5. Environmental Issues During the Production and Handling of Wood Fuels

5.1 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.

Plant Nutrients

Historicaly, 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 past 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. Figure 12 illustrates an example of the distribution of biomass and of the most important nutrients. Thus the removal of nutrients by chipping depends to a high extent on the parts of biomass that are removed. The max. removal occurs by whole-tree harvesting of green chips (chips with needles and branches). This increases (for the example illustrated in Figure 12) the yield - 8% needles and 13% branches (including a great proportion of bark) - but by this increase in yield, 68% of the nitrogen amount of the trees, 72% of the phosphorus amount, 58% of the potassium amount, and 50% of the calcium amount are removed.

The absolutely predominant part of the Danish harvesting of wood chips is obtained by thinnings in immature stands. In practice, the thinning trees are felled during the winter (in order to reduce the danger of stump infection by fungus *H. annosum*) 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.

Danish practice therefore reduces the amount of plant nutrients removed compared to the chipping of green trees. This has been calculated in the example illustrated by Table 8 in relation to the most commonly used practice of chipping of the first two thinnings. The removal of the largest amount of nutrients occurs in connection with stems and bark by conventional thinning and particularly by clear-cutting. Whole-tree chipping following predrying of the two thinnings increases the removal by approx. 4% and 26% respectively depending on nutrient, while whole-tree chipping of green wood will increase it 2-3 times from 12% to 48% (Table 8).

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. 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.

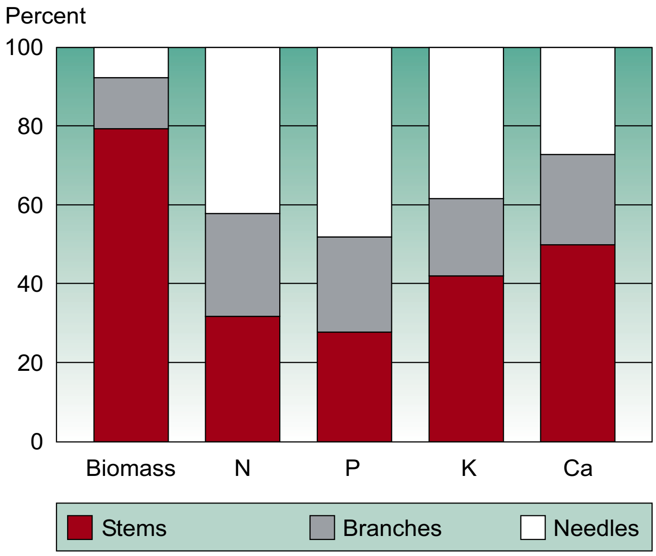

Figure 12: The distribution of biomass on needles, branches, and stems, and the relative content of plant nutrients of the same parts of wood for spruce /ref. 41/.

A range of experiments has been undertaken in Sweden, Finland and Norway with the purpose of clarifying the consequences of increased removal of biofuels from the forest.

A test-series include 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 /ref.81/.

Drilling tests show hat 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 Denmark, 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 in Denmark. For instance the soils of the Western Part of Denmark are poorer in phosphor than the other Nordic countries.

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.

photo: thy statsskovdistrikt/per kynde.

An amount of approx. 2 tonnes of dry ash is spread per ha (which equals approx. 3 tonnes of wet ash) after second or third thinning when the trees are 30-40 years old. The nutrients that have been removed from the stand with the chips are returned by the ash.

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 /ref. 27/. Table 9 illustrates the estimated average amounts of plant nutrients in kg per tonne of dry crude ash.

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. Until recently the application of wood chip ash in forests has been controlled by the Executive Order on Waste Products for Soil Application /ref. 31/, but in 2000 the “Executive Order on Ash from Gasification and the Combustion of Biomass and Biowaste for Soil Applications” was passed /ref.82/.

Humus Content

By whole-tree chips produced from whole, predried 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

Removal of nutrients (kg/ha)	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)
1. Stems	170	54	205	23	234
2. Chipping with predrying	214	58	213	26	259
3. Chipping of green trees	252	61	230	30	294
Increased removal of nut. (% of 1) by					
2. Chipping with predrying	26	7	4	13	11
3. Green trees	48	13	12	30	26

Table 8: Total removal of nutrients (kg/ha) over a rotation of 70 years by different chipping strategies for the two first thinnings in spruce stands at Gludsted Plantage /ref. 42/.

