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PENTTI HAKKILA

FOREST CHIPS AS FUEL FOR HEATING PLANTS IN FINLAND

METSÄHAKE LÄMPÖLAITOSTEN POLTTOAINEENA SUOMESSA

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Metsäntutkimuslaitos on maa- ja metsätalousministeriön alainen vuonna 1917 perustettu valtion tutkimuslaitos. Sen päätehtävänä on Suomen metsätaloutta sekä metsävarojen ja metsien tarkoituksenmukaista käyttöä edistävä tutkimus. Metsäntutkimustyötä tehdään lähes 800 hengen voimin yhdeksällä tutkimusosastolla ja yhdeksällä tutkimus- ja koeasemalla. Tutkimus- ja koetoimintaa varten laitoksella on hallinnassaan valtionmetsiä yhteensä n. 150 000 hehtaaria, jotka on jaettu 17 kokeilualueeseen ja joihin sisältyy kaksi kansallis- ja viisi luonnonpuistoa. Kenttäkokeita on käynnissä maan kaikissa osissa.

The Finnish Forest Research Institute, established in 1917, is a state research institution subordinated to the Ministry of Agriculture and Forestry. Its main task is to carry out research work to support the development of forestry and the expedient use of forest resources and forests. The work is carried out by means of 800 persons in nine research departments and nine research stations. The institute administers state-owned forests of over 150 000 hectares for research purposes, including two national parks and five strict nature reserves. Field experiments are in progress in all parts of the country.

FOLIA FORESTALIA 586

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FOREST CHIPS AS FUEL FOR HEATING PLANTS IN FINLAND

Metsähake lämpölaitosten polttoaineena Suomessa

Approved on 9.3.1984

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The state-of-the-art report deals with procurement of forest chips as fuel for 0,5—10,0 MW heating plants in Finland. Information is given on sources, availability, fuel properties and consumption of forest chips, procuring organisations, harvesting techniques, costs as well as the job-creating effect of the utilization of forest chips as an oil-substituting indigeneous fuel.

There were 115 over 0,5 MW chip-fired house-heating boilers and heating boiler plants in operation at the end of 1982. Their total consumption of forest chips was 393 000 solid m^3/a or 1 310 m^3 per installed MW.

The harvestable reserve of small-sized trees and logging residues is 15,3 mill. m^3/a which exceeds many times the present-day utilization of forest chips. The production potential is expected to remain distinctly greater than the utilization potential.

The true cost level of forest chips made of undelimbed whole trees was 155—175 Fmk/m^3 or 70—80 Fmk/MWh. The cost structure was as follows: stumpage price 13 %, wages 43 %, machine costs 31 % and other costs 13 %.

The forest chip procurement of heating plants corresponded to 565 man-years in 1982. Two-thirds of the manpower requirement consisted of the cutting of fuel chip wood by power saw and one-third of various types of machine work and work supervision.

Tutkimusraportti sisältää tietoja metsähakkeen lähteistä, käytöstä ja ominaisuuksista, hankintaorganisaatioista, korjuutekniikasta, kustannuksista sekä metsähakkeen polttoainekäytön työllistävästä vaikutuksesta.

Vuoden 1982 päättyessä maassamme toimi 115 teholtaan yli 0,5 MW:n lämpölaitosta. Niitten metsähakkeen kulutus oli kaikkiaan 393 000 m^3/a eli 1 310 m^3/teho MW.

Markkinakelvottoman pienpuun ja metsätähteen muodostama korjuukelpoinen polttopuureservi on 15,3 milj. m^{3}a. Reservi on moninkertainen lähivuosien käyttöpotentiaaliin verrattuna.

Karsimattomasta kokopuusta tehdyn metsähakkeen todellinen kustannustaso oli 155—175 mk/m^3 eli 70—80 mk/MWh. Kustannusten koostumus oli keskimäärin seuraava: kantohinta 13 %, työpalkat 43 %, konekustannukset 31 % ja muut kustannukset 13 %.

Lämpölaitosten metsähakkeen hankinta vastasi vuonna 1982 yhteensä 565 miesvuoden työpanosta. Kaksi kolmannesta kokonaispanoksesta koostui polttohakepuun teosta moottorisahalla ja yksi kolmannes koneen kuljettajien ja työnjohtajien työstä.

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PREFACE

Finland has no indigenous oil, coal or natural gas. The share of wood-based fuels in the total consumption of primary energy is probably greater than in any other developed country. To reduce country's dependence on energy imports and to improve the exploitation of domestic natural resources, one of the main objectives of the energy Policy of Finland is to increase the indigenous energy supply, ie. fuelwood and peat. For this reason great attention is being paid to the development of chip-fired heating plants.

The aim of the present state-of-the-art report is to give the reader an idea of the possibilities of forest chips as an oil-substituting fuel for medium-sized 0,5—10,0 MW heating plants. The report is a result of a study financed by the Finnish National Fund for Research and Development, SITRA, as a part of a larger Project on Development of Regional Usage of Peat and Wood Fuels. The study is simultaneously also a part of the PERA (Wood as an Energy Source) Project of the Finnish Forest Research Institute.

The original report of the study appeared in the Finnish under the title "Metsähakkeen hankinta lämpölaitosten polttoaineeksi" (Research Report No. 33 of the Project on Development of Regional Usage of Peat Fuels). As the Finnish experiences on the forest energy have aroused considerable interest abroad, the Finnish Forest Research Institute decided to publish a shortened report also in English. Minor changes have been made in the original report for the benefit of foreign readers. The cost data are presented in Finnish marks (mk). At the end of March 1984 one U.S. dollar equalled to 5.60 marks.

The translation from Finnish into English was done by Miss Päivikki Ojansuu and Mr. L.A. Keyworth.

Many communes, heating plants, timber procurement organizations, forest management associations and private machine contractors contributed to the project. Of especially great value was the support of VAPO (State Fuel Centre) and Osuuskunta Metsäliitto. Almost 200 persons were interviewed about the procurement and use of forest chips all over the country.

The project supervisor in SITRA was Mr. Kari Immonen. The study material was collected by Mr. Hannu Kalaja, Mr. Tapio Nevalainen and Mr. Erkki Salo. Mr. Jukka Hakkila, Miss Armi Korkeaniemi and Mrs. Raili Voipio helped in data processing. The manuscript was typed by Mrs. Aune Rytkönen.

The illustrations of chipping operations (Figures 10—18) were drawn by Mrs. Pirkko Hakkila. Other drawings (Figures 1—9 and 19—29) were made by Mrs. Leena Muronranta. The main part of the photographs are from the archives of the Department of Forest Technology. In addition, Central Forestry Board Tapio, Lokomo Forest Oy and Perusyhtymä Oy gave photo material for the publication.

The author thanks all the organizations, companies and private persons who contributed to various phases of the implementation of the study.

Puuksanharju, March 1984
Pentti Hakkila

1. DEVELOPMENTAL BACKGROUND

Finland, like Alaska, lies between the 60th and 70th parallels across the Arctic Circle. The population density is only 14 persons per square kilometre. The country is poor in natural resources with the exception of vast forests wich cover 65 % of the land area.

The harsh climate, long transport distances and the predominance of process-type industries have raised per capita energy consumption in Finland to one of the highest levels in Europe. The forest industry in particular is a large user of energy.

Energy management was based on wood far longer in Finland than in any other industrialised country. In the early 1930s almost 80 % of the primary energy was still generated from wood-based fuels. As the consumption of energy grew and more raw timber was needed for lumber, plywood and paper, Finland had to turn to other sources on energy.

Because Finland has no indigenous fossil fuels the energy self-sufficiency of the country decreased seriously during the 1960s and 1970s. The total consumption of primary energy by sources in tons of oil equivalent in 1981 is seen in Figure 1. The proportion of indigenous energy, ie. hydroelectric power, peat and wood-based fuels, is presently less than one third of the total consumption.

In order to reduce the country's dependence on energy imports, to improve the exploitation of domestic natural resources and to achieve better utilization of labour, the Council of State approved in 1979 and again in 1983 an Energy Policy Programme. The main objectives of the programme are:

- Energy conservation, ie., avoiding wastage of energy and encouraging economic and appropriate energy use.
- Increasing the indigenous energy supply

Owing to technical development, changed price relations, serious employment situation and the policy and investment subsidies of the State, the declining trend in the utiliz-

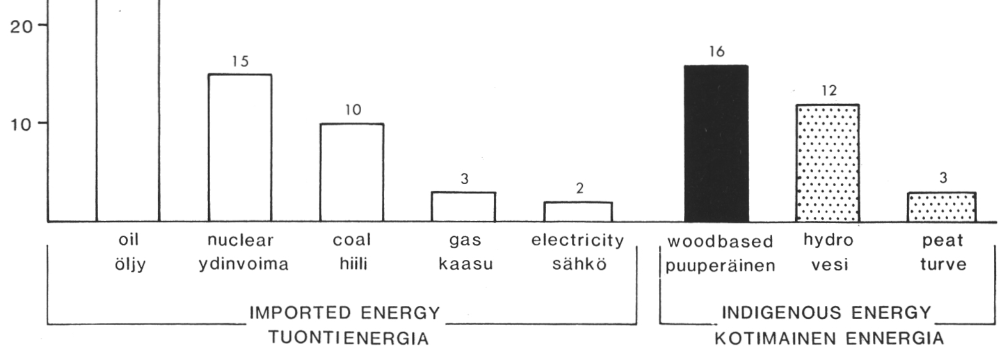


Figure 1. The total consumption of primary energy in Finland in 1982.
Kuva 1. Primäärienergian kokonaiskulutus Suomessa vuonna 1982.

Table 1. The forest chip fired 0,5—10 MW heating plants at the end of 1982 by starting year.
Taulukko 1. Metsähaketta polttavat 0,5–10,0 MW:n lämpölaitokset vuoden 1982 lopussa käyntiinlähtövuoden mukaan.

Starting year *Käynnistys* vuosi	Effect, MW — *Teho, MW* 0,5—1.0	1,1—2,0	2,1—5,0	5,1—10,0	Total *Yht.*	Total effect *Yhteisteho MW*
	Number of plants — *Laitoksia, kpl*					
—1976	1	1	3	3	8	33
1977	1	—	—	—	1	1
1978	—	—	—	1	1	7
1979	3	—	1	—	4	5
1980	9	5	5	—	19	35
1981	17	9	11	1	38	71
1982	13	4	10	4	31	74
Total—*Yht.*	44	19	30	9	102	226

ation of wood-based fuels turned up slightly at the end of the 1970s. In addition to an increase in the use of waste liquor, saw dust and bark in the forest industries, the change in trend was partly due to upsurge in the establishment of 0,5—10,0 MW chip-fired heating plants. Its development can be seen from Table 1.

A total of 87 medium-sized 0,5—10,0 MW heating plants utilising forest chips as their principal or auxiliary fuel were started up in Finland in 1980—1982. In addition, apart from the power plants of the forest industry, eight plants of over 10 MW with a fuel selection which included forests chips were put into use concurrently.

Compared with many other countries Finland has exceptional experience of utilisation of fuel chips ever since the 1950s. This notwithstanding, the abundant construction of heating plants and the rapid expansion of the procurement of forest chips at the beginning of the 1980s did not always proceed smoothly. The planners of the plants in making their decisions were not sufficiently familiar with the problems inherent in the procurement and utilisation of fuel chips. In the absence of up-to-date research data, inadequately-proven plant designs were accepted. Miscalculations were made and had to be corrected later. On the other hand, many procurement systems and chip-fired heating plants functioned fully satisfactorily.

Government investment subsidies have been a decisive impetus for the spread of chip-fired heating plants. Economic support in the construction phase is well motivated from society's point of view. It saves foreign currency, improves energy self-sufficiency, creates new jobs, promotes the progress of silvicultural operations in young forests and has other advantages for the national economy. However, it is clear that the operation and profitability of the plants must not in the long term remain dependent on subsidies.

It is therefore important for the furthering of utilisation of forest chips for energy to weight objectively both its advantages and drawbacks. The experience gained in recent years will help to establish better technical, economic and organisational conditions for the reliability, economicalness and ease of utilisation.

The present state-of-the-art report describes the prerequisites, problems, technology and cost level of the chip procurement of 0,5—10,0 MW heating plants in Finland. It is intended to serve the designers of heating plants, equipment constructors, chip procurement organisations, machine contractors, and decision makers in Finland and abroad.

2. INVESTIGATION MATERIAL

A written enquiry to all of Finland's communes turned up a total of 102 medium-sized 0,5—10,0 MW individual house-heating boilers and district heating boiler plants using forest chips at the end of 1982. There were, moreover, 13 plants of over 10 MW. The forest industry's heating power plants were not included in the study.

Of the above plants, 60 were subjected to detailed scrutiny. The length of the experience was the main criterion of selection. New plants that had been put into operation during 1982 were not accepted in the study.

At each of the 60 plants a representative of the procurement organisation, the chipper contractor and a person participating in the daily operation of the heating plant were interviewed. Detailed information was collected at the interview especially about the following subjects.

- Operation of the chip procurement organisation
- Sources of forest chips
- Harvesting and chipping techniques
- Chip long-distance transport technique
- Technique of chip storage and handling
- Chip quality questions
- Cost level and cost structure of forest chips

The publication is based primarily on interview material. Its base comprises in addition to a number of published and unpublished studies from the Department of Forest Technology, the Finnish Forest Research Institute, as part of the PERA project.

3. AVAILABILITY OF FOREST CHIPS

3.1 Reserves of forest energy

The declining trend in the fuelwood consumption resulted in the 1970s in an increase in weed trees of little value in Finland's forests (cf. Kuusela 1982a). It is therefore important for silvicultural reasons that demand should grow speedily for unmerchantable small-sized trees.

The annual available cut in Finland is 60,4 million m^3 of merchantable stem wood. Were this quantity of stem wood harvested in its entirety there would remain in the forest concurrently as logging residues a potential biomass reserve of 42,6 million m^3 consisting of under-sized stems, tops, branches, stumps and roots (Fig. 2). Small-sized trees of under 7—9 cm and the residues left in the forest in the harvesting of larger trees thus constitute a sizeable renewable energy reserve in Finland.

Utilisation of forest biomass as fuel on this scale is naturally impossible for ecological, technical, economic and market policy reasons. Therefore it is important to estimate the technically harvestable part of the potential biomass reserve as the point of departure for planning.

Table 2 gives an idea of the size class of the technically harvestable biomass reserve and of its sources. The bases of calculation used are reported in publication No. 342 of Folia Forestalia series (Hakkila 1978).

