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Biofuel from Logging Residues

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ABSTRACT

Starting with defining logging residues and giving some principles, e.g. energy content and moisture content, continuing with logistics, terrain transport, bundling, storage of comminute material to measurements to fuel based on bioenergy.

Keywords: Biofuel, Logging residues, Energy content, Moisture content

INTRODUCTION

Biomass refers to the organic material that is used for production of energy.

Logging residues consist of the foliage of trees and tree tops (branches and crowns) unmarketable bolts and undergrowth trees. They form the most notable and also economically significant source of raw material in the production of wood fuels and constitutes roughly about 20% of the bioenergy supply to Swedish energy supply out of 40% of the total energy supply (in Sweden). There is, however, a great variation in the amount and composition of logging residues between different felling sites. Tree species, standing volume, size, the branches of trees and the extent of decay influence the quality of logging residues [1]. Roughly a Norway spruce tree (*Picea abies*) can have more than 50% foliage compared to trunk mass, whereas pine trees (*Pinus silvestris*) might have 20-25% foliage compared to trunk mass and deciduous trees may have 15-20% branches.

All trees have tree tops with a rather high bark proportion, often around 20-50 % according to Nurmi [2] roughly a tree contains 40 % cellulose, 30% hemi-cellulose and 20-30% lignin and about 40% of a tree is the stem.

Tree species

In the Nordic countries softwood are most common like spruce (*Picea abies*) and pine (*Pinus sylvestris*) but also hardwoods like aspen (*Populus tremula*) and birch (*Betula pubescens*) are very common.

The amounts of logging residues depends on the age of the stand and tree species. A cleaning stand (young trees - spacing) could have anything between 20 m^3 to 150 tonnes/ha according to the National Forest Surveys in Sweden and according to own analyses of data.

Incoming materials

In many countries the material is measured by volume and in others by weight (and control of MC (Moisture Content). The drawback is that the material is naturally quite wet and usually about 50% moisture content (MC dry) of the weight. On the other hand most of the material consists of branches. Branches are supported by compression wood (to hold up the needles and twigs on conifer trees **(Figure 1)**. Conifer tree branches are lifted up, and deciduous trees have the support on the upper side to hold up the branches up (tension wood) both the tension and compression wood contain high levels of lignin which both have high energy content (20-35 KJ/kg DM (Dry Matter) due to gluing with lignin of wood cells **(Figure 1)**.

According to Nurmi [2] both conifer and deciduous trees (except *Populus tremula* which has much lower content) the lignin content (22-30%) having an effective heating value of 19-20 KJ/Kg DM [2].

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Figure 1. Cross section of a thick spruce branch showing the heavy reinforcement on the underside to lift up the branch (own material).

Components in the material

The juvenile wood in tree tops contains mostly cellulose and hemi-cellulose (called holocellulose together). This is a young type of wood formation usually occurring in tree tops containing less of lignin but bark may be more occurring and may be more than 20% and bark has a rather high effective heating value (19-21 KJ/kgDM according to Nurmi [2]). Chipped together with the branch wood, the lignin rich branch wood will constitute the major part of the weight and thus give a rather high energy content (around 19-20 MJ/kg for conifers) giving a decent energy content for the crown. The major problem with logging residues is high amount of volatiles 0.5-2% and ash 0.5-4% depending on the amount of bark.

Branch-wood has a higher calorific heat value compared to stem-wood and it increases with decreasing branch diameter [2].

The calorific value is the inherent energy in the material usually determined on laboratories (usually with a bomb calorimeter). After that determination adjustments are made are made for hydrogen (H) in the water produced during combustion, roughly 6% according to Nurmi [3]. This figure is called effective heat value (W_{eff}). The resulting figure is denoted as at delivery and this figure is then adjusted for actual moisture content in the fuel. Energy is measured either in KJ/kg or as KWh/kg, the latter being a common measure for district heating centrals. Water in the material could be either given as moisture content (MC_{wet}) or moisture content (MC_{dry}) the difference being drastic at wet levels **(Figure 2)**.

