PRODUCTION TECHNOLOGY OF FOREST CHIPS IN FINLAND

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PREFACE

This report is made in the project called “Techno-economical assessment of the production and use of biofuels for heating and cooling applications during in South Europe” (BIO-SOUTH EIE/255/S07.38609) 1.5. – 31.5.2005. The project is part of the Intelligent Energy – Europe –programme funded by EU. The project is coordinated by the Renewable Energy National Centre (CENER) from Navarra in Spain. The main project partners in the project are VTT from Finland, ETA Florence from Italy, Energidalen from Sweden, ApE from Sloevenia and EUBIA from Belgium. The target in the project is to increase the use of forest chips for fuel in Spain and Italy. The role of VTT is to submit knowledge from the Finnish wood harvesting and combustion technology for the project. This report is a part of this target. In the report it is presented the current technology of harvesting of forest chips for fuel in Finland. Also there is information of forest chip quality, environmental effects of forest chip harvesting and use of forest chips for fuel. The report is a literature review and based on the reports and articles published in Finland.

30.5.2005 Jyväskylä

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1 INTRODUCTION

In Finland the proportion of wood in overall energy usage is currently the highest among all industrialised countries. The energy content of wood-derived fuels was 84 million MWh in 2004. It is 20% of the total energy consumption in Finland which was 411 million MWh in 2004.

The main potential to increase the use of wood fuel in Finland is related to the forest residues. The target is to increase the use of forest residues up to 10 million MWh (5 million m$^3$ solid) by the year 2010. The use of forest residues for fuel is increased quite rapidly during the last years. In 1995 the utilisation of forest chips for fuel in Finland was only 250 000 m$^3$ solid, since then it has increased being in 2004 2.7 million m$^3$ solid (includes use of heat plants and small-scale).

The harvesting technology of forest residue chips is very well developed in Finland. One reason for this has been the systematic R&D work that has been done related to the harvesting of forest residues for fuel. In Finland there have been two national research programs during 1993 – 2003. In these programmes it has been systematically developed the harvesting technology of forest residues for fuel.

In the report it has been introduced the harvesting technology of forest residues for fuel in Finland. The work is based on the Finnish literature. Logging residues and stumps from final fellings and small-wood from thinnings are the main raw-materials for logging residue fuel in Finland. There are several methods to harvest forest residue fuel. Information on following subjects has been presented in this report for the raw-materials described above:
- selection of production sites for harvesting of logging residues for fuel,
- yield of harvesting logging residues for fuel,
- harvesting technology of forest residues for fuel,
- organisations that harvest logging residues for fuel,
- harvesting costs of forest residue chip for fuel,
- logging residue chips’ quality,
- environmental impacts of harvesting logging residues for fuel and
- examples of plants that using logging residues for fuels.

2 FOREST RESIDUES FOR FUEL IN FINLAND

About 72% of Finland’s land area, or 21.9 million hectares, is forest land. Forest area suitable for wood supply is 20.7 million hectares. On that area is about 1870 million m$^3$ growing wood. Of this, the share of coniferous forest is about 82%. The total harvested area in Finland in 1999 was 525 000 ha and the share of clearcutting was 25% of the total harvesting. From the harvested area 61.0 million m$^3$ solid of wood was produced in 1999. The timber yield was 116.2 m$^3$ solid/ha (Finnish Forest Research Institute 2001).
Finland has a significant wood fuel potential. It is possible to produce forest residues in the form of logging residue chips, stumps or hog fuel from final felling and in the form of chipped small-sized wood from young stand management and thinning areas.

The amount of logging residues generated at the felling stands varies greatly site by site. Logging residue chips generated at final felling of spruce stands have the best potential among forest biomass for producing energy at the competitive price in Finland. For spruce stands, the yield of logging residues is more than twice much as for pine and birch stands (Alakangas et al. 1999). Nowadays also stumps of the spruce stands are exploited at final felling.

Logging residues can be harvested either immediately after felling as fresh with needles, or as seasoned over the summer season. In seasoned case a significant portion of the needles and a small amount of bark and thin branches are left in the felling area.

Net annual increment (NAI) in Finnish forests is calculated to be 72.5 million m³ solid/a (Karjalainen et al 2004). During last years the round wood production has been about 60 million m³ solid/a, for ex. 61.3 million m³ solid/a in 2002. From different sources it is total available to get about 30 million m³/a wood fuel, figure 1.

![Figure 1. Technically harvestable biomass potential of the Finnish forests (Hakkila 2003).](image)

The energy content of wood-derived fuels in Finland was 80 million MWh in 2003. More than a half of the wood-derived fuels was black liquors from pulp- and paper industry, 40.8 million MWh, and the rest was other industrial wood residues and by-products of industry, 25.9 million MWh. Use of firewood was 13.5 million MWh. The black liquors and other wood residues from forest industry are at the moment totally utilized, mainly for fuel (Energy Review 2005).
3 LOGGING RESIDUE PRODUCTION SITES

3.1 PROPORTION OF TREE PARTS

The amount of logging residue left on the site after felling merchantable wood is influenced by the tree species, the amount of timber, the size and branchiness of the trees and the extent of decay. For spruce stands, the amount of logging residue is much bigger than that for pine and birch stands (Table 1). Relatively, the logging residue left from large-sized trees contains more branches than that from smaller trees. If the tree stand suffers from decay, stem wood waste among the logging residue becomes significant (Alakangas et al. 1999).

Table 1. Proportions of biomass components used in the volume estimation. (Aboveground biomasses are based on equations presented by Marklund (1988) and volumes of root estimates on Eggers (2001) study. Stem wood loss corresponds to the share of the stem wood that does not meet the quality requirements of industrial roundwood and is thus not recovered for industrial purposes (Karjalainen et al. 2004).

<table>
<thead>
<tr>
<th>Group</th>
<th>Stem + stem bark</th>
<th>Stem wood loss</th>
<th>Branches</th>
<th>Needles</th>
<th>Tops</th>
<th>TOTAL</th>
<th>Roots estimation (Nordic and Baltic countries)</th>
<th>Roots estimation (rest of Europe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPRUCE Group</td>
<td>55%</td>
<td>8%</td>
<td>24%</td>
<td>11%</td>
<td>2%</td>
<td>100%</td>
<td>21.9%</td>
<td>19.1%</td>
</tr>
<tr>
<td>PINE Group</td>
<td>67.7%</td>
<td>8%</td>
<td>17.7%</td>
<td>4.4%</td>
<td>2%</td>
<td>100%</td>
<td>19.8%</td>
<td>19.3%</td>
</tr>
<tr>
<td>BROADLEAVED Group</td>
<td>78.2%</td>
<td>8%</td>
<td>12.1%</td>
<td>/</td>
<td>1.7%</td>
<td>100%</td>
<td>22.4%</td>
<td>14.7%</td>
</tr>
</tbody>
</table>

In conjunction with timber harvesting, the amount of crown mass residues is estimated using empirical crown mass/stemwood ratios. Crown mass refers to branches with leaves, live and dead. When crown mass is used for energy, it is feasible to compare dry mass rather than volume (Table 1). Since the basic density of branchwood is higher than that of stemwood, the ratio is higher on the mass basis. The crown mass/stemwood ratio (dry mass basis) is typically 40 - 60% for spruce and 20 - 30% for pine (Figure 2).

The availability of logging residue chips or hog fuel is, in practice, not as plentiful as figure 2 seems to suggest. Some of the logging sites are out of question due to small size, long distance, difficult terrain or ecological restrictions, and in all cases it is recommended that 30% of logging residues are left at site. If residues are left to season and they shed a part of the needles before haulage to roadside, the yield of biomass is further reduced (Hakkila 2004).
Chips made of logging residues contain different proportions of stem wood, foliage, branches and twigs as well as bark. There are often also different amounts of so-called unmarketable blocks of stem wood. Compared to the pure stem wood of pine (Pinus sylvestris) and spruce (Picea abies) for instance, branches have the following characteristics (Hakkila 1998):

- high bark content,
- the share of lignin is high and the share of cellulose low, thus increasing the heating value compared to stem wood,
- more terpenes, tannins, resins, waxes and fatty substances, which means that the heating value is higher than in stem wood,
- higher content of mineral substances or ash especially in the needles, which lowers the heating value and may cause extra handling costs. (But on the other hand, high alkali contents in the ash can be utilised in the mixed combustion of wood and peat, because alkali metals bind sulphur of peat and therefore may increase the possibilities of utilising wood fuels),
- denser than stem wood substances, which means that the heating value is higher than in stem wood,
- lower moisture content.

### 3.2 YIELD OF LOGGING RESIDUE IN HARVESTING

On a typical final felling site of spruce, figure 3, approximately 100 m³ solid of logging residue per hectare accrues while 200 to 250 m³ solid of merchantable wood per hectare is harvested (Hakkila 1992).
Nowadays recovery rate of logging residue is 65 - 75% in Finland. Usually forest residue is harvested in summer time, when logging residue is dry. Swedish studies during winter indicated that the recovery rate of logging residue was 75%. For these experiments the branches had been delimbed in piles and were harvested fresh (Larsson 1992, Vesisenaho 1994a). Snow will isolate piles of logging residue from the ground whereby the logging residue can be recovered more completely and with fewer impurities than during summer (Alakangas et al. 1999).

If logging residue is allowed to dry on terrain for a few months in summer, the moisture content of the logging residue decreases from 50 to 60% to as low as 20 to 30%. As the logging residue dries, needles are cast, thin branches are broken off and bark partly peels off (Alakangas et al. 1999). The wood content of logging residue increases and its moisture content decreases. On the other hand, the amount of logging residue that can be harvested decreases as much as 20 to 30%, primarily because of casting of needles. Furthermore, the recovery rate is lower than that for fresh logging residue. The recovery rate of dried logging residue is about 45%. As far as the energy content of logging residue recovered from felling sites is concerned, it makes almost no difference whether fresh or dried logging residue is harvested since drier logging residue will provide additional energy which very nearly compensates for the decreased harvesting yield (Hakkila 1989, Nurmi 1997).
Fresh logging residue chips contain in average 40% of wood, 23% of bark and 37% of needles (Fig. 4). The corresponding figures for chips made from dried logging residue are: wood in excess of 60%, bark less than 30% and needles less than 10% (Hakkila 1989, Nurmi 1997).

![Figure 4. The composition of fresh (left) and dried (right) logging residue of spruce (Alakangas et al. 1999).](image)

If the recovery rate for harvesting fresh logging residue remains significantly below 50% of the total amount of logging residue, the site has been poorly chosen or the work on the site has been careless. However, it is not worthwhile to increase the recovery rate too much since the percentage of impurities often increases as well. That will affect on chipping and the quality of chips. Moreover, the productivity of the forest haulage of logging residue and of terrain chipping will be decreased if logging residue is attempted to recover too thoroughly (Alakangas et al. 1999).

**Recovery rate of logging residue:**
- depends on the logging method,
- harvesting season and
- if harvested fresh or dried.

**An average recovery rate in Finland is:**
- 65 to 75% of the potential logging residue mass,
- recovered forest residue is about 20 to 30% of merchantable wood harvested in a logging area and
- greater recovery rates are achieved when harvesting fresh logging residue.

Coefficients and measures for logging residue are shown in appendix 3.
3.3 SELECTION OF PRODUCTION SITE FOR LOGGING RESIDUE HARVESTING

The proportion of spruce should be as high as possible at sites where logging residue is harvested, preferably in excess of 70%. Sites of this kind accrue a large amount of logging residue and the productivity of harvesting logging residue is good. Spruce dominant sites are also naturally situated on nutrient rich soils where the effect of harvesting logging residue on nutrient resources is minor and harmless (Alakangas et al. 1999).

The greater the variety of timber assortments and tree species in a stand marked for cutting is the more space will be required for sorting merchantable wood at the cutting stage. The need for sorting space makes it more difficult to bunch logging residue in piles, which means that the piles of logging residue in the felling area will be smaller and the productivity of harvesting logging residue will be lower. On sites like this, the recovery rate of logging residue will be lower as well (Alakangas et al. 1999).

The minimum size of a stand that can be harvested is also influenced by the transfer distance from the previous stand. If the distance is short and/or can be traversed with harvesting equipment, it is possible to harvest smaller sites. If separate transportation equipment is required for moving the harvesting equipment, the size of the stand required for profitable operation will necessarily be larger (Alakangas et al. 1999).

The stoniness and bearing capacity of the soil impose further limitations for the forest haulage of logging residue. Stony ground slows forestry machinery and easily leads to increased impurities in logging residue. Sites with soft soil cannot be harvested for logging residue when the soil is unfrozen because the logging residue will be needed for improving the bearing capacity of strip roads. Easily traversed, well bearing uplands are, consequently, the best sites for harvesting logging residue around the year (Alakangas et al. 1999).

Another limitation linked with the soil is nutrient content. It is inadvisable to harvest logging residue, particularly fresh with needle mass, from nutrient poor soils and from peat lands. On the other hand, spruce does not usually grow on soils poor in nutrients. The general rule is that logging residue can be harvested on moist uplands or on even more mineral rich soils (Alakangas et al. 1999).

If the felling area contains abundant undergrowth, harvesting logging residue becomes significantly more difficult. The stumps of undergrowth left under piles of logging residue introduce soil material into the harvested logging residue. Careful harvester operation makes it possible to place piles of logging residue on spots without undergrowth but this decreases the productivity of logging. This is why stands with abundant undergrowth and marked for cutting in summer should be cleared in advance or their logging residue should be left unharvested. Undergrowth does not present as much of a problem in winter because undergrowth trees are often broken off during felling under piles of logging residue and their stumps remain in the ground (Alakangas et al. 1999).
Even if compartment specific qualification criteria would be met, a site is not necessarily suited for harvesting logging residue. Additional limitations are also imposed by the length of forest haulage and the need for landing space. In order to achieve an economically profitable level for harvesting logging residue, the length of forest haulage must remain fairly short. Long distances imply that the proportion of the time spent for loaded and unloaded trips of the total working time becomes excessive. The landing area and the entry road must be sufficiently roomy and in good condition. If logging residue is stored next to a road alongside merchantable timber the total requirement for space must be taken into account (Alakangas et al. 1999).

A good harvesting site (Alakangas et al. 1999):

- as much spruce as possible; good recovery rate and productivity,
- fertile soil,
- a sufficiently large felling site or a concentration of stands,
- easily traversed, well bearing ground,
- no undergrowth which hinders logging,
- short terrain transport distance and
- a spacious roadside storage area for long distance transport.

During the last decade it was much discussion about which part of the bioenergy should be left on the logging area cause of nutrients. Also was discussed how strong the soil of felling area should be regenerated. There are both advantages to harvest logging residue and also disadvantages (Alakangas et al. 1999):

ADVANTAGES OF HARVESTING LOGGING RESIDUE

- Nutrient leaching to waterways is decreased,
- Soil preparation can be accomplished with less radical means,
- More natural develop in regeneration areas,
- Because planting can be done earlier regeneration areas are not covered with grass and there is less need for fighting against grass,
- Planting is easier, it is often possible to use smaller sapling,
- Aesthetic and recreational value of involved areas is enhanced,
- Forest regeneration costs are remarkably decreased and
- Forest regeneration is faster and results are expected to be better.

POSSIBLE DISADVANTAGES OF HARVESTING LOGGING RESIDUE

- Organic material is removed from the nutrient cycle,
- The amount of humus protecting the soil is decreased,
- Some nutrients are removed from the ecosystem,
- Risk of acidification is increased and
- Danger of growth losses.
4 INDUSTRIAL TIMBER HARVESTING

In 2003, a total of 55 million m³ solid of industrial and energy wood were harvested from the Finnish forests. About 83% of the indigenous wood was purchased from private forests, mainly on the stump but also delivered to roadside by the forest owner.

Three large forest industry companies, Stora Enso, UPM and Metsäliitto-Yhtymä are responsible for the procurement of more than 80% of all commercial timber. They operate nationwide and perform their wood procurement through special forestry departments that contract the implementation to independent entrepreneurs. Cutting and off-road haulage are included in a single logging contract, whereas secondary transport is subject to a separate contract (Hakkila 2004).

4.1 TIMBER PRODUCTION METHODS IN FINLAND

Felling is carried out on about 1.5% of Finland’s forest land each year. About half of this is for regeneration purposes and the rest is thinnings. Individual landowners usually take felling decisions in accordance with a forestry plan they commission for their holding. The legislation on forests guarantees that the future development of Finnish forests will not be jeopardized (Finnish Forest Industries 2000).

The technology of wood procurement is based exclusively on the mechanized cut-to-length system (Pulkki 2005, Nordansjö 2005), figure 5. Both the delimming and cross-cutting of stems are carried out with one-grip harvesters at the stump. An exception is early thinnings where cutting is still commonly performed with a chainsaw (Hakkila 2004).

Harvesters were used in about 80% of all felling, and manual labour in about 20%. The majority of the transportation within forests was done by forwarders and an estimated 10% or less by agricultural tractor. In practice, all of Finland’s 3500 harvesters and forwarders are owned by small timber harvesting companies with just 1-6 machines. Harvesters nowadays also include equipment that can measure certain aspects of timber handling and the volume of timber harvested, which is largely done automatically at the time of felling (Finnish Forest Industries 2000).

Under the tree-length logging system, more popular worldwide, the trunks are cut at a transportation terminal en route or at the processing plant; this system is hardly used at all in Finland. Mass handling methods for trunks are sometimes used in Finland, mainly for first thinning, whereby the trunks are transported untrimmed to be chipped at the place of storage. This method may become more common especially in integrated harvesting of industrial wood and fuelwood (Finnish Forest Industries 2000).
Timber for industrial use is harvested almost exclusively by the shortwood method, where the trunks are cut on the felling site to the length required by the processing plant.
Finnish timber harvesting is considered to be the most highly developed system in the world in terms of productivity, cost-effectiveness and working conditions. Thanks to the present, highly automated harvesters and their highly professional operators, the environmental impact of timber harvesting is also very low in Finland. Special attention has been paid to environmental considerations in the development of forest machines in an attempt to reduce the impact of harvesting and minimize damage. Harvesting consistent with sustainable use of forests is possible in all seasons (Finnish Forest Industries 2000).

