an increased nitrogen deficiency after whole-tree utilisation. This will probably not be experienced in other European regions, where the nitrogen absorption from the atmosphere is capable of covering the nitrogen requirements of the trees. The conclusion drawn from the Nordic trials is that the supply of other nutrients from weathering and deposition is apparently able to compensate for loss due to whole-tree utilisation. However, this is not necessarily the case everywhere.

The practice of drying the felled trees in the stands before chipping reduces the probability of growth reduction due to whole-tree reduction. Particularly on nutrient poor localities a growth reduction can not be prevented.

The ash from the combustion of wood chips contains more or less the amount of nutrients being removed from the stand by chipping (with the exception, though, of nitrogen). It is therefore obvious to solve the nutrient problem by returning the wood chip ash to the forest. The amount of ash that is produced by the combustion of wood is often expressed in percentage of the dry weight of the wood (0% water). Here, pure wood ash should be distinguished from crude ash. By pure wood ash is understood the pure ash without a content of sand, unburned wood, or other substances. By crude ash is understood the pure ash plus the inevitable content of other substances.

On average, the pure ash content is estimated at 2.5% by the combustion of whole-tree chips. The amount of crude ash varies a lot, but the crude ash content is estimated at 5% by the combustion of whole-tree chips. Table illustrates the estimated average amounts of plant nutrients in kg per tonne of dry crude ash.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>P (kg)</th>
<th>K (kg)</th>
<th>Ca (kg)</th>
<th>Mg (kg)</th>
<th>Fe (kg)</th>
<th>Na (kg)</th>
<th>Mn (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>13</td>
<td>48</td>
<td>137</td>
<td>17</td>
<td>12</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>(kg/t dry crude ash)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Wood ash contains small amounts of heavy metals, e.g. cadmium 0-0.08 g/kg dry ash and lead 0.02-0.6 g/kg dry ash. The content of such matter may be problematic in connection with the recycling of the ash for forest and field applications.
6.2 Humus Content

By whole-tree chips produced from whole, pre-dried trees, more wood is removed from the stand than by means of well-known, conventional harvesting of delimbed roundwood. This means that fewer branches and tops are left on the forest floor for natural decomposition. Dead, organic matter contains the flora and fauna involved in decomposition.

Whether or not chipping thus contributes to reducing the biodiversity in the forests is a highly debated issue which at present is uninvestigated.

Another issue that is debated for the time being is the embedment of carbon in the soil content of stable humus matter (humus formation). Any stand of trees produces a continuous stream of dead, biological material ending on the forest floor. It may be leaves, needles, branches, twigs, dead trees etc. By conventional harvesting of delimbed roundwood, branches and tops are left on the forest floor, but by whole-tree chipping, a larger proportion of the total biomass production of the stand is removed. However, by normal chipping primarily taking place in connection with the two first thinnings in the stands, only a small extra proportion of wood is removed from the stand compared to roundwood logging.

The major part of the dead, organic matter is mineralised, i.e. it is decomposed into plant nutrients, carbon dioxide, and water, while a minor proportion, of varying and unknown size, enters into the soil content of permanent humus matter. The proportion and importance of this entering is currently being debated and investigated. Based on the first measurements of the carbon pool in mineral soils after 25 years of chipping there is no conclusive evidence showing a reduced content of humus matter. However, it is still unknown whether long-term chipping will reduce the soils content of permanent humus matter, and whether or not it is of any importance to the growth and health of the trees.

6.3 Sustainable Utilisation

Harvesting of whole trees in first and second thinning where the trees are left to dry in the stands before chipping causes a modest extra drain on nutrients. It is only on nutrient poor localities that loss of nutrients may cause concern. Clear-cutting cleaning by chipping of logging residues often substitutes a normal cleaning by burning the logging waste. The extra drain of nutrients due to removal of logging residues after clear-cutting is more extensive than the extra drain due to the thinnings. However, the extra drain from the thinnings can prove to be as important as an extra drain from clear-cutting. The reason for this is that new-planted trees are unable to exploit the amount of nutrients, which are released from the logging residues in the first years after a clear-cutting. If the logging residues dry for at least one summer before chipping, there should be no immediate risk in that respect by chipping. In both cases, attention should be paid to the need for supplementary fertiliser.
7 THEORY OF WOOD FIRING

Efficient and complete combustion is a prerequisite of utilising wood as an environmentally desirable fuel. In addition to a high rate of energy utilisation, the combustion process should therefore ensure the complete destruction of the wood and avoid the formation of environmentally undesirable compounds.

In order for combustion to continue, there are certain basic conditions to be complied with:

- An adequate mixture of fuel and oxygen (air) in a controlled ratio should be ensured.
- The fire already started in the boiler furnace should transfer some of its heat to the infeed in order to ensure a continuous combustion process.

It is important to understand that gases burn like flames, that solid particles glow, and that during the combustion of wood, approx. 80% of the energy is released in the form of gas and the remaining part from the charcoal.

During mixing of the fuel and air, it is important to achieve good contact between the oxygen of the air and the combustible constituents of the wood. The better the contact is, the faster and more complete is the combustion. If the fuel is in the form of gas, such as natural gas, the mixing is optimal, since there are two gaseous substances that can be mixed to exactly the desired ratio. The combustion may then occur rapidly, and thus the control is fast too, since more or less fuel can be introduced. In order to achieve approximately the same situation with wood, it may be necessary to pulverise the wood to very small particle size (like that of flour). These fine particles will follow the movements of the air. A good mixture can thus be achieved with a combustion resembling a gas or oil flame. The production of wood powder is very expensive, though, and therefore wood powder is only used to a limited extent. In practice, fuel is therefore marketed in sizes varying from wood chips to logs.

Firing technology for wood and other solid fuels is thus difficult and more complicated than for example the firing technology in a natural gas or oil-fired heating system.

7.1 Stages of Combustion

In order for combustion to occur, the fuel must pass through various stages, which are illustrated in Figure @@

When wood is heated, water begins evaporating from the surface of the wood. Hence two things occur: Gasification occurs at the wood surface, pyrolysis and the temperature deeper inside the wood will increase resulting in evaporation of moisture from the interior of the wood. As the water evaporates and is passed away, the area that is pyrolysed spreads into the wood. The gas thus produced is ignited above the fuel and transfers heat to the ongoing evaporation and pyrolysis. The combustion process is continuous. The gasified wood becomes glowing charcoal, transformed by oxygen, until only ash is left.

---

1 the heating of a fuel without the introduction of gasification medium, i.e. oxygen and water
The wood combustion route

7.2 Fuel Size

The larger the fuel particle is, the longer the combustion process takes. Imagine a handful of sawdust quickly burning if it is thrown into a hot fire. There is a good contact between fuel and air, since the small particles quickly dry, give off gases and burn, resulting in a high combustion intensity.

If instead a log is thrown into a hot fire, it will take a long time before it is burnt out. It can be compared to a roast that is put in the oven. Although it has roasted for an hour in the oven, it is still raw in the middle. The size of the fuel, therefore, is of great importance to the speed of combustion.

7.3 Moisture Content

The moisture content in fuel reduces the energy since part of the energy will be used for evaporation of the water. Dry wood has a high calorific value, and the heat from the combustion should be drawn away from the combustion chamber in order to prevent overheating and consequent damage to material.

Wet wood has a low calorific value per kg total weight, and the combustion chamber should be insulated so as to avoid reduction in boiler efficiency and enable a continuous combustion process. This is typically accomplished by using refractory linings round the walls of the chamber so as to conserve the heat which is generated. The boiler chamber will therefore normally be designed for burning wood within a certain moisture interval.

A moisture content in wood above 55-60% of the total weight will make it very difficult to maintain the combustion process.

7.4 Ash Content

The fuel contains various impurities in the form of incombustible component parts - ash. Ash itself is undesirable, since it requires purifying of the flue gas for particles with a subsequent ash and slag disposal as the result. The ash contained in wood comes
primarily from soil and sand absorbed in the bark. A minor proportion also comes from salts absorbed during the period of growth of the tree.

The ash also contains heavy metals, causing an undesirable environmental effect, but the content of heavy metals is normally lower than in other solid fuels.

A special characteristic of ash is its heat conservation property. For wood stoves, the ash layer at the bottom of the stove forms a heating surface, transferring heat to the final burnout of the char. For heating systems using a grate, the ash content is important in order to protect the grate against heat from the flames.

Wood also contains salts that are of importance to the combustion process. It is primarily potassium (K) and partly sodium (Na), based salts resulting in sticky ash which may cause deposits in the boiler unit. The Na and K content in wood is normally so low that it will not cause problems with traditional heating technologies.

Table ... Typical mineral fractions in wood chips (in % of the dry matter of the wood).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>K</th>
<th>Na</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction (% of DM)</td>
<td>0.1</td>
<td>0.015</td>
<td>0.02</td>
<td>0.2</td>
<td>0.04</td>
</tr>
</tbody>
</table>


7.5 Volatiles

Wood and other types of biomass contain approx. 80% volatiles (in percentage of dry matter). This means that the component part of wood will give up 80% of its weight in the form of gases, while the remaining part will be turned into charcoal. This is one reason why a sack of charcoal seems light compared to the visual volume. The charcoal has more or less kept the original volume of the green wood, but has lost 80% of its weight.

The high content of volatiles means that the combustion air should generally be introduced above the fuel bed (secondary air), where the gases are burnt, and not under the fuel bed (primary air).

7.6 Excess Air

A given fuel requires a given amount of air (oxygen) in order to be converted stoichiometrically, i.e. the amount of excess air λ (lambda) should be equal to 1. The fuel is converted stoichiometrically when the exact amount of oxygen that is required for the conversion of all of the fuel under ideal conditions is present. If more oxygen is introduced than an amount corresponding to λ = 1, oxygen will be present in the flue gas. At, e.g. λ = 2, twice as much air is introduced as necessary for the combustion of the fuel.

In practice, combustion will always take place at an excess air figure higher than 1, since it is not possible to achieve complete combustion at a stoichiometric amount of air. In Table @@@, the typical excess air figures λ are shown together with the corresponding, resulting oxygen percentage in the flue gas. As shown in the table, the excess air figure depends to a high extent on the heating technology and to some extent on the fuel.
Table@@: Typical excess air figures, $\lambda$, and the resulting oxygen content in the flue gas

<table>
<thead>
<tr>
<th>Excess air ratio $\lambda$</th>
<th>$O_2$ dry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fireplace open</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Wood stove</td>
<td>2.1-2.3</td>
</tr>
<tr>
<td>District heating forest chips</td>
<td>1.4-1.6</td>
</tr>
<tr>
<td>District heating wood pellets</td>
<td>1.2-1.3</td>
</tr>
<tr>
<td>CHP wood powder</td>
<td>1.1-1.2</td>
</tr>
</tbody>
</table>

Source Handbook of Biomass Combustion and Co-firing

Figure @@ illustrates that ideal combustion of wood takes place at an excess air figure $\lambda$ between 1.4 and 1.6. The oxygen percentage in the flue gas will thus be 7.5%. The curve illustrates that the carbon dioxide percentage is approx. 13% and the excess air 1.5

Figure @@: Ideal combustion of wood

Source Wood for Energy Production

7.7 Emissions to air

The fuel has an influence on the combustion efficiency. At complete combustion, carbon dioxide ($CO_2$) and water ($H_2O$) are formed. An incorrect mixture of fuel, type of heating system, and introduction of air may result in an unsatisfactory utilisation of the fuel and a consequent undesirable environmental effect.

An efficient combustion requires sufficient:
- High temperature
- Excess oxygen
- Combustion time
- Mixture
This ensures a low emission of carbon monoxide (CO), hydrocarbons, polyaromatic hydrocarbons (PAH), and a small amount of unburned carbon in the slag. Unfortunately, these conditions (high temperature, a high amount of excess air, long combustion time) are also directly related to the formation of NO₅. The technology applied should therefore be a so-called “low-NO₅” technology, i.e., a technology applying methods resulting in a reduced NO₅ emission.

In addition to CO₂ and H₂O, the flue gas will contain air (O₂, N₂ and Ar) and a high or low amount of undesirable reaction products, such as CO, hydrocarbons, PAH, NO₅ etc.
8 WOOD CHIP PLANT TECHNOLOGY AND OPERATION

The typical wood chip plant is constructed around a solid fuel boiler with step grate or travelling grate. The boiler has refractory linings round the walls of the chamber in order to ensure the combustion temperature despite the relatively wet fuel. The plant designs are highly automated so that e.g. the feeding system of wood chips from the storage onto the grate is carried out by means of a computer controlled crane that simultaneously keeps track of the storage.

All systems have the same main components:
- Wood chip storage
- Crane or other chip handling
- Feeding system
- Combustion chamber and boiler
- Flue gas purifying
- Flue gas condensation
- Chimney
- Handling of ash

Figure: Diagram of a biomass fired hot water boiler.

Explanations: (1) Fuel supply; (2) Fuel feeding; (3) Combustion chamber and boiler; (4) Flue gas treatment and (5) Ash handling

The following describes the main principles of the technique that is typically used at wood chip-fired plants.

8.1 Wood Chip Storage

The size of the fuel storage depends on various factors, e.g. the contract made with the fuel supplier. However, a storage of wood chips that equals the consumption of a minimum of 5 days and nights at maximum heat production should always be available for the purposes of operation during weekends and for security of supply during extreme weather conditions.
Most plants settle for an indoor storage and leave the handling of larger storages to the suppliers of wood chips. However, a few plants also have an outdoor storage of their own and may therefore receive a discount from the supplier of wood chips. Due to the risk of spontaneous fire, the wood chips are piled to a height of max. 7-8 metres and this also applies to indoor storages.