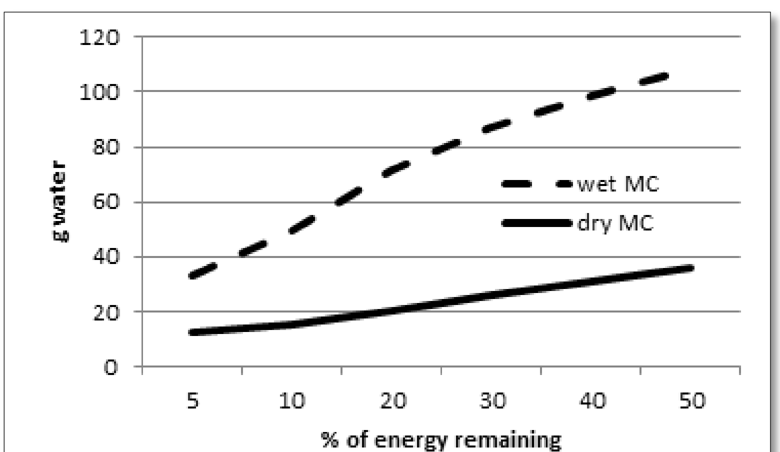

Figure 2. Energy content versus moisture content with comparison between wet weight as a base and dry weight as a base (vs. MC wet vs. MC dry).

Moisture can be determined in different ways, **dry MC**=H_2O / (H_2O – DM), where, DM is the Dry Matter (determined at 105°C during 20-25 h) or, **wet MC**=H_2O / H_20 + DM, when the water is determined the same way as described above but added in the nominator.

Facts

The energy content (calorific heat value, W_{eff}) is determined in the laboratory and given after adjustment of water vaporisation in the bomb calorimeter (2.45) and the MC at delivery. In the example below there is also a conversion between KJ and KWh and adjustment for ash (2% is a common value for ash content in branches).

For the sale of bio fuels a final adjustment is done for the ash content: W_{eff} (1 - ash), thus 19 × (1 - 0.02) = 19 × 0.98=18.2. Ash is given in percentage on DM, % (e.g. 0.02).

W_{eff} *deliv* = W_{eff} - 2.45 (100 – DM / DM) / 3.6 × tonnes dry material MWh - (1 - ash)

Where,

DM: Dry Matter Content %

2.45=Water Vaporization MJ/kg

3.6=Conversion Factor from MJ to Wh

Example: An incoming lorry load of 20 tonnes chipped logging residues having 19 KJ/kg (pine branches), with a moisture content of 40%, we get 20 - 2.45 (0.4) / 3.6 × 20 × 0.02 = 780 KWh will be delivered.

This will pass a vehicle scale and at the same time sample will be taken for determination of moisture content. The problem is that most often sample will be taken on the top of the lorry, because that is the only place where the personal can reach in an easy way (this will be more discussed later in chapter 7).

Most commercially important woody plants are classified into two groups (a) conifers, also called softwoods and (b) deciduous, also called hardwoods. It is most commonly used terminology that is, however, misleading because several of the softwood species are somewhat harder than many of the so-called hardwoods.

Wood is composed of organic chemical substances produced in living cells of a tree near its cambium (growth cells near the inner bark). At the time of cutting, the major portion of a tree contains no living cells wood is composed of organic chemical substances originally produced, in living cells of a tree near its cambium. Major portion of a tree contains no living cells, such as proteins and other nitrogenous materials associated with living cells. The composition of woody substance is approximately 50% carbon, 6% hydrogen and 44% oxygen, with an average ash content of about 0.2-0.3% and nitrogen value of 0.1% or less. The ash content is an indicator of the mineral constituents, which are primarily calcium and magnesium carbonates, oxalates and occasionally silica crystals (after [4]).

Cellulose is the primary component of the cell wall. Furthermore, it is the single most abundant organic chemical in the nature. It is one of the few natural compounds that retain the same structure regardless whether its source is wood, cotton grass or a host of other plants. Structurally cellulose is the simplest of the wall components – a linear polymer of glucose units [4].

Hemi-cellulosic fraction of wood accounts for approximately 30% of the total mass of the cell wall. Hardwoods contain more cellulose than do softwoods (45% vs. 41%) and less lignin (22% vs. 28%) Hardwoods are relatively rich in xylose, whereas softwoods contain more mannose. The hemicellulose fraction is composed of at least two types of compounds (xylose and mannose), which differ depending on whether the source is a softwood or a hardwood. Pectin substances form a minor group of carbohydrate cell wall constituents. Because pectins are present in small amounts are rare readily removed by mild chemicals, they are often included with extractives (after [4]).

Lignin is a phenolic polymer forms a third important component of the cell wall differing from the carbohydrates in its water repellency. It is a phenolic polymer and results from the random free-radical polymerization of three closely between softwood and hardwoods related phenolic substances. Through various side linkages these building block form large macromolecules. The proportions of the three phenolic differ between softwoods and hardwoods. Lignin is completely amorphous and under normal conditions begins to soften at temperatures of 165-175°C.

Water depresses and broadens the range of softening temperatures of lignin. Consequently, molecular displacement by viscous flow under pressure becomes more prevalent under conditions of elevated temperatures and moisture content (after [4]).