4.2 INTEGRATED HARVESTING OF LOGGING RESIDUE AND ROUND WOOD

When working at a final felling site the harvester operator cuts trees on either one or both sides of the strip road. Then he moves the butt of the trunk in front of the machine where the delimming and cross cutting of the trunk is done. As the harvester is moving to the next working spot logging residue is trampled under the tires. Forwarders use the same strip roads for forest haulage of timber and logging residue is trampled again. Such traditional logging methods mean that logging residue is difficult to harvest and the harmful soil material is easily collected with it (Alakangas et al. 1999).

It is possible to harvest logging residue if the residue is located in fairly large, clearly delineated piles beside the strip roads and have not been run over. This requires that working methods are modified in such a way that logging residue is piled on either side of the harvester. In practice this can be accomplished either with the single-sided or with the double-sided method. These methods are described in Fig. 6 (Alakangas et al. 1999).

Figure 6. Logging methods which accommodate harvesting logging residue (Hakkila 1998).
Harvesting logging residue is possible (Alakangas et al. 1999)

- logging residue is placed in fairly large and clearly delineated piles,
- they have not been run over by forest machines and
- logging residue is piled on the side of strip roads.

When harvesting logging residue in piles (Alakangas et al. 1999)

- the recovery rate of logging residue is higher,
- the forest haulage of logging residue is more productive and
- logging residue is cleaner and of better quality.

4.2.1 Single-sided method

With the single-sided method felling, delimbing and cross-cutting of trees are done on one-side of the strip road only. Merchantable wood is left perpendicularly or diagonally in relation to the strip road and is placed directly along the next strip road. Logging residue is piled between the strip road and the merchantable wood. This method presents only few differences to the method usually employed for harvesting merchantable wood (Alakangas et al. 1999).

Timber processing occurs somewhat further away from the machine, which means that the crane's movements are somewhat longer. The balance of the harvester is slightly influenced by the fact that the delimbing and cross cutting point is moved further away from its centre of gravity, which should be taken into account in difficult terrain. Since the harvester operator is unable to observe the cross cutting point directly, using the single sided method on sites which contain considerable amounts of rotten wood means that the quality of merchantable wood is jeopardised to some extent. Harvesting merchantable wood may be adversely affected by the fact that the bolt ends fall into the pile of logging residue which prevents the forwarder operator from seeing the colour codes at the top end of the blocks (Alakangas et al. 1999).

Adopting a felling technique which accommodates single sided harvesting of logging residue is easy for the harvester operator because the changes from traditional felling method are minor. Handling very large stems is difficult at a distance from the machine, it is then advisable to process large butt blocks in front of the machine and to move the harvester head sideways only when processing smaller but branchier trunk sections (Alakangas et al. 1999).

The single-sided method (Alakangas et al. 1999)

- Felling and cross cutting of trees is done on one side of the strip road only,
- Merchantable wood is placed perpendicularly or diagonally,
- Merchantable wood is placed directly along next strip road and
- Logging residue is piled between the strip road and merchantable wood.

The advantages and disadvantages of the single sided method

- easy to adopt,
- more sorting space than in the double-sided method,
timber is processed further away from the machine,
- the crane's movements are longer,
- the machine's centre of gravity shifts,
- the cross cutting point cannot be seen by the driver and
- forwarder operator will not necessary see the colour codes of the blocks behind a pile of logging residue.

4.2.2 Double-sided method

In the double sided method trees are processed on either side of the strip road. This means that the harvester processes more timber using a single strip road and from a larger area than with the single-sided method. After felling, timber is placed in bundles parallel to the strip road and logging residue is placed between the bundles of timber (Alakangas et al. 1999).

The advantage of the double sided method is that large trees need not be processed at a distance from the machine, which also makes quality marking easier. It is even easier for harvester operators to see the cross cutting point of the trunk using the double sided method rather than the traditional method. Because cross cutting is performed alongside the machine, the quality of dividing the trunk into timber assortments is improved (Alakangas et al. 1999).

The technical specifications of some harvesters prevent using a "pure" double sided method. Then it is possible to process trees parallel to the strip road on one side of the road only. Logging methods should always be adapted to the equipment in use and to the standing crop and terrain of the felling area (Alakangas et al. 1999).

The double-sided method (Alakangas et al. 1999)
- timber is processed on either side of the strip road,
- the harvester processes more timber from a single strip road and from a larger area than in the single sided method,
- after felling, timber is placed in bundles parallel to the strip road and logging residue is placed between the bundles.

The advantages and disadvantages of the double sided method
- large trees need not be processed at a distance from the machine,
- the harvester operator can see the cross cutting point and the quality of the trunk even better than in the traditional method,
- more difficult to adapt by the operator,
- not possible with all types of machines,
- smaller logging residue.
5 PRODUCTION TECHNOLOGY OF LOGGING RESIDUES FROM FINAL FELLING STANDS

5.1 PRODUCTION METHODS

A forest chip production system consists of a sequence of individual operations performed to process biomass into commercial fuel and to transport it from source to plant. The main phases of chip procurement are purchase, cutting, off-road transport from stump to roadside, comminution, measurement, secondary transport from roadside to mill, and receiving and handling at the plant. The system offers the organization, logistics and tools to control the process (Hakkila 2004).

A forest fuel production system is built around the comminution phase. The position of the chipper or crusher in the procurement chain largely determines the state of biomass during transportation and, consequently, whether subsequent machines are dependent on each other, i.e. whether the system is hot or cool. Comminution may take place at the roadside or landing site, at the source, at a terminal, or at the plant where the chips are to be used (Hakkila 2004).

The main methods used in Finland for production of forest chips are chipping at the roadside, at the terminal and at the mill. In minor scale is used chipping at the terrain. There is also a new harvesting technology which is based on bundling of forest residues. In next chapters the different methods and their phases are represented in details. In a catalogue “Market actors of wood energy technology in Finland 2002” has represented most actors of Finnish wood energy market.

5.1.1 Chipping at the roadside landing -method

Logging residues are hauled to the roadside landing all year round from the surroundings of the terminal, figure 7. Residues are stored at the terminal and dried there over the next summer, so it is possible to improve the quality of the fuel. Chipping of residues is carried out in all-year round, and chips are delivered by common solid fuel transportation vehicles. The objective is that logging residues are chipped directly to the long distance transport trailers without any storage of forest residue chips at the landing (Leinonen 2004).
5.1.2 Chipping at the terminal -method

The production phases of the forest residues harvesting chain of forest residues for fuel based on the chipping at fuel terminal, figure 8, are terrain haulage, storage and drying, chipping or crushing of forest residues and road transport of forest residue chips to power plant. The working phases are the same as in the harvesting chain as in the chipping at the roadside (Leinonen 2004).

5.1.3 Chipping at the stand -method

Terrain chipping is based on a single machine so called terrain chipper, which chips forest residues into a container at the stand and haul the chips in a container to the landing or to the roadside, figure 9. The container is emptied by tipping the chips into
exchangeable containers at the roadside. The truck picks up the exchangeable containers and transports them to the power plant and returns the emptied containers to the landing (Leinonen 2004).

Figure 9. Chipping at stand with terrain chipper (VTT).

5.1.4 Chipping or crushing at the power plant -method

The fourth major chain of processing logging residues for fuel is chipping or crushing them at the end use facility, which normally can be implemented more economically than in terrain or at the roadside. Also processing at the plant avoids the problems of the hot chain, and chipping/crushing can be implemented more economically than at the stand, landing or roadside (Savolainen & Bergren 2000). A promising alternative for transporting whole logging residues is bundling before long distance transport and chipping at power plant, figure 10.

Figure 10. Bundled forest residue chipped or crushed at power plant (VTT).
5.2 CHIPPING AT THE ROADSIDE LANDING -METHOD

In the next chapters it is presented the different production phases and techniques of the method “Chipping at the roadside landing”.

5.2.1 Forest haulage of logging residue

The productivity of a forwarder with regular equipment remains low for hauling logging residue because of a small load space. The load space needs to be enlarged or the load of logging residue needs to be compacted in order to achieve better hauling productivity. Since the green density of logging residue is low (80 to 150 kg/m$^3$ of logging residue) the mass of the load will remain below the loading capacity of the machine (Alakangas et al. 1999).

In order to improve the hauling productivity, the load space has to be enlarged or the load of logging residue compacted. The load space can be extended backwards, sideways and upwards. It is possible to enlarge the load space sideways by widening the bolsters, (Figure 11). The sole restriction for sideways extension is the width of the strip road if the load of logging residue needs to be hauled through a forest standing forest.

Figure 11. A forwarder equipped with a mounter between the front and rear bogies on both sides, and with an extendable load space for simultaneous site preparation and residue collection (FFRI, Finnish Forest Research Institute).

The simplest and cheapest way to achieve larger loads is to lengthen the load space and install extra lateral and rear supports. This equipment makes it possible to increase load size up to nearly double that of a regularly equipped forwarder. A separate load space can be disassembled in less than one hour, and the forwarder will again be ready for
hauling timber (Brunberg et al. 1994). A medium-size forwarder with a regular load space can accommodate an approximate load of to 5 m³ solid of fresh logging residue. By extending the load space backwards and installing extra bolsters load size of 8 to 14 m³ solid can be attained (Mellström & Thörmnlind 1981, Sauranen & Vesisenaho 1996a).

**Extending the load space**
- lengthening or widening of load space,
- installing extra lateral and rear supports,
- compressing the load,
- size increase with technical solutions up to 8 - 14 m³ solid.

Finnish forwarder makers are Oy Wikar Ab, Kesla Oyj and Farmi Forest Oy.

Loading techniques can influence the solid volume content and stability of the load. Long tops and undergrowth are best placed as the rear overhang of the load space. Longitudinal bundles should be placed at the edges of the load space for holding the rest of the logging residue in the load. Bundles of tops residue can also be placed transversely across the load space. This makes the load more compact although unloading may become more difficult because of crossed bundles. The rear of the load space should be filled to the maximum level, after which bundles with nothing but branch residue should be placed closest to the cabin. The final grapple load should be left in the grapple and the crane lowered over the load space. Thus the crane helps compact the logging residue and will support the load (Vesisenaho 1994b).

Mixed forest haulage of logging residue and logs is not profitable although logs will compact logging residue to some extent when loaded on top of the logging residue. It is advisable to haul logging residue only in loads which contain nothing else (Sauranen & Vesisenaho 1996a).

If logging residue is harvested in winter, the forest haulage of logging residue must be done immediately after felling so that snow will not be collected over the piles of logging residue. If more than 10 cm of snow has been deposited on the piles of logging residue, there is a good reason to delay the forest haulage until the spring. If logging residue mixed with snow is stacked on storage place the pile will freeze so solidly that it can only be chipped in the following summer. Even then the moisture content of the pile will be extremely high (Alakangas et al. 1999).

5.2.1.1 Use of farm tractor in terrain haulage

During summer a large number of farm tractors are at work in agriculture and on peat lands. In winter there is hardly any use for this machinery. Farm tractors with minor modifications could be utilised for harvesting logging residue and thus the utilisation rate of this equipment could be improved.

The harvesting chain of regular timber is usually bound with logging of merchantable wood. Machinery based on farm tractors harvesting logging residue would not disturb the operation of the harvesting chain for actual timber. Cross hour costs for a farm
tractor equipped with a forest trailer and a hydraulic crane are approximately 50 to 70% of the cross hour costs of a forwarder. The load space volume of forest trailers can be increased with minor modifications and thus additional productivity can be reached (Järvenpää & Peltonen 1995).

In an examination of forest trailer the width of the load space was manually adjusted from 2.0 m to 4.2 m and, additionally extended supports were used. Productivity for a hauling distance of 80 m was approximately 15% better than with a reference trailer (Ryynänen & Mononen 1998, Sauranen & Vesisenaho 1996a).

Vapo Oy has manufactured and introduced Havu-Hukka logging residue trailers (figure 12) with solid sides to compress logging residue, designed to be towed by farm tractor. The dimensions of this "tractor/trailer" combination conform to the highway validity since it has been intended for extended forest haulage of logging residue from the felling area to a roadside landing or terminal. The operative goal is to collect logging residue in fairly large storage facilities where logging residue can be dried, chipping rationalised and deliveries better guaranteed under all conditions (Alakangas et al. 1999).

The trailer, equipped with powerful mechanical drive, is towed by a strong peat/farming tractor of at least 140 horse power. Tractor should be equipped for forest operation. Efficient use of the hydraulic crane installed on the shaft of the trailer also requires that an addition hydraulic pump is installed in the tractor. With the compressing side panels the volume of the trailer is approximately 45 m³ loose and it carries about 10 tons of fresh logging residues, double the amount carried by a regularly equipped forwarder.

When the trailer is filled the compression sides are closed to road transport width and to keep the logging residues inside the trailer. The sides closed the trailer is suitable for road transport and so the logging residues can be transported directly from the lot to the terminal. The maximum transportation distance is about 10 km. Collection of logging residues can be done all-year round (Leinonen et al. 2000).

Using farm tractors for the forest haulage of logging residue (Alakangas et al. 1999)
- improved utilisation rate of existing equipment,
- cross hourly cost is 30 to 50% lower than with a forwarder a compacting,
- logging residue trailer allows highway transportation of logging residue.
5.2.1.2 Grapple for forest residue loading

The size of the loading bundle exerts a significant influence on the loading productivity. Bundle size depends on the construction and size of the grapple and on the size and shape of the piles to be loaded. A regular timber grapple is not suited for loading logging residue because the lip plate easily lifts up soil material. Furthermore, it does not penetrate a pile of logging residue in the desired fashion. Sufficiently large, commercial grapples suited for harvesting logging residue exits.

The best grapple model has been found out to be the so called fingered grapple (Fig. 13). This has the general shape of a timber grapple but the lip plates have been removed, its construction has been strengthened and the grapple has been extended horizontally by adding more spikes. A logging residue grapple needs to have a durable construction but should not be very heavy. Extra grapple weight leads to lowered crane power, especially when lifting bundles far away from the machine. A suitable number of spikes for a logging residue grapple are 2 to 4 per side. Due to the width of a logging residue grapple, longitudinal bundles are formed and they are consequently easy to fit in the load space. Because of large bunch size the load becomes more compacted than one made with a timber grapple (Alakangas et al. 1999).
If the logging residue is scattered on the felling site, a so called raking logging residue grapple can be used to make harvesting logging residue more effective. A raking grapple makes loading more than 30% faster than a regular logging residue grapple. However, raking involves a risk of introducing impurities in the grapple load during the unfrozen season. If logging residue is piled a raking grapple brings no benefit (Ryynänen & Mononen 1998).

The advantages of using a logging residue grapple (Alakangas et al. 1999)
- the grapple does not pick up impurities,
- the grapple sinks into the pile better than a timber grapple,
- loading and unloading is faster,
- the load is more compact because of large grapple loads,
- the productivity of forest haulage improved 15 to 25%, depending on the distance.

When using a logging residue grapple, the bundle size is almost 45% larger at the loading and unloading stages than when using a normal timber grapple (table 2). Bundle size is mainly influenced by grapple width (Sauranen & Vesisenaho 1996a).

Figure 14 describes the improvement in the productivity of the forest haulage of logging residue when logging residue grapple is used instead of a timber grapple. Depending on the hauling distance, productivity increases 15 to 25%.
Table 2. Crane bundle sizes using different grapple types, m$^3$ (Sauranen & Vesisenaho 1996a).

<table>
<thead>
<tr>
<th></th>
<th>Loading</th>
<th>Unloading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logging residue grapple</td>
<td>0.32</td>
<td>0.38</td>
</tr>
<tr>
<td>Timber grapple</td>
<td>0.22</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Figure 14. The relative productivity of the forest haulage of logging residue using a logging residue grapple (upper) instead of a timber grapple (lower) (Sauranen & Vesisenaho 1996b).

5.2.2 Storing of logging residues beside road

5.2.2.1 Requirements for the roadside landings

Large and heavy machinery are used at a roadside landing, which causes multiple requirements on the landing site. If timber is stored simultaneously with logging residue, the storage space requirements and long distance transportation of both raw materials must be taken into account. The bearing capacity of the landing site must be good since a chipping unit may weigh 30 tons and a full chip trailer lorry a maximum of 60 tons (Alakangas et al 1999).

A chipper and a chip lorry require a lot of room, because the length of a chipper on a lorry chassis is 10 to 12 m. Correspondingly the length of a full chip trailer lorry is over 20 m and its width is 2.6 m. When a side feeding chipper with a working width of 4 to 5 m and a chip lorry are placed side by side for loading, there must be 7 to 8 m of room. For a rear feeding chipper, the working width is less than for a side feeding chipper.
Chippers on a forwarder chassis can operate outside the road area. Thisrelaxes the space requirements for the landing site somewhat (Alakangas et al 1999).

The centre of gravity of a fully loaded chip lorry is high. The bearing capacity of road edges must therefore be assured, especially in curves. When road conditions are slippery the landing should not be located at the bottom of a long uphill because a chip lorry needs a sufficient distance for accelerating before the hill. Snow covered and icy hills on side roads should be gravelled in order to ensure the flow of traffic (Kuitto et al. 1994).

The chipper/chip lorry chain is a so called hot chain where idle time of one unit is immediately reflected in the operation of the entire chain. This is why landing operations require careful planning and linking. It is preferable to locate landing sites along a private road or a spur road. If it is necessary to locate a landing site along a public road the highway code must be observed (Hakepuun varastointi 1986).

The roadside landing (Alakangas et al. 1999)
- requires careful planning because of the hot chain,
- the landing area must be spacious and well-bearing,
- the landing site should be wide enough for a chipper and 1-2 lorries,
- length of a chipper on a lorry chassis 10 to 12 m and weight 30 tons,
- full trailer chip lorry is more than 20 m long and weighs 60 tons,
- the crucial quality factors of forest energy wood are management of dryness and cleanness.

5.2.2.2 Storing of logging residues at roadside chipping

Storage pile formations has to be large. The size of a separate storage unit must be at least equal to a full chip lorry load of processed chips (80 to 120 m$^3$ loose = 35 to 50 m$^3$ solid). Several smaller piles may be located along a single road/transportation route. Small storage piles become more easily wet during extended storage than large ones (Alakangas et al. 1999).

Storage piles must be located on even and bearing ground without rocks, preferably on the outer curve of the load. This is for ensuring that no rocks or soil material is introduced into the chipper. The piles must not be located near electrical or telephone lines. Storage piles must be located within reach of the crane of a crusher or chipper. In practice the rear edge of a pile may be located at a maximum of 5 to 6 m from the road edge (Alakangas et al. 1999).