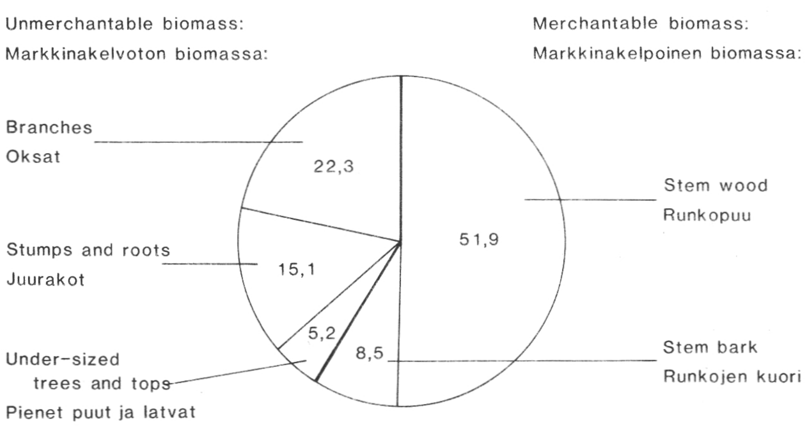


Fig. 2. Allowable biomass cut (million m^3/a) based on the national allowable stemwood cut.
Kuva 2. Valtakunnallisen runkopuun hakkuusuunnitteen pohjalta laadittu biomassan hakkuusuunnite (milj. m^3/a).

Table 2. Technically harvestable biomass reserve which does not meet the present quality requirements of the forest industries.

Taulukko 2. Teknisesti korjuukelpoinen biomassareservi, joka ei täytä metsäteollisuuden raakapuun nykyisiä vaatimuksia.

Assortment — *Tavaralaji*	Technically harvestable *Teknisesti korjattavissa* Mill. m^3/a *Milj. m^3/a*	Mill. toe/a *Milj. toe/a*
Slash, excl. green matter *Hakkuutähde viheraineetta*	3,01	0,61
Stump and root wood *Kanto- ja juuripuu*	2,42	0,48
Small trees, incl. branches *Pienikokoiset puut oksineen:*		
From sapling stands *Taimistoista*	3,26	0,58
From early commercial thinnings *Ensiharvennusmetsistä*	1,02	0,19
From poorly productive hardwood stands *Vajaatuott. lehtimetsistä*	5,54	1,01
Harvestable reserve, total *Korjuukelp. reservi yhteensä*	15,25	2,87

Technically harvestable *slash* consists of waste stem wood of under 6—7 cm and branches that are left in clear-cutting areas in the harvesting of industrial wood. Needles are not included. The main part of the slash consists of branches which are most numerous in spruce-dominated stands. Only 14 % of the potential slash output is classified as harvestable.

Harvestable *stump and root wood* also consists in accordance with certain logging technical requirements of the stump-root systems of sawtimber trees of clear-cutting areas. Parts of roots under 5 cm in thickness are not included. About 16 % of the potential reserve of stump and root wood is classified as harvestable.

Uncommercial thinnings of sapling stands yield very small-sized trees. The reserve as a whole has been classified as technically harvestable but on account of the small size of the trees cost factors limit recovery. Tending of sapling stands is of great silvicultural importance.

The small-sized trees of *commercial thinnings of young stands* are chiefly softwood. The part of the biomass that does not conform to pulpwood measurements has been included in Table 2 and classified as technically harvestable. The quantity of small-sized wood from early thinnings will increase in the future as a result of the age class structure of Finland's forests.

When *poorly productive hardwood stands* are regenerated a good deal of small-sized wood, especially birch and alder, is obtained in addition to pulpwood. In this stand type is included in Table 2 also *under-sized shelter trees of hardwood to be removed from young spruce plantation areas.* The aim of silvicultural programmes is to reduce the amount of poorly productive forests as fast as possible.

It is possible in the present situation to classify the above-mentioned annual biomass reserve of 15,3 million m^3 as harvestable.

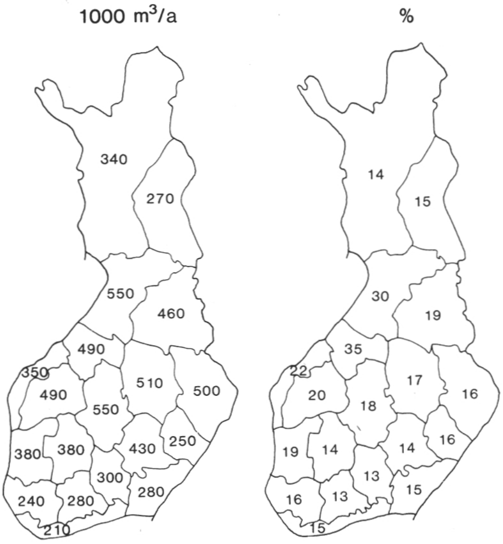


Fig. 3. The fuelwood reserve excluding stump- and rootwood by forestry board districts of private forests (left map, 1,000 m^3/a) compared with the allowable stemwood cut (right map, %) according to areal forest management plans (Ranta 1983).

Kuva 3. Yksityismetsien piirimetsälautakunnittainen polttopuureservi ilman kanto- ja juuripuuta (vasen kartta, 1000 m^3/a) verrattuna aluesuunnitelmien mukaiseen kertymäsuunnitteeseen (oikea kartta, %) (Ranta 1983).

However, it should be noted that it may be regarded not only as a renewable energy reserve but at the same time alternatively also as a raw material reserve of the pulp, board and chemical industries.

The harvestable biomass reserve in the Finnish forests is on average 0,7 $m^3/ha/a$, in the north distinctly smaller than in the south. National averages cannot, however, be used as a starting point for regional energy planning.

Central Forestry Board Tapio has calculated fuel wood reserves of the private forests by district forestry boards (Fig. 3). The figure arrived at as the harvestable fuel wood reserve of the private forestry, excluding stump and root wood, is 7,3 million m^3/a. The harvestable fuel wood reserve compared with the total allowable cut is especially great on the western Ostrobothnian coast where there are a great many birch-dominated young stands that have arisen as the result of large-scale drainage of peatlands in the 1950s and 1960s.

A poorly productive hardwood stand which should be regenerated.

A young spruce regeneration. The overstory trees should be removed.

Estimation of the volumes of small-sized trees and logging residues is difficult because of the inadequacy of basic data and problems of measuring technique. Margins of error are essentially greater than with respect to other timber assortments. According to all estimates the reserve is in any case many times present-day utilisation of small-sized trees and logging residues. According to Ekono's estimation the production potential of fuel wood will be in 1995 still distinctly greater than the utilisation potential (Ekono Oy 1983).

3.2 Present sources of forest chips

Production of forest chips has grown in Finland appreciably from the beginning of the 1980s. Utilisation is, however, still modest compared with the use of traditional fuelwood and the possibilities offered by forests. The situation in 1982 was as follows:

- With minor exceptions, *slash chips* of clear-cutting areas was not used as fuel for 0,5—10 MW heating plants. An obstacle to exploitation had previously been the absence of efficacious chipper equipment, but new chippers and crushers especially designed for slash became available in 1982. These new heavy machines are especially well-suited to use by the forest industry. Thanks to the new technique slash chips are becoming more competitive than other fuel wood as regards costs.
- Utilisation of *stump and root wood* for fuel is so far unprofitable on account of the high harvesting costs and impurities. It has not made progress at any heating plant. However, new prototype machines, including a forwarder-mounted stumpwood processor, are under development. An alternative to utilisation as fuel in the future will be processing in the sulphate pulp industry as fibre raw material.
- Forest chips made of under-sized trees were utilised in 1982 as fuel and raw material in all Finland 766 000 m^3 (1 915 000 m^3 loose measure) of which heating plants used nearly 400 000 m^3 (1 million m^3 loose measure). Utilisation was less than 10 % of the annual harvestable small-wood reserve of forests.

As the consumption compared with reserves was small it was possible to harvest forest chips at a short transport distance from the heating plants. The majority of the forest areas consequently were still outside the range of forest chip harvesting.

Stand data are available only for small-sized wood bought through stumpage sales (Table 3). The most important sources of forest chips at present are hardwood shelter trees to be removed from above young spruce plantations, poorly productive hardwood stands to be clear-cut and small-sized softwood and hardwood from early thinnings.

The forest industry has felt concern occasionally about the utilisation of good quality pulpwood as fuel chips. In reality only VAPO (State Fuel Centre) makes a great proportion of chips from pulpwood. For other procurement organisations the share of pulpwood-sized timber is only 20 % of chips (Fig. 4). Even then it often derives from basically unmerchantable stands in which the hectare yield of pulpwood proper remains below harvestability limit fixed by the forest industry.

3.3 Whole tree or delimbed stem

For yield, scaling, pricing, harvesting and handling, it is essential to know whether the trees are to be chipped with or without branches. The cost difference between whole-tree and stem chips is not always recognised in plant planning in practice.

Branches constitute a considerable proportion of the biomass of small-sized trees (Fig. 5). The additional biomass with needles included of the branches of 4—10 cm trees in

Table 3. Average properties of fuel chip stands in stumpage sales in 1982.
Taulukko 3. Keskimääräisiä tietoja pystykaupalla myydyistä hakepuuleimikoista vuodelta 1982.

Stand type *Leimikkotyyppi*	Proportion *Osuus* %	Area of site *Pinta-ala* ha	Yield — m^3/ha	*Kertymä* m^3/site *m^3/yht.*
Uncommercial thinning *Taimiston perkaus*	3	5,3	19	100
Removal of shelter trees *Verhopuuston poisto*	27	5,2	44	227
Clear-cutting *Avohakkuu*	20	5,8	56	326
First commerc. thinning *Ensiharvennus*	19	6,6	36	239
Later commerc. thinning *Myöhempi harvennus*	13	6,2	45	280
Other *Muu*	18	8,3	23	192
All stumpage sales *Kaikki pystykaupat*	100	6,0	41	245

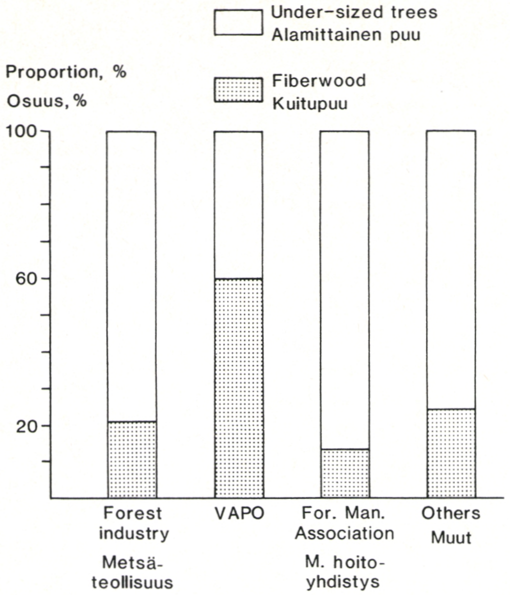


Fig. 4. Share of pulpwood-sized timber in forest chips sold in stumpage sales, by type of organisation.
Kuva 4. Kuitupuun mitat täyttävän puutavaran osuus pystykaupalla myydyssä metsähakkeessa organisaatiotyypeittäin.

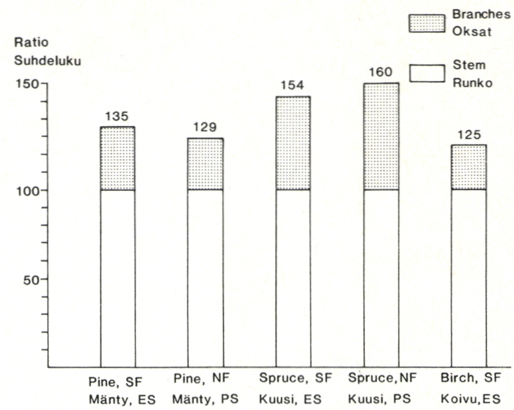


Fig. 5. Additional biomass in the branches of small-sized trees when the value 100 is assigned to stem biomass.
Kuva 5. Pienpuun oksissa oleva lisäbiomassa, kun rungon biomassalle annetaan arvo 100.

a young pine stand is generally 25—35 % and in a spruce stand correspondingly as great as 50—60 % (cf. Kanninen, Uusvaara and Valonen 1979). The additional biomass of small-sized birches is 20—30 %. Delimbing thus means a considerable loss of biomass and additional costs. On the other hand, it facilitates the later handling of both small-sized trees and chips. When the appropriateness of delimbing is considered it is well to pay attention to the following standpoints.

— If small-sized trees are recovered with their branches the biomass yield per stand increases almost as shown in Fig. 5. This increases the size of the sales lots and shortens the average highway transport distance.
— When delimbing is abandoned use can be made of the new felling-piling technique specially developed for small-sized trees at the Finnish Forest Research Institute. The daily output in cutting work for a professional forest worker rises from 5 to 10 m^3.
— Forest haulage of undelimbed trees requires a tractor with boom loader and is therefore not well suited to delivery sales by small farms. Undelimbed trees need more storage space.
— Truck transport of undelimbed trees is expensive because of slow loading and poor use of load space. Whole-tree chipping consequently lends itself poorly to centralised terminal methods unless new truck transport solutions are found.
— Branches slow feeding of the chippers and, in the winter, separation of frozen trees from the pile. Twigs may also clog the discharge spout of the chipper. The difficulties are most apparent when the equipment used is of light weight.
— Whole-tree chips are nearly 10 % cheaper than stem chips. The delimbing requirement adds direct additional costs of 7—10 marks/MWh to the price of forest chips.
— Whole-tree chips may contain twigs and tussocks of needles, depending on the type of chipper and its knives. Over-sized particles may cause bridging and unloading problems in the chip silos and disturbances on the conveyors and the automatic infeed equipment unless precautions are taken in the equipment planning stage.
— When the trees are harvested with their branches the nutrient losses of forest soil are possibly doubled.

Planners of heating plants have not always paid sufficient attention to the advantages offered by whole-tree harvesting at the forest end. Conveyor and infeed devices have often been selected and dimensioned in such a way that handling of whole-tree chips is not possible. There are, however, also successful examples in practice of infeed and handling systems for whole-tree chips. As a matter of fact, the share of whole-tree chips in all forest chips of heating plants appears to be growing.

The municipal district heating plant of Virrat. Effect 6,0 MW + 3,5 MW + 1,8 MW.

The heating plant of the Mikkeli Dairy. Effect 3,3 MW + 3,3 MW.