Extractives have little or no effect of the mechanical properties of wood but can modify many mechanical properties indirectly. Extractives can control durability, color, odor and taste. In some species phenolic extractives can modify the mechanical properties of wood. Some wood extractives were food reserves for the living tree. The types and amounts of extractives are extremely variable within species and even within a single tree. The heartwood of so-called extractive free species such as spruce normally has extractives of only 2-5%. By the way of contrast, extractive-rich woods may have as much as 25% of extractable material, most of it in the form of tannins ([4]).

TECHNICAL ASPECTS

Present techniques for biofuel from the forest are mainly based on gathering of tree tops and branches at clear-cuttings or thinning operation. In the Nordic countries the Cut-to-Length-system (CTL) is prevailing with trees cut with a harvester which cut the tree on the growing spot and delimbs the tree on the growing spot and then the logs are transported carried on a forwarder, thus two machines makes the whole operation and these machines are also the basis for both cutting and transport of logs but also for bio energy harvest. In North America a feller buncher is common and delimbing can be done at landing with pushing the tree through a gate limber and then the branches are simply found near the gate. For bio energy material the logging residues are collected with a forwarder with a loading crane and then often brought to the chipping at road side as the most common technique in the southern Sweden and, whereas transport to a big terminal is used in northern Sweden. In the south almost all acceptable amounts of slash is utilised whereas there are still some potential in the Northern Sweden. Technique for gathering slash on the clear-cut area and chipping at road side is known since mid-70s and the economy in the handling is not good.

For thinning operations a more varied size of minimum cutting diameter for pulpwood (6-12 cm top) can be used. Depending on market prize a smaller or a bigger part of the top can be used as biofuel. At present prices the separation in top cutting diameter between pulpwood and biofuel may be between 9 to 11 cm. With larger tops the amount of biofuel may increase to such extent that it is feasible to collect biofuel at thinning operations. However, the amount of soil damage at thinning operation when the protecting slash on the ground is removed may be discouraging. Usually logging residues are used as reinforcement for ground to decrease damage on the ground due to heavy forestry machines [5].

The interesting thing is that this type of logging residues is not really any obstacles or causes any major negative economic effects for the CTL cutting operation. On the other hand all spacing and cleaning of young trees is always a costly operation.

Power-lines must be kept clean from trees growing too high. Present technique is to just cut the trees down when the tree height reaches the lowest safety height for the power line. Larsson [6] investigated three different cutting modes and found the best economic alternative to be two successive cuttings with collection of biofuel material. Although with adjustment of areas with too long transport distances and too low productive soil, the amount of biofuel could amount to 0.5-2.5 TWh (8-30% of present use of primary forest fuel.

Spacing and cleaning of young stands is a costly operation (2000-3000 SEK/ha) (10 SEK~1 €) which has to be done for the development of valuable trees. In the mid-80s, experiments with mechanised cleaning started [7]. With development of small machines the damage level was acceptable and the operation economic as long as the young trees were not too high. However, in the 90s it became clear that if the cleaning was delayed to a later stage the number of cleanings could be kept to only one but at that stage no machine could enter the stand successfully and the forestry went back to brush saws. Today these areas (150 000 to 200 000 ha/year) could have a high potential for delivery of biofuel if collection of material could be done in a proper way.

The handling costs (collection, forwarding, storage and lorry transport) for biofuel as slash and small trees are very high (>75% of the final value) although the stumpage price is very small or Nile. Thus, the whole process must be scrutinised.

Storage of stem bunches

Studies of the drying pattern for bundles patterns and the drying process will be followed by weighing the bundles.

Wood pellets

Wood pellets may give a clean combustion if they are produced in a good way. Badly produced wood pellets may have both high ash content and added stuff that are less good at combustion such as high bark content, diesel or glue, that both give dirty smoke, high ash content and bad combustion.

Collection

To pick up logging residues the operator must be very careful not to pick up stones or other material from the ground. These things might damage the chipper. I have seen big stones, loading stakes and undercover shields sorted out from logging residue piles before comminution at district heating wood yards (gives more weight for the seller at delivery. I have heard about district heating central that even had to pick out a V8 engine from the ash container! **(Table 1)**.

Table 1. Conversion factors between units.

	GJ	MWh	toe	Mcal	MBTU
GJ	1	0.28	0.02	239	0.95
MWh	3.6	1	0.086	860	3.412
toe	41.9	11.63	1	10 000	39.72
Mcal	0.0419	0.00116	0.0001	1	0.0398
MBTU	1.055	0.2954	0.0211	252.145	1

BTU: Brittish Thermal Unit

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