When the pile is being built a few bundles of whole trees or rotten bolts of tops should be placed transversely on the bottom in order to prevent the lowermost logging residue becoming contaminated with sand or freezing to the ground. Additionally, they will indicate the location of the bottom of the pile to the chipper operator. Logging residue should be placed in a roadside pile so that the butts of the tree tops face the road, and piling crosswise should be avoided. This can be accomplished fairly easily when a logging residue grapple is used since it forms longitudinal bundles. When the storage pile is correctly built chipping can proceed without difficulty (Kuitto & Mäkelä 1984).
When unloading logging residue it is advisable to turn the forwarder perpendicular to the road. This makes it easiest to unload the logging residue and the pile of logging residue can be raised up as quickly as possible. The pile must be built so that the logging residue that has been piled last can be chipped first. A pile, which has been built in this way, is easy to unload at the chipping stage (Alakangas et al. 1999).

At least 6 m of storage space for logging residue needs to be set aside for each 100 m³ of harvested merchantable timber, when the pile height is 4 to 5 m and the width 5 to 6 m (lengthwise two logging residue bundles can be placed side by side). For example, if the stand marked for cutting yields 500 m³ of merchantable wood, a storage space of 30 m x 6 m will be needed for the logging residue (Kuitto 1983).

The technical specifications of the chipper determine on which side of the road the logging residue should be piled or if piles can be built on both side of the road. Likewise, the feed direction of the raw material into the chipper must be considered, i.e. if a side/rear feeding chipper or a top feeding crusher will be used. When a rear feeding chipper or a top feeding crusher is used the piles can be located on either side of the road. Furthermore, it is necessary to take into account the direction in which the chipper will blow the processed chips: forward, sideways or back. It is advisable to turn the empty chip lorry towards the long distance transportation direction so that it will not be necessary to turn it with a full load (Alakangas et al. 1999).

When the frame dimensions of a pile are large enough the chipper need not be moved during chipping and the chip load can be filled from a single location. Another benefit is that in large piles during storage logging residue does not become as wet as in small piles (Fig. 15).

![Figure 15. The seasonal variation of moisture content in logging residue (Alakangas et al. 1999).](image-url)
The stockpile dries effectively during the summer (Fig. 16), from the initial moisture content of 50 - 60%, at the last even to less than 30%. The best possible place for drying a logging residue stockpile is an open and windy site and if possible located in south-north direction. The stockpiles shall not, however, be placed too close to each other because this slows down the drying process. The stockpiles can be made as high as possible because it has been noticed that making the stockpile 5 m high did not slow down the drying compared to the drying of 3 m stockpiles. The tops of the stockpiles should be covered already during the stockpiling, or latest in August before the autumn rain season (Leinonen et al. 2000).

So the forest residues that come out during spring and summer should be left for drying before forwarding them to the stockpile. The forest residues on the stand dry faster than in the stockpiles (Leinonen et al. 2000).

Figure 16. A forest residue stockpile beside the road (VTT).

Fagernäs et al. (2003) have researched besides drying of wood chips in stockpiles during storage, also chemical and biological behaving of the stockpile.

The storage of logging residue always entails wastage of raw material. The extent of the wastage depends on the length of the storage period and on the size of the storage piles. Small piles lead to higher wastage than large ones. The wastage is highest at terrain, nearly half of the logging residue will decay and decompose within a year. In a large pile the wastage will be only a few percent. In addition, the residue left at the bottom of large piles after chipping is proportionally less than in small piles (Alakangas et al. 1999).

In wintertime, snow must not be cleared from a pile of logging residue because soil material might be introduced into the pile. After the chipping operation has been completed, the road section must be cleaned up by removing the logging residue and chips, which have been fallen on the road during chipping (Alakangas et al. 1999, Paananen & Kalliola 2003).

Storage piles (Alakangas et al. 1999, Paananen & Kalliola 2003)

- must be located on even ground without rocks,
- the storage must be as large as possible,
- must not be located near electrical or telephone lines,
• a high and narrow storage heap is most suitable for logging residues,
• residue bundles are stored in heaps of about 3 m in height in such a way that the bundles do not roll down from the heap and thus cause danger to people (ramblers, passers-by, climbers),
• Energy wood should be stored sufficiently close to the chipper, not more than 6-7 m from the lorry or a working machine, but not too close to the road,
• a few bundles of whole trees or tops should be placed on the bottom,
• most of the top butts should face the road,
• piling crosswise should be avoided,
• the logging residue piled last should be possible to be chipped first,
• chipper specifications determine on which side of the road a pile of logging residue should be built or if piles can be built on either side,
• snow must not be kept away from the pile,
• no logging residue, needle mass or other energy wood waste should be left in ditches adjacent to the storage site, as the nutrients released run off direct into watercourses,
• small understorage trees should be cleaned off from the storage site to prevent root clods from ending up into the chipper and hampering chipping,
• the trailer truck and the chipper should be able to drive simultaneously on the storage road. The total combination requires a space of 50 m in length.

5.2.2.3 Covering the logging residue pile

Covering storage piles with tarred brown paper is fairly common both in Finland and Sweden, figure 17. The paper protects the pile from becoming wet and, consequently, chipping can be done even during periods of bad weather. The forwarder operator rolls the paper over the pile using the crane of the forwarder. A few bundles of logging residue are placed on top of the paper so that it would stay there even in windy weather. The paper can be chipped with the logging residue and will not remain at the landing site. According studies, chips manufactured from covered logging residue in winter are approximately 10 percentages drier than chips produced from uncovered logging residue. Moreover, covering logging residue is effective against mould growth during storage. The cost of covering logging residue is 0.5-0.6 €/MWh (Jirjis 1995, Lehtikangas 1995, Nurmi 1998).
It has been found out, that covering dry logging residue at open terminal storage sites is profitable, figure 18. In order to prevent the raw material becoming wet, it is advisable to cover dry (moisture content approximately 30%) logging residue, which is stored over summer, before the rain- and snowfalls of autumn and winter. In contrast, covering fresh and wet logging residue is not similarly advantageous (Hillebrand & Nurmi 2001, Lehtikangas 1995).

Figure 18. A graph of forest residues drying at a stand and in covered and uncovered stockpile (Hillebrand & Nurmi 2001).
5.2.3 Chipping and crushing at the roadside landing

High efficiency is required from the chipper and crusher alike because of the properties of logging residue. If the feed rate of logging residue varies suddenly, peak stresses can be generated. This is why a logging residue chipper should have a long feeding table which facilitates an even chipper load. Additionally, the chipper needs to have forced feed but still be resistant to clogging (Alakangas et al. 1999).

Specifications of a good logging residue chipper
- high productivity,
- long feeding table,
- must have forced feed but be resistant to clogging,
- drum chippers are not as sensitive to impurities as disc chippers,
- drum chippers produce a more even quality of chips than crushers.

Disc chippers are best suited for whole trees. The feeding hole of a disc chipper is often too small for logging residue. Furthermore, logging residue chips made with a disc chipper contain large amounts of long splinters. This is why drum chippers are usually employed for chipping logging residue. They make it possible to produce more evenly sized chips than disc chippers or crushers. Drum chippers are also not as sensitive to impurities as disc chippers (Alakangas et al. 1999).

The productivity of chipping is influenced by the raw material, the storage and working site arrangements and the specifications of the chipper and crushers. For chipping logging residue the productivity varies between 40 and 80 m³ loose of logging residue chips/effective hour. Fresh logging residue is usually faster to be chipped than drier logging residue. Excessive recovering the bottoms of logging residue piles is not profitable. Considering the amount of extra chips achieved, large costs may result for the chipper because of impurities. A chipper operation analysis indicated that the chipper's relative productivity is increased when the working site exceeds the limit of 400 m³ loose of logging residue chips and the pile 200 m³ loose of logging residue chips (Fig. 19) (Asikainen & Ikäheimo 1998, Lahti & Vesisenaho 1996, Mutikainen & Korpilahti 1994, Norden & Andersson 1997, Pulkkinen 1996).
The form of the intermediate store, purity of raw material and moisture does effect in the productivity of chipping (Asikainen et al. 2001). Moisture of the forest residue has minor influence on the affectivity of the crusher (Tiihonen & Korpi 2004).

Distribution of working time during chipping was studied by VTT. The Evolution drum chipper of Kotimaiset Energiet Pekka Lahti Ky spent for actual chipping average 57% of the working hours (Fig 20). The proportion of idle time was 26%. The most of the idle time consisted of waiting for chip lorries (12%) and changing chipper knives (6%).

The medium-sized drum chipper TT-97RM made by Heinola Sawmill Machinery has a width a 90 x 40 cm feed opening. It is designed primarily to operate at landing sites and small satellite terminals. The basic model is equipped with a bogie axle, and it is driven by a 100-140 kW farm tractor (model TT-97RMT). The weight is 7.5 tons without the tractor. It can also be mounted on a truck (model TT-97RML). The power source is then a 225-375 kW auxiliary engine, or the engine of the truck (Hakkila 2004).
In tests made by TT-97RMT and Jenz HEM 25Z drum chippers with the tractor drive the average output of chippers was 50 m$^3$ loose of chips per productive hour. The power demand of the tractor was 100 kW. A fundamental feature of the tractor-driven equipment is the agility and mobility even in hard conditions and on a ground with poor loadbearing capacity. The present tractor operated chippers are equipped with turntable outlet pipe, which makes it possible to place the chip stockpile on a clean surface by the side of the machine combination (Tiihonen et al. 2000).

Lorry-based chipping device can be used in terminal chipping and at the roadside landing. The advantage of this is the large momentary chipping output. The limitations in operation are caused by the high total weight of the lorry-based chipping equipment as well as the high axle loads, which make the operation on the areas with low load-bearing capacity difficult or even impossible. The lorry-based JENZ chipper, equipped with 380 kW chipper, was tested at a terminal. The outlet pipe of the chipper can be turned sideward so it is possible to chip the logging residues either to the ground or directly into the longdistance transportation vehicle. The output of the chipper was low, being only same as with a tractor chipper (Tiihonen et al. 2000).

Seven Sisu chipper trucks worked for Biowatti Oy at the beginning of 2004 (Figure 21). The Sisu chipper truck performs both chipping at the landing and transportation of chips to the customers. As the same unit carries out two subsequent work phases, the production chain remains cool. The base components are the Sisu E14 truck, the Loglift 75ZT crane, the TT-97RMS drum chipper from Heinola Sawmill Machinery, three chip containers with a total capacity of 100 m$^3$, and Multilift LHS 260.5 system for moving the containers (Hakkila 2004).

![Figure 21. Sisu chipper-truck (Biowatti Oy).](image)

The truck-mounted Giant chipper from LHM Hakkuri Oy is designed to operate at landing sites (Figure 22). The power source is a 367 kW auxiliary engine. The reach of the Loglift 95 crane is 10 m. The drum chipper has a 140 x 60 cm feed opening, and it can be fed from both sides. It is equipped with a litter screw for salvaging loosened fine material from the feeding table. The total mass of the unit is 32 tons. High efficiency
makes the Giant chipper suitable for large-scale operations, but flexible mobility allows also shuttling and small-scale chipping on farms (Hakkila 2004).

Figure 22. Truck-mounted Giant chipper of LHM Hakkuri Oy.

The MOHA multi purpose chipper of Meter Ky is a combined chipper and chip lorry (Fig. 23). For operation, a forwarder is used to build a preliminary pile of logging residue on the cutting area or at roadside. The off road capable MOHA then chips the logging residue in a 35 m³ demountable container that it carries. The container can be transported directly to the end use facility or to a road for eventual long distance transportation (Alakangas et al 1999).

Figure 23. The MOHA multi purpose chipper is a combination of a chipper and a chip lorry.

According to the studies of University of Joensuu, 40% of MOHA's working time was chip transportation, 32% chipping and the rest various breaks (Asikainen&Ikäheimo 1998). In a study the efficient hourly productivity of the method was measured to be 29 - 38 m³ loose of logging residue chips. On several occasions, the MOHA chipper has been assessed to be more advantageous in the production of logging residue chips with a
short long distance transportation range (less than 30 km). However, only one unit of this multi purpose chipper is in service and the findings can hardly be generalised yet.

5.2.4 Long distance transportation of chips in chipping at the roadside landing -method

The chip lorries, which are used for roadside chipping are often equipped with either a rear unloading conveyor or a side tipper and their capacity is usually 90 to 120 m³ loose of logging residue chips. The unloaded weight of a chip lorry is approximately 23 tons whereby a load of 37 tons can be transported. With wet logging residue chips it is possible to have a definite overload whereas with dry chips the load remains clearly below the maximum allowable total mass (max 60 tonnes) (Alakangas et al. 1999).

Rear unloading facilities of a chip lorry make it possible to deliver chips to more plants than the option of a side or rear tipper. Depending on the type of the chipper/crusher, the load space of a chip lorry needs to have the option of being filled either from above or from behind. The lorry must have a ground clearance and tyres suitable for the conditions on forest truck roads. In winter a chip lorry needs to carry chains as well in order to guarantee mobility through winter by truck roads (Alakangas et al. 1999).

VTT together with the companies have carried research work to lighten the mass of truck trailer.

Attaining a satisfactory annual output of 65,000 to 70,000 m³ loose for a logging residue chipper on a lorry chassis requires using two full trailer lorries or three lorries without trailers for a long distance transportation range of 80 km. Two lorries without trailers are sufficient for shorter distances below 40 km (Kuitto 1983).

The use of an internet-based, general-purpose logistics control system applying mobile terminals are studied. Among the aspects investigated were vehicle control and terminal logistics, navigation of vehicles, work planning, and instructions for deliveries by internet to mobile terminals. The advantages mentioned by the participants of the project included paper free truck cabin, decrease of cellular phone calls, and GIS/GPS supported navigation. Technology should be developed further to support the whole business process of the truck entrepreneur so that the information needed in planning, operative work and invoicing could be monitored by the system (Ranta 2003, Figure 24).

Long distance transportation of chips (Alakangas et al. 1999)

- lorries equipped with rear unloading conveyor can make deliveries to several end use facilities,
- tipping lorries require greater height of end use storage it must be possible to fill the load space either from the top or from the rear,
- a load of wet logging residue chips involves a risk of overload a weight of dry chips remains clearly below maximum allowable total weight,
- managing the logistics of the chipper and the chip lorry significantly influence the cost.
Figure 24. Transport is the biggest single element of cost formation in the forest chip procurement chain. That is why effective transport is an important competitive factor; cost savings can be achieved by full loads and less waiting. IT-applications have been successfully used in logistics and navigation. Their usability has increased, as they can be tailored to meet the specific needs of the user (Biowatti Oy).

5.3 CHIPPING AT THE STAND OF LOGGING RESIDUE - METHOD

5.3.1 Description of the chipping at the stand -method

The terrain chipper must be suited for efficient chipping of logging residue so that when chipping is done on terrain the operator does not need to wait for the chipper to finish its work before loading the next bundle. For chipping logging residue, the chipper must have a feeder, which facilitates the feeding of logging residue to the chipper knives. Such a feeder is often a feed table equipped with a powered chain conveyor (Alakangas et al 1999).

For terrain chipping the productivity of the work at forest haulage of 200 m is 15 to 20 m$^3$ loose/cross hour. In the case of terrain chipping the logging residue is mostly processed when it is still fresh. Consequently, the resulting logging residue chips can have lower moisture content than fresh logging residue only in the summer season. When chips are stored the moisture content decreases no more, but remains high, and dry matter losses will lower the profitability of storage (Laurila & Vesisenaho 1997).

The grapple of the terrain chipper crane needs to be designed for logging residue, much like in forest haulage of logging residue. Using a fingered grapple significantly reduces
the risk of introducing impurities into the chipper. However, a wide grapple, as used for a forwarder is not suited for terrain chipping because it is difficult to feed logging residue into the chipper with a wide grapple (Alakangas et al. 1999). With equipping the harvester head with a branch guide the logging residue can be piled better for chipping phase than in the case of regular logging, this means that the butts of branches and tree tops will face in the same direction. The productivity of terrain chipping improves 6% due to a branch guide (Laurila & Rinne 1998).

The advantage of terrain chipping, compared to roadside chipping, is that less machinery is required for harvesting, which remarkably improves the organisation of the work. Additionally, less space is required for terrain chipping than for roadside chipping, and the chipping and lorry transportation do not function as a hot chain, as in the case of roadside chipping. Since the produced chips are immediately tipped on a container platform, the chips will be less contaminated with impurities than in the case of roadside chipping (Hakkila 1989).

The disadvantages of terrain chipping include a fairly poor off road capability and a difficulty of achieving a satisfactory chip quality throughout the year, including periods of snowfall. The cost competitiveness of a terrain chipper is not very good for long distance forest haulage either. In addition, the chain of terrain chipping requires even storage space for the containers and a sufficient amount of containers depending on the long distance transportation (Hakkila 1989).

Figure 25. Pika Loch 2000 is an 8-wheeled terrain chipper manufactured by S. Pinomaki Ky. The cabin is levelled automatically and slews 330 degrees. The weight is 23 tons, including the 10-m-reach Lo-lift 71 FT 100 crane, the Bruks 604 CT drum chipper with a 60 x 36 cm feed opening, and 20 m³ chip space. Unloading takes place from 4.2 m height, and so it is not necessary to lower a truck's chip containers to the ground for loading (Pinox Oy).

There have been several terrain chipper models available on the market, but nowadays production method is considered expensive. The terrain chipper made by S. Pinomäki was equipped with 20 m³ container, figure 25. In the Nordic countries a large
manufacturer of terrain chippers is Allan Bruks Ab of Sweden. Oy Logset Ab of Finland made a Chipset terrain chipper in which dedicated chassis design had been developed.

The advantages and disadvantage of terrain chipping (Alakangas et al. 1999)

- terrain chipping does not involve a hot chain,
- organisation of work is easier,
- storage space requirements are less than for roadside chipping,
- it is difficult to produce good quality chips around the year,
- poor ability to work in difficult terrain conditions,
- competitiveness weaker in long forest haulage distances than it is in roadside chipping.

5.3.2 Long distance transportation of chips in terrain chipping - method

Regular chip lorries are not always suited for the long distance transportation of chips produced by terrain chipper if the tipping height of terrain chippers is limited. A chip lorry with a fixed load space, transporting chips from terrain chipper, would also need to stay at the roadside landing for excessive periods if the lorry should wait for a full load of 100 m$^3$ loose to be accumulated. On the other hand, the terrain chipper would often need to wait for the chip lorry to return to the working site for a new load (Alakangas et al. 1999).