During work in the wood chip storage, there may be a risk of breathing in allergy-causing dust and micro-organisms, such as fungi and bacteria. It must be strongly recommended never to work alone in wood chip silos.

8.2 Handling of Fuel

The majority of operating problems experienced is no doubt caused by the system for transport of wood chips from storage to the feeding system. The entire transport system from storage to boiler should be viewed as a chain in which the reliability of operation of the individual links is equally important. The entire wood chip plant stops in case of a “missing link” in the transport chain, e.g. a defective crane wire.

Wheel Loader
At plants with outdoor storage, it is normal to use a wheel loader with a large shovel for the transport of wood chips to the indoor wood chip storage.

Crane Transport
Between the indoor wood chip storage and boiler feeding system, a crane is often used for the transport of wood chips. The crane is flexible, has a high capacity, and is also the transport equipment that best tolerates a poor wood chip quality. However, it is important for the crane shovel to be toothed. If not toothed, it is difficult to fill and it easily turns over on top of the pile. For relatively large plants, the crane is also relatively inexpensive, while it is a too expensive solution for very small systems.

Hydraulic Push Conveyor
The hydraulic push conveyor is used for unloading rectangular silos with level floors. It is normally not as technically reliable as the crane solution. The hydraulic push conveyor is relatively inexpensive and is therefore particularly suitable for smaller systems (nominal boiler output 0.1-1 MWth).
**Tower Silos**
Although suitable for wood pellets, tower silos with rotating screw conveyor should not be used for wood chips. The silo is time-consuming to fill due to the great tower height, and the mechanical parts in the silo bottom are not very accessible for the purposes of maintenance and repair work. Technical problems normally arise when the silo is full of wood chips. Before starting any repair work, it must be emptied - manually or preferably with crane grab. For storage of wood pellets the equipment used in animal feed industry is normally suitable.

**Screw Conveyors**
Conveyors are inexpensive, but vulnerable to foreign matter and slivers. In general, screw conveyors with bolted-on top are recommended instead of conveyors enclosed in tubes. The recommendation is easily understood after just one experience of manually emptying of a tube conveyor blocked by slivers or foreign matter. Similarly, it may be considered erroneous projecting if screw conveyors are embedded in concrete floors or otherwise located so that repair work and replacement of parts are impossible. Like other mechanical conveyors, screw conveyors should be considered a part prone to wearing and must be easily accessible for maintenance work.

Correctly dimensioned, screw conveyors are an acceptable solution at smaller systems (nominal boiler output 0.1-1 MW). But unless hardened steel is used, normal wear and tear will result in a relatively short life of the screw conveyor. Screw conveyors are seldom used as transport equipment at large district heating plants.

**Belt Conveyors**
Belt conveyors are rather insensitive to foreign matter. At this point, they are better than screw conveyors, but unless equipped with barriers, the belt conveyor cannot manage as high inclinations as the screw conveyor. High price and dust emissions (which may necessitate covering) are the major drawbacks of the belt conveyor.

**Pneumatic Conveyors**
In general, wood chips are not suitable for transport in pneumatic systems. If wood chips are available in a particularly uniform size, however, transport by pneumatic conveyors may be a possibility, but the energy consumption of pneumatic conveyors is substantial.

### 8.3 Feeding Systems
There are several types of feeding systems for wood chip-fired boilers. The choice of feeding system depends on the size of the plant and whether the use of other solid fuels than wood chips is desired.

**Hydraulic Feeding System**
Many plants use this quite reliable feeding system. Wood chips fall from a hopper into a horizontal, square box, from where hydraulic feeding devices force wood chips on to the grate. The construction of the system is of decisive importance to its reliability. If correctly designed as most often seen today, it is among the best feeding systems for wood chips.
**Stokers**

Smaller systems (nominal boiler output 0.1-1 MWth) often have screw stokers feeding the boiler. At some plants, the screw stoker is positioned across the longitudinal direction of the grate. This gives a good distribution of the fuel over the width of the grate.

![Schematic of a stoker boiler](image)

Source: Elomatic, 2002

**Grate with Feed Hopper**

Some wood chip plants have a simple hopper that feeds the wood chips on to the grate. The system is known from coal-fired boilers with travelling grate and requires that the height of the wood chips in the hopper will be high enough so as to function as an airtight plug between the feeding system and the boiler. The problem of the blocking of the hopper can be remedied by an appropriate design of the hopper, and as a last resort by mechanical stirring/scraping systems.

**Spreader and Pneumatic Stoker**

In a spreader stoker, wood chips are thrown into the combustion chamber by a rotating drum. Only a few plants use the system. In a pneumatic stoker, wood chips are blown into the combustion chamber and fall on to the grate. Spreaders and pneumatic stokers are often used in connection with combustion of wood chips with high moisture content.

### 8.4 Combustion Chamber and Boiler

For the combustion of biomass a wide range of combustion chamber types is commercially available. In this chapter technologies for the combustion of wood chips in the capacity range 0.1-10 MWth are briefly introduced. The most commonly used technologies are:

- Compact boilers
- Underfeed stokers
- Grate furnaces

**Compact boilers**

Compact boilers are scaled-up versions of small woodchip boilers. Due to standardisation and mass production the price of the boiler has come down. The competitive price combined with a high degree of automation makes the boiler an attractive alternative for a
fossil-fuel fired system. The maximum capacity of a compact boiler is in the range of 150 kW, sufficient for space heating of a limited number of objects (but not suitable for district heating). Fuel humidity should be lower than 35%.

**Underfeed stokers**
Underfeed stokers are suitable for the combustion of sawdust, chips and pellets (but not bark). They are available in sizes between 0.1 and 6 MWth. Underfeed stokers have low investment costs. Load control is simple and good due to continuous fuel feeding. Emissions at partial load operation are low due to good fuel dosing. A drawback is the low flexibility in regard to fuel particle size. Fuel humidity should be lower than 40%.

**Grate furnaces**
Grate furnaces are available in the capacity range 0.5-20 MWth. They are appropriate for biomass fuels with a high moisture content, varying particle sizes (with a downward limitation concerning the amount of fine particles in the fuel mixture), and high ash content. They are characterised by rugged construction, moderate investment costs, and low operating costs. Drawbacks are that at partial load operation low emission levels are difficult to achieve and that to achieve efficient NOx reduction special technologies are required. There are a wide variety of grate furnaces. For wood chip fired systems travelling grates and moving grates are the most commonly used.

**Travelling grates**
Travelling grates are built of grate bars forming an endless band (like a moving staircase) moving through the combustion chamber. Fuel is supplied at one end of the combustion chamber onto the grate e.g. by screw conveyors, or is distributed over the grate by spreader stokers injecting the fuel into the combustion chamber. The fuel bed itself does not move, but is transported through the combustion chamber by the grate, contrary to the moving grate furnaces where the fuel is moved over the grate. At the end of the combustion chamber the grate is cleaned of ash and dirt while the band turns around (automatic ash removal). On the way back, the grate bars are cooled by primary air in order to avoid overheating and to minimise wear-out. The speed of the travelling grate is continuously adjustable in order to achieve complete charcoal burnout.

**Moving grates**
Moving grates have an inclined grate consisting of fixed and moveable rows of grate bars. By alternating horizontal forward and backward movements of the moveable sections, the fuel is transported along the grate. Thus unburned and burned fuel particles are mixed, the surfaces of the fuel bed are renewed, and a more even distribution of the fuel over the grate surface can be achieved (which is important for an equal primary air distribution across the fuel bed). The moving grate is commonly used at capacities larger than 1-2 MWth, but even in the lower capacity region, there are many boilers with moving grates.

### 8.5 Combustion Quality
The requirements for a good combustion quality can be summarised to the three T’s: Temperature, Turbulence and Time. The temperature should be sufficiently high to enable efficient drying, gasification, and combustion. Air and combustible gases should
be mixed adequately (turbulence), and finally there should be space and time for the gases to burn out before they are cooled too much by the boiler water.

8.5.1 **Boiler**

The flue gases pass from the combustion chamber to the part of the boiler, where the heat is given off to the circulating boiler water. Most often, the boiler is situated above the grate. The flue gas flows inside the tubes that are water cooled on the outside surface. In small systems, the combustion unit and the boiler may be completely separated, since wood chips are burnt in a separate pre-combustor, from where the flue gases are passed into the boiler. In the boiler unit or as a section after this unit, an economiser may be installed that cools the flue gas down to a temperature of approx. 100 °C. The increased cooling improves the efficiency.

The boiler room should be large enough for repair work and for ordinary maintenance work, including boiler purifying, to be carried out in a proper way. The building around the boiler should be designed so as to give room for purifying of the boiler tubes and replacements of tubes.

With respect to the boiler life, it is important that the temperature of the return water to the boiler is sufficiently high. It is recommended to keep a return water temperature of at least 75-80°C in order to reduce the corrosion of the boiler tubes in particular. The life of tubes varies a lot at the various wood chip-fired plants. In addition to the operating temperature, the boiler life depends on the operational patterns, fuel, combustion quality, and choice of material.

8.5.2 **Flue Gas Purifying - Fly Ash**

Fly ash is the part of the ash that remains in the flue gases on its way through the boiler. Flue gas purifying is first and foremost a question of reducing the amount of fly ash emitted through the chimney. The emission of other pollutants is discussed later on in this chapter.

The fly ash is transported from the flue gas purifying unit to the remaining part of the ash system by screws. The separation of fly ash from the flue gas may be accomplished either by means of multi-cyclone, bag filter, or other flue gas purifying equipment.

The fly ash from the combustion of wood consists primarily of relatively large particles that can be trapped by means of a multi-cyclone. Most plants are equipped with multi-cyclones. A well-dimensioned system can purify to a level of approx. 200 mg/m³

Multi-cyclones that are inexpensive to buy and maintain, are used for pre-cleaning before the flue gas condensation unit.

Bag filters can purify to a level of 10-50 mg/m³. Normally, bag filters are only capable of withstanding flue gas temperatures of up to approx. 180°C. In order to avoid embers and sparks in the bag filters, the flue gas must pass cyclones or a filter chamber situated

---

2 1 m³n is a normal cubic metre, i.e., a cubic metre of gas converted to standard conditions 0°C and 1 bar
before the bag filters. Bag filters are automatically deactivated if the maximum temperature or the maximum value for the oxygen content in the flue gas are exceeded.

Like the bag filter, the electrostatic precipitator (ESP) cleans efficiently, but it is more expensive to install in relatively small wood chip-fired systems. Operating costs are lower, however, than those of the bag filters.

8.5.3 Flue Gas Condensation

Flue gas condensation units are now in general use in both new and existing systems. It is a technique that both purifies the smoke/flue gas for particles to a level almost similar to that of bag filters at the same time of increasing the energy efficiency. Most recently installed wood chip fired district heating plants have been delivered with flue gas condensation.

Like most other fuels, wood contains hydrogen. Together with oxygen from the air, the hydrogen is converted to water vapour by combustion, and the water vapour forms part of the flue gas together with other products of combustion. Wood chips used in combustion plants typically have a moisture content of between 25% and 55% of the total weight. By the combustion, this water is also converted to water vapour in the flue gas.

The flue gas water vapour content is interesting because it represents unutilised energy that can be released by condensation. The theoretical amount of energy that can be released by the condensation of water vapour is equal to the heat of evaporation for water plus the thermal energy from the cooling.

When flue gas is cooled to a temperature below the dew point temperature, the water vapour will start condensing. The more the flue gas is cooled down, the larger is the amount of water that is condensed, and the amount of heat that is released is increased. The lowering in temperature from the normal flue gas temperature of the system to dew point temperature automatically increases the heat output. The effect increases, however, when the condensation starts, and the heat of evaporation is released. Figure XXX illustrates in percentages the increased generation of heat that can be achieved by lowering the flue gas temperature. The normal operating situation that forms the basis of the calculations is a flue gas temperature of 130°C with CO2 being 12%. The various lines in Figure @@@ illustrate various values for the wood chip moisture content in percentage of the total weight.

Figure @@@ Flue gas condensation and plant efficiency
Explanation: Flue gas condensation increases the generation of heat and the efficiency of the plant. The graph illustrates how the additional heat output depends on the flue gas temperature and on the wood chip moisture content.

Source: Wood for Energy Production

The curves show the theoretical improvement of the efficiency that can be calculated on the basis of the moisture content and the flue gas temperature. Experiences acquired from condensation units in operation indicate that an increase in efficiencies can also be achieved in practice. Thus, the annual efficiencies for almost all plants are above 100% (based on the net calorific value of the fuel which does not include the condensation heat). The return water from the district heating system is used for cooling the flue gas. The water should be as cold as possible. The flue gas cooling unit is therefore the first unit the water passes when it returns from the district heating system.

8.5.4 Condensate

Condensate consists of water with a small content of dust particles and organic compounds from incomplete combustion. There is also a minor content of mineral and heavy metal compounds, and of chlorine and sulphur from the wood.

The condensate should be treated before being discharged. The minerals and heavy metals contained in wood, such as cadmium that has been absorbed during the growth in the forest, concentrate in the condensate and may reach a level exceeding the limit values for discharge. Investigations have shown that the large amount of cadmium contained in the condensate is found in the condensate particles and not in dissolved form in the water. The particles can be removed from the condensate liquid by filtering, so that the cadmium content is reduced to below the limit values for discharge. This is the reason why filtration equipment for the separation of condensate particles is being installed in an increasing number of plants.

After treatment and neutralisation, the condensate is generally discharged into the municipal sewage system. When the flue gas leaves the flue gas condenser, it should pass
through an efficient mist eliminator for the collection of entrapped droplets, thereby avoiding mist being carried further into the tube, exhaust fan, and chimney.