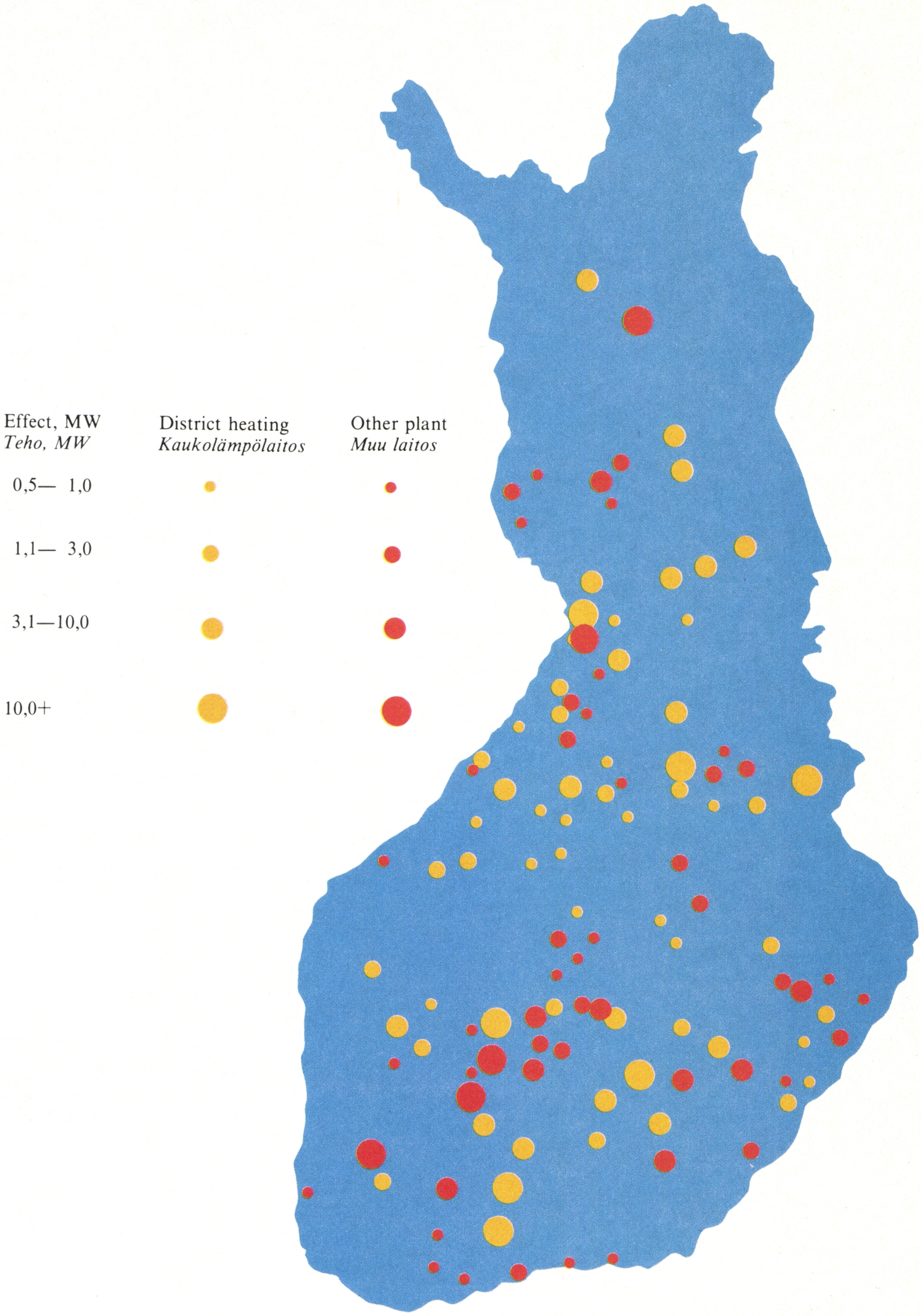


Fig. 6. Forest chip fired heating plants in Finland at the close of 1982. Forest industry power plants are not included in the map.
Kuva 6. Suomen metsähaketta polttavat lämpölaitokset vuoden 1982 päättyessä. Metsäteollisuuden voimalaitokset puuttuvat kartasta.

4. CONSUMPTION OF FOREST CHIPS

4.1 Forest chip fired heating plants

There were in Finland at the close of 1982 a total of 102 heating plants of size class 0,5—10,0 MW which utilised forest chips as fuel. The average nominal capacity of the plants which can generally be exceeded momentarily by approx. 10 % was 2,2 MW.

Over a half of the forest chip fired plants of 0,5—10,0 MW were municipal district heating plants. Other important users were armed forces garrisons, dairies, educational institutions and hospitals.

In addition to the medium-sized plants listed in Table 4, forest chips were burnt also by 13 plants of over 10 MW. Excluding the forest industry, they included 6 district heating plants, 3 garrisons, 3 industrial plants, and a hospital.

The majority of the heating plants had been completed in 1980—1982 and they were thus still in the running-in phase at the time of the study. The building costs of the plants constructed during these years, calculated according to nominal capacity and excluding the heat piping network, was an average of 0,8—1,0 million marks per installed MW. It should be noted that the State has generally participated in defraying the costs through an investment subsidy mounting to 20 % of this total expenditure.

Nominal capacity of heating plant, MW	Number of plants providing information	Building costs, marks/MW
0.5—1.0	12	801 000
1.1—2.0	10	859 000
2.1—5.0	14	1 044 000
0.5—5.0	36	912 000

The price of bigger plants was higher on account of more advanced automation, more complete handling and storage system, and more expensive structures. An average of

Table 4. The forest chip fired 0,5—10,0 MW heating plants by groups of users at the end of 1982.
Taulukko 4. Metsähaketta käyttävät 0,5-10,0 MW:n lämpölaitokset vuoden 1982 lopussa käyttötarkoituksen mukaan ryhmiteltyinä.

Plant group *Laitosryhmä*	Number of plants *Lukumäärä*	Effect, MW *Teho, MW* Aver. *Kesk.*	Total *Yht.*	Use of chips in 1982 *Hakkeen käyttö v. 1982* m^3/plant *m^3/laitos*	m^3/MW	m^3 total *m^3 yht.*
District heating plants *Aluelämpölaitokset*	54	2,4	131,9	3040	1240	164000
Garrisons *Varuskunnat*	14	3,1	42,7	3870	1260	54200
School buildings *Oppilaitokset*	9	1,1	9,7	1470	1360	13200
Industrial plants *Teollisuuslaitokset*	5	1,2	6,2	1600	1290	8000
Dairies *Meijerit*	4	4,6	18,5	7900	1710	31600
Hospitals *Sairaalat*	4	2,4	9,7	3880	1600	15500
Research institutes *Tutkimuslaitokset*	4	1,6	6,2	2080	1340	8300
Other buildings *Muut kiinteistöt*	4	0,5	2,0	800	1700	3400
Greenhouses *Puutarhat*	2	0,7	1,5	400	1170	900
Other institutions *Muut laitokset*	2	0,6	1,3	700	1110	1400
Total — *Kaikki*	102	2,2	229,7	2950	1310	300500

70 % of the investment costs refer to equipment, 20 % to buildings, 3 % to planning and 7 % to other cost items (Toropainen 1982).

Fig. 6 shows the location of forest chip fired heating plants in Finland. Density is especially great in North and Central Ostrobothnia possibly on account of the abundance of young birch forests in drained peatlands. The number of forest chip fired heating plants in south-west Finland is limited by the scantier supply of small-sized wood and the economy of foreign coal, in South Ostrobothnia by, for instance, the good competitiveness of local sod peat and in North Finland by small utilisation potential due to the sparse population.

The profitability of heating plants is often burdened by a low capacity utilisation rate. According to Table 4, utilisation of forest chips calculated per installed effective megawatt of the heating plant was on average 1 310 m^3/a. If average annual efficiency is 65 %, this corresponds to an annual peak utilisation time of 2 850 hours for forest chips. Additional fuels were also used.

Under-utilisation of capacity is due to temporary over-capacity, problems inherent in the running-in phase and especially to the small need of heat during the summer season. Table 5 shows the variation of the average capacity utilisation rate by quarters at dairies, garrisons and communal district heating plants.

The even utilisation at dairies means an appreciable advantage to the forest chip procurement organisation. In contrast, seasonal variation is very great at communal district heating plants. In the summer, when the conditions are favourable for production of chips and the thermal value of wood is at its highest thanks to low moisture content, utilisation by district heating plants is fairly small and is often based on the burning of oil.

The peak of heat production and chip deliveries tends to fall in midwinter. Snow cover, darkness and cold weather make chipping difficult at that time. Chipping is sometimes done in three work shifts during the coldest days. For rational dimensioning of chipper equipment and smoothing the work load, it would be beneficial to meet the peak heat requirement which exceeds a certain basic load level by means of an oil-fired auxiliary boiler. During the summer period of lowest heat requirement the additional oil-fired boiler can be used as the sole source of heat when a small load in a chip boiler is uneconomical on account of poor efficiency.

Table 5. Rate of capacity utilization of dairies, garrisons and municipal district heating plants by quarters in 1982.

Taulukko 5. Meijereitten, varuskuntien ja kunnallisten aluelämpölaitosten käyttöaste vuosineljänneksittäin vuonna 1982.

Quarter *Vuosi neljännes*	Dairies *Meijerit*	Garrisons *Varuskunnat*	Distr.heat.plants *Aluelämpölait.*
	Utilization rate, % — *Käyttöaste, %*		
1	68,7	71,5	68,0
2	68,3	51,6	35,0
3	67,3	44,2	14,9
4	65,7	58,0	57,6
Whole year *Koko vuosi*	67,5	56,3	43,9

4.2 Forest chip production quantities

Forest chips are used in Finland for energy production and to some extent also as industrial raw material. The output of commercial forest chips excluding use by farms and other small-scale consumers totalled 646 000 m^3 (1 613 000 m^3 loose measure) in 1982. About 20 % of it went to the sulphate pulp or particle board industry as raw material, 20 % to the forest industry as fuel and the remaining 60 % to heating plants as fuel (Table 6).

Because of the fairly high cost level, some plants cut down the burning of chips in 1983 but as a counterbalance an appreciable increase probably took place especially at heating plants completed in 1982. As some new plants were also started up, total consumption by heating plants appears to have grown in 1983.

However, in consequence of the price development of oil and coal the growth was probably slower than predicted. Heating plants considered primarily the following factors as growth-limiting reasons in the situation prevailing in the first half of 1983:

Primary factor limiting increase in forest chip firing	Share of heating plants, %
High price of chips	55
Unsatisfactory quality of chips	13
Structural factors in the plant	5
Uncertain availability of chips	2
Labour shortage	2
Absence of a procurement organisation	2
No need to increase utilisation	21
Total (60 plants)	100

Only a fifth of the heating plants used forest chips on such a scale that an increase was not possible at the present utilisation level. Growth of consumption was limited in most cases primarily by the high price compared with alternative fuels.

An obstacle to an increase at many heating plants was also the unsatisfactory and irregular variation in quality of the chips. On the other hand, the role of moisture content and over-sized particles was generally not focal at the large-scale forest industry power plants. The question at issue at the forest industry's power plants was solely price competitiveness as an alternative to coal, peat and heavy fuel oil.

The short-term development prospects of the forest industry's own fuel consumption and utilisation for processing are illustrated in Table 7. The forest chips delivered by the forest industry's procurement organisations to outside heating plants are not included in the figures of the table.

Consumption of forest chips as fuel is thus growing also in the forest industry. This concerns particularly chips made of slash from clear-cutting areas harvested by multi-purpose machines. In consequence of the smoothed price trend of fossil fuels, the growth of the consumption of forest chips was, however, slower than expected even by the forest industry at the beginning of the 1980s. As a matter of fact, the use of forest chips in the forest industry was already in 1979 approx. 79 000 m^3 for sulphate pulping, 56 000 m^3 for particle board manufacturing and 97 000 m^3 for combustion (Eeronheimo 1981).

Table 6. The use of forest chips for energy and industrial processing in 1982.
Taulukko 6. Metsähakkeen polttoaine- ja jalostuskäyttö vuonna 1982.

	Use of forest chips *Metsähakkeen käyttö* m^3	%
Processing in forest industries *Metsäteollisuuden jalostuskäyttö:*		
Particle board industry *Lastulevyteollisuus*	36000	5,5
Pulp industry *Massateollisuus*	91000	14,1
Total — *Yhteensä*	127000	19,6
Combustion in forest industries *Metsäteollisuuden polttoainekäyttö:*		
Screenings in pulp industry *Massateoll. erotettu polttojae*	42000	6,5
Fuel chips proper *Varsinainen polttohake*	84000	13,1
Total — *Yhteensä*	126000	19,6
Combustion in heating plants *Lämpölaitosten polttoainekäyttö:*		
Delivered by forest industry *Metsäteollisuuden toimitukset*	72000	11,2
Delivered by VAPO *VAPO:n toimitukset*	123000	19,0
Delivered by for.manag.assoc. *Metsänhoitoyhdistysten toimitukset*	74000	11,4
Delivered by other organizations *Muitten organisaat. toimitukset*	124000	19,2
Total — *Yhteensä*	393000	60,8
Commercial forest chips, total *Markkinahake yhteensä*	646000	100,0
Chips burned by farms *Maatilojen polttohake*	120000	
Grand total — *Kokonaiskäyttö*	766000	

Table 7. The use of forest chips in the forest industries. The actual use in 1982, a preliminary estimate for 1983 and a plan for 1984.
Taulukko 7. Metsähakkeen käyttö metsäteollisuudessa. Vuoden 1982 toteutunut käyttö, vuoden 1983 ennakkoarvio sekä vuoden 1984 suunnite.

Intended use *Käyttötarkoitus*	Use in forest industries, m^3/a *Metsäteollisuuden käyttö, m^3/a* Actual *Toteutunut* 1982	Estimated *Arvio* 1983	Planned *Suunnite* 1984
For processing: *Jalostuskäyttöön:*			
Accepted for processing *Prosessiin hyväksytty*	127000	155000	
Screened for fuel *Polttoon erotettu*	42000	52000	
For fuel *Polttoaineeksi*	84000	137000	
Total use — *Kokonaiskäyttö*	253000	344000	430000

Small-sized trees left unutilized in an uncommercial thinning.

Small-sized trees bunched alongside a strip road in an early thinning.

5. CHIP PROCURING ORGANISATIONS

Procurement of forest chips for a heating plant is done flexibly within the present forestry organisations. Their activity is based on the use of independent machine contractors (Table 8). There appears to be no need to establish special chip procurement organisations.

The *forest industry's timber procurement organisations* manage 50 % of all procurement of commercial forest chips. However, the forest industry delivers only 18 % of the forest chips of heating plants. The most important supplier is Osuuskunta Metsäliitto.

The greater the chip consumption of a heating plant, the most appropriate is the forest industry as the supplier. The forest industry has in its employ a sufficient number of professional forest workers and contractors and it has a regional network that covers the whole country. It is able to allocate labour and equipment for the procurement of chips flexibly as required, for the share of forest chips in all timber harvested by industry is under 1 %.

The State Fuel Centre VAPO, from the beginning of 1984 Vapo Oy, managed in 1982 the forest chip procurements of state establishments. The main part of the chips go to military garrisons in various parts of the country. Their heating plants are among the oldest of chip-fired plants and they generally require chips of homogeneous quality without over-sized particles.

Forest management associations responsible for private forestry supply chips on the cost-price principle to heating plants. Their activity is confined to private forests, and their primary aim is to improve demand for small-sized wood with a view to furthering the silviculture in young forests. Forest management associations have an important role in activating forest owners to participate in the delivery of fuelwood.

Steady and assured deliveries are especially important for procurement costs. Unfortunately the majority of heating plants close down in the summer or burn oil because of the small heat requirement. As many as half of the chip-fired plants are totally closed in June-August. Because of the fast deterioration of forest chips and the lack of buffer storage, chipping and chip transport must be discontinued although the working conditions are best in the summer.