Because of the technical limitations imposed by terrain chippers and in order to avoid hot chain problems, lorries with containers are used for long distance transportation of chips. Lorries use demountable chip containers of 30 to 50 m$^3$ loose (figure 26) and can accommodate 2 to 3 of them at once, whereby the total volume of the load is 80 to 100 m$^3$ loose (Alakangas et al. 1999). Long distance transportation with chip containers and chips produced with terrain chipper has been studied by Laurila & Vesisenaho (1997) and Kokko (1998).

Figure 26. Harvesting chain of forest residues based on the terrain chipper – harvester (left), loading of chips into the exchangeable container (in the middle) and loading of the container for truck transport to power plant (right) (Biowatti Oy, VT).

Long distance transportation of chips produced with terrain chipper (Alakangas et al. 1999)

- lorries with containers are used, each carrying 2 to 3 containers,
• containers must be placed on an even surface so that tipping chips into a container and mounting containers could be done efficiently,
• there must be enough containers so that the chipper needs not to wait,
• transportation cost can be reduced by using containers which fit inside each other.

5.4 CHIPPING AT THE TERMINAL -METHOD

5.4.1 Fuel terminal

In the terminal method (Fredriksson 2005) the forest residues are hauled from the surroundings to the fuel terminal. The haulage distance is about 100–500 m to roadside landing while it is less than 10 km to fuel terminal. For the terrain haulage of forest residues e.g. the Havu-Hukka forest residue trailer is used. It is more effective than the normal forwarder and also is allowed to be used for road transport (Leinonen et al. 2000).

When chipping at the fuel terminal, it is possible to chip forest residues either onto the ground or directly to the truck trailer. With chipping onto the ground it is possible to get rid of the so called hot chain, provided the amount of forest residues is big enough and the chip storages become large enough (Leinonen et al. 2000).

The main factors affecting the selection of the location for a multi fuel terminal are the sufficient fuel reserves, sufficient space for storage piles of both raw material and the chips, roads with sufficient load bearing capacity and proper condition, open and windy location of the terminal area, and flat and load bearing ground with no extra impurities. Stockpile areas of gravel pits and storage field, etc. are proper locations for the terminals (Leinonen et al. 2000).

In the studies, the size of the terminal varied on the basis of the working site conditions and raw material stocks, being 5 000-20 000 m$^3$ loose of logging residues. If the height of the storage is 5.0 m, the corresponding amount of chips is 2 000-8 000 m$^3$ loose. A circular terminal, dimensioned for logging residues, is presented in the figure 27. The volume of the terminal is about 5 000 m$^3$ loose of logging residues. The height and the width of the logging residue stockpile in this model is 5 m, so the volume of terminal chips produced from this amount is about 2 000 m$^3$ loose (Leinonen et al. 2000).
The ground of the fuel terminal area, especially the raw material and chips stockpile area, has to be load bearing and flat, and it must not contain stones. If operated on unpaved areas, the stockpile areas have to be backed in order to prevent the impurities such as stones from getting into the logging residues and chips. Additionally, the backing of the areas makes the terminals flat, which ease the loading of the chips. Bark, saw dust or ash can be used as backing material for the stockpile areas (Leinonen et al. 2000).

There are some advantages to use fuel terminal – harvesting chain. Forest residues dry very well at open fuel terminals. Also the harmful impurities like stones are easily avoided in this harvesting chain. By using terminal chipping of logging residues it is possible to produce high quality chips, the properties of which include homogenous chip size and low moisture content. These high quality chips are excellent fuels for communal scale heating plants.

Several of the working phases are alike between roadside landing -method and fuel terminal -method, for ex. forest hauling, chipping and storage of forest residue, but some work phases differ and about those it is told in next chapters.

5.4.2 Chipping and crushing at the terminal

Hammer and plate crushers are also suited for processing logging residue due to their construction. Several manufacturers offer tub grinders on wheels, which are suited for processing logging residue. Crushers tolerate impurities, such as rock and metal, much better than chippers. The only option for processing raw material with rocks and metal is crushing. A problem is presented by the low quality of the resulting chips since crushing produces in fairly long splinters. This is why chips made by a crusher can only be used at large end use facilities where even long splinters cause no conveyor malfunctions (Alakangas et al 1999).

VTT and Joutsan Konepalvelu Oy have developed a two stage crusher (Tiihonen & Korpi 2004), which can be mobile or stationary. High quality and homogenous wood fuel is done by the two-stage crusher.
The power requirements of crushing are significantly higher than those of chipping. In crushing the raw material is comminute by tearing and in chipping by cutting. Crushers are usually heavy units, which are difficult to transfer. Consequently, they are better suited for processing logging residue at an end use facility or terminal than for operation at a roadside landing. Crushed chips made from snow mixed logging residue are wetter than chipped chips made from corresponding raw material. When logging residue is chipped most of the accompanying snow falls off. For crushing logging residue the effective hourly output is in the range of 60 to 100 $m^3$ lose of logging residue chips (Pulkkinen 1996).

In terminal chipping Morbark 1100 bucket-crusher and Jenz 55 hammer-crusher, equipped with moving hammers were tested. Both of the crusher units were relatively large and the axle loads were high so they only could be used on areas with high load-bearing capacity. The maximum output of this equipment was 100 $m^3$ loose of logging residue chip per productive hour. The power demand of the crusher was 225-275 kW (Tiihonen et al. 2000).

**Advantages and disadvantages of using a crusher** (Alakangas et al 1999)

- crushers tolerate impurities better than chippers,
- low quality of crush because of splinters,
- crusher produced chips can be used at large end use facilities only,
- crushers are heavy and difficult to transport.

### 5.4.3 Storing of forest residue chips

Chips have to be stored for several months before the use in order to ensure constant delivery of chips to the plant throughout the year. The storage problems include dry substance (DS) losses, wetting and freezing of the chips. Biological and chemical reactions, as well as the activity of wood decaying fungi cause dry matter losses. Wetting of the chips in stockpiles is caused by rainfall and chemical reactions in the wood (Leinonen et al. 2000).

The main factor affecting the stockpiling of logging residue chips is the initial moisture content of the chips. The high the initial moisture content is the greater are also the dry matter losses. In long-term storage it is possible to prevent dry matter losses by covering the stockpiles (Leinonen et al. 2000).

Long-term storage of the chips is not recommended due to high moisture and dry matter losses. If long-term storing is necessary the initial moisture content of the chips has to be less than 30 w-% and the stockpile has to be covered, so that the dry matter losses remain under 5 w-%. Long-term storing of chips is reasonable if the deliveries are to be ensured under all circumstances (Leinonen et al. 2000).

It is usually profitable to store the chips only for short-term to keep the moisture and dry matter losses as low as possible. In short-term storing the dry matter losses are low (< 1.0%) if the storage time is less than two weeks. Short-term chip-stockpile does not
need to be covered, but the stockpile has to be made as large as possible. The initial moisture content should also be as low as possible (< 30 w-%) (Leinonen et al. 2000).

5.5 CHIPPING AT THE POWER PLANT - METHOD

5.5.1 Road transport of loose logging residues

Over short distance, it may still be economical to transport logging residues to the plant as unprocessed loose material (Figure 28). Logging residue is hauled from forest and stored on road side equal way as described chapters before. The stationary crushers currently in use are capable of comminuting loose logging residues, although the productivity is not as high as for bundled material. An ongoing project of the programme aims to develop an enlarged load space and compressing techniques for residue trucks (Tiihonen et al. 2004).

*Figure 28. Loading unprocessed logging residue into a biomass truck (Metsäteho).*

From the point of view of long distance transportation with a lorry and trailer, transporting unchipped, incompact logging residue is problematic because its low density, table 3. While the solid volume content of chips is 35 to 40% it is only 15 to 20% for whole logging residue (Alakangas et al 1999).

In order to achieve maximum loads with a full trailer combination (110 m³ loose), the density would need to be as high as 336 kg/m³ loose. The profitability of transportation can be improved by compacting the load or by extending the load space.
Table 3. The effect of moisture content on the green mass of logging residue.

<table>
<thead>
<tr>
<th>Solid volume content, %</th>
<th>Basic density, kg/m³ loose, Moisture content varies</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-20</td>
<td>30%</td>
</tr>
<tr>
<td>In compacted logging residue</td>
<td>130</td>
</tr>
</tbody>
</table>

Long distance transportation of logging residue places the following demands on the transportation equipment (Alakangas et al 1999):

1. The load space of the lorry must be built according to the maximum allowable dimensions, yet maximum allowable total weight will not be achieved.
2. The load space must have a closed bottom and sides which prevent the material from falling out during transportation.
3. In principle, logging residue can be transported with the same equipment as chips or peat. However, this requires that lorries are equipped with dedicated cranes.
4. Loading and unloading with a heavier crane than a standard timber one is faster, and it can be also used for compacting the load against the sides.
5. The crane should have as long as possible so that it could be used for loading as far as the rearmost part of the load space without disconnecting the trailer. If the length of a timber crane is limited, the combination can be driven to "jack knife position" at the loading stage or the trailer disconnected for loading logging residue.
6. When a special logging residue grapple is used instead of timber grapple logging residue can be loaded faster. Due to the width of the logging residue grapple, longitudinal bundles are formed, which means that placing them in the load space is easy. Large grapple loads result a more compact load compared to one made with a timber grapple.
7. If the intention is to compact logging residue in the load space, the grapple of the crane must operate in two directions so that logging residue can be compacted when the grapple is opened and closed.

One option would be to use a heavy, separate crane unit on a lorry chassis for loading logging residue but this would lead to the same hot chain problems as the chipper/chip lorry combination. In other words, the idle time of one machine affects the operation of the entire chain (Alakangas et al 1999).

Using a heavy crane for the long distance transportation of unprocessed logging residue is an absolute operative requirement. Trip frequency can be improved an average 29% when a heavy crane is used instead of a regular crane. Furthermore, working with a heavy crane is faster than with a regular crane. According to a Swedish study the loading productivity of a heavy crane is approximately 34% better than that of a regular crane (Norden 1992). Norden has also studied the use of heavy crane to compressing of forest residue load of the lorry.

Since full load capacity cannot be achieved with the lorry transportation of logging residue, the load must be compacted or the load space extended. If the entire load space of the lorry is to be utilised, a crane with the so called "Z" rest position, folding behind
the load space and taking up hardly any usable volume, can be used (Alakangas et al 1999).

The productivity of the chipper is improved when there is no idle time because of waiting for chips lorries. End site chipping is 20% more productive than chipping carried out at a roadside landing site. This means that for transportation distances below 55 km the most economical solution is the transportation of whole logging residue and chipping it at the end use facility. For longer transportation distances the most economical solution is roadside chipping and long distance transport with two chip lorries. Long distance transportation with a logging residue trailer lorry equipped with a regular crane is not competitive with the other methods (Asikainen 1995).

VTT has developed compacting technology for truck transport of forest residues from forest to power plant. By using the VTT’s compacting technology it is possible to increase the net load of the truck by 50%. Tiihonen et al. (2004) researched different loading methods and trailer constructions in Finland and Sweden. At VTT were done compression tests for prototype trailer to define forces and strength of the trailer construction.

**Chipping/crushing logging residue at the end use facility** (Alakangas et al. 1999).

- hot chain problems are avoided,
- chipping/crushing can be done more economically than in terrain or by the roadside,
- productivity is 20% better than for roadside chipping,
- chipping at the end use facility is the most economical option when the transportation distance is less than 55 km,
- lorry transport of logging residue is not economical without compacting,
- the profitability of transportation can be improved either by compacting the load or extending the load space,
- heavy crane must be used.

### 5.5.2 Crushing logging residue at the power plant

Crushers and heavy power chippers are best suited for end site processing of logging residue because they require little maintenance and can easily be automated. In addition, crushers tolerate impurities well. Consequently, idle time for knife maintenance can be minimised. In contrast, using chippers for end site processing would tie up significantly more operational and maintenance resources (Alakangas et al. 1999).

End site crushing of logging residue is the most efficient if logging residue loads can be unloaded directly on the feed conveyor of the crusher with the unloading/loading equipment of the transportation lorry. Thus no additional storage or feeding of the raw material would be required and crushing cost below 2 €/m$^3$ could be achieved (Rinne 1998).
Fixed installations of electric powered crushers are suited for end site crushing of logging residue. Crushers can be either plate or hammer crushers. High speed crushers are probably the best for crushing logging residue.

The problems of end site crushing include noise and dust. The sound intensity level produced by crushers may reach 100 to 110 dB. The dust problem can be mitigated for example with water spray.

In Finland Alholmens Kraft's power plant has a rapidly rotating stationary crusher of Saalasti Oy with 180 x 120 cm feed opening, powered by two 500 kW engines. The capacity is 160 m$^3$ solid/h of logging residue chip. Jämsänkoski power plant has a slowly rotating 2-drum ECO Crusher with a 330 x 420 cm feed opening. The capacity is 50-180 m$^3$ solid/h, depending on the properties of the biomass. BMH Wood Technology makes complete fuel receiving systems and when a crusher is included, receiving systems is capable of handling all kinds of forest fuels (Hakkila 2004).

Variety wood fuels have been crushed by the pilot line of two-stage crusher of VTT (Tiihonen & Korpi 2004). The low costs, efficient feeding, high capacity, tolerance against impurities and low power demand are the main advantages of this crushing method. Both crushing stages can be utilised separately depending on the combustion process, figure 29.

![Figure 29. Two-stage crusher is used for research on variety of wood fuels. Crushing is carried out in two stages. The first phase is preliminary crushing and the secondary phase is the final fine crushing (VTT).](image)

During the research project, carried out at the VTT, by using the two-phase crushing line, wood fuel was made from logging residues, demolition wood, forest stumps and arboricultural residues. Average production capacity was 40-100 m$^3$ loose/h depending on material. Energy use 0.6-1.0 kWh/m$^3$ loose in crushers and 0.9-1.8 kWh/m$^3$ loose in whole production line including hydraulic feeding crane.
Crushing logging residue at the end use facility (Alakangas et al. 1999)
- electric powered fixed disc or hammer crushers are optimal little need for maintenance work,
- crushers tolerate impurities,
- downtime for knife maintenance minor,
- it must be possible to unload a lorry directly to the feed conveyor of crusher or by using equipment installed on the lorry without intermediate storage.

5.6 BUNDLING LOGGING RESIDUES -METHOD

A promising alternative for transporting whole logging residues is a method, in which bundling is done at logging area before long distance transport.

5.6.1 Bundling technology

It is necessary to increase the bulk density of residues, and for this an interesting prototype bundler, Fiberpac, had been introduced earlier in Sweden. Experiences with the technique were encouraging, but it did not achieve wide acceptance at a time when the use of forest biomass was not growing and there was little room or need for new production capacity. The situation was reverse in Finland where the use of forest chips had started to grow rapidly. Consequently, Timberjack purchased the rights to the Fiberpac technology and developed the technology further (Hakkila 2004).

Figure 30. The bundling method is a solution for boosting the large-scale use of forest biomass. It is already in wide use in Finland and has, for example, provided the Ahlholmens Kraft power, the largest biomass in the world, with a reliable and an effective forest chip production system. Bundling provides a more effective way to manage and control the procurement process. The transport of biomass as bundles integrates industrial and energy wood logistics, since bundles can be transported by standard timber trucks (Tekes 2003).

John Deere's subsidiary Timberjack has developed since 1997 bundling technology for forest residues in Finland, figure 30. The whole harvesting chain consists of the bundling machine, forwarder, truck and crusher which are situated at the power plant. The bundling machine is constructed on a normal forwarder chassis. The bundling machine (Timberjack 370) produces ‘slash logs’ which are about 3 m long and about 0.6-0.8 m in diameter. The bundles are wrapped with strings in every 0.4 m. The bundling machine produces about 20 bundles in one hour. Each bundle contains about 1 MWh of energy and weights 500 kg. Forest residues like tops, branches and small trees
from clear cuttings are suitable raw material for a bundling machine. Also small trees from thinnings are suitable for bundling. The bundler is developed to be used together with the cut-to-length felling method. In this method the trees are delimbed on cutting site and the forest residues are left there. The bundles are hauled with a standard forwarder to the road side. The bundles are handled like other assortments and the bundles form their own stacks at the roadside landing. The bundles are transported to the power plant with standard on-road trucks. Crushing or chipping is done at the power plant. The power demand of the crushers is 500-1000 kW. The capacity of the crushers is between 130-200 m³ solid/h (Timperi 2000).

The new model of Timberjack 1490D residue bundler (Hakkila 2004) is used for bundling logging residues and small-sized trees in clear-cut areas. The total mass, including the 10-m-reach crane, is 32 tons. The revolving bundling device is fed from the side. The bundle is formed by compressing and tying with cord. The process is continuous, and the bundles of 70 cm diameter are cross-cut with a chainsaw, normally to 3.2 m lengths to fit ideally with the measurements of the vehicles used for transportation. Bundles are transported to the road side using a conventional forwarder and on to the plant using a conventional timber truck. About 12 bundles form one forwarder load, and 65 bundles or 30 tons form one truck load.

![Figure 31. Effect of haulage of forest residue in the productivity as a function of the haulage way and haulage distance in the forest (Asikainen et al. 2001).](image)

Figure 31. Effect of haulage of forest residue in the productivity as a function of the haulage way and haulage distance in the forest (Asikainen et al. 2001).

Before all the harvested material effects on the productivity of bundling. Productivity spruce based areas is 9 m³ solid/h, pine based 6.5 m³ solid/h and in a deciduous forest 8.3 m³ solid/h (Korpilahti 2002). Besides, bundling of dry forest residue is slower than bundling of fresh forest residue (Asikainen et al. 2001). Also, if forest residue is bunched, that contributes the harvesting. During the forest haulage productivity depends on the extent of load as figure 31 shows.
5.6.2 Experiences of the bundling -method

The real advantages of the system did not show up as long as the profitability of the bundling techniques was evaluated simply by adding successively costs from separate work phases of the chain. In a holistic systems analysis, the new technology compares well with the traditional alternatives, because attention is also given to logistics, operative availability, process control, reliability, scaling and environmental impacts (Hakkila 2004):

- The machines involved operate independently of each other making the system cool and reliable.
- The integration of bundle production in the procurement of industrial roundwood is simple, as off-road and on-road transportation can be performed with standard equipment.
- The bundler produces accurate real-time information about the daily production and inventories. Scaling becomes cost-free.
- The storage of bundles is simple: storage space requirement is reduced, little loss or deterioration of biomass occurs, and long-term storage for the winter season is easy.
- The noise, dust and litter problems, which may occur in conjunction with comminution at a landing, are avoided.
- The reliability of the fuel deliveries is greatly improved, while the overhead costs are reduced.
- Bundles can be unloaded from a vehicle and stored at any stage of the production chain. This possibility, as well as reliable information about the biomass inventories, create excellent conditions for efficient process control.