The first prerequisite of success with flue gas condensation is a return flow temperature in the district heating system that is so low that the vapour in the flue gas can be condensed. In addition, the fuel should have a high moisture content. Wetter fuel increases the overall efficiency of the plant! This applies only as long as the moisture content is not so high as to result in incomplete combustion. Forest chips with a moisture content in the range of 40 and 50% are ideal for systems with flue gas condenser.

The installation of flue gas condensers may often make the installation of other equipment for flue gas purifying unnecessary. If the installation of a bag filter can be avoided, the money thereby saved can often pay the investment in the flue gas condensation unit. Consequently, the energy saved is almost free.

8.5.5 Chimney

Before chimney and flue gas condenser an exhaust fan is installed, which creates negative pressure throughout the flue gas passes of the heating system. A control device ensures that the exhaust fan in interaction with the combustion air fans keeps a preset negative pressure in the combustion chamber. The exhaust fan then forces the flue gas into the flue gas condenser and the chimney. Individual chimney heights should be determined on the basis of the environmental requirements.

For small plants with flue gas condenser, the chimney should be designed so as to avoid corrosion damage, i.e. glass fibre or rust-proof materials should be used. Soot emission from chimneys of systems with flue gas condensation causes problems at some heating plants. The smoke is saturated with water vapour. It also contains dissolved salts and perhaps impurities from the flue gas condensate, which may be deposited in the chimney. Soot emission occurs when the deposits in the chimney loosen and are passed along with the flue gas flow. Efficient mist eliminators, low velocities in the chimney, and perhaps the installation of a wash-down system in the chimney can be recommended so as to eliminate the problem.

Fig @@: Diagram of a wood-chip fired boiler
8.6 Handling of ash

Wood chips contain 0.5-2.0% of the dry weight in the form of incombustible minerals which are turned into ash in the combustion process. The ash is commonly handled automatically at district heating plants. The manual work in connection with the ash system is limited to ordinary inspections and intervention in case of operations stoppage. The composition of wood ash means that slagging is not a widespread phenomenon at wood chip fired heating plants.

The ash drops from the grate onto an ash conveyor or other ash collection system. The sludge from the flue gas condensate contains a large amount of heavy metal and is collected separately for later disposal. The ash system may be arranged as a wet or dry ash system. A wet ash system is a dual function system, since it is efficient as a trap hindering false air entering the boiler at the same time as extinguishing glowing ash. A drawback of the system is the heavy weight ash in the ash container and the corrosion resulting from the wet ash. The emptying of the containers varies with the consumption of wood chips, i.e., from approx. every second week to once every three months.

8.7 Noise

The heating plant must comply with the conditions of the environmental authorities regarding the limitation of noise. Noise limits may vary with the type of area (residential or industrial) or the time of day/week. The lowest limits normally apply in residential neighbourhood during nights.

The noise comes primarily from fans and air inlets or exhaust systems (including the chimney), but also from other machines (compressors, cranes, belt conveyors, screw conveyors, and hydraulic systems) and from all the traffic on the plant site. For most areas, the noise limit is lowest during the night, and it will therefore normally be this limit that will form the basis of the dimensioning. However, the delivery of fuel may often give rise to problems, although it takes place during the day if the driveway of the plant is inexpediently located.

It is important to take into the noise emission levels already into account at the stage of planning, since subsequent anti-noise measures are often very expensive, and also operational restrictions (such as how to avoid all traffic during evening and night periods) may be problematic. Today it is possible to forecast the noise in the surrounding neighbourhood, so that the suppliers should warrant not exceeding the noise limits.

8.8 Fire Protection

When firing with forest wood chips, the risk of fire is smaller than by firing with dry fuels. However, certain safety regulations must be complied with.

The fuel system should be equipped with an airtight dividing wall, thereby preventing fire from spreading backwards from the combustion chamber to the storage. At most plants, the feeding systems are designed with an airtight “plug” of wood chips and a sprinkler system located just before the combustion chamber.
Attention should be paid to the risk of flue gas explosions. Unburned gases in an incorrect mixture with atmospheric air may cause extremely violent explosions if gases, e.g. due to a positive pressure in the combustion chamber leaking into the boiler room or the feeding system. Flue gas explosions may also occur in the combustion chamber if, e.g. the fuel due to suspension of operations has been smouldering with too little atmospheric air, and air is suddenly introduced.

In the wood chip storage one should beware of the risk of spontaneous combustion. Here storage height, wood chip storage time, moisture content, and the access to air will be a decisive parameter. During firing with wood pellets and dry wood waste, there is a risk of dust explosion in the storage and the feeding system. Here fire extinguishing equipment should be built in just before the boiler. The risk of fire in the fuel storage also applies to pellets.

8.9 Control, Adjustment, and Supervision

The control, adjustment, and supervision system is designed on the basis of two computers:
- A PLC (Programmable Logic Control) with system data recording controls the plant’s various flows according to pre-set operating values.
- An ordinary computer displays the flow of data from the PLC to the operators’ monitor. The pre-selected operating values in the PLC can be changed via the computer.

The system is divided into three main functions covering the following:
- The control ensures that the system performs according to a pre-selected sequential order.
- The adjustment unit ensures that the pre-selected values for pressure, temperature, etc. are complied with.
- The supervision unit sets off alarms in case of malfunctions.

The control, adjustment, and supervision system enables automatic operation of the plant, thereby making the permanent presence of operators unnecessary. In case of operation failures, the remote supervisory and monitoring unit calls in the operators via the public telephone network. In emergency situations, a conventionally fired furnace is automatically started, taking over the supply of heat.

8.10 Plant Manpower

Manpower is needed for the operation and maintenance of the plant. The manpower necessary for plant operation naturally depends on the degree of automation, the scope of own wood chip handling, the age of the heating plant etc. Individual small heating plants are designed so as to remove the need for permanent on-site attendance even during the day. By being on call via telephone and daily inspections, the plant manager can occupy another job at the same time. The amount of manpower required for maintenance is mainly determined by the construction of the system.
9 ENVIRONMENTAL ASPECTS OF BIOMASS COMBUSTION

This chapter describes the impact on the air environment in connection with firing with fuel chips and other woody biomass

9.1 Emissions from complete combustion

Carbon Dioxide (CO₂)
CO₂ is a major combustion product from all biomass fuels, originating from the carbon content in the fuel. In general, the emission of CO₂ to the atmosphere is problematic, since CO₂ is considered a major cause of the greenhouse effect. However, during the combustion of wood chips and other wood fuels, not more CO₂ is developed than bound during the growth of the tree. Furthermore, during combustion the same amount of CO₂ is developed as during the decomposition that is the final alternative to the use of the wood for energy purposes. Wood chips are thus considered CO₂-neutral.

Nitric oxides (NOₓ)
During the combustion of wood chips, approximately the same amounts of NOₓ are produced as during the combustion of other fuels. NOₓ is the sum of NO and NO₂.

NOₓ emissions from biomass combustion applications are mainly a result of complete oxidation of fuel nitrogen, both from gas-phase combustion and char combustion. Additional NOₓ may be formed from nitrogen in the air given certain conditions. However, these reaction mechanisms are not considered to be of significant importance in most biomass combustion applications. The main nitric oxide is NO, which is converted to NO₂ in the atmosphere.

Important parameters for low NOₓ-formation include:
- Low nitrogen content of the fuel.
- Staged combustion at low excess air during the first stage /ref. 69/.
- Low flame temperature.
- Recirculation of flue gases.

Nitrous oxides (N₂O)
N₂O emissions are the result of complete oxidation of fuel nitrogen. The N₂O emission levels measured in biomass combustion appliances are very low but they contribute to some degree to the greenhouse effect because of the high Global Warming Potential (GWP) factor of N₂O and to ozone depletion in the atmosphere.

Sulphur Oxides (SOₓ)
Sulphur oxides are a result of complete oxidation of fuel sulphur. Mainly SO₂ (>95%) is formed. However, some SO₃ (<5%) may be formed at lower temperatures. Sulphur from the combustion of wood chips comes from sulphur compounds that have been absorbed by the tree during its growth. Therefore, the combustion of wood chips does not change the total amount of sulphur present in the environment, but it entails that the emission of sulphur with the smoke contributes to the pollution of the air. However, pure wood from
the forestry contains only a very limited amount of sulphur, and the sulphur content in fuel chips often show values that are below the laboratory equipment limits of detection. Fuel sulphur will not be completely converted to SO\textsubscript{x}; a significant fraction will remain in the ashes while a minor fraction is emitted as salt (K\textsubscript{2}SO\textsubscript{4}) or as H\textsubscript{2}S at lower temperatures.

Firing with wood chips at heating plants causes much less SO\textsubscript{2} emission than the fuel oil or coal the wood chips often replace. If the alternative is natural gas, and if it is sulphur-free at production, there will be no SO\textsubscript{2} advantage by using wood chips as a fuel.

**Hydrogen chloride (HCl)**

Part of the chlorine content in the fuel will be released as HCl. The chlorine content of wood is very low. However, significant amounts of HCl may be formed from biomass fuels containing higher amounts of chlorine, such as miscanthus, grass and straw, or when wood chips from nearshore forests containing salt from sea fog are used.

The fuel chlorine will not be completely converted to HCl; the main fraction is retained in salts (KCl, NaCl) by reaction with K and Na, while traces are emitted as dioxins and organic chlorine components. Like sulphur dioxide, hydrogen chloride (HCl) contributes to the acidification, but condenses faster (to hydrochloric acid) and can therefore locally contribute to damage to materials in particular, but also to plants.

**Particles**

Particles originate from several sources. Among these are fly ash, which is a result of entrainment of ash particles in the flue gas, and salts (KCl, NaCl, K\textsubscript{2}SO\textsubscript{4}) which is a result of reactions between K or Na and Cl or S. Other particles, occurring as a result of incomplete combustion, are discussed in the next subchapter.

**Heavy metals**

All virgin biomass fuels contain heavy metals to some degree (most important: CU, Pb, Cd, and Hg). These will remain in the ash or evaporate, and also attach to the surface of particles emitted to the atmosphere or be contained inside fly-ash particles. Contaminated biomass fuels, such as impregnated or painted wood may contain significantly higher values of heavy metals. One example is the presence of Cr and As in impregnated wood.

9.2 **Emissions from incomplete combustion**

Emissions caused by incomplete combustion are a result of either:
- inadequate mixing of combustion air and fuel in the combustion chamber, which produces local fuel-rich combustion zones;
- an overall lack of available oxygen;
- too low combustion temperatures;
- too short residence times

These variables are linked together, however, in cases in which sufficient oxygen is available temperature is the most important variable.
The following components are emitted to the atmosphere as a result of incomplete combustion in biomass combustion appliances.

**Carbon Monoxide (CO)**
The CO content is an important indication of the combustion quality. High CO concentrations are the result of incomplete combustion, which may be caused by insufficient or excess combustion air, too short residence times (resulting in poor mixing of combustion air and combustible gases), or too rapid cooling of combustible gases. The CO content should be as low as possible, because:

- CO is a combustible gas. A high CO content results in poor efficiency.
- Odour nuisance and a high CO value go together.
- PAH, dioxin and a high CO value go together.
- Exposure to high concentrations of CO is hazardous

**Unburned hydrocarbons (C\text{\textsubscript{x}}H\text{\textsubscript{y}})**
Methane (CH\text{\textsubscript{4}}) is usually mentioned separately from the other hydrocarbons since it is a direct greenhouse gas. In biomass combustion it is an important intermediate in the conversion of fuel carbon to CO\textsubscript{2} and fuel hydrogen to H\textsubscript{2}O. As for CO, emissions of CH\textsubscript{4} are a result of too low combustion temperatures, too short residence times, or lack of available oxygen. Other unburned hydrocarbons (C\textsubscript{x}H\textsubscript{y}) are also the product of incomplete combustion. They originate during the devolatisation of the fuel. As earlier intermediaries than CO the emission of C\textsubscript{x}H\textsubscript{y} are generally lower. Polycyclic Aromatic Hydrocarbons (PAHs), a group of hundreds of organic components consisting of two or more aromatic rings, constitute a special category of hydrocarbons due their carcinogenic effects.

**Dust**
Particle emissions from incomplete combustion can be found as soot, char, or condensed heavy hydrocarbons (tar). Soot consists mainly of carbon, and is the result of a local lack of available oxygen in the flame zone and/or local flame extinction. Char particles may be entrained in the flue gas due to their very low specific density, especially at high flue gas flow rates. As for CO, emissions of particles may be a result of too low combustion temperatures, too short residence times, or lack of available oxygen. However, due to the diversity of particle emission components, reducing particle emission levels is not as straightforward as it is for CO, except for particles consisting of condensed heavy hydrocarbons.

**Polychlorinated dioxins and furans (PCDD/PCDF = PCDD/F)**
Polychlorinated dioxins and furans are a group of highly toxic components. They can originate during the combustion of chlorine-containing biomass fuels in the temperature range 180-500°C and in the presence of carbon, catalysts (Cu) and oxygen. The emissions of PCDD/F are highly dependent on the conditions under which combustion and flue gas cooling takes place; therefore, wide variations are found in practice. In general, the PCDD/F emission level from biomass combustion applications using virgin wood (e.g. forestry chips) as fuel is well beyond the health risk limit. However, the combustion of painted, impregnated, chlorine or Cu-containing wood can easily lead to the production of dioxins if the combustion plant is not specially designed for these fuels.
**Ammonia (NH₃)**

Small amounts of NH₃ may be emitted as a result of incomplete conversion of NH₃ to oxidised nitrogen-containing components. This occurs in special cases in which the combustion temperature is very low. Additionally, secondary NOₓ reduction measures utilising NH₃ injection may contribute to the NH₃ emission level due to NH₃ slippage.