If it were possible to time chip deliveries evenly, 8,3 % of the total annual requirement would be produced per month. However, in reality the deliveries may be almost double in severe winter months (Fig. 7). The work is distributed more evenly in VAPO which

Table 8. The procurement organizations delivering forest chips in 1982.
Taulukko 8. Metsähakkeen hankintaorganisaatiot vuonna 1982.

Procurement organization *Hankintaorganisaatio*	Deliveries *Toimitukset* m^3/a	All forest chips *Kaikki metsähake*	Heating plant chips *Lämpölaitosten hake*
		Proportion, % — *Osuus, %*	
Forest industry for its own use *Metsäteoll. omaan käyttöönsä*	253000	39,2	
Forest industry for heating plants *Metsäteoll. lämpölaitoksille*	72000	11,0	18,4
VAPO for state institutions *VAPO valtion laitoksille*	123000	19,0	31,4
Forest manag.assoc. for heating plants *Mh. yhd. paikallisille lämpölaitoksille*	74000	11,5	18,8
Heating plants for their own use *Lämpölaitokset omatoimisesti*	89000	13,8	22,6
Forest service, etc., for heating plants *Metsähall. ym. lämpölaitoksille*	21000	3,3	5,3
Private chip contractors *Yksityiset hakeurakoitsijat*	14000	2,2	3,5
Total — *Yhteensä*	646000	100,0	100,0

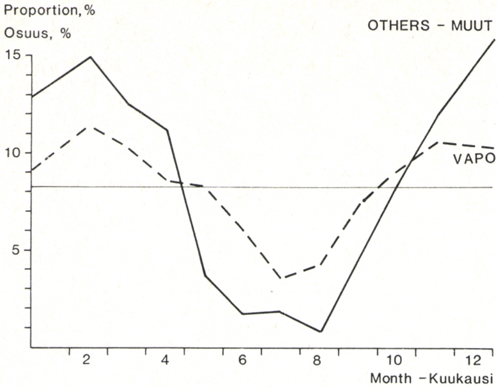


Fig. 7. Monthly distribution of the chip deliveries of the State Fuel Centre (VAPO) and other procurement organisations.
Kuva 7. VAPOn sekä muitten hankintaorganisaatioitten haketoimitusten jakaantuminen kuukausittain.

Table 9. The sales alternatives for fuel chip wood of heating plants by procurement organizations in 1982.
Taulukko 9. Lämpölaitosten hakepuun kauppatavat hankintaorganisaatioittain vuonna 1982.

Procurement organization *Hankintaorganisaatio*	Delivery sales *Hankinta-kaupat*	Semi-delivery *Puoli-hank.*	Stumpage sales *Pysty-kaupat*	Total *Yhteensä*
	Proportion, % — *Osuus, %*			
Forest industry *Metsäteollisuus*	32	4	64	100
State Fuel Centre (VAPO) *VAPO*	66	1	37	100
Forest manag. assoc. *Metsänhoitoyhdistys*	66	4	30	100
Others *Muut*	29	3	68	100
All — *Kaikki*	48	3	49	100

further eases the conditions of the winter season by concentrating chipping to a great extent at central landings.

Fuelwood can be bought on the stump, on semi-delivery or full delivery terms (Table 9). In *stumpage sales* the procurement organisation looks after all the work phases of the harvesting and transport schedule. In *semi-delivery sales* the forest owner is responsible for the cutting of fuelwood and for its bunching to the side of strip road in the forest. In *full delivery sales* the forest owner delivers the fuelwood to a landing alongside a truck road and is thus responsible also for off-road haulage.

The work supervision input of the procurement organisation is generally the greater the smaller-sized the trees to be harvested. The work is thus especially great for fuelwood. This is due above all to the small sales volumes, low labour productivity caused by small tree size, the functional vulnerability of the hot logging schedule, scaling problems and the inconveniences of the running-in phase of new harvesting technique, and method development.

Especially the cutting and off-road haulage of fuelwood take up a great deal of the time of the work supervisors. Purchases and the organisation of chipping and on-road transport also occupy supervisors.

Phase of work	Supervision days/ 100 m^3 of chips	Share %
Purchasing	0,6	21
Cutting and off-road haulage of fuelwood	1,3	44
Chipping and transport of chips	0,6	20
Other jobs	0,4	15
Total	2,9	100

The average cost of work supervision including social security expenses was about 550 marks/day at the 1983 level. The cost of supervision is thus an average of 16 marks/m^3, i.e., approx. 10 % of the total cost of the chips. The supervision input can be expected to decrease and its costs to diminish when the activity stabilises and expands.

A forwarder hauling slash to landing site.

Slash at a landing site ready for chipping.

6. CUTTING AND OFF-ROAD HAULING OF SMALL-SIZED TREES

6.1 Cutting and hauling in delivery sales

The average breast height diameter of fuel chip trees in delivery sales is 6—7 cm. The requirement of delimbing is dependent on the equipment adopted at the plant. To facilitate tractor haulage, however, forest owners often delimb delivery sale timber even when the heating plant will accept whole-tree chips.

Fuelwood is mostly felled, bucked and delimbed by a light-weight power saw. Felling frames, which are useful only when small-sized trees are recovered with their branches, are hardly used at all as additional equipment to the power saw in delivery sales.

In delivery sales fuelwood is most commonly hauled to the road side by a farm tractor with trailer. To an increasing extent the tractor is equipped with a hydraulic loader (Table 10). A grapple boom loader is especially important when fuelwood is transported undelimbed. The loader can be used to make high road side piles which in turn reduce the need of storage space, speed the working of the chipper and reduce snow problems in the winter.

Table 10. Off-road haulage vehicles in delivery sales of fuel chip wood in different parts of Finland.
Taulukko 10. Hakepuun hankintakaupoissa käytetty metsäkuljetuskalusto maan eri osissa.

Vehicle *Kuljetusväline*	South Finland *Etelä-Suomi*	Ostrobothnia, Kainuu *Pohjanmaa, Kainuu*	North Finland *Pohjois-Suomi*	Whole country *Koko maa*
	Proportion, % — *Osuus, %*			
Horse *Hevonen*	1	1	0	1
Snowmobile, light crawler *Lumikelkka, telamaasturi*	1	1	13	3
Farm tractor: *Maataloustraktori:*				
— Skidding equipment — *Laahusjuontovälineet*	4	1	1	2
— Trailer, without loader — *Peräk. kuormaimetta*	35	49	18	37
— Trailer, with loader — *Peräk. kuormaimella*	38	22	7	27
Forwarder *Metsätraktori*	21	26	61	30
All — *Kaikki*	100	100	100	100

In delivery sales timber is hauled to the road side primarily by the forest owner's own equipment but sometimes also by forest or farm tractors hired from outside. Forwardertype forest tractors are used especially in North Finland and when trees are harvested undelimbed inclusive of their branches.

6.2 Cutting in stumpage sales

Preliminary marking of small-sized trees, if carried out as a separate measure, is very expensive in stumpage sales. Selection of the trees to be removed is therefore usually left to the forest worker. The method has been found to increase the forest worker's work motivation, lower total costs and lead to a faultless work result.

The productivity of cutting can be improved most significantly by abandoning delimbing of small-sized trees and chipping them with their branches. The forest industry in particular has rationalised harvesting in this way. Work then proceeds most effectively by means of the felling-piling technique in which the power saw is furnished with a felling frame. The operator can stand upright while cutting.

The felling frame enables the forest worker after cutting the tree to free his grip on the saw and guide the falling tree with both hands for a distance of a few metres, using the kinetic force of the tree. As this working technique calls for experience and skill, it is employed first and foremost only by trained professional forest workers in the forest industry.

The productivity and costs of felling-piling depend greatly on logging technical conditions. Piece rate factors considered in wage tables are, among others, the following (Pieniläpimittaisen... 1983):

— Work is faster in clear-cutting than in thinning.
— The cutting of hardwood is speediest and that of spruce slowest.
— Productivity increases steeply with tree size (cf. Fig. 8).
— Work is faster as per-hectare yield grows.
— Increasing branchiness slows the work.
— Snow slows the work steeply.

Productivity varies widely according to the delimbing requirements and the work difficulty factors in the stand. Delimbing reduces productivity in practice by a half. As regards time and piece rate differences they do not reflect only the differences between the payment systems but largely also the significance of the forest worker's occupational skill. The proportion of permanent forest workers is greatest in work with piece rate payment. Time wages have, on the other hand, been applied in, for instance, unemployment relief work during the winter season when the conditions are often difficult.

	Cutting of delimbed stems	Felling-piling of whole trees
	Productivity, m^3/day	
Time rates	2,9	4,2
Piece rates	4,9	9,8

A day's average earnings of a forest worker, inclusive of the share of the power saw, was around 240 marks in 1982. The social security outlays defrayed by the employer raised the costs of the working day without travel costs to 330 marks. As the daily output is relatively small even at its best because of the small size of the trees, the total costs of chips are influenced significantly by the work difficulty factors of cutting, the quality requirements of fuelwood, planning of the cutting work and the worker's occupational skill.

Cutting should be concentrated for logging technical reasons in the summer when seasoning is best. Felling in summer permits use of transpiration drying in which the trees are left with branches intact on the ground for a couple of weeks to season.

The timetable of the harvesting of fuel chip wood bought on the stump from the moment of purchase is presented in Fig. 9. It takes an average of 14 months after the transaction before the chips reach the plant.

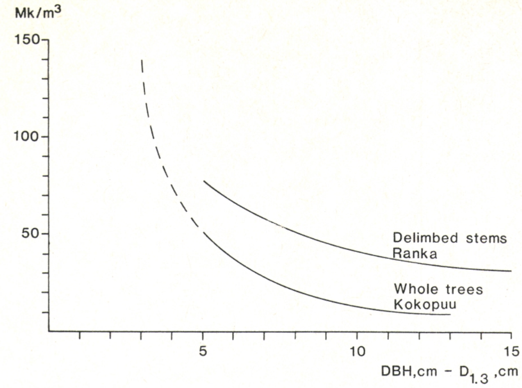


Fig. 8. Costs of the felling-piling of whole trees and the cutting of delimbed fuelwood bunched alongside the strip road for small-sized pine, depending on DBH, at the beginning of 1984. Social security costs of 40 % have been added to the wage total.
Kuva 8. Kokopuun siirtely-kaadon ja uran varteen kasatun karsitun rangan teon kustannus pienikokoisella männyllä puun rinnankorkeusläpimitasta riippuen vuoden 1984 alussa. Palkkasummaan lisätty 40 % sosiaalikustannuksia.

This time lag must be taken into consideration when a new heating plant is being planned. Purchasing and cutting must be commenced sufficiently early.

6.3 Off-road hauling in stumpage sales

In stumpage sales the fuel chip wood is hauled to the landing mainly by a forwarder with standard equipment, generally during the snowless period (Table 11). The tractor requires a 4 m wide strip road and these strip roads are opened up at distances of 25—30 m.

The majority of forwarders are equipped with a knuckle boom loader with a reach of 6—7 m, but extending slide and telescope boom loaders of 9—10 m are becoming more widely used. The latter are not suitable for some light-weight forwarders because of balance problems, and they are slower than knuckle boom loaders. However, they have the advantage of a long reach so that the forest worker need not pile bunches of whole trees or stems close to the strip road even in thinnings. This expedites and eases cutting and permits a wider strip road spacing.

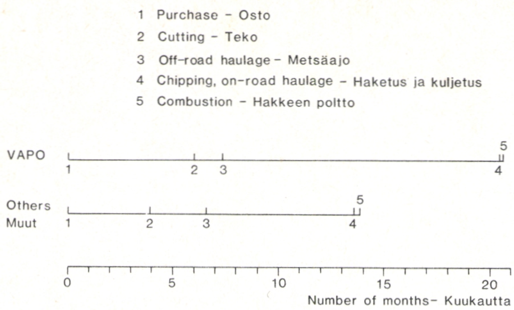


Fig. 9. The time that elapses from the moment of purchase to the delivery time of forest chips in the procurements of VAPO and other organisations.
Kuva 9. Metsähakkeen toimittamiseen ostohetkestä kuluva aika VAPOn ja muitten organisaatioitten hankinnoissa.

Table 11. Off-road haulage vehicles in stumpage sales of fuel chip wood, by procurement organizations.
Taulukko 11. Pystykaupalla ostetuissa hakepuuleimikoissa käytetty metsäkuljetuskalusto.

Procurement organization *Hankintaorganisaatio*	Farm tractor *Maatalous-traktori*	Forwarder *Metsätraktori*	
		with knuckle boom loader *nivelpuomilla*	with extending boom loader *jatkopuomilla*
	Proportion, % — *Osuus, %*		
Forest industry *Metsäteollisuus*	8	50	42
State Fuel Centre (VAPO) *VAPO*	16	82	2
Forest manag.assoc. *Metsänhoitoyhdistys*	11	44	45
Others *Muut*	3	74	23
All — *Kaikki*	9	65	26

The output and costs of off-road haulage of stems and whole trees vary greatly from site to site. The average work result is seen in the following schedule. The daily output is distinctly smaller than when hauling conventional pulpwood.

	Load size, m^3	Output, m^3/day
Farm tractor	3,6	26
Forwarder	5,6	50

The average forest haulage costs of undelimbed whole trees in 1983 in piece rate work using a forwarder was 23 marks/m^3. For farm tractors which were used to transport mainly delimbed trees and probably in easier terrain the average costs amounted to 18 marks/m^3.

7. CHIPPING

7.1 The Finnish chipper park

Over 2 000 light-weight chippers designed for farm use with a farm tractor as their power source are in use in Finland (Fig. 10). Farm chippers are fed by hand and they have been purchased primarily for domestic use. It is estimated that they produce yearly at least 120 000 m^3 of chips for this purpose. Farm chippers are used to produce fuel for heating plants only exceptionally.

Contractors use bigger machines which are equipped with a hydraulic feeding device and grapple boom loader. The greatest part of them are farm tractor operated, but compared with farm chippers they require a more powerful prime mover. There are also forwarder-mounted large terrain chippers and truck-mounted large landing chippers. A few towable large landing chippers have also been made.

7.1.1 Farm tractor-driven chippers

Contractors using farm tractor driven chippers produced in 1982 approx 320 000 m^3 of forest chips for heating plants. The farm tractor functions concurrently as both prime mover and the power source of the chipper and loader. The chips are blown

The felling frame enables the forest worker to stand upright while cutting and to guide the falling tree.

directly into the prime mover's own trailer or into a separate one (Fig. 11).

The following list contains the commonest Finnish chippers employed by contractors, beginning from the lightest equipment. The prices which do not include the prime mover represent the situation at the close of 1983. In addition to a large number of farm tractor driven Finnish chippers some Swedish chippers (Bruks, Erjo and Poma) are also in use.

Hakki H 200 S

The Hakki H 200 S is a disc chipper with three knives. It is mounted on the three-point linkage of the tractor. The 105 cm disc weighs 240 kg. The measurements of the feeding opening are 15 × 22 cm. When used by a contractor a hydraulic feeder roll is attached to the chipper. The nominal particle size of chips can be adjusted over the range 4—22 mm.