The system based on residue bundles and comminution at a plant was developed jointly by UPM, Pohjolan Voima, Alholmens Kraft and Timberjack to supply forest biomass to the world's largest biofuel-fired CHP plant. Since then, more large plants have installed a stationary crusher and started to apply the same technology. Total capacity of residue bundlers was 0.6 million m³ solid or 1.2 TWh per annum, corresponding to one third of the forest chips used by all heating and CHP-plants. The organizations responsible for the procurement of raw material to the forest industries have found the bundling technology an attractive way to integrate fuel production in their operations (Hakkila 2004).

In the beginning of the year 2004 as many as 24 residue bundlers operated in Finland. The structure of the base machine is designed for working at the terrain, but one bundler has been mounted on a truck for Central European conditions, figure 32.
Driven by logistic advantages and improved reliability of fuel deliveries, bundling technology has developed rapidly, and new manufacturers have appeared. For example, Pinox Oy (former S. Pinomaki Ky) has developed RS2000 residue bundler, which is mounted on Pika Combi 828 harwarder. The 21 ton unit can be converted easily to forwarder for the off-road transportation of the bundles (Figure 33).

Although bundling is a proven technology, it still has significant development potential. Among the possibilities are (Hakkila 2004):

- Improved productivity of bundling by making the feeding and compressing functions faster, and forwarding more efficient through enlarged load space.
• Broadening the application area from logging residues to small-tree material. The problem is the narrow working space in young thinning stands rather than the bundling process itself.
• Use of mobile chippers and crushers for comminution of residue bundles at small plants or terminals where the use of a stationary crusher is not economical.
• Solving some minor problems: keeping stones out of the bundles, use of rear and side walls in trucks for traffic safety, and tangling of cords with the axles of crushers and disc screens.

6 PRODUCTION OF FOREST RESIDUES FROM THINNINGS

6.1 BACKGROUND FOR THINNINGS

Thinning attempts to replicate the forest’s natural development, the aim normally being to achieve a uniform age composition. Thinning is used to ensure growing space for the forest’s best trees by felling those with retarded growth and those which are diseased and of poor quality. The forest is thinned between one and three times in the rotation, depending on the growing conditions and tree species. The thinning frequency has been reduced in order to improve its cost-effectiveness and to reduce damage to the growing stock (Finnish Forest Industry 2000).

The production of forest chips for fuel was started in the mid-1950s. The primary raw material was then small trees from young thinning stands. Trees were carefully delimbed, and the product was of high quality as required by the then existing chip feeding and combustion techniques (Hakkila 2004).

As the cost of labour increased, the competitiveness of stemwood chips suffered, and the use of chips stagnated. The introduction of hydraulic crane in the 1970s made multi-tree handling possible. Only then could the production of small-tree chips be rationalized and delimbing was abandoned. The appearance of a new concept, whole-tree chips, resulted in many changes (Hakkila 2004):

• The yield of chips increased 15-50%,
• The productivity of harvesting increased 15-40%,
• The cost of procurement was reduced 20-40%,
• The loss of nutrients from forest soil reduced 50-150%,
• The particle size distribution and other quality properties of chips suffered,
• The machines had to be more robust.

The cost of small-tree chips nevertheless remained high. Production was subsidized for silvicultural reasons, but in the 1990s logging residue chips otherwise became more competitive. The increase in use was restricted exclusively to logging residue chips due to their cheaper cost, but a number of reasons have gradually appeared for extending the raw material base to young thinning stands (Hakkila 2004):
• *Tending of young forests* needs to be intensified,
• *Broadening the raw material base* improves the availability of forest fuels and shortens transport distances,
• *Independence of the timber markets assists* the acquisition of fuel during times of depression in the forest industries when the production of other wood fuels is reduced,
• *Independent chip producers* who are not involved in the harvesting of industrial timber have an easier access to raw material in young thinning stands,
• *Seasonal fluctuation of employment* may be levelled by performing small-tree harvesting in the summer time when round wood and sawlog operations slow down,
• *Diameter requirements round wood* can be made more elastic to respond the fluctuation of demand, if round wood and fuelwood are parallel products,
• *Small-tree chips are of better quality* compared to logging residue chips. Small trees are easier to store and season and they produce drier chips with lower needle content. This is important, especially for small heating plants,
• *Small-tree operations create more jobs* which are definitely needed in rural areas. However, in the long term the availability of labour is, expected to decrease, and a higher need for labour may actually become a problem unless the operations are fully mechanized.

Under-sized small-tree material is available mainly in young stands where good tending practices have been neglected. Two types of fuel harvesting operations occur. If fuel is the primary product, the treatment is called *energywood thinning*. If the removed trees are thick enough to allow round wood to become the primary product, with fuelwood as a by-product, the treatment is called *first thinning*. In both cases, technical logging conditions are difficult because of the small size of the trees (Hakkila 2004).

Table 4 presents an example of the management regime and biomass yield of coniferous forests in southern Finland. The lower values of the biomass residues refer to Scots pine and the higher values to Norway spruce. These biomass residues form the bulk of the energy potential of a stand during a rotation period. An additional source is stump and root wood (Hakkila 2004). Management of young stands is generally carried out once or twice during the 15 years or so of the young stand stage. At its final treatment the stand is thinned to a density of about 1600–2000 saplings, depending on the species, in advance of the first actual thinning harvest (Anon 2000).

The total production of forest chips was 388 000 m$^3$ solid in Finland in 2003. Of this the share of whole tree chips was 288 000 m$^3$ solid and the share of log chips was 100 000 m$^3$ solid.

At the moment the target is to decrease the production costs of small tree chips by developing harvesting technology, management and logistics. This R&D work has been done in a national Wood energy technology -research program.
Table 4. An example of forest management regime in southern Finland (Hakkila 1995, 2004).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stand age years</th>
<th>Yield of timber m³ solid/ha</th>
<th>Biomass residues m³ solid/ha</th>
<th>Biomass residues toe/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-commercial thinning</td>
<td>10-20</td>
<td>-</td>
<td>15-50</td>
<td>3-9</td>
</tr>
<tr>
<td>1st commercial thinning</td>
<td>25-40</td>
<td>30-80</td>
<td>30-50</td>
<td>6-9</td>
</tr>
<tr>
<td>2nd commercial thinning</td>
<td>40-60</td>
<td>50-90</td>
<td>20-40</td>
<td>4-8</td>
</tr>
<tr>
<td>3rd commercial thinning</td>
<td>50-70</td>
<td>60-100</td>
<td>20-40</td>
<td>4-8</td>
</tr>
<tr>
<td>Final harvest</td>
<td>70-100</td>
<td>220-330</td>
<td>70-130</td>
<td>13-24</td>
</tr>
<tr>
<td>Total during rotation</td>
<td></td>
<td>360-600</td>
<td>155-310</td>
<td>30-58</td>
</tr>
</tbody>
</table>

Besides making small tree chips young forest is used for production of chopped wood. It is important fuel at country side and also in towns as a fuel in saunas, fireplaces and free time use. For chopped firewood there is many dealers nation wide and it is important mercantile fuel in Finland.

6.2 MANUAL HARVESTING TECHNOLOGY FOR ENERGYWOOD FROM THINNING STANDS

Many times the felling for energywood thinning is made manually (Fig. 34) with a chainsaw, using a felling-piling technique. In this method the trees are cut and piled beside the striproad as whole trees or as 5 - 7 m long tree sections. The chainsaw is equipped with a so called felling frame (Ihonen, M. 1997b), which allows the user to fell the trees with his/her back straight. The performance of chainsaw felling varies between 1.5 - 4 m³ loose of delimbed trees per hour, depending on tree size, tree species, undergrowth, terrain, snow cover etc. (Mielikäinen & Hakkila 1998). In another study the performance of chainsaw felling has varied from 0.24-0.64 m³ solid/h (Hämäläinen et al. 1998a). In the work phase studies carried out by the TTS Institute, moving from a stem to another took 18 – 27% of the efficient working time. Piling of the energy wood along the strip roads took 17 – 30% of the working time. The share of cross cutting of the trees being between 10 and 15 percent and the so called auxiliary time (consisting for example of bush clearing from the cutting area and from the strip road, and planning of the work) approximately 4% (Ryynänen et. al 1998).

The smaller the harvested trees are, the more profitable it is to harvest them manually (using chain saw). Thus logging sites with only energy wood should be harvested manually using felling piling method.
6.3 HARVESTING TECHNOLOGY FOR FIRST THINNING

The first thinning harvest is carried out about 30–35 years after regeneration, when the trees are 12–14 metres tall. The number of trunks in the growing stock is reduced to about 1000 per hectare. Significantly more of these first thinnings ought to be carried out than is in fact the case today. This neglect considerably weakens the profitability of forest growth. In later thinnings the number of trunks is reduced in one or more stages to 450–550 trunks per hectare, before regeneration is later carried out (Finnish Forest Industry 2000).

6.3.1 Mechanical felling of young forest

To substitute the expensive and sometimes less pleasant manual work several companies have developed a mechanized method for restoring and managing young forests with different techniques. In the table 5 is a list of felling heads planned for young forest and thinning and www-addresses of the companies making those models.
Table 5.  
Table 5. **Felling heads of different companies for thinning of young forest.**

<table>
<thead>
<tr>
<th>Company / www-address</th>
<th>Felling head for thinning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ponsse Oyj / <a href="http://www.ponsse.fi">www.ponsse.fi</a></td>
<td>EH25</td>
</tr>
<tr>
<td>S&amp;A Nisula Oy / <a href="http://www.sanisula.fi/fi/index.htm">www.sanisula.fi/fi/index.htm</a></td>
<td>280E</td>
</tr>
<tr>
<td>Oy Logset Ab / <a href="http://www.logset.fi">www.logset.fi</a></td>
<td></td>
</tr>
<tr>
<td>Kone-Meskus Oy / <a href="http://www.kone-meskus.fi/">www.kone-meskus.fi/</a></td>
<td>AM-230</td>
</tr>
<tr>
<td>Evimet-Group Oy / <a href="http://www.evimet.com/Karsintakoura.htm">www.evimet.com/Karsintakoura.htm</a></td>
<td></td>
</tr>
<tr>
<td>Metso-Metalli Oy / <a href="http://www.arbro.fi/2-metsakoneet.htm">www.arbro.fi/2-metsakoneet.htm</a></td>
<td>ARBRO 400 S</td>
</tr>
<tr>
<td>Kone-Ketonen Oy / <a href="http://www.kone-ketonen.fi/fi/mallisto.html">www.kone-ketonen.fi/fi/mallisto.html</a></td>
<td>Keto 100, (150)</td>
</tr>
<tr>
<td>Timberjack / <a href="http://www.timberjack.fi/">www.timberjack.fi/</a></td>
<td>720, 730</td>
</tr>
<tr>
<td>Lako Forest Oy Ltd / <a href="http://www.lakoforest.fi/">www.lakoforest.fi/</a></td>
<td>Loko 43HD, 53HD</td>
</tr>
</tbody>
</table>

The harvesting devices of thinning are mounted in the grabble of the hydraulic crane. The devices are either stroke- or roller-fed. In the stroke-fed model the delimming action is activated by a hydraulic cylinder, which makes the sliding boom to move to and fro. In the roller-fed models the principle of function is the same as in the feeders of the big, real harvesting machines. Crosscutting can be done either with a guillotine cutter or with a chainsaw. The diameter of the processed trees is about 20-30 cm. In modern harvesters the felling head can take several thin stems during the thinning process.

The productivity of the harvesting is dependent on the size of the processed stems and the area. In two studies of Ihonen (1997 and 1998) the productivity of integrated merchantable and fuelwood harvesting with two different felling heads was about 3.2 - 3.9 m³ solid per effective hour. In this method round wood was delimited and crosscut. The tops of the round wood and other material unsuitable for round wood were bunched with branches. The productivity of the harvesters was about 1.8 - 2.2 m³ solid per effective hour in the felling bunching operation of mere small-diameter trees. It is more effective to harvest as whole trees.

With Timberjack 720 accumulating felling head (Asikainen et al. 2004) the average productivity of summer and winter experiments was 5.9 m³ solid/h, when average volume of stem was 24 dm³.

Timberjack 720 and 730 accumulating felling heads allow the multi-tree handling in young stands. Any harvester suitable for thinning, such as Timberjack 770 (Figure 35), may act as the base machine. The felling head replaces the conventional harvester head. Trees are cross-cut by shearing, the maximum stem diameter being 20 cm for the former
and 30 cm for the latter. The feller-head automatically collects several small trees at a time to reduce the movements of the crane and to improve productivity. The felling heads 720 and 730 weigh 340 kg and 620 kg respectively (Hakkila 2004). After cutting, the trees are hauled to the landing area with the forwarder.

![Timberjack 770 harvester equipped with the accumulating Timberjack 730 feller head for small-tree operations (Timberjack).](image)

When harvesting small size whole trees, at least one third is left at site. This part left in the forest consists, as far as possible, of tops and branches. The generation pattern usually includes drying of energy wood at site. One aim is that the needle and leave mass left in the forest is distributed evenly over the whole logging site. From this point of view conditions of the stand may be even superior to those in conventional mechanical harvesting, which leaves the space between strip roads more or less clean of logging residues as the major part of needle and leave mass and nutrients is accumulated on a narrow area along the strip roads in conjunction with delimbing with a harvester. In the harvest of small whole trees, accumulation along the strip road is reduced, and the nutrients released from the needles can be utilised by a higher number of trees (Paananen & Kalliola 2003).

### 6.3.2 Terrain haulage of small-wood

After felling the tree bunches are transported with the forwarder to the landing beside the road. At the landing site the trees are piled.

The agricultural tractor machinery can easily be adapted to forest haulage of stems and whole trees. The great advantage of agricultural tractors is easy and quick maneuverability from one site to another. Thus also smaller sites can be effectively worked. Especially when hauling whole trees the mass of the payload can be smaller than the volume of the hauling machine. Because of this the productivity of forest
haulage can be improved by widening the loading space, for example by mounting extra poles in the trailer. Productivity might also improve by using load-compacting devices. Hydraulic compacting devices increase costs, so they are more suitable for bigger forest entrepreneurs. Figure 36 presents an agricultural tractor-based combination, in which the loading width of the trailer can be hydraulically adjusted from 2.0 m to 4.2 m. The capacity of the load increases from 15 m³ to 30 m³, respectively. The narrowing of the load space allows forest haulage across growing stands. This combination is also suitable in hauling logging residues (Mutikainen 1999).

The capacity of the forwarder was 4.1-5.5 m³ solid/h at the first commercial stand in the study of Hämäläinen et al. (1998b). Asikainen et al. (2004) measured 8.6 m³ solids/h, when hipping was done by harvester and 6.5 m³ solid/h, when hips were made manually. Distance of forest transport was 250 m.

Figure 36. Valtra farm tractor-based residue forwarder of Metsäenergia with enlarging load space (TTS Institute).

The roadside landing must be free of haulage-hindering obstacles, such as rocks, stumps or pits in the ground. The best possible place is located higher than the surrounding terrain; it is moreover windy, flat and solid. The storing place has to be large enough for the machine move there without difficulty. The machinery used varies from case to case and so do the requirements for the storing place. In order to avoid any problems, it is advisable to plan the use of the processing and hauling machines carefully in advance (Savolainen & Berggren 2000).

The snowless season is the best for hauling and bunching of energy wood. A bed timber should be placed under the pile as was done in the logging phase. If the piled trees are to be chipped, the butt ends must face the strip road. In this way chipping is easiest. It is advisable to make the piles high, so in case of rain the wet surface will be small. As the front edge of the pile is like a spout, water won't spoil the whole pile. Bunching should
be done carefully so that rocks, raw humus or pieces of stumps won't accidentally get into the piles and finally break down the knives of the chipper (Savolainen & Berggren 2000).

6.3.3 Chipping the thinning residue

Chipping machines are divided according to their function principles into disc-, tapered screw- and drum chippers. Disc- and tapered screw chippers are most suitable for homogenous raw material such as whole trees and delimbed long wood. Drum chippers aren't as sensitive to inequalities as disc chippers, so they are also suitable for processing logging residues. The chippers have either an engine of their own or the driving power is supplied by a vehicle: a tractor or a truck. The biggest chippers are usually equipped with an own engine. The productivity of the chipper is affected by the properties of the chipper, raw material and storing arrangements. The chipping capacity of the small, domestic use chippers is 5 - 20 m³ loose per working hour. The biggest drum chippers can achieve a productivity of 150 m³ loose per working hour. The feeding of the big chippers is carried out by a hydraulic crane. Working is thus safer and more efficient than manual feeding (Savolainen & Berggren 2000).

There are several makers of chipping machines, for example Junkari Oy and Farmi Forest Oy chipping machines for farmers and Kesla Oyj makes bigger chippers for entrepreneurs.

The chipping at the terrain method is used also for harvesting small tree chips for fuel in Finland. In this method the trees are felled manually with a chainsaw using the felling-piling technique. The capacity of the terrain chipper is about 8 m³ solid per hour (Mielikäinen & Hakkila 1998).

7 PRODUCTION OF STUMP AND ROOT RESIDUE

The stump-root system is defined as all wood and bark of a tree below the stump cross-section. Stump-root systems can only be salvaged from clear-cutting areas, figure 37. Extraction of stumps is carried out with heavy machines and, therefore, only stumps from saw timber-sized trees can be accepted. Moreover, thin roots break- and stay in the ground. Sand and stones prevent comminution with sharp knives and so crushers are used instead of chippers (Hakkila 2004).