**(Ground level) Ozone (O₃)**

O₃ is a secondary combustion product formed from photochemical atmospheric reactions including CO, CH₄, non-methane volatile organic components, and NOₓ. It is a direct greenhouse gas and also influences the local and regional environment. As such, it is a highly unwanted by-product of biomass combustion appliances.

Table 1 shows the various pollutants form biomass combustion and their impacts.

<table>
<thead>
<tr>
<th>Component</th>
<th>Biomass sources</th>
<th>Climate, environmental and health impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>Major combustion product from all biomass fuels</td>
<td><strong>Climate</strong>: Direct GHG. However, biomass is a CO₂-neutral fuel</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>Incomplete combustion of all biomass fuels</td>
<td><strong>Climate</strong>: Indirect GHG through ozone formation. <strong>Health</strong>: Reduced oxygen uptake especially influences people with asthma, and embryos. Suffocation in extreme cases.</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>Incomplete combustion of all biomass fuels</td>
<td><strong>Climate</strong>: Direct GHG. <strong>Indirect GHG through ozone formation</strong></td>
</tr>
<tr>
<td>Non Methane Volatile Organic Components (NMVOC)</td>
<td>Incomplete combustion of all biomass fuels</td>
<td><strong>Climate</strong>: Indirect GHG through ozone formation. <strong>Health</strong>: Negative effect on human respiratory system</td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons (PAH)</td>
<td>Incomplete combustion of all biomass fuels</td>
<td><strong>Environment</strong>: Smog formation.  <strong>Health</strong>: Carcinogenic effects</td>
</tr>
<tr>
<td>Particles</td>
<td>Soot, char and condensed heavy hydrocarbons (tar) from incomplete combustion of all biomass fuels. Fly ash and salts</td>
<td><strong>Climate and environment</strong>: Reversed greenhouse effect through aerosol formation. Indirect effects of heavy-metal concentrations in deposited particles. <strong>Health</strong>: Negative effect on the human respiratory system. Carcinogenic effects</td>
</tr>
<tr>
<td>Nitric oxides (NOₓ = NO and NO₂)</td>
<td>Minor combustion product from all biomass fuels containing nitrogen. Additional NOₓ may be formed from nitrogen in the air under certain conditions</td>
<td><strong>Climate and environment</strong>: Indirect greenhouse effect through ozone formation. Reversed greenhouse effect through aerosol formation. Acid precipitation. Vegetation damage. Smog formation. Corrosion and material damage. <strong>Health</strong>: Negative effect on the human respiratory system. NO₂ is toxic</td>
</tr>
</tbody>
</table>
Nitrous oxide (N₂O) | Minor combustion product from all biomass fuels containing nitrogen | **Climate:** Direct GHG. **Health:** Indirect effect through ozone depletion in the stratosphere
---|---|---
Ammonia (NH₃) | Small amounts may be emitted as a result of incomplete conversion of NH₃ from pyrolysis/gasification | Environment: Acid precipitation. Vegetation damage. Corrosion and material damage. **Health:** Negative effect on the human respiratory system.
Sulphur oxides (SOₓ = SO₂ and SO₃) | Minor combustion product from all biomass fuels containing sulphur. | **Climate and environment:** Reversed greenhouse effect through aerosol formation. Acid precipitation. Vegetation damage. Smog formation. Corrosion and material damage. **Health:** Negative effect on the human respiratory system., asthmatic effect
Heavy metals | All biomass fuels contain heavy metals to some degree, which will remain in the ash or evaporate | **Health:** Accumulate in the food chain. Some are toxic and some have carcinogenic effects
(Ground level) Ozone (O₃) | Secondary combustion product from atmospheric reactions, including CO, CH₄, NMVOC and NOₓ | **Climate and environment:** Direct GHG. Vegetation damage. Smog formation. Material damage. **Health:** Indirect effect through ozone depletion in the stratosphere. Negative effect on the human respiratory system, asthmatic effect
Hydrogen Chloride | Minor combustion product from all biomass fuels containing chlorine | **Environment:** Acid precipitation. Vegetation damage. Corrosion and material damage. **Health:** Negative effect on the human respiratory system.
Dioxins and Furans PCDD/PCDF | Small amounts may be emitted as a result of reactions including carbon, chlorine, and oxygen in the presence of catalysts (Cu) | **Health:** Highly toxic. Liver damage. Central nervous system damage. Reduced immunity defence. Accumulate in the food chain

*Source: Handbook of Biomass Combustion and Co-firing*

### 9.3 Emission reduction measures

Reduction of harmful emissions through flue gases and effluents can be obtained by either avoiding the creation of such substances (primary measures) or removing the substances from the flue gas (secondary measures).

Primary emission reduction measures aim at preventing or reducing formation of emissions and/or reduction of emissions within the combustion chamber. Several measures exists, including: (a) modification of the fuel composition, (b) modification of the moisture content of the fuel, (c) modification of the particle size of the fuel, (d) selection of the type of combustion equipment, (e) improved construction of the combustion application, (f) combustion process control optimisation, (g) staged-air combustion, (h) staged fuel combustion and reburning and (i) catalytic converters.
In practice, these measures often are interrelated.

Secondary measures can be applied to remove emissions from the flue gas once it has left the boiler. For virgin wood combustion, particle removal is of particular relevance. For other types of biomass, additional secondary measures may be necessary, depending on the elementary composition and the fuel characteristics of the selected biomass fuel, and the combustion technology.

Details of primary and secondary emission reduction technologies can be found in the Handbook of Biomass Combustion and Co-firing.

9.4 Emission limits

Maximum emission limits allowed for biomass combustion plants vary significantly from country to country, and are expressed in various units, making companions difficult. A recent BIOS publication (Obernberger and Thek, 2004) presents an overview of the emission limits for CHP plants based on biomass combustion in Austria, Finland, Belgium, Denmark and Sweden. The parameters for which emission limits are defined include dust, CO, NOx, SOx, total organic carbon (TOC) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F). Not all 5 countries have defined emission limit for all parameters mentioned. The Finnish emission limits are expressed in mg/MJ and were re-calculated to mg/Nm$^3$.

The maximum emission limits have a large influence on the technology selection and system configuration.

9.5 Ash

9.5.1 Definition

Ash contains the unburned constituents of fuel, including a range of nutrients, such as potassium, magnesium and phosphorus, and it can therefore be used as fertiliser in the forests if the content of other substances that are problematic to the environment (such as heavy metals) is not too high. Wood ash is defined as ash from the thermal utilisation of chemically untreated woody biomass like wood chips, bark and sawdust. The wider terminus biomass ash also includes ashes from the thermal utilisation of straw, cereals, hay, and other agricultural residues.

9.5.2 Ash content of woodfuel

Due to increasing thermal utilisation of biomass, the amounts of residues from the combustion process also increase, given the fact that the ash content of woody biomass fuels ranges from 0.5% for soft wood to 5-8% for bark. Table shows that the quantity of ash is strongly influenced by the bark content in wood fuels. This is a result of higher ash content in bark, on the one hand, and a higher level of mineral impurities (sand, earth, stones) in the bark, on the other hand.
Table @@@: Overview of the emission limits for biomass combustion CHP plants

<table>
<thead>
<tr>
<th>Country</th>
<th>Austria</th>
<th>Finland</th>
<th>Belgium</th>
<th>Denmark</th>
<th>Denmark</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>mg/Nm³</td>
<td>mg/Nm³</td>
<td>mg/Nm³</td>
<td>mg/Nm³</td>
<td>mg/Nm³</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Dust</td>
<td>&lt; 0.12</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.12 - 1</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>150</td>
<td>300³</td>
</tr>
<tr>
<td></td>
<td>1 - 2</td>
<td>150</td>
<td>265</td>
<td>-</td>
<td>150</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>2 - 5</td>
<td>50</td>
<td>265</td>
<td>-</td>
<td>150</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>5 - 10</td>
<td>50</td>
<td>35⁴</td>
<td>-</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>10 - 50</td>
<td>50</td>
<td>15⁴</td>
<td>-</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>30 - 50</td>
<td>50</td>
<td>79⁴</td>
<td>-</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>50 - 100</td>
<td>50</td>
<td>50⁴</td>
<td>50</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>100 - 300</td>
<td>50</td>
<td>50⁴</td>
<td>30</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>300 - 500</td>
<td>50</td>
<td>30⁴</td>
<td>30</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 500</td>
<td>50</td>
<td>30⁴</td>
<td>30</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>0.1 - 0.12</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.12 - 1</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>500⁴</td>
</tr>
<tr>
<td></td>
<td>1 - 5</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>500 / 625</td>
</tr>
<tr>
<td></td>
<td>5 - 50</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>500 / 625</td>
</tr>
<tr>
<td></td>
<td>&gt; 50</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>NO₂</td>
<td>&lt; 0.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>r.c.o.</td>
<td>50 - 200</td>
</tr>
<tr>
<td></td>
<td>0.1 - 5</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>r.c.o.</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>5 - 10</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>r.c.o.</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>&gt; 10</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>r.c.o.</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>&gt; 100</td>
<td>200</td>
<td>199 / 23⁴</td>
<td>-</td>
<td>r.c.o.</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>&lt; 30</td>
<td>r.c.o.</td>
<td>-</td>
<td>-</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>30 - 100</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>50 - 100</td>
<td>200</td>
<td>37⁵</td>
<td>300</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>100 - 300</td>
<td>200</td>
<td>37⁵</td>
<td>300</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>300 - 500</td>
<td>200</td>
<td>12⁵</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>&gt; 500</td>
<td>200</td>
<td>12⁵</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>SO₂</td>
<td>&lt; 50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>50 - 100</td>
<td>-</td>
<td>-</td>
<td>200 / 400</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 100</td>
<td>-</td>
<td>-</td>
<td>200 / 200</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>TOC</td>
<td>&gt; 0.1</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PCDD/F²</td>
<td>&lt; 5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

Explanations: PCDD/F...dioxins and furans; FEI...fuel energy input; r.c.o....range covered otherwise; W...woody biomass; S...straw; P...peat; BM...biomass; WW...waste wood; ex....existing plant; new...new plant; TEQ...toxicity equivalent; 1)...expressed in ng TEQ/Nm³; 2)...for plants built before 12 February 1987 to be calculated using emission limit [mg/MJ] = 85 – 4 x (FEI – 5) / 3; 3)...higher value valid for peat using burners, lower value valid for peat (other techniques) and wood or straw; 4)...valid for biomass; 5)...200 mg/Nm³ from 1 January 2016; 6)...6% O₂; 7)...daily / hourly average.

Source Handbook of Biomass Combustion and Co-firing.

Table @@@: Fuel-specific ash content (wt%) of various woody biomass fuels

<table>
<thead>
<tr>
<th>Biomass fuel used</th>
<th>Ash content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bark</td>
<td>5.0-8.0</td>
</tr>
<tr>
<td>Wood chips with bark (forest)</td>
<td>1.0-2.5</td>
</tr>
<tr>
<td>Wood chips without bark (industrial)</td>
<td>0.8-1.4</td>
</tr>
<tr>
<td>Sawdust</td>
<td>0.5-1.1</td>
</tr>
<tr>
<td>Waste wood</td>
<td>3.0-12.0</td>
</tr>
</tbody>
</table>


### 9.5.3 Ash fractions of wood combustion

In biomass combustion plants three different ash fractions are normally distinguished:
**Bottom ash**: Ash fraction produced on the grate and in the primary combustion chamber, often mixed with mineral impurities contained in the biomass fuel like sand, stones and earth or with bed material in fluidised bed combustion plants. These mineral impurities can, especially in bark fixed-bed combustion plants, cause slag formation (due to a lowering of the melting point) and sintered ash particles in the bottom ash.

**Cyclone fly ash**: Fine, mainly inorganic, ash particles carried with the flue gas and precipitated in the secondary combustion zone, in the boiler and especially in multi-cyclones placed behind the combustion unit. This ash fraction mainly consists of coarse fly-ash particles.

**Filter fly ash**: Second and finer fly-ash fraction precipitated in electrostatic filters, fibrous filters or as condensation sludge in flue gas condensation units (normally placed behind the multi-cyclone). In small-scale biomass combustion plants without efficient dust precipitation technology, this ash fraction is emitted with the flue gas. A small part of the filter fly ash remains in the flue gas anyway and causes dust emissions (depending on the efficiency of the dust precipitation technology used). This ash fraction mainly consists of aerosols (sub-micron ash particles).

Table @@@ shows the standard values for the average mass distribution of various ash fractions related to the total amount of ash for fixed-bed combustion plants. The differences are due to different combustion technologies and different particle sizes of the biomass fuels used. The mass distribution depends also on the geometry of the furnace, combustion air inlet, the process control system, and the dust separation technology applied.

**Table @@@: Percentage of the various ash fractions on the total ash amount**

<table>
<thead>
<tr>
<th>Biomass fuel</th>
<th>Bark</th>
<th>Wood chip</th>
<th>Sawdust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom ash</td>
<td>65-85</td>
<td>60-90</td>
<td>20-30</td>
</tr>
<tr>
<td>Cyclone fly ash</td>
<td>10-25</td>
<td>10-30</td>
<td>50-70</td>
</tr>
<tr>
<td>Filter fly ash</td>
<td>2-10</td>
<td>2-10</td>
<td>10-20</td>
</tr>
</tbody>
</table>

**Explanations**: Data for bark and wood chips are from grate furnace or underfeed stokers. Data for sawdust are from underfeed stokers. All furnaces are equipped with cyclones, followed by a second and more efficient dust precipitation unit.