The total weight with the roller included is 535 kg. The price of the chipper depending on the feeding device is 16 250 or 20 600 marks. The manufacturer is Karjalan Rautarakenne Oy; the seller in Finland is Kesko.

Junkkari HJ 10 SL

The Junkkari HJ 10 SL is a 2-knife or 4-knife disc chipper mounted onto the three-point linkage of the tractor. The diameter of the disc is 80 cm and it weighs 175 kg. The feeding device has two pulling rollers. The nominal particle size of the chips can be adjusted by means of a 2-knife disc over the range 20—40 mm and by a 4-knife disc from 6 to 26 mm. The chipper can be placed between the tractor and trailer thus permitting both terrain and landing chipping.

The total weight of the machine is 650 kg. Its price is 29 000 marks. It is manufactured by Junkkari Oy and sold in Finland by Hankkija.

HS-500 HD

The HS-500 HD is a 3-knife drum chipper mounted on the three-point linkage of the tractor. The drum, diameter 450 mm and weight 200 kg, is equipped with a screen with the desired hole size for the crushing of over-sized particles. The feeding opening measures 20 × 40 cm. The feeding device has two pulling rollers. The nominal particle size of the chips can be adjusted over the range 5—38 mm.

The total weight of the machine is 1 100 kg. The basic model costs 42 000 marks. It is possible to get a 40 × 150 cm chain conveyor for the chipper by way of additional equipment chiefly for the chipping of slash. The total price is then 80 000 marks. The manufacturer and seller is H-Steel Oy.

Junkkari HJ 30

The Junkkari HJ 30 is a 2-knife disc chipper constructed on a 1-axle chassis. The diameter of the disc is 106 cm and it weighs 400 kg. The measurements of the feeding opening are 30 × 35 cm. The feeding device has two rollers. The nominal particle size of chips can be adjusted over the range 15—40 mm. A trailer can be linked to the chipper.

The total weight of the machine is 1 350 kg. Its price is 79 000 marks and when equipped with the auxiliary feeding equipment 89 000 marks. The manufacturer is Junkkari Oy, the seller Hankkija.

TT 1250 M

The TT 1250 M is a 1- or 2-knife disc chipper constructed on a 1-axle chassis. The diameter of its disc is 125 cm. The feeding device incorporates two pulling rollers. The measurements of the feeding opening are 33 × 33 cm. The nominal particle size of the chips can be adjusted over the range 10—32 mm.

The total weight of the machine is 2 250 kg. Its price, depending on its accessories, is about 135 000 marks. It is made by Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy and sold in Finland by Työväline Oy.

Pete 1000

The Pete 1000 is a 2-knife cone drum chipper constructed on a 1-axle chassis. Its cone drum weighs 800 kg. The size of the feeding opening in 38 × 32 cm. The feeding device consists of three rollers below and one above. The nominal particle size of the chips can be adjusted over the range 24—50 mm.

The total weight of the machine is 1 700 kg. It costs 128 000 marks. The same chipper can be constructed a terrain chipper equipped with a tippable chip bin. Its price without the forwarder functioning as the chassis is then 335 000 marks. The manufacturer is Zerne Oy and it is sold by the manufacturer and by Metsätyö Oy.

Karhula 312 CS

The Karhula 312 CS is a 3-knife disc chipper constructed on a 1-axle chassis. Its disc is 120 cm in diameter and weighs 650 kg. Contrary to other farm tractor-driven chippers feeding is done from behind the machine. The feeding device consists of two superimposed 38 cm wide chain mats the lower one of which is 200 cm long. The measurements of the feeding opening are 31 × 31 cm. The nominal particle size of the chips can be adjusted over the range 8—36 mm. This chipper type is common at VAPO work sites in which most of the raw material is delimbed pulpwood and in which chipping is often done at large central landings.

The total weight of the machine is 2 350 kg. When equipped with a chain feeder it costs 154 000 marks. When short delimbed bolts are being chipped it is possible to operate without the chain feeder, in which case the price is 96 800 marks. The manufacturer and seller is Karhulan Konepaja engineering works of A. Ahlström Osakeyhtiö.

TT 1000 TU

The TT 1000 TU is a 2-knive disc chipper constructed on a 1-axle chassis. The diameter of its disc is 107 cm. The feeding device consists of a 125 cm chain conveyor and a pulling roller above it. The measurements of the feeding device are 28—31 cm. The adjustment for the nominal particle size of the chips is either 24—32 mm or, on special order, 16—25 mm. TT 1000 TU is the commonest chipper type serving heating plants in Finland. A total of about 100 units have been manufactured.

The total weight of the machine is 3 200 kg. Its price is approx. 200 000 marks, depending on the accessories. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy and seller in Finland Työväline Oy.

Hake-Jakke 2000

The Hake-Jakke 2000 is a 2-knife disc chipper constructed on a 1-axle chassis. The diameter of its disc

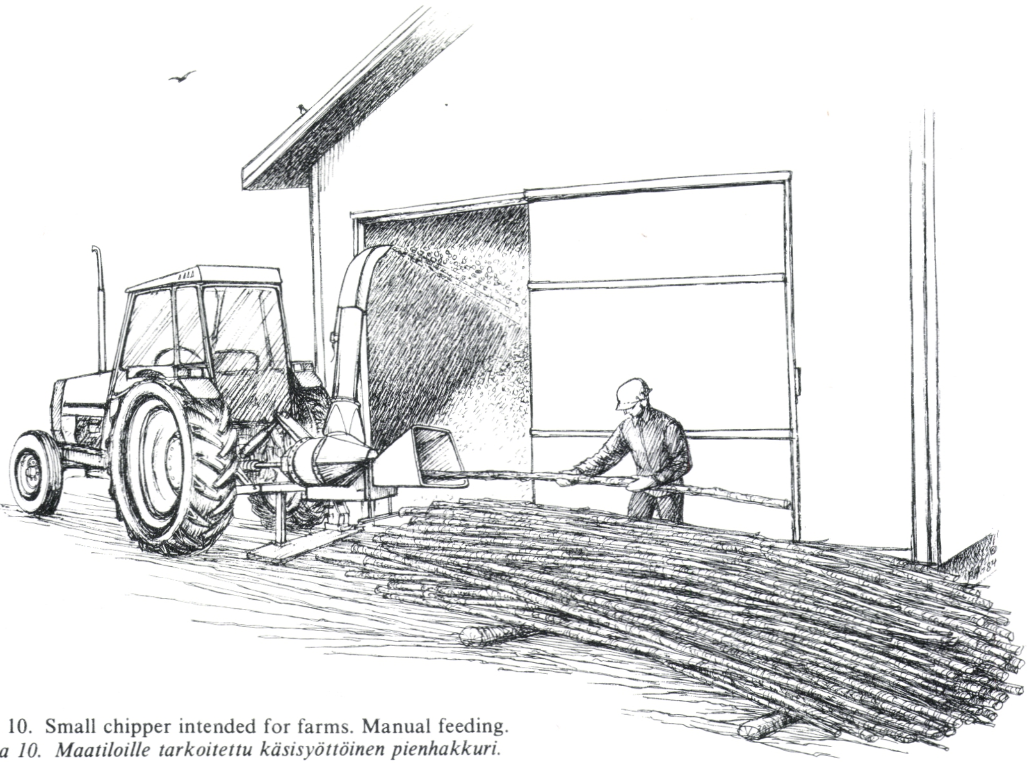


Fig. 10. Small chipper intended for farms. Manual feeding.
Kuva 10. Maatiloille tarkoitettu käsisyöttöinen pienhakkuri.

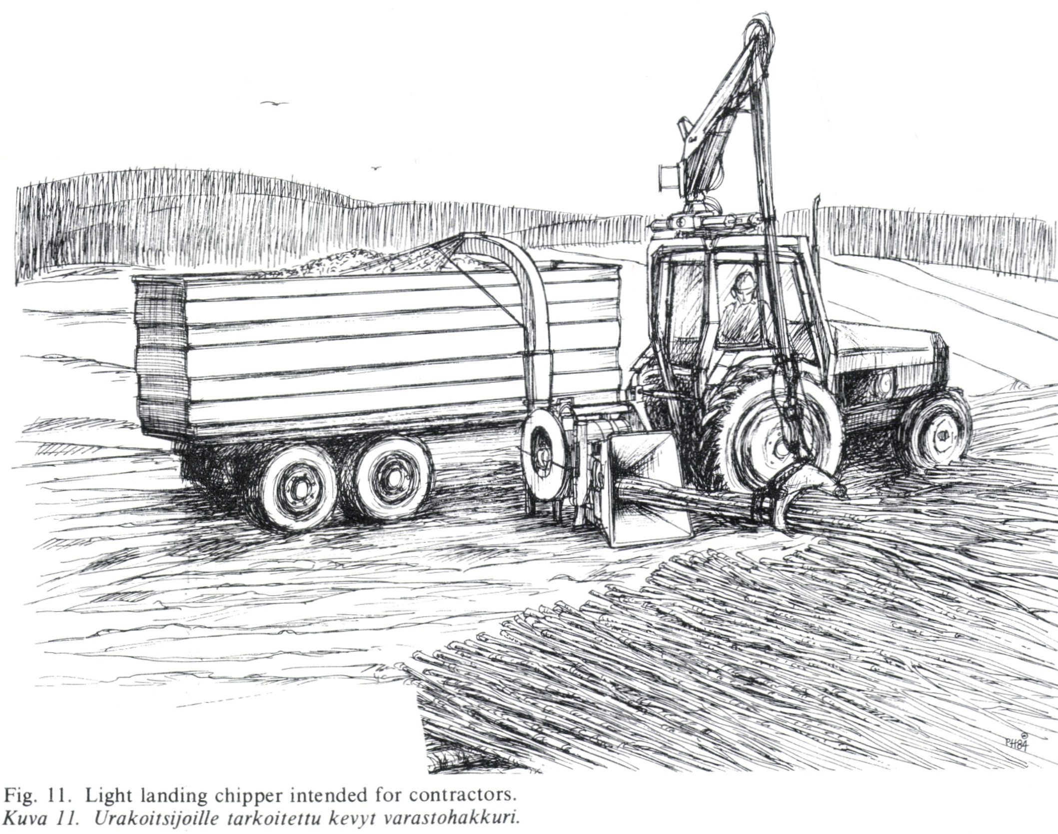


Fig. 11. Light landing chipper intended for contractors.
Kuva 11. Urakoitsijoille tarkoitettu kevyt varastohakkuri.

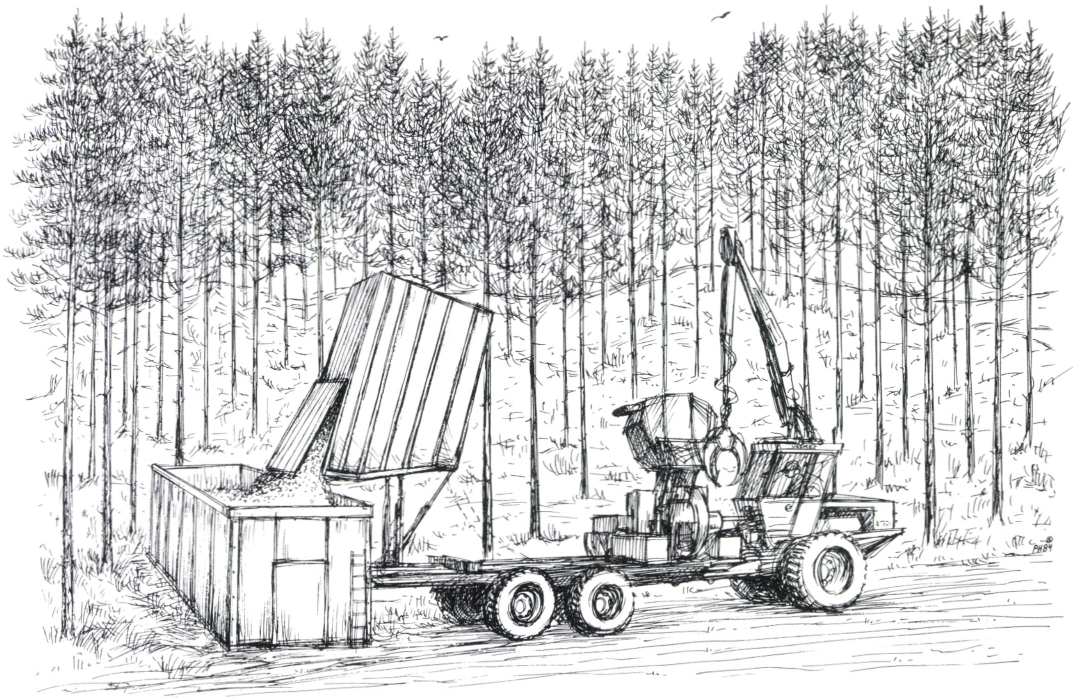


Fig. 12. Forwarder-mounted heavy terrain chipper unloading its chip bin.
Kuva 12. Metsätraktorisovitteinen järeä palstahakkuri purkamassa hakesäiliötään.