There is an important difference in the structure of a stump-root system between pine and spruce (Figure 38). Wet peatlands and the northernmost Finland excluded, pine typically has a taproot, and only a half of the total mass is composed of lateral roots. Spruce, on the other hand, has no taproot at all, hut thicker lateral roots. In spruce, therefore, the central section of the stump-root system covers only one third and the lateral roots two thirds of the total mass. The difference between the species affects the techniques of uprooting and splitting. A spruce stump is easier to harvest and causes only a shallow hole in the ground (Hakkila 2004).
The use of stump and root wood for fibre and fuel was studied actively in Finland and Sweden during the 1970s and 1980s, but the cost was found to be excessive. UPM recently started to again develop the production of stump wood for fuel, and progress has been rapid. In 2003, UPM harvested stump and root wood from an area of almost 1000 ha. In 2004 (Ylitalo 2005) it was used stumps as fuel 144 million m³ solid.

In the earlier studies by the Finnish Forest Research Institute (FFRI), the harvestable dry mass of a stump-root system is 23-25% of the stem mass, when side-roots thinner than 5 cm are not recovered. Figure 39 shows the dry mass and energy content of a stump-root system as a function of tree size. The yield of fuel exceeded the FFRI research findings because stump height has increased following the replacement of manual felling by harvesters. A part of the root section thinner than 5 cm is also recovered (Hakkila 2004).

The removal of stump-root systems facilitates site preparation for regeneration. It also involves in opportunity to exterminate the root rot fungus from the stand, since the fungus survives in a regeneration area in the stumps and gradually infects the trees of the new generation (Piri 2003, Korhonen&Lipponen 2001).
Figure 39. Dry mass and heating value of a stump-root system as a function of stump diameter. Stump cross-section at root collar height, under 5 cm root sections excluded (Hakkila 2004).

Stumps are extracted mainly from final felling areas on fresh mineral soils. Soil disturbance is minimized as organic substances bind releasing nutrients and metals. In principle, the target is similar to that of conventional soil preparation, i.e., the humus layer is opened to as small extent as possible. 70 – 85% of humus surface is left untouched. Humus (organic material) can be in part covered or mixed with mineral soil. This procedure secures that the release of nutrients, heavy metals and aluminum to the groundwater is as small as possible. The ecological impact on the soil does not deviate significantly from that of normal soil preparation (Paananen & Kalliola 2003).

About 1/4 of stumps and greater part of all roots are left in the soil for forming rotten wood for use of organisms and for securing humus porosity required to maintain its oxygen content. A filtration zone is left along ditches and watercourses. It binds the humus and nutrients contained in surface waters to vegetation. The width of this zone should be 7 - 10 m (Paananen & Kalliola 2003).

Stumps can also be extracted from paludified final felling sites, where the peat layer is thin and the nutrient content is equal to that of fresh mineral soils. Stumps shall not be extracted from essential peatlands (Paananen & Kalliola 2003).

The new Finnish guidebook (Opas kannonnostoon 2004) presents the modern stump lifting technique in detail. In figures 40 - 43 is shown some main parts of the production method. Stump and root wood is rapidly became a preferred fuel at the CHP plants that possess a stationary crusher. The technology is new, and it has considerable development potential.
Figure 40. The area for stump lift has to be chosen: All places are not suitable and all stumps are not lifted. The best areas are spruce dominating forests and nutrient rich, low mineral and stones containing soils, where the logging residue is harvested (VTT).

Figure 41. There can be a delay of few months between logging and stump lifting. Best time for lifting is from May to November. Developing work is done all the time to advance the stump lifting techniques. Stump is shaked strongly during the lift, part of the soil and stones fallout and fill the pit. Lifting head can split big stumps to several parts and drying, cleaning, storage, transport and crushing at power plant become easier (VTT).
Figure 42. Stumps are stored in stocks over summer. Stumps dry and rains clean them up during the storage. It is wise to choose the stock place for easy transport. Special build big stump-trucks need much space on the forest roads. Also length of the boom, usually 7 m, makes requirements for construction and the place of the sump stock (VTT).

Figure 43. At the power plant the biggest problem is the stumps existing (mineral-) soil, stones and other impurities. With right lifting techniques and choose of production places the amount of impurities can be diminish (VTT).

8 QUALITY OF FOREST CHIPS

The quality of chips is affected by many properties such as moisture content, net caloric value, energy density, foliage content, ash content and particle size. It is not only the averages that matter. Perhaps even more important is the random variation of properties. Variation occurs within a truck load, between truck loads, and according to the season. An important goal of quality control is to reduce such variations. The Wood Energy Programme contained several projects that dealt with chip quality issues (Hakkila 2004).
To promote the trade of biofuels European biofuel standards (CEN TC 335) are under preparation (Alakangas 2005). Aim is that the customer and the seller can unanimously define the quality of solid biofuels.

Different boilers demand different fuel properties. The larger the plant, the more tolerant it usually is of random variations in fuel properties. Even so, knowledge of fuel properties and careful control of quality are essential to the operational reliability and efficient combustion of all boiler systems, large CHP plants included. The role of quality becomes more pronounced as the production of forest chips increases (Hakkila 2004)

The most important single quality factor is the moisture content of chips. Moisture content is a direct cost factor, and it is taken into account in the pricing of the fuel. Excessive moisture content results in a price reduction, while low moisture content brings a bonus. It affects the heating value, storage properties and transport costs of the fuel (Hakkila 2004):

- Net caloric heating value (dry). Vaporization consumes 0.7 kWh of heat energy per a kilogram of water. If the moisture content of fresh softwood is reduced from 55% to 40%, the initial amount of water is reduced by half, and the effective heating value increases 8%,
- Efficiency of combustion. Moist wood tends to combust incompletely, and a part of the heat energy of the fuel is then lost. This is a problem particularly in small boilers where the temperature remains too low if the fuel is moist,
- Emissions. Incomplete combustion results in increased emissions of carbon monoxide, hydrocarbons and fine particles,
- Storage properties. Chemical and biochemical reactions take place during the storage of chips, particularly if the biomass contains active nutrient-rich material such as foliage. Dry matter loss can be avoided only when the moisture content is less than 25%,
- Handling problems. In winter, moist chips may freeze in a truck load or silo causing blockages and damage to the fuel handling system of a plant.

Large plants are more tolerant of high and variable moisture content of chips, because they apply FBC technology and co-combust chips with peat. Anyhow, excessive moisture content strains the energy efficiency even of a large plant. The moisture content of wood fuels should not be too high, and it should not vary randomly from load to load (Hakkila 2004).

A common goal is to maintain the moisture content of forest chips below 50% at large plants and below 40% at small plants. In 2001, average moisture contents remained considerably below these target limits during the summer, but during the winter the limits were exceeded slightly. The annual average was 48% and 38% for large and small plants respectively, figure 44 (Hakkila 2004).

Besides moisture there are also other important fuel properties. Energy density refers to the amount of energy per unit volume of load space in a truck or storage pile. The energy density of wood fuel is determined by (Hakkila 2004):
• The basic density of wood, bark and needles (kg dry mass/m$^3$ solid). It is typically 450-500 kg/m$^3$ for small-sized birch and 370-410 kg/m$^3$ for other tree species in Finland. The lowest basic density, only 270 kg/m$^3$, is found in pine bark,
• Net caloric heating value (kWh/kg fuel) depends on the chemical content and moisture content of wood. Lignin has a higher heating value than carbohydrates, and softwoods therefore have a higher heating value than hardwoods. However, the effect of moisture content is stronger than the effect of wood properties,
• Solid volume factor (m$^3$ solid/m$^3$ loose) refers to the ratio of solid and loose volumes of fuel. For example, the Solid volume factor of uncommiminated logging residues is 0.15-0.20, but comminution raises it to 0.36-0.46. The common conversion factor for forest chips is 0.40. Compressed residue logs have about the same bulk density as chips in a truck load.

Figure 44. Monthly variation of the moisture content of forest chips in 2001. Averages of 4 large power plants and 7 small heating plants (Impola 2002, Hakkila 2004).

In 2001, the average energy density of forest chips arriving by truck at large power plants was 0.77 MWh/m$^3$ loose. Variations in moisture content caused seasonal fluctuations (Figure 45).
Compared with other fuels, the space requirement of forest fuels is large (Figure 46). Forest chips are, therefore typically a local fuel. If international trade of forest fuels becomes common in the future and forest fuels are transported over long distances, it may become profitable to refine biomass into pellets or liquid fuels (Hakkila 2004).

During combustion the contents of metal alkaloids and chlorides in needles are unusually high. Depending on the combustion conditions, the alkali metals can be oxidized or they can form sulphates or chlorides. If only wood chips are burned, the sulphur content is low and chlorides are formed. The chlorides then tend to condense on heat transfer surfaces of the boiler, slowing down the heat transfer and causing the risk of high-temperature corrosion. If the sulphur content of the fuel is increased, e.g. by blending peat with chips, sulphates are formed instead of chlorides, and the risk of corrosion is avoided. Unless the needle problem in combustion is solved, forest chips cannot be allowed to have high needle content. Reducing the amount of needles slows down the procurement process causing friction in the logistics and increased costs (Orjala & Ingalsuo 2000).

The content of ash is less than 0.5% in wood proper, but in bark 6 - 7 times and in foliage 6 - 11 times as much. The content of pure ash is thus about 1% in whole-tree chips and 2% in logging residue chips, or 4 - 6 kg/m$^3$ and 8 - 12 kg/m$^3$ fuel respectively. In practice, the yield of crude ash is higher, as forest chips contain impurities such as sand, and the ash may also contain char. Since ash causes costs and landfill problems, biomass should be as clean as possible when harvested (Hakkila 2004).

![Figure 45. Monthly variation of energy density of forest chips in 2001. Averages of three large plants (Impola 2002, Hakkila 2004).](image)
DIFFERENT ORGANISATIONS FOR PRODUCTION OF FOREST CHIPS

There are three large forest industry enterprises in Finland: UPM, StoraEnso and Metsäliitto Yhtymä and Biowatti Oy. They all have an advantage over other fuel producers in the access to biomass sources of private forests in conjunction with the normal timber trade. The fifth major actor is Vapo, the leading producer and developer of technology of fuel peat. Each of them has organized the production of forest chips in its own way (Hakkila 2004):

- **Metsäliitto-Yhtymä.** The forestry department of this concern is responsible for the purchase and harvesting of biomass. At the road side, the biomass is given over to a subsidiary company.

- **Biowatti Oy** was former responsible for comminution at the road side and delivering of the fuel of Metsäliitto-Yhtymä to the customers. In 2003, the wood fuel deliveries of Biowatti amounted to 4 TWh. Forest chips alone corresponded to 1 TWh, and together with pellets they were the fastest growing assortment in the company's fuel selection in 2003. Nowadays Biowatti Oy is independent fuel company after trade agreement in the beginning of year 2005.

- **UPM.** The procurement of forest chips belongs entirely to the company's forestry department, and it is integrated with the procurement of industrial raw material. In 2003, the production of forest chips was 1 TWh, most of which was delivered to CHP plants owned by Pohjolan Voima. Five of these plants are equipped with a stationary crusher for comminution of residue logs and stump and root wood.

- **StoraEnso.** Compared to the volume of timber harvesting, the scale of forest chip production is modest. The company's forestry department is responsible for production, which amounted to 0.1 TWh in 2003.
- **Vapo Oy.** As a peat producer Vapo lacks a forestry department and direct access to biomass sources. Synergy is sought by integrating wood fuel procurement with the peat business. Vapo is also a pellet producer and an owner of heating and CHP plants.

These five companies control three quarters of the commercial production of forest chips. Strong actors are creating the foundation for a robust supply regime. They can benefit from the large scale and the logistics systems available. However, as a large part of the chips is actually used by these producers themselves, competition is reduced (Hakkila 2004).

There is different ways to organize (Tahvanainen 2004, Asikainen 2001) the big scale wood residue delivery and trade:

1) one organisation purchases, harvests, delivers and sells both round wood and forest residue. Example UPM,

2) in an organisation two (affiliated) companies, one for harvest log wood and forest residue, one for chipping and selling the forest residue. Example; former cooperation between Metsäliitto and Biowatti Oy.

3) contract between two separate companies, one for harvest log wood and forest residue, one for chipping and selling the forest residue. Example; contracts between StoraEnso and Vapo Oy.

4) contract between two separate companies, one for harvesting, chipping forest residue and the other for trade. Example; Vapo Oy and private entrepreneurs.

Boundary line between two enterprises is usually at road side stock, one looks after the harvesting and forest haulage to stock, the other will chip or crush the forest residue and transport it to customer.

Instead of working as contractors for the large companies, some forest machine and truck entrepreneurs act as independent fuel producers (Alakangas 2003), either alone or through a network. Because of the small size of the enterprises, they operate only locally. Nevertheless, they have a positive effect on competition in the field. The Trade Association of Finnish Forestry and Earth Moving Contractors encourage its members to sign independent chip delivery contracts by promoting networking (Salo et al. 2003). The Wood Energy Programme examined possibilities to use an internet-based information and marketing system to promote the mobilization of the smalltree reserves of young thinning stands, and to improve the operating environment of small local fuel producers (Jokinen et al. 2002, Jaakko Pöyry consulting 2001). Kotimaiset Energiat Ky, Metsäenergia Ky and Lähienergia Oy are pioneers among the independent chip entrepreneurs in Finland (Hakkila 2004).

In addition to the fuel producers mentioned above, 200 small heat entrepreneurs operated in Finland at the end of 2004. They were either private persons such as farmers, or co-operatives or limited liability companies that were responsible for both fuel supply and heating of rural buildings, and they were paid for the heat rather than fuel. The average size of a boiler was 0.48 MW. The total capacity of the boilers was
100 MW, the annual consumption of forest chips 200 000 m³, and the turnover 5 M€ (Alakangas 20003, Lemola et al. 2003, Solmio 2001).

10 PRODUCTION COSTS

10.1 PRODUCTION COSTS OF FOREST RESIDUAL FUEL

10.1.1 Production costs of forest residue chips from final cutting

While fossil fuels occur in large deposits and can be produced at a constant cost, forest fuels are scattered and must be collected from a large number of locations. Technical logging conditions vary widely, and the variations are reflected in the productivity and cost of work (Hakkila 2004).

Knowledge of the cost factors of forest chip production has been vague. There is shortcoming from the viewpoint of technology development. The effect of factors such as stand conditions and hauling distances should be known in order to (Hakkila 2004):

- Identify the most advantageous stands for chip production,
- Estimate the change in the cost when the demand for chips increases or when the quality requirements of the fuel are tightened,
- Focus on the key problems in machine and method development,
- Collect basic knowledge needed by decision makers who direct subsidies to the production of forest chips.

Korpilahti (2000, 2001) has calculated the harvesting costs of forest residue chips for four main methods used in Finland, table 6. The calculations based on research data.

The most economical harvesting chain of forest residue chips was chipping at the power plant. The production costs of the chips at the power plant using this method was 8.19 €/MWh, when the road transport distance was 80 km. This method is used in a few plants in Finland. The road transport costs in this method can be decreased by increasing the net load of the trucks. This is possible by compressing the forest residues in the truck (Korpilahti 2000, 2001).

Production costs of forest residue chips using chipping at the roadside chain was 8.44 €/MWh. This is only 3% more than using chipping at the power plant chain. This chain is the primary production chain in Finland. Much depends on affiance of the chipping machine and other delays at the loading place (Korpilahti 2000, 2001).

Production costs using bundling technology chain was 9.09 €/MWh. This is 10 % more than when chipping at the power plant. The bundling technology has just recently been developed and it has been in use in Finland for only some years. Therefore there are lots of possibilities to develop it further, especially associated with the bundler efficiency and truck transport (Korpilahti 2000). The economy of bundling becomes better, when
transport distance grows. Developing the bundling technology cost degrees (Korpilahti 2001).

Table 6. The costs of the four harvesting chains of forest residues (Korpilahti 2001). Bundle means bundling harvesting chain, Terrain chip is chipping at terrain chain, Road chip is chipping at roadside chain and Plant chip is chipping at the plant harvesting chain.

<table>
<thead>
<tr>
<th>Production method</th>
<th>Haulage 150 m, transport 40 km</th>
<th>Haulage 300 m, transport 80 km</th>
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<tbody>
<tr>
<td></td>
<td>Bundle €/MWh</td>
<td>Terrain chip/ €/MWh</td>
</tr>
<tr>
<td>Bundling</td>
<td>3.31</td>
<td>-</td>
</tr>
<tr>
<td>Forest haulage</td>
<td>1.22</td>
<td>-</td>
</tr>
<tr>
<td>Chipping at stand or roadside</td>
<td>-</td>
<td>6.03(^1)</td>
</tr>
<tr>
<td>Road transport</td>
<td>2.26</td>
<td>2.64(^2)</td>
</tr>
<tr>
<td>Chipping at power plant</td>
<td>0.71</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7.50</strong></td>
<td><strong>8.67</strong></td>
</tr>
</tbody>
</table>

\(^1\) Includes forest residue chipping and terrain haulage of chips
\(^2\) Road transport is carried out by using exchangeable containers

The most expensive harvesting chain of forest residues was chipping at the terrain. The harvesting costs using this method were 37% more than using the chipping at the power plant chain, being 8.67 €/MWh (Korpilahti 2000, 2001). This method is used in some extent in Finland.

A significant gap exists between cost of fuel from the early thinnings and that from final cuttings. The gap is caused by the high cost of cutting and bunching of small-sized trees from thinnings, whereas in the other phases of the procurement chain cost differences are modest. If no stumpage is paid, the cost level is 10 €/MWh for logging residue chips and 15 €/MWh for whole-tree chips (Figure 47). The former meets the solvency of the users, but the latter exceeds it by some 5 €/MWh. This is why whole-tree chips are subsidized but logging residue chips are not (Hakkila 2004).
Average costs may be misleading, since costs vary considerably. For example single productivity factor, stem volume, affects the cost of cutting and, consequently, the cost of the entire procurement chain. The effect is steeper in mechanized than in manual cutting.

There exist new computer based calculation programs (Laitila 2005) for the production costs of forest residue. It is possible to order these calculation programs from Juha Laitila (juha.laitila@metla.fi).

### 10.1.2 Production costs of forest residues from thinnings

The costs of the harvesting chains of thinning are dependent on harvesting machinery, harvesting method and harvesting conditions in different stands. The harvesting costs are furthermore affected by total amount of merchantable and energy wood, haulage distance, terrain accessibility and other factors. The mechanical harvesting devices are most applicable to logging sites, which produce both energy wood and merchantable round wood (Savolainen & Berggren 2000).