### 9.5.4 Ash utilisation and disposal

Currently, biomass ash is either disposed of or recycled on agricultural fields or forests, often without much control. Considering the fact that the disposal costs are rising (the actual prices for the disposal of one tonne of wood ash range from 200 to 500 €), and that biomass ash volumes are increasing, a controllable ash utilisation has to be established. A start was made in the late nineties with research activities focusing on the characterisation of biomass ashes and their environmentally compatible utilisation. This research is ongoing.

Austria is the first European country that introduced clear legislation for the utilisation of biomass ashes. Other countries that are planning, or have introduced, guidelines or
regulations on the appropriate use of ashes from biomass combustion include Denmark, Germany and Sweden.

In Austria, bottom ash, cyclone fly ash, and filter fly ash from biomass combustion plants are legally considered industrial waste but not hazardous waste. The utilisation of waste materials makes them a secondary raw material, provided the process is ecologically friendly and meaningful. Moreover, ashes from biomass combustion are not regarded as fertilisers as their chemical composition varies too much. The utilisation of biomass ashes as a secondary raw material must be regulated.

On the basis of comprehensive research results, the Austrian Ministry for Agriculture and Forestry worked out two guidelines for the proper utilisation of biomass ashes on agricultural fields and in forests. These guidelines regulate:

- Which kind of biomass ash can be used as fertilising and liming agent for agricultural and forests soils (the guidelines cover the kind of ash fractions as well as the concentration of heavy metals in the ash);
- How and when ash spreading is possible (spreader technology, climatic and weather conditions);
- The maximum amounts of ash to be applied; and
- The demands on the composition of the soil (kind of soil, chemical analysis).

The recommended maximum application of wood ash on soils is (a) 1000 kg per ha per year on agricultural land, (b) 750 kg per ha per year on greenland and 3000 kg once in 50 years in forests. Legal limits and guiding values for the utilisation of biomass ash on agricultural land, in forests and for soils are given in Table @@@

**Table @@@:** Limiting values for concentrations of heavy metals in biomass ashes used on agricultural land and in forests and guiding values for soils according to Austrian regulations

<table>
<thead>
<tr>
<th>Element</th>
<th>Limiting value forest</th>
<th>Limiting value agriculture</th>
<th>Guiding value for soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>250</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Zn</td>
<td>1,500</td>
<td>1,000</td>
<td>300</td>
</tr>
<tr>
<td>Ni</td>
<td>100</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Cr</td>
<td>250</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Pb</td>
<td>100</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Cd</td>
<td>8</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>


Usable ash has to be analysed for its content of nutrients and its content of ecologically relevant heavy metals before it is used on soils. Ash analysis should be repeated at regular intervals.

The use of filter fly ash on soils is forbidden. This ash fraction must be treated as industrial waste. Disposal of filter ash without treatment is only possible in qualified landfills.
10 BIOMASS DISTRICT HEATING

District heating involves the centralised generation and distribution of heat required for heating buildings and service water and for industrial processes. The basic principle of district heating is to generate, transfer and distribute district heat for consumers as efficiently and profitably as possible. To reach this target, several sub-factors should be studied both separately and together. Such factors of significance are, e.g., definition of consumers’ heat demand, main dimension principles of wood fired boiler plants, summer and peak loads, and correct dimensioning of the district heat network.

10.1 Determination of heat demand

The heat demand of consumers determines the dimensioning of the district heating plant, the choice of suitable boiler technique, and the dimensioning of district heat pipelines. The district heat demand is based on the heating of buildings (radiator network and air-conditioning) and of service water. Heat demand for space heating follows changes in outdoor temperature. As a result annual, weekly, daily and even hourly variations in heat demand can be significant. It is not uncommon that in summertime, heating of service water requires less than 10% of the connection value. Consumption peaks can be evened out, e.g. with a heat accumulator. Attention should also be paid to distribution losses.

If real energy demand data is available the annual energy quantity and the output required can be defined very exactly. However, this requires the follow-up of consumption during a period before employing district heating. The shorter the periods, for which the consumption can be defined, the more accurately the changes in power and energy consumption of consumers can be calculated, and the more exactly the system can be dimensioned. When no measuring data is available on energy consumption, the output and annual energy demand of consumers can also be determined by employing model values for the specific heat demand (in W/m³) and heat index (in kWh/m³). Such model values depend on various factors, including the climate, the age of the building and the type of building, and can vary from country to country.

![Figure @@: A model of annual variations in heat demand. Source: Elomatic, 2002.](image)

![Figure @@: A model of weekly variation in heat demand. A typical curve of consumption during the heating season. Source: Elomatic, 2002.](image)
10.2 Duration diagram

The distribution of the heat demand can be illustrated by so called duration diagrams, see Figure @@. The diagrams show how many hours a certain capacity will be required during a year. This is shown in two different ways. In the diagram to the right the annual hourly outputs are arranged by magnitude, in order from the highest value to the smallest one. The curve indicates the maximum output demand for each moment whereas the area beneath the curve corresponds to the total energy consumption during a year.

The duration curve is very case-specific. It can be defined for the energy consumption of a single building, for a micro-grid or for an extensive district heating network.

Figure @@: Duration diagrams

![Duration diagrams](image)
The diagram to the left shows the monthly average heat capacities in percent of the maximum heat capacity.
The diagram to the right shows how many hours a certain capacity is needed during the year.

10.3 Main dimensioning principles

The dimensioning of combustion and heat-recovery equipment is based on the heat demand of buildings, on daily variations of heat consumption and on heat demand variations according to outdoor temperature. In order to achieve a good overall operation economy more than one boiler is usually required. A wood fired boiler has a high investment cost but can utilise cheap fuels. It should therefore be used as a base load source, i.e. to cover the base need of heat. An oil or gas burner, which has a lower investment cost but uses a more expensive fuel, could then be used for the peak load. The wood fired boiler will in this way achieve a long period of operation at high loads, which the high fixed costs can be distributed among. How high capacity the alternative heat supply should have compared to the wood fired boiler depends on, among other things, the kind of building(s) which will be heated.
The base load boiler is usually dimensioned for between 40-60% of the maximum capacity need. With 50% of the connected capacity as base load it is possible to produce 80-90% of the total heat required during a year.

The network is dimensioned optimal to the demand of peak output and, as regards the main line, to potential new customers. Losses in the district heat network range from 8% to 12% of the heat generated, depending on the outflow and return temperatures of district heat water. E.g., when the mean temperature in the network is lowered to 20°C, the heat losses are reduced by 10-15%. Network losses can also be affected by operative measures, like regulation of the temperature of outflow water, lowering the night-time temperature, elimination of leakages, and regulation of consumer equipment.

10.4 Summer load

In summertime, the output required by the heat consumers is often reduced to such an extent, that it is beyond the minimum control range of the wood fired boiler. This problem is often solved by constructing several parallel, often conventional (oil or gas fired) boilers. In a system with several parallel wood fired boilers, even the summer load may be run in some smaller wood fired boiler to save expensive oil. However, this is ultimately a matter of economics.

In Austria, biomass district heating plants (micro grids) are nowadays often equipped with solar thermal collectors so that the wood chip boiler need not be used in the summer period. In case the yield of the solar thermal collectors is insufficient the hot water production can be boosted using the back-up boiler. Alternatively the biomass boiler can be used. There are good technical reasons building hybrid biomass-solar thermal heating plants and running on solar in the summer seasons. Operating the boiler in the summer season means that is has to be operated at small partial loads. Operational losses will be higher when running at small loads and pollutant emissions will be higher when starting up the boiler. Mechanical stress to the system will continue also when the load is small. Temporary taking the system out of operation in the summer period will extend the biomass boiler lifetime.

Picture: Biomass and solar thermal hybrid supplying home for the elderly in Wettmannstätten
10.5 Winter load

In the coldest winter weather, the demand exceeds the maximum output of the wood fired boiler, although using a drier fuel. Hence, additional heat generation capacity should be in reserve. Reserve capacity is also needed for possible operation troubles of the wood fired boilers. As the regulation range, controllability and startability of the conventional boilers are good, all the tasks mentioned above can be performed with the same conventional boilers. Hence, only two boilers are usually needed: one wood-fired and one conventional boiler.

Box @@@: …. Strategies for compensating for load variations in winter

In winter every heating system is subject to great load fluctuations that depend on the weather, users’ habits etc. The maximum output is only utilised very briefly during periods of very cold weather. In contrast, the boiler is operated for long intervals at low load. It is therefore important for the boiler to be operated efficiently in off-peak periods. This can be achieved in one of the following ways:

- A conventional (oil or gas) boiler supplements the wood one to cover the peaks and act as a back-up system. The wood boiler’s capacity is reduced to around 60-70% of the maximum output. It can thus provide 90-95% of the power required for heating, as the demand peaks are only of short duration. To guarantee 100% supply security, the capacity of the oil boiler should be able to cover the maximum output. This solution is particularly good if an existing oil or gas heating system can be used.

- The wood boiler can provide the maximum capacity, while a buffer (a hot water tank) covers short-term load fluctuations and ensures that the boiler can be operated efficiently during off-peak periods. In summer the buffer can be used for storing solar energy. This solution has the advantage that only one fuel is required.

- Combination of two wood boilers. The second boiler increases the reliability of supply (for this reason it should have a separate fuel supply system) and ensures that the heating operates efficiently, even in off-peak periods.

The best of the three alternatives has to be worked out in each individual case. What is important is that the heat load calculations are correct.

Source Bioheat brochure

10.6 Heat accumulator

Changes in heat demand can be evened out by employing heat accumulators. The heat accumulator is best suitable for levelling daily peaks of heat demand. The heat accumulator is charged during low consumption and discharged during high consumption. The boiler plant can be smaller and savings in investments are obtained, or delays in power governing due to rapid load variations can be managed with the heat accumulator.

Heat accumulators are rarely used in heating plants due to their high investment. They are mostly used by greenhouse enterprises, often for purposes other than load balancing. The use of heat accumulators may offer greater advances in combined heat and power (CHP) production, if the consumption peaks of power and heat are not simultaneous.
10.7 District heating in rural areas

In many rural areas, it is not viable to build a district heat network. Still, it is profitable to have a centralised heating system or heating municipal buildings such as schools, residences for the elderly and health care centres. A centralised system may utilise a boiler plant that typically has a capacity of a few hundred kilowatts.

Heating entrepreneurship is an innovative way of doing small-scale energy business in rural areas. A single entrepreneur, a co-operative, a limited company or a consortium of entrepreneurs can act as a heating entrepreneur and sell heat instead of fuels. The business is usually local, the main fuel most often being wood chips. In most cases, the heating entrepreneur is responsible for the fuel supply, operation and management of the heating plant. A municipality, local energy utility or industrial company owns the plant. The fuel is supplied from the entrepreneurs’ own forest or other local forests, or by a local sawmill or other wood processing company. Income is based on heat delivered to the client, which is usually a municipality. The goal is to automate the entire plant operation and to apply remote control for plant operations.

10.8 Heat pricing

The aim of heat pricing is that the heat price is as favourable and fair as possible to the customers independent of the output ordered, while it covers the costs of heat generation. The district heat company is in a dominant position in its field in the region concerned, and hence the tariff applied should be public. The district heat tariff is very case-specific. Tariff prices are weighed case by case even within the same heat company depending on the age, size, and energy consumption of the house and on the age of the in-house heating system. The district heat fees include usually connection fee (€), basic fee (€/month) and energy fee (€/MWh). The tariffs are based either on the ordered water flow or output.

When defining the connection charge and basic fee, a cost level factor \( n \) is usually applied to allow price adjustments resulting from inflation. The energy fee is dependent on the energy prices of fuels. Usually, the energy fee is linked with the price of fuels, e.g., the proportion of oil (or other fuel source that is being used off-peak) being 20% and that of wood fuel 80%. The most profitable, suitable and available fuel is chosen. As the price of oil may fluctuate sharply a mechanism to dampen the impact on the energy fee may be applied.

There are many alternatives of constructing the tariff of district heat and connection fees, but in general the tariff should set in such a manner to comply with the following:

- The income should cover the costs due to heat generation activities, over a sufficiently long period
- The district heat fees should be competitive with house heating in such a way that the costs to the customer (investment in the in-house distribution system and the rate of connecting fee) can be amortised
- The energy fee should be linked with the price development of the fuel.
11 CO-GENERATION AND POWER PLANTS

11.1 Advantages of co-generation

In a traditional steam based power plant with condensing operation, only 40-45% of the energy input is converted into electrical power. The remaining part is lost with the cooling water and with the hot flue gas. In a co-generation plant (commonly referred to as Combined Heat and Power, or CHP plant) the electrical power is generated in the same way as in a power plant, but instead of disposing of the cooling water, the steam is cooled by the return water in a district heating system and thus used for generation of heat. As society needs both heat and power, combined heat and power generation is environmentally and energetically advantageous. The exploitation of the fuel input is much better, which is the main reason that the development within the CHP sector has a high priority in European energy policy (e.g. the co-generation directive 2004/8/EC of 11 February 2004).

Figure: Energy efficiencies of CHP and heat or power-only plants

Explanation: By separate electrical power generation and generation of heat at a power plant and at a district heating plant, total losses are much larger than by combined heat and power production at a CHP plant.

Another advantage of a CHP plant instead of a power plant is that there is no need for (sea or river) water for cooling. The plant can therefore be located near large towns with sufficient demand and a distribution system to cope with demands.

Box 1 provides more details on the benefits of co-generation.