(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 Danish 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.

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

photo: biopress/torben skøtt

Wood chip storage with crane for the feeding of the wood chip boiler furnace at Harboøre. The crane can be automatically controlled and monitored from a screened control room.

5.2 Working Environment During the Handling of Chips and Pellets

The handling of biofuels, as e.g. wood chips, may cause working environment problems especially in relation to dust and micro organisms, such as fungi and bacteria. With regard to wood chips, especially the propagation of fungi and bacteria in stored wood chips may be problematic, while dust is considered the greatest risk factor involved in the handling of wood pellets.

Health Problems

Health problems in connection with the handling of biofuels typically occur when small particles are breathed in with the air passing through the throat to the lungs. Dust, fungal spores, and bacteria, are generally the size of 1-5 µm i.e. 1-5 thousandth mm. They are easily whirled up and may be suspended in the air for a long time. Besides the direct irritation of the mucous membranes and lung tissue, many fungal spores and bacteria cause allergy.

Phosphorus (P)	13 kg
Potassium (K)	48 kg
Calcium (Ca)	137 kg
Magnesium (Mg)	17 kg
Iron (Fe)	12 kg
Sodium (Na)	20 kg
Manganese (Mn)	13 kg

Table 9: The content of plant nutrients in kg per tonne of dry crude ash /ref. 27/.

The typical symptoms are respiratory trouble, colds, fever, shivers, cough, headache, muscle pain, pain in the joints, stomach trouble, loss of weight, and general malaise and tiredness. Disease caused by breathing in bacteria and fungal spores may be either acute or chronic.

Acute Disease

The acute disease is often termed ODTS or "organic dust toxic syndrome". This disease typically occurs when exposed to a high concentration of spores and/or dust in the air, often amounting to 9-10 million particles per litre of air or more. By way of comparison, it may be mentioned that air normally contains 10-30,000 spores per litre /ref. 43/. The ODTS is characterised by symptoms like those of influenza, such as fever, shivers, muscle pain, pain in the joints, perhaps accompanied by cough and slight difficulty in breathing. The symptoms often occur 4-8 hours after exposure and they seldom last longer than 1-3 days. The disease does not require treatment and does not cause permanent injury, but repeated exposures should be avoided. The reasons are both the unpleasant symptoms and sickness absence suffered by the victim, and also the risk of developing a chronic disease /ref. 44, 45/.

Chronic Disease

The chronic bronchial problems are normally named after the connection in which they originally occurred, i.e. thresher lung. The international name of the chronic disease is "allergic alveolitis" (AA), i.e. an allergic reaction in the lung tissue. This does normally not occur before having been exposed to air with an average content of fungal spores or bacteria, generally at least 2-3 million micro-organisms per litre of air for a prolonged period of time. Among the most important symptoms of AA are respiratory trouble, cough, fever, and loss of weight, perhaps accompanied by a combination of the other symptoms. As with ODTS, the symptoms do not occur until 6-8 hours after exposure. The disease often develops insidiously, and it gradually becomes a chronic disease that is aggravated if the person is again exposed to fungal spores and bacteria /ref. 46, 44/.

The chronic disease is very rare and probably requires a predisposition in the victim. When occurring, however, the consequences are rather serious. This is due to both the permanent injuries of the lungs and that AA often causes a higher sensitivity to micro-organisms in the air /ref. 46/. The symptoms and illness may then occur at lower spore concentrations than those originally causing the disease. Persons with allergic alveolitis may thus be forced to find a new job that does not involve the risk of being exposed to spores. Allergic alveolitis must be reported to The National Board of Industrial Injuries.

Hazardous Working Processes

If wood chips are used shortly after chipping, problems with micro-organisms will seldom occur. The storage of wood chips in the forest or at heating plants will normally be in the form of uncovered chip piles, in the forest also covered with tarpaulins or plastic. It is wood chips from such storages that may cause working environment problems due to bacteria and fungal spores.