Integrated production of round wood and energy wood is cheaper than production of alone (table 7). The smaller the harvested trees are, the more profitable it is to harvest them manually (using chain saw). Thus logging sites with only energy wood should be harvested manually using felling piling method. It's hard to compare the different harvesting methods because working conditions differ so much. Forest haulage has been assumed to be done by the same unit, thus the actual harvesting methods can be in the focus of the comparison. If energy wood is delimbed to long wood (as AM 240 does), the harvesting costs are higher than when harvesting whole trees (Savolainen & Berggren 2000).

In another study at the pre-commercial thinning stand (energywood thinning) only whole tree chips were harvested. In the study the harvesting chain was based on the chipping at the terrain. The felling was made manually. On the study site the amount of trees cut was 5 300 – 22 000 trees/ha, mean height 3 – 5 m and the total harvested biomass amounted to 26 –
75 m³ solid/ha. The total costs of whole-tree chips from the pre-commercial stand was 8.5 – 11.1 €/MWh). This is 19 – 54% more than the costs from the final felling areas (Hämäläinen et al. 1998a).

In the study made at the first commercial stands two methods were used for wood fuel harvesting, integrated timber and fuel chips harvesting method and in the other method all cut trees at the stands were chipped for fuel. The initial stand-density was 6 500 trees per ha. The two stands were thinned to a density of about 1 000 trees per ha. Harvesting yield at the stands was 30 – 110 m³ solid/ha. The trees were cut with a multi-tree handling felling device. Whole-trees were hauled by a forwarder to the landing. In the integrated harvesting method the whole-trees were processed with a flail-debarking chipper. The yield of the pulp chips was 50 – 66%. In the combined harvesting method the residues were used for fuel chips and the harvesting costs of fuel chips at the power plant were 12.3 €/MWh, 50 w-%. The harvesting costs were 14.3 €/MWh, 50 w-% when all whole-trees were made for fuel at the landing (Hämäläinen et al. 1998b). In this method the harvesting costs were higher than in the combined harvesting method.


<table>
<thead>
<tr>
<th>Costs €/m³</th>
<th>Manual Felling-Piling (with felling frame)</th>
<th>Narva-Syke-felling head</th>
<th>AM 240-felling head</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole tree Delimbing long wood Integrated round- and energy wood Only energy wood Integrated round- and energy wood Only energy wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest haulage of whole trees</td>
<td>4.54-5.88</td>
<td>4.54-5.88</td>
<td>4.54-5.88</td>
</tr>
<tr>
<td>Forest haulage of delimbed long wood</td>
<td>3.19-3.86</td>
<td>3.19-3.86</td>
<td>3.19-3.86</td>
</tr>
<tr>
<td>Delimbing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, €/m³</td>
<td>8.74-12.94 17.97-18.64 11.60-13.78 9.74-13.60 18.48 16.97</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chips from energywood thinning and first thinning are made from whole trees (whole tree chips) or from delimbed stems (stem chips). Farms and small-houses excluded, the use of small tree chips is tiny in Finland because of the higher price of the chips compared to the forest residue chips. The reason for the higher price of small tree chips is the small tree volume and the small total yield of wood biomass that is possible to be collected from the stands. Small sized tree chips are mainly used by heating plants. They are able to pay for the fuel more than power plants (Leinonen 2004).

10.2 SUBSIDES FOR WOOD FUEL

The Government’s aim is to make renewable energy economically competitive on the open markets.

The following support measures are employed (Hakkila 2004):
• **Energy taxation of fossil fuels used for heat production.** A carbon-based fuel tax was imposed in 1990, but wood-based fuels are free of the tax because of their carbon neutrality. In the beginning of 2004, the energy tax on different fuels was as follows: coal 6.3, light fuel oil 6.0, heavy fuel oil 5.3 and natural gas 1.9 €/MWh. The energy tax changes the price ratios of fuels, greatly enhancing the competitiveness of wood in heat production.

• **Support for electricity production.** The carbon-based fuel tax is limited to heating. It is not collected if fuel is used for the production of electricity. Instead, a tax 4.2 €/MWh for other wood fuels (is levied from consumers of electricity, independently of the source of energy. If the source of energy is forest chips or wind or small scale hydro power (< 1 MWe), the tax is refunded to the producer and it is 6.9 €/MWh.

• **Support for the production of forest fuels.** When small-diameter wood is harvested from young thinning stands, a subsidy of about 5.5 €/MWh is paid to chip producers. The stands must meet specific silvicultural criteria. When stump and root-wood is harvested from regeneration areas which have been logged in summer time, a subsidy of about 0.9 €/MWh is paid because the treatment helps to protect the next tree generation from root rot fungus. No direct support is awarded for the production of fuel chips from logging residues from late thinnings or final harvest.

• **Grant for investments.** Financial support can be granted to promote the introduction of new technology in the production of forest chips. For special equipment, such as chippers, crushers, bundlers, accumulating felling heads and biomass vehicles, the subsidy is typically 10 - 25%. Projects involving innovative technology are given priority.

• **Financial support for the development and commercialisation of technology.** The primary channel for funding applied R & D is the National Technology Agency Tekes, which gives a high priority to the use of renewable sources of energy. Annual funding is about 10 M€, of which more than 50% is allocated to bioenergy.

11 ENVIRONMENTAL IMPACTS

11.1 EFFECTS OF NUTRIENTS RESOURCES

The balance of forest ecosystem is disturbed when timber is harvested. Furthermore, when foliage is removed in addition to the stem wood, disturbance becomes more serious, nutrient losses are evident and the fertility of the forest soil may decrease. Especially needles are rich in nutrients, figure 48. For instance in young pine stands (first thinning phase) 60 percent of (N), Phosphor (P) and. Potassium (K) located above ground level Nitrogen are in the crown mass (Hakkila & Fredriksson 1996).
Figure 48. Depletion of nutrients caused by harvesting logging residue. The material has been adapted from the data presented on whole tree harvesting. The starting point of the calculations has been a mature spruce stand ready for final felling with a merchantable wood content of 200 m³/ha. A recovery rate of 75% for logging residue has been assumed (Mäkelänen 1975).

The accrual of logging residues also causes indirectly some other effects on the growth and ecological condition of the forest. It may change the micro climate and microbe activity, acidify soil and also slow down the mineralization of nitrogen in the humus layer (Hakkila & Fredriksson 1996).

The cycle of nutrients between soil and vegetation is an essential part of the forest ecosystem. A part of the nutrients taken up by trees returns back to the soil with the forest litter, but a larger part is accumulated in the biomass and is released only when the biomass starts to decompose after the death of the tree. The circulation is not totally closed, as leaching causes nutrient losses whereas the disintegration of minerals and fallout from the atmosphere increase the nutrients available for the vegetation. The nutrient circulation in the forest ecosystem is presented in the figure 49 (Savolainen & Berggren 2000).

The nutrient losses cause slow but long-lasting effects. For instance the release of nitrogen and phosphorus from the branches may take place only after one decade after cutting. This is why the effects of biomass removal on the forest ecosystem need to be studied in long lasting experiments.
In the study series of Finnish Forest Research Institute, whole tree harvesting in early thinning areas of pine stands has not caused any notable losses in wood production whereas in spruce stands the growth loss has been approximately 10 percent (Mälkönen & Kukkola 1998). In ecologically sensitive areas (e.g. nutrient poor soils) crown mass should not be recovered at all. UPM Kymmmene (Paananen & Kalliola 2003) does not harvest energy wood from dry forest soils thin in humus, from peatlands or from soils where growth disturbances due to the lack of phosphorus, potassium or boron can be expected.

The forest soil is naturally acidified during the growth of the tree crop, as positive ions (i.e. cations such as NH$_4^+$, Ca$^{2+}$ and K) are bound to the growing stock. Only after the death of the tree and the decomposing of the biomass, these cations return to the soil and the acidity returns to the original level. In the case of a full removal of the biomass this compensation is lost. In some Swedish studies the effect of slash removal to the acidity of the forest soil has been about 0.1 pH units in the final felling stands (Savolainen & Berggren 2000).

On the other hand, harvesting logging residues at the final felling stands decreases the leaching of minerals, e.g. nitrate nitrogen, during the first few years after cutting. The leaching of nitrogen, calcium and magnesium from the wholletree harvesting stands has been 67 - 78 percent of the leaching from stands where only stem wood has been harvested (Alakangas et al. 1999). Also the eutrophication of the ground cover vegetation has decreased because of the logging residue removal, figure 50. This has positive effects on the forest regeneration (Savolainen & Berggren 2000).
There is a significant difference between nutrient losses depending whether forest fuels, e.g. logging residues, are collected fresh (green) or dry (brown). As has been stated before, needles and green foliage in general contain a considerable share of nutrients. If needles are left in the stand for instance by leaving the crown mass to dry on the spot for a few weeks or months so that the needles fall down, most of the nutrients are released to the soil. However, at the same time the rate of biomass accrual decreases and costs of harvesting increase. This is a trade off that needs to be taken into account in each case (Savolainen & Berggren 2000). Usually about two thirds of the forest residue is taken away.

An ecologically sustainable solution would be the recycling of wood ash formed in the combustion, so that all nutrients (excluding Nitrogen) lost during the accrual of the biomass would be returned to the stand in question. There are, however, some problems and restrictions in the practice. Wood ash recycling is further discussed in chapter 9.3.

11.2 FOREST REGENERATION

Forest regeneration is an integral part of the sustainable use of forests. Growing stock is removed with the idea of replacing it with a new generation either by natural regeneration, planting or seeding. Natural regeneration is always the aim wherever possible: about 100–150 trees are left standing at the cutting site for the purposes of seeding a new generation of trees (Finnish Forest Industry 2000).

The choice of dominant tree species and regeneration method is largely on the grounds of nutrient availability and soil type at the regeneration site. For the most nutrient-poor sites, the possibility of natural regeneration is normally considered first, and is the cheapest and easiest alternative – provided it succeeds. If natural restocking does not succeed, it will be necessary to introduce supplementary planting, grass suppression and seedling management, which are all time-consuming and expensive (Finnish Forest Industry 2000).
In about 60% of the total regeneration area in Southern Finland, the aim is to produce a pine-dominant regenerated forest; in the remaining 40% the aim is either spruce or birch-dominant forest. The proportion of spruce and birch has increased in recent years at the expense of pine, and will continue to do so. About 40% of the total pine regeneration area is regenerated naturally. Spruce, on the other hand, is mostly regenerated by planting, figure 51, because the results of natural regeneration have proved disappointing. Conditions in Northern Finland are poorer, on average, than in southern parts of the country, and so pine has a greater presence there (Finnish Forest Industry 2000).

Soil preparation is of critical importance to the success of regeneration. Ensuring an appropriate coming up of mineral soil is essential to the growth of planted seedlings and the success of natural restocking, and especially encourages the arrival of birch as an admixed species. Site preparation methods have changed in recent years, and forest ploughing has been almost completely abandoned; today about two thirds of the site preparation area is harrowed or scarified and the rest is mounded with a tractor-digger or excavator, figure 52. There is a revival of interest in prescribed burning, but the area affected is still insignificant (Finnish Forest Industry 2000).

The stumps are pulled in such a way that a sufficient number of planting spots, equal to conventional soil preparation, are formed for saplings, figure 53. Proper planting and seeding spots are, e.g., mineral soil spots exposed when pulling stumps, and tussocks formed at such spots or on the humus layer in accordance with accepted present principles of soil preparation. The soil opened in stump extraction is used as planting spot, and when necessary, additional spots are formed, where stumps are not extracted. Different tools have been developed for stump extraction, e.g., rakes, by which tussocks can also be made (Paananen & Kalliola 2003).

Regeneration sites in Finland are small, having an average size of less than two hectares. Sites of larger than ten hectares are very few. Regeneration succeeds quite well in small sites because present timber harvesting and regeneration methods do not require the preparation of large areas (Finnish Forest Industry 2000).

Finland originally had about 10 million hectares of mires, of which about 5.3 million hectares have been drained. To ensure that drained mires can continue to produce timber in the future, the ditches must be cleaned. Ditch cleaning is carried out about once every 20 years and most ditching areas are now in need of cleaning. Forest drainage requirements have been revised on the basis of experience, and some the most nutrient-poor drained mires have been left to return to a natural state. The forest organizations and environmental authorities have drafted new guidelines on water conservation in forestry, and these also apply to ditch cleaning (Finnish Forest Industry 2000).
Figure 51. Bräcke planting machine mounted on a harvester in a regeneration area. Logging residues have been salvaged (FFRI).

Figure 52. Tenkkanen’s stump harvesting head on an excavator for simultaneous pulling, splitting and site reparation (FFRI).
Fertilization of forests has been reduced dramatically during the last ten years. The aim of fertilization is shifting from improvement of wood yield towards maintaining the nutrient balance in the forest and the health of the trees. Forest fertilization has a comparatively low environmental impact, provided it is carried out correctly. For instance, an unfertilized protective belt alongside a waterway prevents seepage of nutrients (Finnish Forest Industry 2000).

11.3 WOOD ASH RECYCLING

Ash developed in the burning of forest residues can be returned to forest, figure 54. Then part of the nutritive substances is brought back to the former growing area and same time acidification of soil is prevented. In Finland wood ash develops about 100 000 t/a.

Figure 54.  Bioash recycling (Savolainen & Berggren 2000).

The content of nutrients in tops and branches, the parts of the tree which are mainly used as fuel, is higher than in the stem. Significant for the long-term production capacity of the forest land is the balance between the mineral substances, such as calcium (Ca), potassium (K) and magnesium (Mg). As has been stated before, minerals are mainly
brought to the forest by decomposition and are withdrawn by harvesting biomass (Ström 1994).

Table 8. Comparison of the heavy metal contents in peat and wood ash. 1) An average value from 12 different heat producers in Sweden. 2) An average value of 10 different heat producers in Sweden. 3) An average value from 3 different heat producers in Sweden. 4) A value from 1 heat producer in Sweden (Eriksson 1993).

<table>
<thead>
<tr>
<th>Ashes</th>
<th>P, %</th>
<th>S, %</th>
<th>Si, %</th>
<th>As mgkg⁻¹</th>
<th>Cd mgkg⁻¹</th>
<th>Cu mgkg⁻¹</th>
<th>Pb mgkg⁻¹</th>
<th>Zn mgkg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash – wood¹</td>
<td>0.83</td>
<td>1.3</td>
<td>9.6</td>
<td>15.1</td>
<td>13.1</td>
<td>152.2</td>
<td>154.3</td>
<td>1667.5</td>
</tr>
<tr>
<td>Bottom ash – wood²</td>
<td>0.9</td>
<td>0.4</td>
<td>15.3</td>
<td>19.6</td>
<td>4.0</td>
<td>155.2</td>
<td>118.5</td>
<td>1156.8</td>
</tr>
<tr>
<td>Fly ash – peat³</td>
<td>0.7</td>
<td>1.7</td>
<td>20.0</td>
<td>44.3</td>
<td>7.0</td>
<td>133.7</td>
<td>272.3</td>
<td>240.0</td>
</tr>
<tr>
<td>Bottom ash – peat⁴</td>
<td>0.36</td>
<td>0.0</td>
<td>25.0</td>
<td>7.2</td>
<td>0.0</td>
<td>52.0</td>
<td>15.0</td>
<td>140.0</td>
</tr>
</tbody>
</table>

Ash contains various amounts of heavy metals. When recycling wood ash, table 8, however, no new "external and unnatural" heavy metals are brought to the system (Ström 1994). The heavy metal content of wood is rather low compared to for example that of coal and peat. In some ash fertilization experiments of Mälkönen et al. (2001) it has been possible to measure from soil higher concentrations of heavy metals for 1 – 2 years.

Wood ash is basic and can therefore be used in the same way as lime to decrease the negative effects of detoxification. The lime effect of the ash corresponds to 150 - 450 kg calcium (Ca) per one tonne of ash. The recycling of ash and returning it to the forest cannot be viewed as a method to deposit waste. Instead, we should see wood ash as a natural resource and recycling ash to forest as one condition to a sustainable utilisation of bioenergy (Ström 1994).

The National Board of Forestry (SKS) in Sweden has taken an initiative to a so-called MKB (“Environmental Consequence Description”) in order to raise discussion and consideration of matters related to the withdrawal of forest fuels, ash recycling and the compensation of nutrient loss. Proposals give general guidelines for ash recycling (Egnell 1998). In guidelines is discussed about following subjects: Demand on compensation; The level of ash recycling; Highest dose of ash compensation; The rate of ash stabilisation; The content of nutrients and toxic substances of ash; What is the suitable time for ash recycling during a tree generation?; What is the suitable time of year for ash recycling?.

In Sweden, also Skogsstyrelsen (the National Board of Forestry) has prepared recommendations for wood ash utilisation in forest fertilizing. The recommended maximum contents of harmful components as well as minimum nutrient amounts will be included in the Swedish Ash Handbook, which will be prepared during the RecAsh project. In the Finnish part of the project, the quality characteristics of a range of ashes
have been compared with the Swedish recommendations (Lindh et al. 2005a, Lindh et al. 2005b). In Finland the ash spreading is controlled by environmental permits, which are required because ash is classified as waste fraction.

11.3.1 Methods for treating ash

Ash is basic and contains easily leaching salts. An overly rapid change of pH and mineral content in the ground can have negative effects to the flora and to the micro-organisms of the ground. To prevent this ash can be treated in a way that makes its leaching speed slower, i.e. makes ash stabilised. An increased pH-value in the ground leads to an increased amount of nitrates which can further lead to increased losses of nitrogen. As ash is basic there is a risk for increased leaching of nitrates if the ash causes a too rapid change in the acidity conditions of the ground (Ström 1994).

Mälkönen et al. (2001) got especially good result ash fertilising of peat based soils. The volume grow of pine was even 200 – 250% higher than unfertilised areas (100%) after 10 – 20 years.

No negative ecological effects of recycling stabilised ash in moderate amounts (1 - 3 ton/ha) have been found in a research which has continued for several years. Ash fertilising is most effective during thinnings (Mälkönen et al. 2001), when the forest grows fast.

To produce a stabilised ash product ash needs to be mixed with water and then hardened. This can be accomplished by granulating ash or by making it to self harden. Leaching tests show that granulated ash has the slowest leaching time (Hansson 1998).

11.3.2 Granulating of ash

Granulating is the basic term of the process of how to treat fine grained material in order to change it to a more bulky form. There are two techniques to granulate ash: compacting and rolling. Compacting means that ash is put under both pressure and movement, whereas in the rolling technique ash is only exposed to movement (Nilsson 1993).