Box 1: Benefits of Co-generation

- Increased efficiency of energy conversion and use: co-generation offers energy savings ranging between 15-40% when compared against the supply of electricity and heat from conventional power stations and boilers;
- Lower emissions to the environment, in particular of CO₂, the main greenhouse gas;
- In some cases, where there are biomass fuels and some waste materials such as refinery gases, process or agricultural waste (either anaerobically digested or gasified), these substances can be used as fuels for cogeneration schemes, thus increasing the cost-effectiveness and reducing the need for waste disposal;
- Large cost savings, providing additional competitiveness for industrial and commercial users, and offering affordable heat for domestic users;
- An opportunity to move towards more decentralised forms of electricity generation, where plant is designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier;
- Improved local and general security of supply - local generation, through co-generation, can reduce the risk that consumers are left without supplies of electricity and/or heating. In addition, the reduced fuel need which co-generation provides reduces the import dependency - a key challenge for Belarus’ energy future;
- An opportunity to increase the diversity of generation plant, and provide competition in generation. Co-generation provides one of the most important vehicles for promoting liberalisation in energy markets;
- Increased employment - a number of studies have now concluded that the development of co-generation systems is a generator of jobs.

Source: Biomass Co-generation Network, [www.cres.gr/network](http://www.cres.gr/network)

### 11.2 Applications of co-generation

Large and small co-generation applications provide heat (usually in the form of steam) and electricity for use in activities such as mineral processing or the manufacture of pulp and paper, petrochemicals, food and textiles, as well as in hospitals, hotels, office complexes, commercial buildings and swimming pools.

Typical co-generation is two or three times more efficient than the major conventional forms of power generation. Co-generation efficiency gains are achieved by harnessing the heat that would otherwise be wasted. When the thermal energy can also be recovered for cooling, this is termed tri-generation. As well as heating a commercial building in winter, tri-generation can also be applied in the summer for cooling.

**Industrial co-generation**

Schemes are typically located on sites that have a high demand for process heat and electricity all year. Suitable examples are found in the refining, paper, chemicals, oil, greenhouses and textile sectors. The bulk of cogeneration capacity on industrial sites come from schemes of over 1 MW, and these tend to be designed on an individual basis to meet the specific requirements of each application. A much larger number of industrial sites have smaller systems, using technologies similar to the cogeneration systems used in buildings and commerce. Although numerous, these account for lower levels of total capacity.

**District heating**

The heat provided by cogeneration is ideal for providing space heating and hot water for domestic, commercial or industrial use. The use of district heating networks is common in urban areas in northern, central and eastern Europe where the colder and longer winters require longer heating seasons, and hence entail longer running periods for the heating system. Engines, providing electricity and heat, in combination with boilers, can introduce more cogeneration into existing networks. A feature of cogeneration driven
district heat is the option of fuel diversity to suit environmental, economic or strategic priorities. For example, district heating systems are sometimes based on the incineration of municipal waste which, with adequate emission controls, is a better environmental solution than disposing waste to landfill. Other biomass fuels are also used, particularly wood and straw.

**Individual buildings - residential and commercial**

Cogeneration systems used tend to be smaller systems, often based on 'packaged' units. All equipment is housed in an acoustic container and the only connections to the unit are for fuel, normally natural gas, and the connections for the heat and electricity output of the unit. These systems are commonly used in hotels, leisure centres, offices, smaller hospitals, and multi-residential accommodation. Larger applications are based on technology that is similar to the cogeneration systems used in industry, gas turbines, or larger reciprocating engines. Such systems are used in larger hospitals, large office complexes, universities and colleges.

### 11.3 Biomass co-generation processes

Processes and engine types used for power generation from biomass include:

- **Steam turbines** used as expansion engines in the Rankin cycle with water as process medium; the water is evaporated under pressure and superheated;
- **Steam engines** used in the Rankine cycle with or without superheating;
- **Steam turbines** used in an *organic Rankine cycle (ORC)* with evaporation of an organic medium in a tertiary cycle separated from the heat production (the combustion heat is transferred to a thermal oil in the boiler which is fed to an external evaporator for the organic medium with a lower boiling temperature than water);
- **Stirling engines** (indirectly fired gas engines) which are driven by a periodic heat exchange from flue gas to a gaseous medium such as air, helium or hydrogen;
- **Closed gas turbines** using a hot gas cycle with a turbine as expansion engine

The various technologies cover a wide capacity range from a few kWe (Stirling engines) to several hundred MW$_e$ (steam turbines). The current state of the various processes varies from concept to proven technology.

**Table @@@:** Processes for power production by biomass combustion

<table>
<thead>
<tr>
<th>Working medium</th>
<th>Engine type</th>
<th>Typical size</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid and vapour (with phase change)</td>
<td>Steam turbine</td>
<td>0.5-500 MW$_e$</td>
<td>Proven technology</td>
</tr>
<tr>
<td>Gas (without phase change)</td>
<td>Steam piston engine</td>
<td>0.1-1 MW$_e$</td>
<td>Proven technology</td>
</tr>
<tr>
<td></td>
<td>Steam turbine with organic medium (ORC)</td>
<td>0.5-1 MW$_e$</td>
<td>Some commercial</td>
</tr>
<tr>
<td></td>
<td>Closed air turbine (hot air turbine)</td>
<td>Not established, similar size as steam turbine</td>
<td>Concept &amp; development</td>
</tr>
<tr>
<td></td>
<td>Stirling engine</td>
<td>20-100 kWe</td>
<td>Development &amp; pilot</td>
</tr>
</tbody>
</table>
11.4 Operation of biomass co-generation plants

Combined heat and power production can be accomplished in many different ways. The use of heat is usually dominant when planning the plant construction. Heat used as process steam has to be in higher pressure than the steam used in a district heating exchanger. Typical pressure of process steam for example in a paper mill are 3 and 10 bars. Steam pressure used in a district heating exchanger is closer to atmospheric pressure depending on the temperature of the district heating water. The basic back-pressure turbine supplying a district heating network works on back-pressure between 0.2 and 0.6 bar. The higher temperature of outgoing heating water requires also higher back-pressure at the expense of electricity production. The temperature of outgoing district heating temperature is normally dependent on outdoor temperature but also the quality of a district heating network and customer equipments. In Nordic countries the temperature of the outgoing district heating water is 75-120°C and returning water 35-55°C.

The use of heat is one important character when choosing a proper turbine type. The most common type is the back-pressure turbine, In this case steam expands to the desired pressure needed for the heating purpose. By an extraction back-pressure turbine it is possible to get steam for heating purposes on two or more pressure levels. This is a common construction in industrial plants. Extractions are also used for boiler feed water pre-heating to raise overall efficiency. The electricity to heat ratio of an industrial cogeneration plant is 0.2-0.3 and for district heating plants 0.45-0.55. These are typical values for steam processes based on solid fuels. The reason for the difference is the lower steam temperatures needed in district heating compared to industrial processes. The lower temperature enables longer expansion work in the turbine and thus greater amount of electricity.

11.5 Development of biomass co-generation

Most sold biomass co-generation plants are located in countries that have a considerable forest industry. Many successful examples of biomass cogeneration exist in e.g. Scandinavia, Germany, and Austria. Smaller capacities (<1 MW<sub>e</sub>) are found in Central Europe, whereas larger capacities (>20 MW<sub>e</sub>) are mainly found in Northern Europe. The largest plant, capable of producing 240 MW of electricity, 100 MW of process steam and 60 MW of district heating is based in Jakobstad (Finland). It uses biomass along with peat, plus coal as reserve fuel. In Germany, strong Government support in the form of guaranteed feed-back rates has led to a massive increase in the capacity and use of biomass based CHP and power plants in recent years (see Figure @@@). Fuels used in German plants include bark, sawdust, straw and methane from landfill sites and biogas plants. In Finland a similar development in the application of biomass cogeneration took place. In the next chapter more information is presented on the status and development of biomass district heating and cogeneration in selected countries.

Figure @@@: Capacity of solid biomass based CHP/power plants in Germany
11.6 Potential for biomass co-generation

A recent survey by the EC sponsored BioCogen project identified potential sectors where newly build or retrofit biomass cogeneration plants could be used. Potential customers are listed in Table @@@.

**Table @@@: Potential customers of biomass co-generation plants**

<table>
<thead>
<tr>
<th>Industry: mainly private sector companies and investors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Agro-industries (eg livestock and poultry farms, greenhouses, mills, canneries)</td>
</tr>
<tr>
<td>• Wood processing industries</td>
</tr>
<tr>
<td>• Other industries in rural or semi-rural locations</td>
</tr>
<tr>
<td>• Waste management industry</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commercial and residential buildings in rural locations: mainly private sector, some government sector and some community organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Centres for leisure (including museums) and sport activities</td>
</tr>
<tr>
<td>• Offices</td>
</tr>
<tr>
<td>• Multi-residential accommodation</td>
</tr>
<tr>
<td>• Hotels and resorts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Various public facilities: government sector, some private sector companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Authorities dealing with waste including sewage</td>
</tr>
<tr>
<td>• Combined power and district heating</td>
</tr>
<tr>
<td>• Schools and other education facilities</td>
</tr>
<tr>
<td>• Military establishments</td>
</tr>
</tbody>
</table>

Source: BioCogen
12 STATUS OF CHP/DH IN SELECTED EUROPEAN COUNTRIES

This section gives an impression on the development and current status of biomass district heating (DH) and combined heat and power (CHP) generation in half a dozen selected Nordic and Central European countries. More details can be found in individual country reports that were compiled in the frame of the recently completed OPET Combined Heat and Power / District Heating project (www.opet-chp.net).

12.1 Austria

Around 70% of the Austrian district heat supply derives from CHP plants. Typical biomass CHP applications are heating systems for the domestic sector with a capacity well below 100 kW\textsubscript{th} or heating systems with more than 100 kW\textsubscript{th} used mainly in public buildings as well as in industry.

Biomass-fired DH networks have been developed and built in rural areas since the mid-1980’s. Small stations with an output between a few 100 kW and 5 MW produce heat by burning woods chips from forestry or sawmill residues. Approx. 50 new installations were built per year around the turn of the century, and as many as 694 plants had become operational by the end of 2001. The plants had a total capacity of 822 MW\textsubscript{th} (capacity range: 0.1-20 MW\textsubscript{th}). Figure @@ illustrates existing biomass-fired DH plants in Austria.

Figure @@: Biomass-fired DH plants (boiler output) in Austria.

Up to now biomass CHP plants have been realised mainly in decentralised plants close to locations where high amounts of biomass accrue, e.g. plants of wood or paper industry. In the 1980’s the application of fluidised bed combustion boilers was enforced in the pulp and paper industry, mainly for the utilisation of bark, waste liquor and sewage sludge deriving from the production process. Furthermore, two co-combustion plants (i.e. plants that fire biomass in combination with other fuels) should be mentioned: St. Andrä and Zeltweg, both with an installed capacity of 10 MW\textsubscript{th}. Figure @@@ gives an overview on biomass-fired CHP plants in Austria.

Since several decades, the steam power process is the most common used procedure for electricity generation. In most cases the steam power process is applied with fossil fuels, but there are several commercial biomass fuelled steam power plants (above all in wood and paper industry).
Figure @@@: Biomass-fired CHP plants in Austria.

Explanation: Green = existing plant; Red = under planning.

12.2 Finland

Finland is the world leader in biomass CHP production. CHP is applied widely in Finland for the heating of communities and for the generation of heat and power in industry. In 2001, industrial CHP plants accounted for 45% and district heating CHP plants for 55% of the cogeneration. As much as 75% of district heat was produced by CHP in 2001.

In Finland there are a total of 130 CHP plants, from which 82 plants are DH CHP plants and 48 industrial CHP plants. Almost half of the CHP plants have electricity capacities over 50 MW, one-quarter has capacities from 10 MW to 50 MW and one quarter has capacities less than 10 MW. Finland also has a single micro-CHP plant fuelled by landfill gas.

In 2001, 189 030 TJ (52 508 GWh) fuels were used for the production of district heat and CHP in Finland. The dominant fuels of DH and CHP are natural gas, coal and peat (natural gas 35%, coal 28%, peat 18%, wood 8%, oil 7%, others 4%). Oil is only used for peak load production and in small DH systems.

The fuel mix is anticipated to change considerably in the future. The use of natural gas and wood is scheduled to increase. The Finnish District Heating Association estimates that about 300 MW of new electricity production capacity by biomass CHP will be built before 2020. This is about 30% of total CHP electricity capacity.

Use of forest chips is increasing in CHP sector. In 2002 about 400 plants used forest chips produced mainly from logging residues. Figure @@@ presents the potential of logging residues within 100 km driving distance, where the darker green area means the greater potential. Figure @@@ illustrates the use of forest chips.
Figure @@@: Potential of logging residues within 100 km driving distance

Figure @@@: Use of forest chips in Finland in 1999 and 2002

12.3 Lithuania

DH systems are widely developed in Lithuania. Currently DH covers about 75% of residential area in Lithuania’s towns and is produced mainly in heat plants. At present, there are around 25 CHP plants in Lithuania, and most of these are connected to DH networks. Total DH production was 13.7 TWh. Fuels used in DH production in 2002
include natural gas 67%, wood 12%, oil 12%, liquid gas 5%, sawdust 2%, and other fuels 2%. The latter category includes peat, coal, straw and other liquid fuels.

Installed biomass CHP capacity by the end of 2003 was a modest 2.3 MW\textsubscript{e} (one 1.5 MW\textsubscript{e} solid biomass plant plus one 0.79 MW\textsubscript{e} biogas plant). Installed capacity of DH plants utilising biomass was 301.4 MW\textsubscript{th}, (which includes 264 MW\textsubscript{th} based on woody biomass).