Wood pellets consist of shavings and sawdust in compressed form. Dust problems are assumed to be associated with the handling of wood pellets, but the issue has not been further investigated. Anyhow, a range of working situations involving the risk of problems in connection with dust and micro-organisms can be pointed out in relation to both wood chips and wood pellets.

- During the moving of chip storages in forests and at heating plants, a tractor or tractor loader may often be used. As the wood chips are lifted, spores and bacteria are whirled up in the air. Without an enclosed cabin, the driver will be exposed to micro-organisms in the air. The same applies to the unloading of wood chips.
- When wood chips arrive at the heating plant, samples are taken for the determination of the moisture content. Sampling is done by a shovel by which the chips are taken out from the loaded or unloaded pile. The person taking out the samples is exposed to micro-organisms in the air.
- The indoor wood chip storage is no doubt the place with most dust and most micro-organisms in the air. The feeding of wood chips into the heating system is normally performed by means of an automatic crane, and the process can be monitored from outside. Staying in the wood chip storage takes place only in connection with repair work or the solution of other problems. Persons who are staying in the wood chip storage are therefore highly exposed to the risk of breathing in large amounts of particles if not protected.
- In small wood chip heating systems, the feeding system of the furnace is often manual, and wood chips are moved from the intermediate storage by tractor or manually. Persons who perform this work frequently run a certain risk of being exposed to pathogenic amounts of dust and micro-organisms. Locating wood chip storages in connection with dwellings should definitely be avoided.
- If wood chips are stored in silos, ensilage processes may occur, thereby using up the oxygen of the air so that nitrous gases are formed.
- For wood pellets, dust problems may be expected during unloading, moving, and during the loading of the wood pellets into the heating system.

Countermeasures

If wood chips have been stored (for a long time) under conditions encouraging the growth of fungi and bacteria, the persons handling the chips should be protected. This applies to both storage in the forest and at the consumer's place. The

photo: nils rosenvold

Worker at Måbjergværket wearing P3 filter respirator for toxic particles during the purifying of machinery.

same applies if wood pellets cause dust problems.

The first step is to find the places and work situations involving elements of risk. The scope of the problem may perhaps be assessed by means of a spore trapping test. Wood chips undergoing a heavy attack by mould fungi often discharge a “mouldy” odour. The next step is to distinguish between the long-time effect of moderate to high spore levels and the effect of a large amount of spores for a short period of time.

Where the constant presence of suspended dust and harmful micro-organisms in the air may be expected, working processes should be automated so as to be performed or controlled from screened areas. The indoor storage with a crane feeding the heating system is probably the most important place to isolate from employees at the heating plant. To accomplish this task, monitoring takes place from enclosed areas in which the air pressure is kept slightly above the atmospheric standard. Alternatively, the air from the wood chip storage may bee drawn into the boiler furnace, thereby creating a slight negative pressure.

Shielding is not possible in practice during sampling for the determination of moisture content or during unloading. In these instances, the persons involved should be equipped with a personal respiratory protection equipment. Truck drivers who frequently transport wood chips should be informed about the problem.

In relation to chip-fired plants, it is of great importance to inform about the problem of dust and micro-organisms. Already during installation, the subject should be in focus in order for the boiler and the storage to be located appropriately in an extension, and so that the manual handling will be reduced. The ventilation system should be designed so as to drive spores out of areas, frequented by the operators during day-to-day work. A course instructing in how to use individual protection equipment would be useful.

Crane repair work in indoor storage is an example of a task during the performance of which the person is staying for a short period of time in an area with high dust and spore concentrations. Persons involved should be equipped with a P3 filter respirator for toxic particles. This equipment is typically portable, i.e. with filter and fan attached to a belt. Persons who often work in polluted environments, or who are hypersensitive, should be equipped with a breathing apparatus with fresh air supply. These consist of a unit with a compressor at a fixed place in the building and an air supply hose that can be connected at different places. During working in silos with wood chips, a breathing apparatus and a life line should be used /ref. 47/.

As individual protection equipment typically is unpleasant to wear, it should only be used during short-time exposures. Protection equipment is no solution to a constant level of pollutants, such as dust and spores. In that respect, measures should be taken in the form of changes in working conditions and ventilation.