One example of the rolling technique is drum-rolling. A mixture of ash and water is fed in a drum (figure 55). The mixture is formed in a moistening screw. In order to pack the ash compactly the drum is supplied with an inner smooth wearing surface which is made by the ash. The ash is formed into a surface with the help of a rotating scraper which consists of a rotating blade tube with screw formed steel cutting lines. The edges of the cutting blade are made from hard metal and therefore it has a long lifetime and a small need for maintenance. The size of the ash granules is controlled by the angle and the rotating speed of the drum (Nilsson 1993).
One example of the compacting technique is cylinder compacting. The material is pressed together between two cylinders to a uniform dimension and is then crushed to flakes (figure 56). The flakes are then ground and sieved to the desired size.

In Finland, one pulp and paper mill in Northern Karelia produces ash granules on factory scale. The method they use is plate granulation followed by granulation drum as the subsequent granulator. Recently also another company in the same region has started ash granulating with a drum granulator. Both companies spread the granulated wood ash to the forests with a helicopter.

RecAsh is an on-going EU funded research project on wood ash recycling. The project lasts for several years and it is carried out in co-operation between Finnish and Swedish partners. The aim of the project is to promote wood ash utilisation in forest improvement. The project demonstrates e.g. ash granulating with a mobile drum granulator which operates at the combustion plant sites (Rinne et al. 2005).
11.3.3 Spreading and transporting techniques of ash

In order to make ash recycling profitable in a large scale it is necessary to use cost effective systems for handling and spreading. Ash can be spread with conventional methods, for example by helicopter or with ground vehicles, figure 57. The equipment of spreading is basically the same as for spreading lime to the forest (Ström 1994).

Vattenfall has done practical studies on different systems for transporting and spreading ash products. These studies showed that separate transportation by lorries with exchangeable platforms produced the best results. The exact amount of ash can then be transported to each spreading area. On the other hand, transports by wood chip lorries can be cheaper but it can be difficult to transport the right amount of ash to each area (Hansson 1998).

The same practical studies by Vattenfall also show that ash can be spread by a forest tractor, i.e. a forwarder. This is cheaper than spreading by a helicopter and does not demand such a detailed planning of the spreading areas. Plate or fan spreaders can be attached to the forwarder. The utilisation of the fan spreader results into a more even spreading than the use of plate spreader. However, it is more difficult to spread exactly the intended amount of ash by the fan spreader than with the plate spreader. It is also easier to spread granulated ash than self-hardened and crushed ash (Hansson 1998).

![Figure 57. Recycling ash is spread out in the forest (FFRI).](image)

Both self-hardened and granulated ashes have so far been spread mostly on forests owned by industry or the state. However, plenty of potential ash spreading areas can also be found in private forests. Ash spreading is cheaper with a forest tractor, therefore it has so far been more popular than spreading with a helicopter. In summertime bearing capacity problems restrict tractor spreading in peatlands.
A precondition for feasible ash recycling is proper ash management at the plant. Cofiring of biomass with fossil fuels, municipal waste or peat results in a dilution of the nutrient content, or even the contamination of the ash, and consequently a part of the ash becomes unusable. On the other hand, large quantities of bark ash are available. Technology and logistics of ash recycling should be developed (Hakkila 2004).

12 USE OF FOREST RESIDUE CHIPS IN FINLAND

The development in the use of forest chips began late 1950s. In the early days of fuel chip technology tending of young forests and creating of jobs were the primary drivers. When birch became a round wood species in the 1960s, the demand for low-quality hardwood improved and the urgent silvicultural incentive for forest chip production almost disappeared. The business faded (Hakkila 2004).

Interest revived in the mid 1970s as a result of the global energy crises. The major driving force was then the need to increase energy self-sufficiency, as the high price and uncertain availability of fossil fuels had become serious threats to the national economy and security. Unfortunately, much of the technical readiness and skill acquired earlier had been lost, and despite the efforts of the Government, it took several years before the use of forest chips began to increase. The peak was reached in the early 1980s, when the price of oil collapsed and interest in forest fuels again disappeared, and the use of chips declined (Hakkila 2004).

The deep economic depression of the early 1990s, as well as the mechanization of timber harvesting, aggravated rural unemployment. With the consequent reduction in the demand for wood from thinnings, attention once again shifted to forest fuels. Simultaneously, society began to take notice of issues related to climate change. Gradually, the global environmental threat became the prevailing driving force of forest fuels. The rationale seems to be lasting, and so the industry is in a safer position than before when investing in know-how, machine construction and the utilization of forest biomass (Hakkila 2004).
Since 2000, the average growth rate in the use of forest chips has been 320 000 m³ per annum, probably faster than in any other country in Europe. This has been possible due to a number of advantages offered by natural conditions, the structure of the industry and the high priority set by the Government to renewable energy (Hakkila 2004). The growth has been especially fast during last five years as figure 58 shows.

In 2002, forest chips were burnt by 365 plants larger than 0.4 MW. In the geographic areas of the 13 Forestry Centres, Central Finland (area 8) was the forerunner and leading user. The region has plenty of mature spruce stands that are being regenerated, several local CHP plants have been refitted to handle and combust forest fuels, and the region is the heart of bioenergy research in Finland. Another advanced area is the East-Bothnia Forestry Center on the western coast. In the northernmost part of Finland, the use of forest chips is modest because of the scarce population, long distances, unsupportive structure of forests, and forest conservation issues (Hakkila 2004).

Earlier, forest chips were mainly used for heat production. However, excluding small-scale use, the integrated production of heat and power is currently more important. Growth is, fastest in co-generation, which is in agreement with the Finnish energy
policy goal, and the proposal for an EU directive on the promotion of co-generation (Figure 59).

**Figure 59.** The users of forest chips in 1999 and 2002 (Hakkila et al. 2001, Ylitalo 2003). Small houses in 2001 (Sevola et al. 2003).

In a nutshell (Leinonen 2004) end users of wood for fuel in Finland are following:

**Combined heat and power production**

A typical feature of Finland's energy production is the large proportion of combined heat and power (CHP) both in the district heating of communities and within industry. CHP's advantage in relation to separate heat and power production is that it is efficient, a total efficiency being 80 to 90%. The share of CHP heat is more than 70% of the total heat production. District heating covers about 50% of total Finnish space heating demand. Approximately one third of the total electricity consumed is cogenerated in connection with district heating and industrial processes (Tekes 2002).

Forest chips are mainly used in municipal heating plants, municipal combined heat and power (CHP) plants and industrial CHP plants. The total number of power plants that used different wood fuels for heat or and electricity in 2003 was over 400 (Ylitalo 2004).

**District heating plants**

The district heating plants are situated in small towns and municipalities. The number of the municipal heating plants that used forest fuel chips in 2000 was 215 (Ylitalo 2000). The average heat output of the new municipal heating plants is 3.2 MWh, (Tekes 2002).
The heating plants use also peat besides wood and especially during the winter time in order to increase the fuel quality.

**Municipal cogeneration plants**

The municipal cogeneration plants are situated in the big cities where they generate electricity and provide steam for industrial processes or district heat for the network of a nearby town. The number of municipal CHP plants that use currently wood fuels is 29 and their total heat capacity is 2420 MW heat and 1225 MW electricity (Flyktman 2002). The biggest CHP plant is the Pietarsaari plant with total boiler capacity of 550 MW. It generates 240 MW of electricity, 100 MW process steam and 60 MW district heat. The main fuel of the municipal CHP is normally peat. The combustion technology is based on FBC technology (Tekes 2002).

Besides Pietarsaari there are several other biofuel-fired smaller plants of capacities from 20 to 100 MW (for ex. Iisalmi, Forssa, Kuusamo, Kuhmo, Kankaanpää, Mikkeli, Pieksämäki, Ylivieska,) in Finland. One good example is a district heat and power plant in Iisalmi (Kalmari 2003). In figure 60 is the principal process of the power plant. Nominal capacity of the plant is 15 MW of electricity and 30 MW district heat.

![Figure 60. Iisalmi power plant (foto K. Veijonen) and principal process flow sheet (Kalmari 2003).](image)

**Forest industry**

The main user of wood fuels is forest industry. The number of industrial CHP plants is 40 and the total boiler capacity is 7 860 MW. The number of plants that produce only process steam is 8 and the total boiler capacity is 100 MW (Flyktman 2002). Also these power plants use peat fuel beside the use of different wood residues.
13 REFERENCES


Efficiency Institute). Metsätiedote (Forest Bulletin) 4 (587). In Finnish, Summary in English.


Leinonen, A., Hillebrand, K., Tihonen, I. & Marttila, M. 2000. Hakkuutähteiden terminaalituotannon kehittäminen. (Development of forest residues production at the


Appendix 1: Some useful e-mail addresses for forest residue fuel production

**FUEL WOOD ENTREPRENEURS**
- Biowatti Oy, http://www.biowatti.fi

**MACHINE MAKERS**
- Pinox Oy, http://www.pinox.com
- Timberjack, http://www.timberjack.fi
- Komatsu Forest Oy Ab, http://www.komatsuforest.fi

**FORWARDERS**
- Oy Wikar Ab, http://www.kronos.fi
- Farmi Forest Oy, http://www.farmiforest.fi

**CHIPPERS and CRUSHERS**
- Junkari Oy, http://www.junkkari.fi/?lang=3,
- Farmi Forest Oy, http://www.farmiforest.fi

**CHIPPERS**

**FELLING HEAD FOR THINNING**
- Ponsse Oyj, www.ponsse.fi
- Pentin Paja Oy, www.pentinpaja.fi/UntitledFrameset-1.htm
- Oy Logset Ab, www.logset.fi
- Timberjack, www.timberjack.fi/
- Lako Forest Oy Ltd, www.lakoforest.fi/

There are some more comprehensive lists of forest machines in the web, for example:
- Puuenergia-alan laitevalmistajat Suomessa vuonna 2004 (Machine makers and actors of wood fuel area in Finland 2004). Both www-pages are in Finnish.
Appendix 2: Definitions

Terms used in forest vocabulary are special terms. In appendix 1 is shown a short list of these terms with explanations (Leinonen 2004\(^1\)). If someone needs more detail information, www-page http://flash.lakeheadu.ca/~repulkki/REP_terminology.pdf is an excellent source. Also CEN (TC 335) has a terminology definitions for solid biofuels\(^2\).

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundwood</td>
<td>Logs, bolts and other round sections cut from trees for industrial or consumer use.</td>
</tr>
<tr>
<td>Mill residues</td>
<td>Wood residues from pulp and paper manufacturing and sawmills.</td>
</tr>
<tr>
<td>Sawdust</td>
<td>Dust formed in sawing.</td>
</tr>
<tr>
<td>Bark</td>
<td>Bark residue formed from merchantable wood with different debarking techniques.</td>
</tr>
<tr>
<td>Used wood residues</td>
<td>Post-consumer wood products, broken wood pallets and crates, untreated clean construction and demolition wood, etc.</td>
</tr>
<tr>
<td>Tree trimming</td>
<td>Tree limbs and branches generated from right-of-way trimming near roads, railways, and utility systems such as power lines.</td>
</tr>
<tr>
<td>Forest residues</td>
<td>Forest residues include underutilized logging residues, imperfect commercial trees, dead wood, and other non-commercial trees that need to be thinned from crowded, unhealthy, fire-prone forests.</td>
</tr>
<tr>
<td>Fuel chips</td>
<td>General term used for chips or crush prepared by different techniques for combustion.</td>
</tr>
<tr>
<td>Forest chips</td>
<td>General term for chips made from harvested wood raw material.</td>
</tr>
<tr>
<td>Log chips</td>
<td>Chips made of delimbed stem wood.</td>
</tr>
<tr>
<td>Whole-tree chips</td>
<td>Chips made of the whole superterranean biomass of a tree (stem, branches, needles).</td>
</tr>
<tr>
<td>Logging residue chips</td>
<td>Chips made of branches and tops, after harvesting merchantable wood.</td>
</tr>
<tr>
<td>Stump chips</td>
<td>Chips made of stumps or snags.</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------------------------------------------------</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 a by-product of saw industry, with or without bark residue.</td>
</tr>
<tr>
<td>Cutter chips</td>
<td>Wood residues formed in timber planning.</td>
</tr>
<tr>
<td>Grinding dust</td>
<td>Dust-like wood residue formed in grinding timber and wood boards (shall not contain harmful amounts of adhesives).</td>
</tr>
</tbody>
</table>

2) CEN/TS 14588, Solid Biofuels – Terminology, definitions and descriptions.
Appendix 3. Coefficients, measures and properties of wood fuels

**VOLUME AND DENSITY OF FUEL**

Cubic meter solid fuel $m^3$, cubic meter solid volume including bark,
Bulk cubic meter $m^3$ of bulk volume, cubic meter of chips,
Bulk density $kg/m^3$ bulk volume, mass and volume measured as received,
Solid volume factor of chips, solid-$m^3$/bulk-$m^3$ of volume solid volume/bulk volume.

Table 1. Most common conversion coefficients for wood fuels.2, 3)

<table>
<thead>
<tr>
<th>Wood fuels</th>
<th>Energy density (MWh/bulk-$m^3$)</th>
<th>Density (tightness) (m$^3$/bulk-$m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest residue</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Industry wood residues</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Sawdust</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Cutter chips</td>
<td>0.6</td>
<td>0.28</td>
</tr>
<tr>
<td>Bark</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coniferous wood</td>
<td>0.6</td>
<td>0.35</td>
</tr>
<tr>
<td>Deciduous wood</td>
<td>0.7</td>
<td>0.35</td>
</tr>
<tr>
<td>Demolition Wood</td>
<td>0.7</td>
<td>0.4 - particle density</td>
</tr>
<tr>
<td>Pellet and briquettes</td>
<td>4.8 MWh/t</td>
<td>575 kg/bulk-$m^3$, 1150 kg/m$^3$</td>
</tr>
<tr>
<td>Other woodfuel</td>
<td>0.7</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Prefixes:

k = kilo = $10^3 = 1 000$
M = mega = $10^6 = 1 000 000$
G = giga = $10^9 = 1000 000 000$
T = tera = $10^{12} = 1 000 000 000 000$
P = peta = $10^{15} = 1 000 000 000 000 000$

Taulukko 2. Conversion coefficients between different energy units4)

<table>
<thead>
<tr>
<th></th>
<th>toe</th>
<th>MWh</th>
<th>GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>toe</td>
<td>1</td>
<td>11.63</td>
<td>40.868</td>
</tr>
<tr>
<td>MWh</td>
<td>0.0886</td>
<td>1</td>
<td>3.600</td>
</tr>
<tr>
<td>GJ</td>
<td>0.02388</td>
<td>0.2778</td>
<td>1</td>
</tr>
</tbody>
</table>

For example 1 toe = 11.63 MWh
Table 3. Characteristics of different wood fuels with typical range of variation (Impola et al. 1998)\(^5\)

<table>
<thead>
<tr>
<th>Character</th>
<th>Logging residue chips</th>
<th>Whole tree chips</th>
<th>Log chips</th>
<th>Stump chips</th>
<th>Softwood bark</th>
<th>Birch bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content, w-% (fresh chips)</td>
<td>50-60</td>
<td>45-55</td>
<td>40-55</td>
<td>30-50</td>
<td>50-65</td>
<td>45-55</td>
</tr>
<tr>
<td>Net caloric value in dry matter, MJ/kg</td>
<td>18.5-20</td>
<td>18.5-20</td>
<td>18.5-20</td>
<td>18.5-20</td>
<td>18.5-20</td>
<td>21-23</td>
</tr>
<tr>
<td>Net caloric value as received, MJ/kg</td>
<td>6-9</td>
<td>6-9</td>
<td>6-10</td>
<td>6-11</td>
<td>6-9</td>
<td>7-11</td>
</tr>
<tr>
<td>Bulk density as received kg/bulk-m(^3)</td>
<td>250-400</td>
<td>250-350</td>
<td>250-350</td>
<td>200-300</td>
<td>250-350</td>
<td>300-400</td>
</tr>
<tr>
<td>Energy density, MWh/m(^3) of bulk volume</td>
<td>0.7-0.9</td>
<td>0.7-0.9</td>
<td>0.7-0.9</td>
<td>0.8-1.0</td>
<td>0.5-0.7</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Ash content in dry matter, w-%</td>
<td>1-3</td>
<td>1-2</td>
<td>0.5-2</td>
<td>1-3</td>
<td>1-3</td>
<td>1-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Character</th>
<th>Wood residue chips</th>
<th>Saw residue chips</th>
<th>Sawdust</th>
<th>Cutter chips</th>
<th>Grinding dust</th>
<th>Plywood residue</th>
<th>Uncovered wood (recycled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content, w-% (fresh chips)</td>
<td>10-50</td>
<td>45-60</td>
<td>45-60</td>
<td>5-15</td>
<td>5-15</td>
<td>5-15</td>
<td>5-15</td>
</tr>
<tr>
<td>Net caloric value in dry matter, MJ/kg</td>
<td>18.5-20</td>
<td>18.5-20</td>
<td>19-19.2</td>
<td>19-19.2</td>
<td>19-19.2</td>
<td>19-19.2</td>
<td>18-19</td>
</tr>
<tr>
<td>Net caloric value as received, MJ/kg</td>
<td>6-15</td>
<td>6-10</td>
<td>6-10</td>
<td>13-16</td>
<td>15-17</td>
<td>15-17</td>
<td>12-15</td>
</tr>
<tr>
<td>Bulk density as received kg/bulk-m(^3)</td>
<td>150-300</td>
<td>250-350</td>
<td>250-350</td>
<td>80-120</td>
<td>100-150</td>
<td>200-300</td>
<td>150-250</td>
</tr>
<tr>
<td>Energy density, MWh/m(^3) of bulk volume</td>
<td>0.7-0.9</td>
<td>0.5-0.8</td>
<td>0.45-0.7</td>
<td>0.45-0.55</td>
<td>0.5-0.65</td>
<td>0.9-1.1</td>
<td>0.65-0.8</td>
</tr>
<tr>
<td>Ash content in dry matter, w-%</td>
<td>0.4-1</td>
<td>0.5-2</td>
<td>0.4-0.5</td>
<td>0.4-0.5</td>
<td>0.4-0.8</td>
<td>0.4-0.8</td>
<td>1-5</td>
</tr>
</tbody>
</table>