### 12.4 Poland

Hard coal is the main fuel for CHP and DH plants in Poland, but for small heat production more and more gas, oil and biomass is being used. The scope of DH systems is local, but they play an important role in the national economy.

Table @@ illustrates the application of bio-energy in Poland. The bulk of biomass consumption is to generate heat in small wood fired boilers (< 500 kW), which are mainly installed in individual dwellings, but the use of biomass in DH and CHP plants is envisaged to increase. The use of wood waste for energy is in the order of 20-25 PJ, equivalent to 3.3 Mm\textsuperscript{3}. The annual heat production based on biomass in district heating is estimated at 300 TJ in 2003. There were 3 large-scale wood-waste fired CHP plants in the pulp and paper industry, and 1 black liquor recovery boiler in 2002. One additional industrial CHP plant is planned.

The use of straw for energy was estimated at 40,000 tons in 2001 equalling to around 500 TJ. About 40 small and medium scale (0.5/7 MW\textsubscript{th}) straw-fired DH plants exist; the first of them implemented in the early nineties. In addition there are ca. 100 straw-fired boilers on agricultural farms.

**Table @@: Bio-energy production in Poland (2002)**

<table>
<thead>
<tr>
<th>Biomass Technologies / Specification</th>
<th>No. of units</th>
<th>Power installed (MW\textsubscript{th} / MW\textsubscript{el})</th>
<th>Electricity (GWh/a)</th>
<th>Thermal (TJ/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP in pulp, paper and furniture industry</td>
<td>3</td>
<td>330 MW\textsubscript{th} / 449.1</td>
<td>5298.5</td>
<td></td>
</tr>
<tr>
<td>Wood Industrial &amp; DHP (heat) (&gt;500 kW)</td>
<td>150</td>
<td>600 MW\textsubscript{th} / 9633.6</td>
<td>802.8</td>
<td></td>
</tr>
<tr>
<td>Straw fired DH plants (&gt;500 kW)</td>
<td>35</td>
<td>50,0 MW\textsubscript{th} / 802.8</td>
<td>802.8</td>
<td></td>
</tr>
<tr>
<td>Wood fired heating plants (&lt;500 kW)</td>
<td>110000</td>
<td>5500 MW\textsubscript{th} / 88308</td>
<td>88308</td>
<td></td>
</tr>
<tr>
<td>Straw fired heating plants (&lt;500 kW)</td>
<td>150</td>
<td>45,0 MW\textsubscript{th} / 722.5</td>
<td>722.5</td>
<td></td>
</tr>
<tr>
<td>Biogas CHP and DH systems</td>
<td>32</td>
<td>38.9 MW\textsubscript{el} / 72.5</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Landfill gas CHP and DH systems</td>
<td>17</td>
<td>15.9 MW\textsubscript{el} / 59.0</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>580.6</strong></td>
<td><strong>105117</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 12.5 Slovenia

In Slovenia, the total capacity of biomass CHP installations installed by the end of 2003 was 14.8 MW\textsubscript{e}. Industrial CHP plants covered around 62% of this capacity. None of these biomass CHP plants is a DH plant.
There are 3 wood fired DH plants: Predvor with capacity of 2.5 MW_{th}, Gornji Grad with capacity of 4 MW_{th} and Železniki with capacity of 10.4 MW_{th}. The total capacity of these DH plants is 16.9 MW_{th}.

### 12.6 Sweden

Sweden has well built DH networks. The DH corresponds to half of the total heating for houses and premises. DH exists at 570 locations and the total supply is about 50 TWh (180 PJ). Growth by 10 TWh to about 60 TWh in 2010 is envisaged. In a longer term the DH has the potential to reach a market share of 75% of the Swedish heating market, which would correspond to about 80 TWh. Figure @@ presents the consumption of different fuels for DH in 2001.

**Figure @@**: Fuels used for CHP/DH in Sweden in 2001

Due to unfavourable tax conditions and historically low electricity prices only a modest share of the DH net was used for electricity production in CHP plants. However, policy changes introduced in 2002 will support the growth of CHP production. Based on expected and planned future investments the electricity production from CHP plants is envisaged to increase from today’s 5 TWh to 11 TWh in 2010, equivalent to 5% of the Swedish electricity production.

Bio-energy covers 17% of the total energy supply in Sweden. Figure @@ shows the locations of the largest users of wood-based fuels.
Figure: DH, CHP and industrial plants in Sweden in 2000
13 ECONOMICS OF DISTRICT HEATING AND CO-GENERATION

13.1 Economic calculations according to VDI 2067

The guideline VDI 2067\(^3\) provides a basis for heat, electricity and energy production cost calculations. According to this guideline, the different types of costs are divided into 4 cost groups, which are

- capital costs;
- consumption costs;
- operating costs; and
- other costs.

The annual capital costs (annuity) can be calculated by multiplying the capital recovery factor (CRF, see Equation \(\text{Equation } \@\@\) with the investment costs. They are calculated for each unit of the process, taking the different utilisation periods into account.

\[
\text{Equation } \@\@: \quad CRF = \frac{(1 + i)^n - 1}{(1 + i)^n - 1}
\]

in which \(CRF = \) capital recovery factor; \(i = \) real interest rate [\% per year]; \(n = \) utilisation period [in years]

All costs in connection with the process, e.g. the fuel costs and the electricity costs, are included in the cost category “consumption costs”. The operating costs comprise costs originating from the operation of the plant, e.g. personnel costs and maintenance costs. The annual maintenance costs are calculated as a percentage of the investment costs on the basis of guiding values or of practical experiences and are spread evenly over the utilisation period. They are calculated for each unit of the process, taking the different wear and utilisation periods into account.

The other costs include costs such as insurance rates, overall dues, taxes and administration costs and are calculated as a percentage of the overall investment costs.

13.2 Methodology for the calculation of the electricity, heat and energy generation costs

For co-generation plants the heat and the power production should be considered separately. The capital costs for electricity production should therefore be based on additional investment costs, and consider only the surplus investment costs of a CHP plant in comparison to a conventional biomass combustion plant with a hot water boiler and the same thermal output. This approach seems to be meaningful because decentralised biomass CHP plants primarily produce process or district heat. Electricity production is an alternative and implementation depends mainly on the profitability of the

---

additional investment necessary. Moreover, it is possible by this approach to separate costs for electricity production from costs for heat production. This approach makes clear comparisons of costs for heat only and CHP applications possible and forms the basis for a correct calculation of the electricity generation costs.

When adopting this approach in cost calculations, the additional annual costs of the electricity production in comparison to a heat-only plant with the same thermal power output should be considered and heat generation costs and electricity generation costs should be calculated separately. When the aim is to determine costs that are purely associated with CHP production the costs of the heat distribution system may be excluded from the calculations.

The specific energy generation costs can be calculated by dividing the total annual costs (capital costs, consumption costs, operating costs and other costs) by the total annual energy produced (heat and electricity) according to Equation @@@

\[
C_{\text{spec}} = \frac{C_{\text{tot}}}{Q_{\text{el}} + Q_{\text{th}}}
\]

Explanations:
\(C_{\text{spec}}\) = specific energy generation costs [€/kWh];
\(C_{\text{tot}}\) = annual energy generation costs [€/year];
\(Q_{\text{el}}\) = annual electricity production [kWh/year];
\(Q_{\text{th}}\) = annual heat production [kWh_{th}/year]

(to be finalised)
REFERENCES


Growing Power. Renewable solutions by bioenergy technology from Finland. Tekes, Helsinki (Finland), Second Edition, 2004

Ingwald Obernberger and Gerold Thek, Basic information regarding decentralised CHP plants based on biomass combustion in selected IEA partner countries. Final report. BIOS, Graz (Austria), February 2004

Ingwald Obernberger and Gerold Thek, Techno-Economic evaluation of selected decentralised CHP plants based on biomass combustion in IEA partner countries. Final report., BIOS, Graz (Austria), March 2004)


Solid Biomass Plants. Prepared for the Interim Report for the Biomass Cogeneration Network (BioCogen), Joanneum Research, Graz, Austria, 2003 (?)

Design principles of biofuel-fired heating stations of <10 MW. OPET Finland Report 7. Material collected for the Internet pages of the OPET Network by Markku Lehtinen, Seija Perko and Asko Ojaniemi, Elomatic Oy, Jyväskylä (Finland), 2002

Terhi Lensu and Eija Alakangas, Biomass CHP/DH in selected EU countries. Cross national report. OPET Report 14. VTT Processes, Jyväskylä (Finland), May 2004

Impact of different national biomass policies on investment costs of biomass district heating plants. Final report of the Biocost project. EVA, Vienna (Austria), April 2000.
Heating large buildings with wood fuels. Basic information for project planners. Brochure produced in the frame of the Altener project Bioheat II by the SWS Group, Bandon (Ireland), and EVA, Vienna (Austria), 2003
ANNEX A: GLOSSARY

Definition of fuels

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuel</td>
<td>A fuel which is not in liquid form, for example wood fuels and other types of biomass</td>
</tr>
<tr>
<td>Fuel chips</td>
<td>General term used for chips or crush prepared for combustion by using different techniques.</td>
</tr>
<tr>
<td>Forest chips</td>
<td>General term for chips made from harvested wood raw material.</td>
</tr>
<tr>
<td>Log chips or long-wood chips</td>
<td>Chips made from delimbed stem wood.</td>
</tr>
<tr>
<td>Whole-tree chips</td>
<td>Chips made of the whole superterranean biomass of a tree (i.e. stem, branches, needles or leaves).</td>
</tr>
<tr>
<td>Logging residue chips</td>
<td>Chips made of branches and tops (crowns) after harvesting merchantable wood.</td>
</tr>
<tr>
<td>Stump chips</td>
<td>Chips made of stumps or snags.</td>
</tr>
<tr>
<td>Wood residue chips</td>
<td>Chips made of untreated industrial wood residues (ribs, ends etc.).</td>
</tr>
<tr>
<td>Sawing residue chips</td>
<td>Chips made as by-products of the saw industry, with or without bark residue.</td>
</tr>
<tr>
<td>Sawdust</td>
<td>Dust formed as a by-product in the sawing process.</td>
</tr>
<tr>
<td>Bark</td>
<td>Bark residue from merchantable (commercial) wood produced by using different debarking techniques.</td>
</tr>
<tr>
<td>Cutter chips</td>
<td>Wood residues formed in timber planing.</td>
</tr>
<tr>
<td>Grinding dust</td>
<td>Dust-like wood residue formed in grinding timber and wood boards; should not contain harmful amounts of adhesives.</td>
</tr>
<tr>
<td>Plywood residue</td>
<td>Ply or plywood residue formed in plywood industry; should not contain harmful amounts of adhesives.</td>
</tr>
<tr>
<td>Uncoated wood</td>
<td>Fuel chips made of chemically untreated wood residue from building sites and municipalities; should not contain chemically treated residue.</td>
</tr>
</tbody>
</table>

Volume and density of fuels

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic meter solid fuel</td>
<td>$m^3$: Cubic meter solid volume including bark.</td>
</tr>
<tr>
<td>Bulk cubic meter</td>
<td>$m^3$ of bulk volume: Cubic meter of chips</td>
</tr>
<tr>
<td>Bulk density</td>
<td>$kg/m^3$ bulk volume: Mass and volume measured as received</td>
</tr>
<tr>
<td>Density of chips</td>
<td>$m^3/m^3$ of bulk volume: Solid volume/bulk volume</td>
</tr>
</tbody>
</table>
### Vocabulary of timber harvesting functions and machinery

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bucking (slashing, crosscutting)</strong></td>
<td>Cutting felled trees or parts of trees into logs (timber assortments)</td>
</tr>
<tr>
<td><strong>Bunching</strong></td>
<td>Gathering and arranging trees or parts of trees in bunches or heaps.</td>
</tr>
<tr>
<td><strong>Chipper</strong></td>
<td>A (mobile) machine designed to chip whole trees or parts of trees.</td>
</tr>
<tr>
<td><strong>Chipping</strong></td>
<td>Slicing trees into small pieces of specified dimensions.</td>
</tr>
<tr>
<td><strong>Crusher</strong></td>
<td>A (mobile) machine designed to reduce trees or parts of trees by compression or impacting.</td>
</tr>
<tr>
<td><strong>Crushing</strong></td>
<td>Reduction of trees or parts of trees by compression or impacting.</td>
</tr>
<tr>
<td><strong>Cutting</strong></td>
<td>Felling combined with other processing functions, such as delimbing and bucking.</td>
</tr>
<tr>
<td><strong>Delimbing</strong></td>
<td>Removing branches from trees or parts of trees.</td>
</tr>
<tr>
<td><strong>Feller-buncher</strong></td>
<td>A self-propelled machine designed to fell standing trees and arrange them in bunches.</td>
</tr>
<tr>
<td><strong>Felling</strong></td>
<td>Cutting down or uprooting trees.</td>
</tr>
<tr>
<td><strong>Forest haulage</strong></td>
<td>Transportation of timber or logging residue with forwarders from the forest to a long-distance route.</td>
</tr>
<tr>
<td><strong>Forwarder</strong></td>
<td>A self-propelled machine designed to carry trees or parts of trees from a cutting area to a long-distance transportation route, usually to a forest route.</td>
</tr>
<tr>
<td><strong>Forwarding</strong></td>
<td>Off-the-ground transportation of trees or parts of trees.</td>
</tr>
<tr>
<td><strong>Harvester</strong></td>
<td>A self-propelled multi-function machine which combines felling with other processing functions. Harvesters are generally divided into two types depending on the basic concept used to perform the function of handling the tree for felling and bunching. These are: single-grip (or one-grip) harvester and two-grip harvester.</td>
</tr>
<tr>
<td><strong>Skidding</strong></td>
<td>Transportation of trees or parts of trees by trailing or dragging.</td>
</tr>
</tbody>
</table>
### ANNEX B: WOODFUEL CONVERSION FACTORS