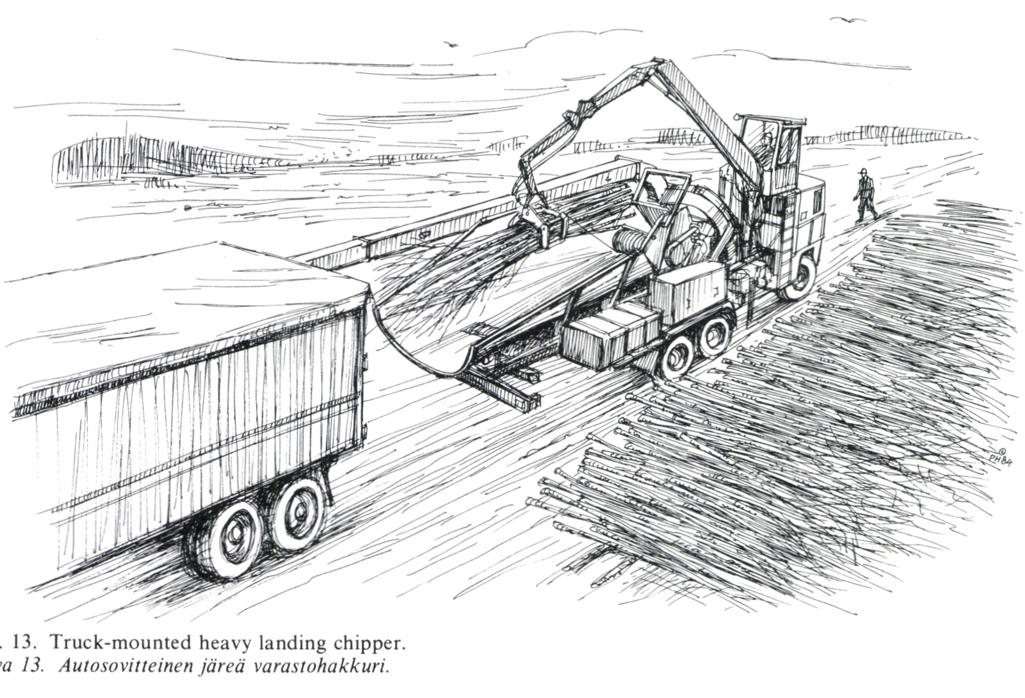
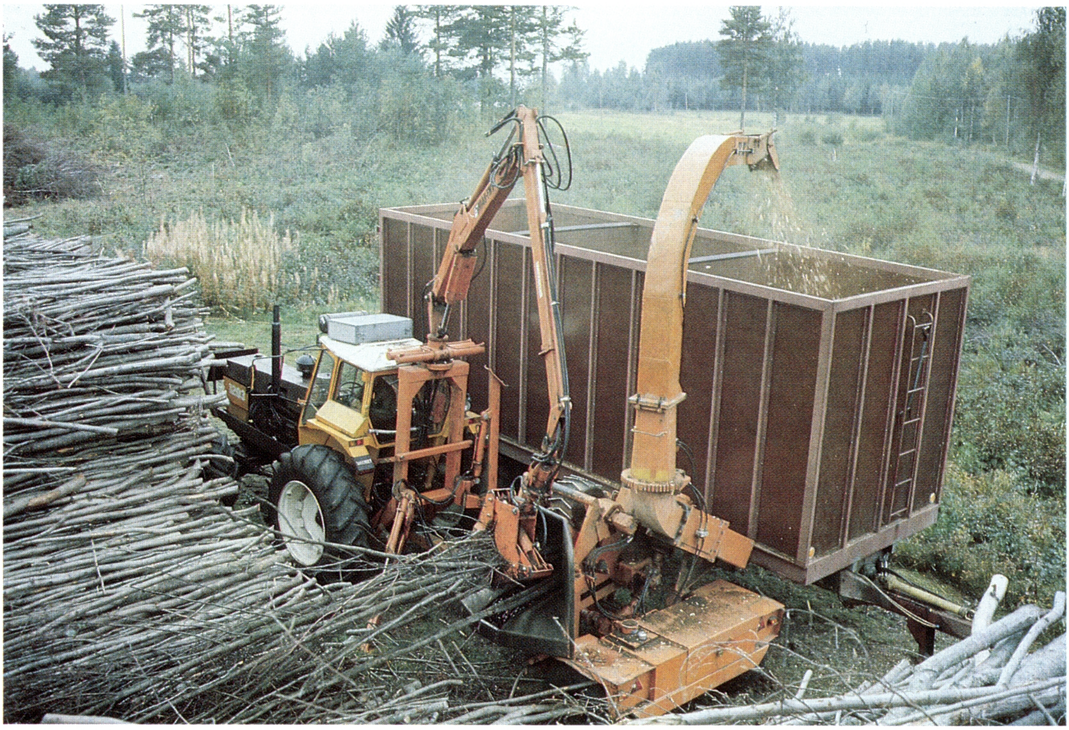


Fig. 13. Truck-mounted heavy landing chipper.
Kuva 13. Autosovitteinen järeä varastohakkuri.



Farm tractor driven TT 1000 TU disc chipper.

Truck-mounted TT 1500 LP disc chipper.

is 160 cm and weight 2 000 kg. The measurements of the feeding opening are 48 × 48 cm. The feeding device consists of three rollers of which two are below and one above. An upper chain cradle of 48 × 100 cm can be attached to the feeding device as auxiliary equipment. The particle size of the chips can be adjusted over the range 10—70 mm.

The total weight of the machine is 3 700 kg. It costs 250 000 marks. The same chipper can also be mounted on a truck in which case the total price of the unit is about 700 000 marks. The manufacturer and seller is Niva-Jakke Ky.

TT 1000 TS

The TT 1000 TS is a 2-knife disc chipper constructed on a bogie chassis. The actual chipper part with its feeding device is the same as in the TT 1000 TU model. The machine is equipped with a 18 m^3 chip bin which makes terrain chipping possible. The tipping height of the bin is 3,1—4,0 m.

Total weight without the prime mover is 7 000 kg. The price is 350 000—400 000 marks, depending on the accessories. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy and the seller is in Finland Työväline Oy.

The farm tractor-driven chippers enumerated in the foregoing cover a broad range of capacity and price. When the prime mover is included the differences between investment costs and per-hour costs increase further for the heaviest chippers also require the most effective prime movers. The profitability of the chipper types depends on the amount of work available, working conditions and the quality requirements of the chips.

7.1.2 Forwarder-mounted chippers

Forwarder-mounted terrain worthy chippers operate as a rule from the strip road in the terrain. They therefore have a bin from which the chips are tipped at the landing onto the interchangeable truck pallet which has been lowered onto the ground (Fig. 12).

Thus, forwarder-mounted terrain chippers perform both the chipping and forest haulage. The hourly output is equally great as with a forwarder with standard equipment in the haulage of whole trees. The method also has the advantage of needing little landing space.

Heavy terrain chippers are competitive in Finnish conditions in easy terrain, especially for early thinnings of pine stands on dry sites. But they are not suitable in difficult terrain and snow conditions.

Bunches piled alongside the strip road are covered by snow in the winter and terrain chippers have to function as landing chippers. Their unit costs then tend to rise higher than those of landing chippers proper. This weakens the competitiveness of terrain chippers in the Finnish conditions as the demand for fuel chips is concentrated largely in the winter season.

The high price level is an obstacle to the generalisation of forwarder-mounted terrain chippers. It is due to the expensive prime mover, the separate motor of the chipper and to versatile operations. These machines produced in 1982 about 25 000 m^3 of chips.

Lokomo 919/P 1000

The Lokomo 919/P 1000 is a terrain chipper mounted on a medium-sized 6-wheel Lokomo 919 forwarder. Chipping is performed by the same 2-knife cone drum chipper, driven by a separate 109 kW motor, as in the farm tractor-driven Pete 1000 unit. The feeding device is turned up while the chipper moves on the strip road. The feeding device consists of a chain conveyor, three pulling rollers and an adjustable upper spike roller. The volume of the chip bin is 16,4 m^3 and tipping height 2,7 m.

The total weight of the unit is 15 000 kg and price 987 000 marks. The manufacturer is Joensuun Konepaja engineering works of Rauma-Repola Oy, the seller Lokomo Forest Oy.

TT 1000 F

The TT 1000 F is equipped with the same 2-knife disc chipper as the farm tractor-driven chippers of the TT 1000 series. The effect of the separate motor of the chipper is 106 kW. It is possible to turn the chipper part proper in the horizontal plane in order to ease feeding. The volume of the chip bin is 18 m^3 and the tipping height is 3,0 m.

The total weight of the unit mounted on a medium-sized 6-wheel Valmet 872 forwarder is 18 500 kg and price about 1,1 million marks. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy. The seller in Finland is Työväline Oy.

7.1.3 Truck-mounted chippers

Truck-mounted chippers are designed for use at landings. The chips are transferred straight into a truck, a trailer or an interchangeable pallet lowered onto the ground (Fig. 13). The truck serves as the chassis and gives the power to the loader. The source of power for the other operations is alternatively a separate motor or the truck's own motor. To reduce costs, a second-hand truck is generally chosen as the basic machine.

The machines are effective and move flexibly from one work site to another. The annual capacity of the biggest units may amount to 40 000—50 000 m^3 (125 000 m^3 loose measure). Because it is not profitable to bring large-sized machines to a very small work site the minimum size of landing is usually the load of a truck-cum-trailer. Truck-mounted chippers require a bearing landing area on firm soil.

Because of the great capacity of the machines truck chipper contractors work primarily for the forest industry. Truck chippers produced in 1982 in all approx. 300 000 m^3 of forest chips for energy and processing purposes.

The most important Finnish truck-mounted chipper types are described briefly in the following. Certain other machines exist, but only in units of prototype nature so far.

TT 1500 L

The basic machine of the TT 1500 L chipper is a bogie truck. The truck's own motor drives the 3-knife disc chipper, its hydraulic feeder and loader. The diameter of the disc is 150 cm. There is in the load space a separate cabin for the driver. Feeding is done from behind the machine. The feeding device has a 45 × 500 cm chain conveyor and above it an adjustable roller. The dimensions of the feeding opening are 45 × 48 cm. The particle size of the chips can be adjusted over the range 24—32 mm or, on special order, a range of 16—25 mm.

The total weight of the unit is 22 000 kg and price around 1,0 million marks. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy and seller in Finland Työväline Oy.

TT 1500 LP

The TT 1500 LP chipper differs from the previous model only in that the disc chipper is driven by a separate 250—300 kW motor and the chipper part is placed on a frame that revolves 90 deg. Feeding is done as a rule from the side. The feeding device consists of a 250 cm conveyor and an adjustable roller above it.

The total weight of the unit is 24 000 kg and price approx. 1,5 million marks. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy and seller in Finland Työväline Oy.

TT 910 R

The TT 910 R is mounted on the frame of a bogie truck. The 2-knife drum chipper, diameter 90 cm, is driven by a separate 235 kW motor. The particle size of the chips can be adjusted over the range 15—40 cm by changing the screen. As with the preceding truck-mounted chippers, the load space accommodates also a loader and a driver's cabin that can be raised. Feeding is from behind, but the chips emerge from a discharge spout pointed forwards. The feeding device has a 100 × 300 cm lamellar conveyor with a roller as its continuation and an upper adjustable roller. Thanks to the feeding device solution and the wide 45 × 100 cm feeding opening the machine is suitable not only for stem-formed wood but also and especially for slash.

The total weight of the unit is 24 500 kg and price 1,5 million marks. The manufacturer is Hämeenlinnan Konepaja engineering works of Perusyhtymä Oy, seller in Finland Työväline Oy.

ALGOL HEM 300—1000 WEA

The Algol HEM 300—1000 WEA is mounted on a bogie truck. It is fed from behind and designed specifically for the handling of slash. The load space of the truck accommodates a drum chipper, driven by a separate 270 kW motor, and its feeding device, loader, discharge spout and driver's cabin that can be raised. There are 20 knives placed stepwise in the drum, diameter 60 cm and weight 2 000 kg. The drum is surrounded by an exchangeable screen which adjusts the particle size of the chips. The feeder has a 300 cm lower conveyor of steel lamella construction and an adjustable upper conveyor formed by four rollers. The feeding opening measures 30 × 100 cm.

The total weight of the unit is 25 000 kg and price 1,3 million marks. The chipper is manufactured and marketed by Oy Algol Ab.

Lokomo MS 9

The Lokomo MS 9 is a laterally fed crusher mounted on the frame of a bogie truck. It is intended primarily for slash. The truck load space accommodates a hammer hog, equipped with a separate 206 kW motor, with its feeder, a loader furnished with a telescope boom and a 6-spike grapple, a rearwards discharging conveyor and a driver's cabin that can be raised. There are two hammer rows and two comblike anvils in the rotors, diameter 92 cm, of the crusher. The feeding device has a lower conveyor of lamellar type and an adjustable upper roller. The measurements of the feeding opening are 60 × 120 cm. The product is crushed material in lieu of the customary chips and its particle size is adjusted by an interchangeable screen.

The crusher part weighs 21 000 kg without the chassis truck. The price is about 1,6 million marks, depending on the basic machine. The manufacturer is Joensuun Konepaja engineering works of Rauma-Repola Oy, seller for forest use Lokomo Forest Oy and for other use the manufacturer.

7.1.4 Heavy chippers mounted on a towable chassis

Three towable American Trelan D 60 landing chippers equipped with a motor of their own were imported to Finland in the latter half of the 1970s and a heavy Morbark 22 for chipping wood residues recovered from fuel peat sites in the beginning of the 1980s. Large-sized domestic landing chippers mounted on a towable chassis are only in experimental use so far.

The actual chipping part with its feeding device corresponds operationally to those in

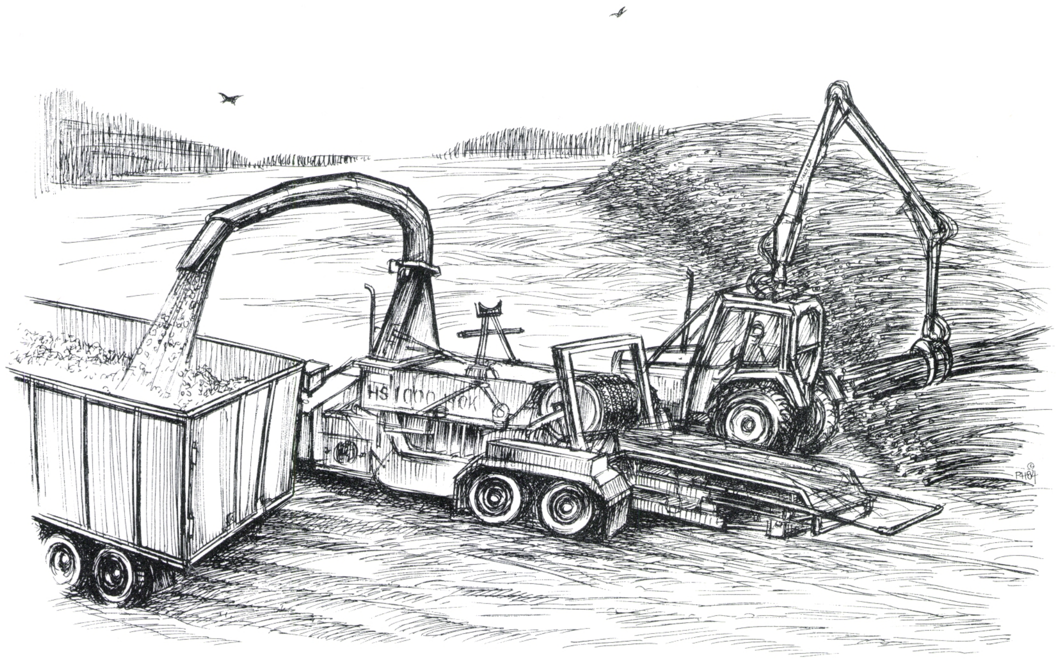


Fig. 14. Heavy landing chipper mounted on a towable chassis. A separate tractor is needed for feeding.
Kuva 14. Hinattavalle alustalle asennettu järeä varastohakkuri. Syöttöön tarvitaan erillinen traktori.

large-sized truck-mounted chippers. A separate prime mover is needed for feeding and movement within and between work sites (Fig. 14). The chassis solution makes towable large-sized chippers lower-priced than truck-mounted chippers and possibly better suited for export.

HS 1000 HDK

The HS 1000 HDK is a drum chipper mounted on a 2-axle chassis and designed specifically for slash. The drum, diameter 100 cm, has two rows of knives, both of them with two 400 mm knives side by side. The drum weighs 1 000 kg. The measurements of the feeding opening are 40 × 80 cm. The feeding device consists of a 80 × 400 cm lamella mat and above it an adjustable roller, diameter 90 cm. The particle size of the chips is adjusted by means of an interchangeable screen around the drum.

The unit has no loader of its own. For feeding a separate tractor is necessary; the remote controls of the chipper are led into its driver's cabin.