*Units and energy values of forest chips*

<table>
<thead>
<tr>
<th>Unit</th>
<th>Wood type</th>
<th>Moisture content</th>
<th>m³ loose</th>
<th>tonne “atro”</th>
<th>MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>0.2</td>
<td>0.17</td>
<td>0.876</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>0.25</td>
<td>0.17</td>
<td>0.847</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>0.31</td>
<td>0.17</td>
<td>0.819</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>0.32</td>
<td>0.27</td>
<td>1.298</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>0.39</td>
<td>0.27</td>
<td>1.252</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>0.49</td>
<td>0.27</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>5</td>
<td>0.85</td>
<td>4.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>4</td>
<td>0.68</td>
<td>3.338</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>3.2</td>
<td>0.55</td>
<td>2.621</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>3.1</td>
<td>0.85</td>
<td>4.024</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>2.6</td>
<td>0.69</td>
<td>3.255</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>2.1</td>
<td>0.55</td>
<td>2.478</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>5.88</td>
<td>1.18</td>
<td>5.151</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>5.88</td>
<td>1.47</td>
<td>4.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>5.88</td>
<td>1.82</td>
<td>4.816</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>3.7</td>
<td>1.18</td>
<td>4.803</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>3.7</td>
<td>1.44</td>
<td>4.632</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>3.7</td>
<td>1.81</td>
<td>4.366</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>1.14</td>
<td>0.228</td>
<td>0.194</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>1.18</td>
<td>0.295</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>1.22</td>
<td>0.382</td>
<td>0.208</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>0.77</td>
<td>0.248</td>
<td>0.208</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 %</td>
<td>0.8</td>
<td>0.307</td>
<td>0.215</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 %</td>
<td>0.85</td>
<td>0.403</td>
<td>0.229</td>
<td></td>
</tr>
</tbody>
</table>
Densities of beech & spruce as a function of stacking method and moisture content

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Beech</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid</td>
<td>Stacked</td>
<td>Loose</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cubic</td>
<td>cubic</td>
<td>cubic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>meter</td>
<td>meter</td>
<td>meter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(kg/m³)</td>
<td>(kg/m³)</td>
<td>(kg/m³)</td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>558</td>
<td>391</td>
<td>229</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>656</td>
<td>460</td>
<td>269</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>797</td>
<td>559</td>
<td>327</td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>1,116</td>
<td>781</td>
<td>458</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Spruce</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid</td>
<td>Stacked</td>
<td>Loose</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cubic</td>
<td>cubic</td>
<td>cubic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>meter</td>
<td>meter</td>
<td>meter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(kg/m³)</td>
<td>(kg/m³)</td>
<td>(kg/m³)</td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>379</td>
<td>265</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>446</td>
<td>312</td>
<td>182</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>541</td>
<td>379</td>
<td>221</td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>758</td>
<td>531</td>
<td>311</td>
<td></td>
</tr>
</tbody>
</table>
Comparison of heating value with other fuels / energy carriers

Heating value comparison with other fuels on mass basis

<table>
<thead>
<tr>
<th>Fuel (Energy carrier)</th>
<th>Heating value (aver.)</th>
<th>KWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg furnace oil (extra light)</td>
<td>42 MJ/kg (36 JM/l)</td>
<td>11,67 kWh/kg (10kWh/l)</td>
</tr>
<tr>
<td>1 kg heating oil (light)</td>
<td>41 MJ/kg</td>
<td>11,40 kWh/kg</td>
</tr>
<tr>
<td>1 kg hard coal</td>
<td>29 MJ/kg</td>
<td>8,06 kWh/kg</td>
</tr>
<tr>
<td>1 kg coke</td>
<td>29 MJ/kg</td>
<td>8,06 kWh/kg</td>
</tr>
<tr>
<td>1 kg brown coal</td>
<td>15 MJ/kg</td>
<td>4,17 kWh/kg</td>
</tr>
<tr>
<td>1 m³ natural gas</td>
<td>37 MJ/m³</td>
<td>10,28 kWh/m³</td>
</tr>
<tr>
<td>1 kWh electricity</td>
<td>3,6 MJ</td>
<td>1,0 kWh</td>
</tr>
<tr>
<td>1 kg wood (m.c. 20 %), aver.</td>
<td>14,4 MJ/kg</td>
<td>4,0 kWh/kg</td>
</tr>
</tbody>
</table>

From the above it can be derived that the heating value of wood is comparable with that of good quality brown coal and that approx. 1 kg of oil can be replaced by 3 kg of wood.

1 kg oil = 3 kg wood

Spruce bark has a heating value which is similar to that of wood. A loose m³ of bark weighs on average 250 to 300 kg and when it becomes available in the common manner - in the winter with approx. 50 % moisture content - a heating value from 500 to 550 kW/h (about 2 kWh/kg).

Heating value equivalents oil ↔ wood

For rough calculations the following indicative reference values can be applied:

1000 litres of fuel oil can be replaced by:
- ca. 5 - 6 stacked m³ hardwood
- ca. 7 - 8 stacked m³ softwood

For chips the equivalent lays, due to the larger loosening and depending upon quality, between

- approx. 10 - 15 stacked m³

These values represent a pure quantity comparison on the basis of the energy content.
**Conversion figures of common firewood assortments**

The conversions stated in the table are approximate values. Actual values can vary depending on layering, grain size, compression due to transport etc. to vary can (as per ÖNORM M 7132).

<table>
<thead>
<tr>
<th>Conversion Type</th>
<th>Solid m³ Roundwood</th>
<th>Solid m³ Chopped firewood</th>
<th>Stere Wood pieces (stacked)</th>
<th>Loose m³ Wood pieces (loose)</th>
<th>Loose m³ Wood chips (fine)</th>
<th>Loose m³ Wood chips (coarse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 solid m³ roundwood</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 stacked m³ chopped firewood, 1m lengths, piled</td>
<td>0.7</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 stacked m³ chopped firewood, ready for furnace use, piled</td>
<td>0.85</td>
<td>1.2</td>
<td>1</td>
<td>1.67</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1 loose m³ chopped firewood, ready for furnace use</td>
<td>0.5</td>
<td>0.7</td>
<td>0.6</td>
<td>1</td>
<td>1.25</td>
<td>1.5</td>
</tr>
<tr>
<td>1 loose m³ forest chips (fine), up to 30 mm</td>
<td>0.4</td>
<td>0.55</td>
<td>0.5</td>
<td>0.8</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>1 loose m³ forest chips (coarse), 30-150 mm</td>
<td>0.33</td>
<td>0.47</td>
<td>0.4</td>
<td>0.67</td>
<td>0.85</td>
<td>1</td>
</tr>
</tbody>
</table>

1 tonne of fine forest chips with a moisture content of 25% equals:
- approx. 4 loose m³ fine forest chips (spruce)
- approx. 3 loose m³ fine forest chips (beech)
- **chopped wood - 25 cm lengths:** 1 loose m³ = 0.72 stacked m³ (Stere)
- **chopped wood - 33 cm lengths:** 1 loose m³ = 0.68 stacked m³ (Stere)

**Sawmill by-products**

<table>
<thead>
<tr>
<th>By-product Type</th>
<th>Tied</th>
<th>Stere</th>
<th>Solid m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slivers, outside planks</td>
<td>Tied</td>
<td>Stere</td>
<td>0.55-0.65 (0.60 on average)</td>
</tr>
<tr>
<td>Wood industry chips (up to 50 mm)</td>
<td>Loose</td>
<td>loose m³</td>
<td>0.35 solid m³</td>
</tr>
<tr>
<td>Shavings up to 5 mm</td>
<td>Loose</td>
<td>loose m³</td>
<td>0.33 solid m³</td>
</tr>
<tr>
<td>Planer shavings</td>
<td>Loose</td>
<td>loose m³</td>
<td>0.20 solid m³</td>
</tr>
<tr>
<td>Bark, not sized</td>
<td>Loose</td>
<td>loose m³</td>
<td>0.25-0.40 solid m³</td>
</tr>
</tbody>
</table>
## Fuel and energy content

### Forestry chips, spruce

<table>
<thead>
<tr>
<th>Water content</th>
<th>0%</th>
<th>10%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space increase</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Weight (loose)</td>
<td>180</td>
<td>191</td>
<td>239.14</td>
<td>273</td>
<td>333</td>
</tr>
<tr>
<td>€ / loose m³</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
<td>16.71</td>
</tr>
<tr>
<td>Lower heating value / kg</td>
<td>5.22</td>
<td>4.63</td>
<td>3.45</td>
<td>2.86</td>
<td>2.27</td>
</tr>
<tr>
<td>Energy / loose m³</td>
<td>939.6</td>
<td>884.35</td>
<td>825.11</td>
<td>780.89</td>
<td>756.08</td>
</tr>
<tr>
<td>Energy costs Cent/kWh</td>
<td>1.74</td>
<td>1.89</td>
<td>2.03</td>
<td>2.11</td>
<td>2.25</td>
</tr>
</tbody>
</table>

### Industrial chips (wood chips from complete tree use)

<table>
<thead>
<tr>
<th>Water content</th>
<th>0%</th>
<th>45%</th>
<th>50%</th>
<th>55%</th>
<th>60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space increase</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Weight (loose)</td>
<td>180</td>
<td>318.27</td>
<td>342</td>
<td>373</td>
<td>423</td>
</tr>
<tr>
<td>€ / loose m³</td>
<td>8.72</td>
<td>8.72</td>
<td>8.72</td>
<td>8.72</td>
<td></td>
</tr>
<tr>
<td>Lower heating value / kg</td>
<td>5.22</td>
<td>2.57</td>
<td>2.27</td>
<td>1.98</td>
<td>1.68</td>
</tr>
<tr>
<td>Energy / loose m³</td>
<td>939.6</td>
<td>816.51</td>
<td>776.51</td>
<td>736.88</td>
<td>710.89</td>
</tr>
<tr>
<td>Energy costs Cent/kWh</td>
<td>0.94</td>
<td>1.09</td>
<td>1.09</td>
<td>1.16</td>
<td>1.24</td>
</tr>
</tbody>
</table>

### Reduction material spruce

<table>
<thead>
<tr>
<th>Water content</th>
<th>0%</th>
<th>45%</th>
<th>50%</th>
<th>55%</th>
<th>60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space increase</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Weight (loose)</td>
<td>100</td>
<td>176.82</td>
<td>190</td>
<td>207.22</td>
<td>235</td>
</tr>
<tr>
<td>€ / loose m³</td>
<td>5.09</td>
<td>5.09</td>
<td>5.09</td>
<td>5.09</td>
<td></td>
</tr>
<tr>
<td>Lower heating value / kg</td>
<td>5.22</td>
<td>2.57</td>
<td>2.27</td>
<td>1.98</td>
<td>1.68</td>
</tr>
<tr>
<td>Energy / loose m³</td>
<td>522</td>
<td>453.62</td>
<td>431.4</td>
<td>409.38</td>
<td>394.94</td>
</tr>
<tr>
<td>Energy costs Cent/kWh</td>
<td>0.94</td>
<td>1.09</td>
<td>1.16</td>
<td>1.24</td>
<td>1.31</td>
</tr>
</tbody>
</table>

### Bark, spruce

<table>
<thead>
<tr>
<th>Water content</th>
<th>0%</th>
<th>50%</th>
<th>55%</th>
<th>60%</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space increase</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Weight (loose)</td>
<td>160</td>
<td>312</td>
<td>339.56</td>
<td>376</td>
<td>433.14</td>
</tr>
<tr>
<td>€ / loose m³</td>
<td>3.63</td>
<td>3.63</td>
<td>3.63</td>
<td>3.63</td>
<td></td>
</tr>
<tr>
<td>Lower heating value / kg</td>
<td>5.22</td>
<td>2.27</td>
<td>1.98</td>
<td>1.68</td>
<td>1.39</td>
</tr>
<tr>
<td>Energy / loose m³</td>
<td>835.2</td>
<td>708.4</td>
<td>670.81</td>
<td>631.91</td>
<td>600.18</td>
</tr>
<tr>
<td>Energy costs Cent/kWh</td>
<td>0.44</td>
<td>0.51</td>
<td>0.51</td>
<td>0.58</td>
<td>0.58</td>
</tr>
</tbody>
</table>

### Shavings, spruce

<table>
<thead>
<tr>
<th>Water content</th>
<th>0%</th>
<th>45%</th>
<th>50%</th>
<th>55%</th>
<th>60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space increase</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Weight (loose)</td>
<td>120</td>
<td>212.18</td>
<td>228</td>
<td>248.67</td>
<td>282</td>
</tr>
<tr>
<td>€ / loose m³</td>
<td>5.81</td>
<td>5.81</td>
<td>5.81</td>
<td>5.81</td>
<td></td>
</tr>
<tr>
<td>Lower heating value / kg</td>
<td>5.22</td>
<td>2.57</td>
<td>2.27</td>
<td>1.98</td>
<td>1.68</td>
</tr>
<tr>
<td>Energy / loose m³</td>
<td>626.4</td>
<td>544.34</td>
<td>517.67</td>
<td>491.25</td>
<td>473.93</td>
</tr>
<tr>
<td>Energy costs Cent/kWh</td>
<td>0.94</td>
<td>1.09</td>
<td>1.09</td>
<td>1.16</td>
<td>1.24</td>
</tr>
</tbody>
</table>