The length of the unit is 9,3 m and weight 12 000 kg. It costs 480 000 marks. The manufacturer and seller is H-Steel Oy.

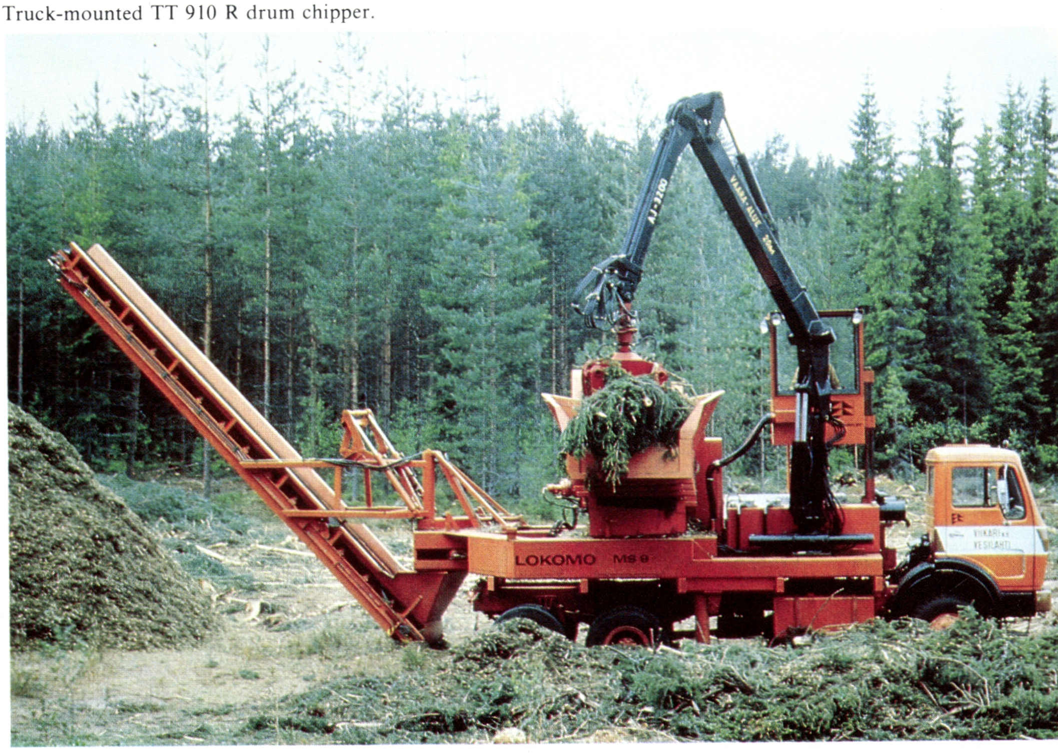
7.2 Organisation of chipping

Cost reasons and reliability of operation require that the chipper capacity is in correct ratio to the annual chip need and occasional demand peaks. The following indicative performances, dependent on work difficulty factors, may be mentioned as examples of average hourly output and the output of a well-organised 8-hour shift corresponding to it.

Chipper	Prime mover	Hourly output m^3	Capacity per shift, m^3
HJ 30	Farm tractor	6— 8	30— 40
TT 1000 TU	Farm tractor	11—16	60— 80
TT 1500 L	Truck	20—25	120—160

Chip consumption is timed unevenly in practice. The demand is at its maximum in November-April. Loosening snow-covered trees that have frozen together taxes the durability of the loader and the unit as a whole and reduces the work output at the very time when chips are needed most. As buffer storage facilities are small in practice it is imperative to dimension chipper capacity in accordance with the peak requirement of the winter. The consequence is under-utilisation for the greatest part of the year. It is exceptional to exploit the full capacity of a chipper.

Truck-mounted TT 910 R drum chipper.



Truck-mounted Lokomo MS 9 crusher.

Landing arrangements have an important role in the planning of chipping. The landing site must be firm and spacious enough for the vehicle to be loaded to position itself behind, in front of or alongside the chipper.

The optimal direction and height of the piles are determined by the chipper loader and method of feeding. The type of chipper in question must therefore be known by the time the trees are being hauled to the landing.

The best height of the landing pile depends on the range of vision of the chipper driver, the strength and range of the loader, the location of the feeding opening and the length of the fuelwood. A 2 m high pile may be suitable for machines of light construction but a 2,5—3,5 m pile is best for most tractor driven chippers. As regards the moisture content of chips, the result is better the higher the piles made.

	The best pile height on average, m
Tractor-driven chippers with whole trees	2,8
Tractor-driven chippers with 3-m delimbed stems	3,3
Truck-mounted chippers	3,6

7.3 Disturbances in chipping

Only about 60 % of the work-site time of the chipper driver is spent on chipping proper. The actual performances of chippers are thus considerably smaller in practice than the outputs per effective time reported for them. Interruptions are caused primarily by waiting for the chip vehicle, movement of chipper from one work site to another, maintenance, machine breakdowns and rest intervals.

Work phase	Share in work-site time, %
Chipping proper	60
Waiting for the chip vehicle	9
Movement between work sites	8
Maintenance	8
Machine breakdowns	5
Rest intervals	6
Other work phases	4
Total	100

Several contractors who use farm tractor as the prime mover for the chipper improve the employment of the tractor by also transporting the chips with the same vehicle. The chipper driver and the tractor are thus relieved from having to wait for the chip vehicle.

Although the present chipper types were not developed until the end of the 1970s or early 1980s, many of them have achieved excellent reliability of operation. Machine breakdowns take up only 5 % of work-site time and the majority of them are due to faults in the prime mover and loader.

Breakdowns are fairly infrequent in the chipper part proper, but slightly more common in the hydraulic feeding device (Table 12). The loss of time caused by the wearing and changing of knives is included here in maintenance time.

Various disturbances that lower output take place in chipping work proper the share of which is an average of 60 % of the driver's work-site time. The *commonest disturbances* are caused by the following factors.

— *Rapid wear-and-tear of knives* due to sand, stones and metal bodies means not only direct knife costs but, due to lowered output and the changing of knives, also additional indirect costs. Reducing impurities requires care in forest haulage, avoidance of small piles and the use of foundation timber under the piles. However, compared with skidding haulage, the Finnish forwarder transport as such helps to keep the fuelwood clean.

— *Clogging of the discharge spout* occurs especially when green undelimbed softwoods, very small undelimbed hardwoods, branchy softwood tops, slash and over-sized trees are chipped. Thawing snow and blunt knives contribute further to the clogging of the discharge spout. The problems can be reduced by delimbing the fuelwood, increasing engine power, using an effective blower and the operator's experience.

— The *freezing together and to the ground of trees* may make the feeding of the chipper difficult. The problem can be reduced by making high piles, using foundation timber under the piles, covering the piles with tarpaulins and increasing the efficiency of the loader.

— The *snow on the piles* makes it difficult to grapple the trees. It accumulates under the conveyor of the feeder and chokes the feeding device especially during a thaw. Snow also increases the moisture content of chips. The snow problem can be lessened by making large and high landing piles and using protective coverings.

— Poor *bearing capacity of ground* may hamper the movements of chippers and chip vehicles in the landing area. Terrain chipping in particular requires firm ground.

Table 12. The sources of chipper breakdowns.
Taulukko 12. Hakkureissa esiintyneitten konerikkojen kohteet.

Source of breakdowns *Konerikon kohde*	Procurement organization — *Hankintaorganisaatio* Forest industry *Metsäteoll.*	VAPO	Manag.assoc. *Mh.yhd.*	Others *Muut*	All *Kaikki*
	Distribution of breakdowns, % — *Konerikkojen jakauma, %*				
Prime mover *Käyttökone*	47	54	15	20	35
Loader *Kuormain*	26	13	46	32	27
Feeding device *Syöttölaite*	11	26	14	22	20
Chipping device *Hakkuriosa*	8	4	16	18	11
Other *Muu*	8	3	9	8	7
Total — *Yhteensä*	100	100	100	100	100
	Proportion of machine breakdowns in work site time, % *Konerikkojen osuus työmaa-ajasta, %*				
Total — *Yhteensä*	2,9	5,7	5,6	5,2	5,0

7.4 Output and costs of chipping

Output depends both on the chipper and its operator and on several work difficulty factors which influence chippers of different sizes in different ways. Some examples are given in the following of factors that affect output.

- — Average output increases with the size of the landing site chiefly because of reduced movement between work sites and easier maintenance. The highest outputs are achieved at chipping terminals.
- — Very small-sized wood is slower to chip unless the tree size exceeds the capacity of the chipper.
- — Undelimbed whole trees are slower to chip than delimbed stems. A typical output difference in chipping proper is about 20 %.
- — The snow on the piles slows the work and at the same time increases the moisture content of the chips. Freezing of trees is particularly detrimental in machines with a loader of poor effect.
- — Stones and sand in the fuelwood slow the work by blunting and breaking knives. The problem is most acute for slash collected during the summer.

The immediate knife costs of the commonest farm tractor-driven disc chippers are on average a good 2 marks/m^3, i.e., 8 % of the chipping wage. Half the knife costs are caused by the purchase price and half by sharpening which can be repeated 20 times. Almost all the knives used in Finland are made by Terätuote Oy.

In Table 13 knife costs are lowest for the Karhula 312 CS chippers which chip mainly delimbed pulpwood at VAPO's chipping terminals. This timber is cleaner with regard to sand and stones than undelimbed whole trees.

Table 13. Examples of direct knife costs of the most common disc chippers.
Taulukko 13. Esimerkkejä yleisimpien laikkahakkureitten välittömistä teräkustannuksista.

	Chipper type — *Hakkurityyppi* TT 1000 TU	312 CS	Light disc chippers *Kevyet laikkahakkurit*
Number of knives per set *Teriä, kpl/sarja*	2	3	2—4
Price of knife set, mk *Teräsarjan hinta, mk*	792	1218	1033
Interval between sharpening, m^3 *Teroitusväli, m^3*	66	97	42
Sharpenings per set *Teroituskertoja/sarja*	16	23	21
Life time of knife set, m^3 *Teräsarjan kesto, m^3*	1130	1960	890
Sharpening cost, mk/set *Teroituskust., mk/sarja*	62	91	53
Knife cost, mk/m^3 *Teräkustannus, mk/m^3*			
Investment cost *Hankintakustannus*	1,10	7,5	1,35
Sharpening cost *Teroituskustannus*	1,05	1,05	1,30
Total knife cost *Kokonaiskustannus*	2,15	1,80	2,65

The average daily output of farm tractor-driven chippers corresponds only to continuous chipping for a good 3 hours (Table 14). The chipping terminals of VAPO, for which the comparable ratio is 4,5, constitute an exception. It would be possible to raise operational availability essentially from the present level by centralisation of operations, careful planning, improvement of buffer storage facilities and avoidance of unnecessarily efficient machines.

A chipper contractor usually owns both the chipper and the transport equipment.

Table 14. Average daily output of farm tractor driven chippers, compared with the output per effective hour.
Taulukko 14. Traktorikäyttöisten hakkureitten keskimääräinen päivätuotos lämpölaitosten haketusurakoinnissa tehotuntituotokseen verrattuna.

Variable *Muuttuja*	Light chipper *Kevyt hakkuri*	Medium-sized chipper *Keskiraskas hakkuri*
Output, m^3/effective h *Tehotuntituotos, m^3*		
Delimbed stems — *Ranka*	10	15
Whole trees — *Kokopuu*	8	12
Real daily output, m^3 *Todellinen päivätuotos, m^3*		
Delimbed stems — *Ranka*	32	46
Whole trees — *Kokopuu*	26	40
Daily output/eff. h output *Päivätuotos/tehotuntituotos*		
Delimbed stems — *Ranka*	3,2	2,9
Whole trees — *Kokopuu*	3,1	3,7

Single ownership seems in fact to be a favourable solution for flexible synchronizing of chipping and transport operations and reducing conflicts.

7.5 Ergonomics of chipping

The operators of forest machines are exposed to various factors detrimental to health. The most serious problems are dust, noise and in the farm tractor-driven chippers also the poor working position (Table 15).

The ergonomic conditions of chipping work depend primarily on the driver's cabin. It can be protected against dust by sealing, over-pressure and filters for the intake air, but this has been done only rarely. A good working position would call also in farm tractors for a rotating seat such is to be found in the new Scandinavian Volvo BM Valmet tractors.

Although the opinions of chipper operators may be regarded as subjective, they indicate certain harmful health factors associated with chipping. Greater attention should be paid in selecting the prime movers of chippers to the properties and condition of the driver's cabin.

Table 15. Distribution of the answers of the chipper operators to questions on certain ergonomic problems.
Taulukko 15. Hakkurin kuljettajien vastausten jakauma eräitä ergonomisia ongelmia koskeviin kysymyksiin.

Ongelma Problem	Tractor chippers *Traktorihakkurit*			Truck chippers *Autohakkurit*		
	Scaling of the problem — *Ongelman vaikeusaste*					
	I	II	III	I	II	III
	Distribution of answers, % — *Vastausten jakauma, %*					
Noise *Melu*	37	49	14	14	57	29
Dust *Pöly*	31	51	18	29	14	57
Vibration *Tärinä*	61	35	4	57	43	—
Swaying *Heilunta*	49	43	8	29	57	14
Vision *Näkyvyys*	59	35	6	57	43	—
Work position *Työasento*	35	39	26	100	—	—
Knife changing *Terän vaihto*	80	18	2	42	29	29

I = Not difficult — *Ei vaikea*
II = Difficult — *Vaikea*
III = Very difficult — *Erittäin vaikea*

8. TRANSPORT OF FOREST CHIPS TO THE HEATING PLANT

The forest chips of heating plants come from within a short radius of 23 km on average. Because chip storage facilities are often insufficient, most of the transport equipment is light.

If the delivery quantities are large the cheapest cost level is produced by truck cum trailer. However, the chip requirement is by no means always sufficient to warrant the use of heavy equipment (Table 16). Large-sized trucks are employed mainly in the forest industry's deliveries.

All told, 41 % of the forest chips of heating plants, especially the deliveries by forest management associations are transported by tractor. A considerable proportion of the transport is based on a system in which the same tractor first performs the chipping into the waiting trailer and then transports the chips to the heating plant. If chipping does not suffice alone to employ the tractor this solution is often advantageous. The load space of the vehicles used is frequently clearly below the permissible maximum size. Possibilities for enlargement of the load capacity will increase as the forest transport quantities grow. This will, in turn, reduce costs.

	Average load capacity m^3 loose measure	m^3 solid measure
Farm tractor	24	10
Truck without trailer	31	12
Truck with trailer	78	31

Forest chipping is a so-called hot logging schedule in which the operations of the chipper and the chip transport vehicle are mutually dependent. A disturbance that occurs in one rapidly upsets the work of the other. It is therefore advisable that the same contractor is responsible for both chipping and onward transport. Moreover, if both tasks are managed by the same tractor the factors of friction in the working schedule are diminished. Flexibility can be increased also by means of interchangeable pallets or trailers.

The transport costs were in 1982 about 22 mk/m^3 on average, and in the forest industry operations due to longer distances 27 mk/m^3. If the consumption of forest chips expands and the operational availability of the equipment increases, cutting of transport costs should be possible. It would be economic for some tractor contractors to increase the load space already today. On the other hand, increasing the consumption of forest chips will probably lengthen the driving distances.

Table 16. The long-distance transport solutions for forest chips in 1982.
Taulukko 16. Metsähakkeen kuljetusratkaisut 1982.

Transport solution *Kuljetusratkaisu*	Proportion of chips, % *Osuus hakkeesta, %*
Tractor which also drives the chipper *Traktori, joka myös hakettaa:*	
With interchangeable pallets *Vaihtolavoilla*	0,4
Without interchangeable pallets *Ilman vaihtolavoja*	16,0
Tractor which only hauls *Traktori, joka vain kuljettaa:*	
With interchangeable pallets *Vaihtolavoilla*	0,4
Without interchangeable pallets *Ilman vaihtolavoja*	23,7
Truck without trailer *Kuorma-auto ilman perävaunua:*	
With interchangeable pallets *Vaihtolavoilla*	13,1
Without interchangeable pallets *Ilman vaihtolavoja*	13,2
Truck with full trailer *Kuorma-auto täysperävaunulla:*	
With interchangeable pallets *Vaihtolavoilla*	17,7
Without interchangeable pallets *Ilman vaihtolavoja*	15,5
Total — *Yhteensä*	100,0

In landing chipping schedules whole-trees are forwarded to the road side for chipping.

In terrain chipping schedules fuelwood is hauled to the road side in the form of chips. Lokomo 919/P 1000 chipper.

9. EXAMPLES OF THE HARVESTING SCHEDULES

The work phases in the harvesting of forest chips are the cutting of fuel chip wood, off-road haulage, chipping and on-road transport of chips to the plant. These phases of work form harvesting schedules in the structure of which the chipper solution has a focal role. The following alternatives are distinguished between on the basis of the location of the chipping site. Several applications of each schedule pattern are in use.

— In *terrain chipping schedules* the chippers operate in the forest on the strip road. When the chip bin is full the terrain chipper returns to the landing area and tips the bin onto the interchangeable pallets that have been lowered on to the ground. In order to improve terrain worthiness, heavy terrain chippers are often mounted on a forwarder. The method is most suitable for summertime use, especially in easy terrain and driving distances of under 400 m. Finding, loosening and chipping of fuelwood bunched alongside the strip road involves difficulties in the winter owing to the snow cover.

— In *landing chipping schedules* timber is brought to the landing site by farm tractor or forwarder before the snow arrives and chipping is carried out later. Chips are loaded by blowing or conveyor straight into the transport vehicle or onto interchangeable pallets on the ground. Chippers achieve essentially greater outputs at landings than in the terrain and no great terrain worthiness is required of the machines. More than 90 % of whole-tree chips in Finland is made at landings. A difficulty of the method is the lack of sufficiently spacious landing sites.

— In *terminal chipping schedules* timber is hauled from the landing site to the centralised terminal, or lower landing site, which is generally in the immediate vicinity of the heating plant. This facilitates the programming of chipping, control of chip quality and maintenance of machines, and eliminates the loss of time and costs due to movements of the chipper. A serious cost problem is the cumbersome and expensive truck transport of undelimbed small-sized wood and slash to the terminal and sometimes also the back-and-forth transport and extra materials handling. The method is employed by VAPO which chips mostly delimbed birch pulpwood rather than unmerchantable under-sized trees.

The details of the solutions vary with the delivery quantities, conditions governing the harvesting and chipping techniques, properties of the timber, chip quality requirements, the harvesting equipment locally available, and other factors. Some harvesting schedules in general use are described in simplified form in the following in the light of hypothetical cases.

9.1 Example of a light chipping schedule

The hypothetical heating plant consumes 1 500 m^3/a (3 700 m^3 loose measure/a) of forest chips. The 24-hour peak consumption in the winter is 15 m^3. The average chips transport distance is 15 km. The fuelwood can be bought delivered to the road side.

It is possible to store 50 m^3 of chips at a time. The stoker feeder of the heating plant requires homogeneous chips with no over-sized particles. To prevent feeding difficulties, the chips must be made of delimbed raw material despite the higher costs. The following simplified model offers a reliable alternative for the organisation of chip procurement.

Cutting of fuelwood is started early in the spring and brought to a conclusion at the latest in July. Transpiration drying during a couple of weeks is advisable before the trees are delimbed and bunched.

Transport to the road side is performed by the forest owner with a farm tractor. The piles are made as high as possible. Piles that will be chipped in midwinter are covered with a tarpaulin.

Chipping and chip transport are done by the contractor who manages both work phases with the same farm tractor. A small chipper in the price class 30 000—40 000 marks must suffice. Feeding is done, however, by grapple loader. The load space of the tractor trailer is 30—35 m^3 piled measure.

When the above simplified harvesting schedule (Fig. 15) is employed the labour requirement in average conditions is as follows. Manpower requirement naturally depends in practice greatly on logging technical factors.

	Manpower requirement, man-days/m^3	Work costs, marks/m^3
Work of the forest owners:		
Cutting	0,285	92
Hauling	0,050	
Work of the contractors:		
Making and hauling of chips	0,060	53
Work supervision	0,020	11
Total	0,415	156

The manpower requirement is 0,415 man-days per solid m^3 of forest chips. A plant which consumes 1 500 m^3 of chips thus offers in the forest and transport phase work for 644 days per annum. This corresponds to 2,7 direct man-years of work. Most of the work goes to the farms. As a result of chip harvesting, approx. 40 ha of young forests are tended per annum concurrently.

9.2 Example of a medium-sized chipping schedule

The forest chip requirement of the hypothetical heating plant is 6 000 m^3/a. The peak consumption of the winter season rises to 50 m^3 in 24 hours. Fuelwood is obtainable within a radius of 25 km from the plant, but only a small proportion of it can be bought delivered to the road side. The average transport distance is 20 km. It is possible to store 150 m^3 of chips. The chip handling equipment has been designed to permit a moderate amount of over-sized particles in the chips.

All the timber in the simplified example is bought on the stump. Professional forest workers cut the trees in May-August using the felling-piling technique, for which the procurement organisation gives the forest workers felling frames as auxiliary equipment for the power saw.

The undelimbed trees are hauled by forwarder after 4—6 weeks of transpiration drying to the landing and placed into 3-m high piles. A small proportion of the piles is covered for midwinter. Chipping is done by a medium-sized farm tractor-driven landing chipper which blows the chips directly into the 35—40 m^3 (loose measure) trailer of the tractor (Fig. 16).

If additional chipping work is not available from outside, the same tractor is generally used for chipping and chip transport. The chipper contractor's investment in equipment then amounts in total to approx. 350 000 marks.

When a single tractor is employed the chipping and transport capacity per shift is 25 m^3. The tractor works in two shifts during the peak consumption period or an outside tractor cum trailer is hired to help with the transport.

The labour requirement of the schedule is as follows when all fuelwood is produced by professional forest workers by the felling-piling method. If some of the fuelwood is delivered by the farmers delimbed to the road side, the manpower requirement increases in accordance with example 9.1.

	Manpower, requirement, man-days/m^3	Work costs, marks/m^3
Work of the forest workers:		
Felling-piling of whole trees	0,102	44
Work of the contractors:		
Hauling of whole trees	0,022	24
Making and hauling of chips	0,042	52
Work supervision	0,025	14
Total	0,191	134

The average manpower requirement per solid m^3 of forest chips is 0,191 days. The heating plant then provides directly in the forest and transport phase work that corresponds to about 5,0 direct man-years of work. As a by-product, silvicultural tending is carried out concurrently in an area of about 150 ha per annum.

9.3 Example of a heavy whole-tree chipping schedule

The hypothetical procurement organisation in this case delivers forest chips to three heating plants with a combined annual consumption of 30 000 m^3 and 24-hour peak requirement during the winter of 250 m^3. The average transport distance to the heating plants is 35 km. The combined storage capacity of the plants is 1 500 m^3 and all of them accept a truck with full trailer. Handling of whole-tree chips is technically possible.

Cutting work and forest haulage are done by the same methods as in example 9.2. Wood piles are made up to 3,5—4,0 m in height for the heavy landing chipper and to reduce snow problems.

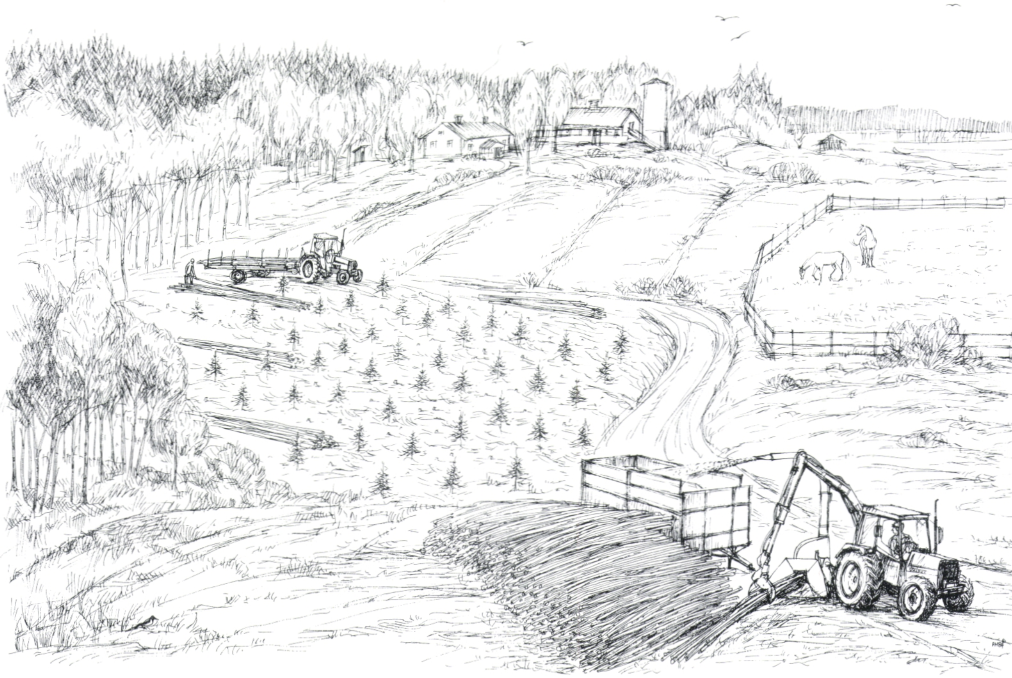


Fig. 15. Example of a light chip procurement schedule for small-sized delimbed stems.
Kuva 15. Esimerkki kevyestä karsitun pienpuun haketusketjusta.

Fig. 16. Example of a medium-heavy chip procurement schedule for small-sized whole trees.
Kuva 16. Esimerkki keskiraskaasta pienkokopuun haketusketjusta.

Fig. 17. Example of a heavy chip procurement schedule for small-sized whole trees.
Kuva 17. Esimerkki raskaasta pienkokopuun haketusketjusta.

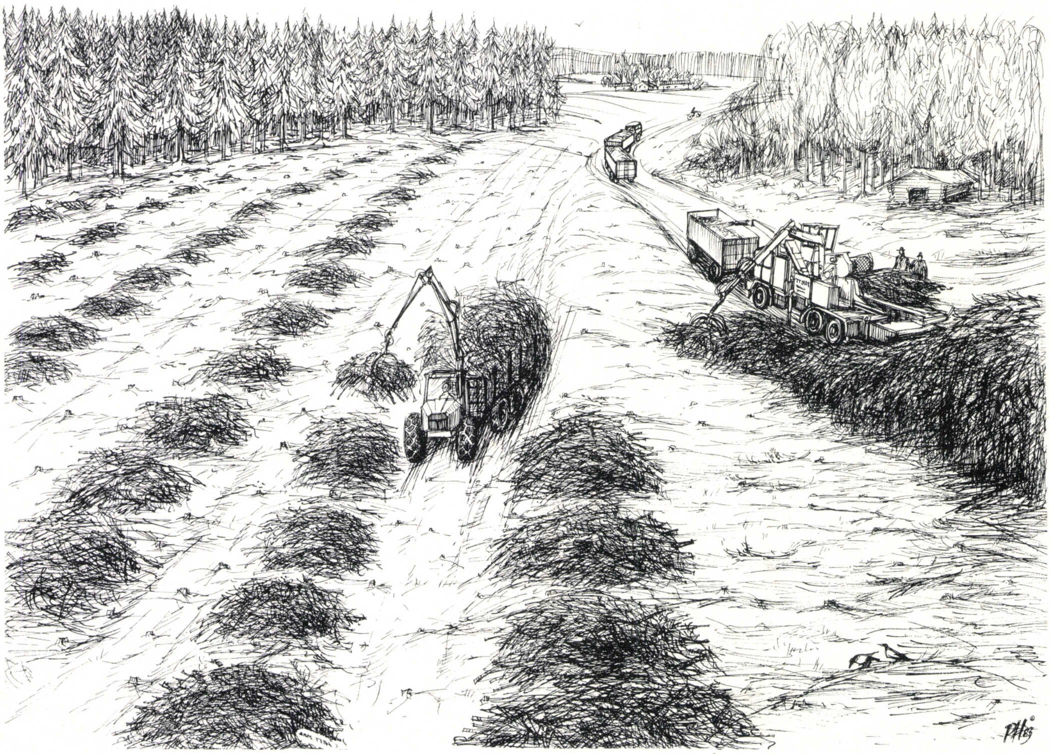


Fig. 18. Example of a heavy chip procurement schedule for slash.
Kuva 18. Esimerkki raskaasta hakkuutähteen haketusketjusta.

Chipping is performed by a truck-mounted chipper which moves flexibly from one work site to another. Chips are transported by two full-trailer trucks equipped with interchangeable pallets. Their total load space is 90 m^3 loose measure (Fig. 17). The investment in the chipping and chip transport equipment amounts to about 2,3 million marks. Work is done in two or three shifts during the period of peak consumption.

The harvesting schedule model represents the most effective alternative for small-sized trees in Finnish conditions. The manpower requirement of the schedule is as follows.

	Manpower requirement, man-days/m^3	Work costs, marks/m^3
Work of the forest workers:		
Felling-piling of whole trees	0,102	44
Work of the contractors:		
Hauling of whole trees	0,022	24
Chipping	0,010	28
Hauling of chips	0,020	28
Work supervision:	0,025	14
Total	0,179	138

The schedule provides at the forest end 0,78 man-years per 1 000 m^3 procured. The direct employment effect would correspond at the forest end to 23 man-years. The silvicultural effect of the activity would cover yearly 750 ha of uncommercial treatments of young forests.

9.4 Example of a heavy slash chipping schedule

In this hypothetical example, the forest industry's procurement organisation must deliver 35 000 m^3/a of fuel chips for the company's own use and 5 000 m^3/a for an outside heating plant. Thanks to alternative fuels, consumption of forest chips is divided relatively evenly between the various seasons of the year. The conveyors and landing facilities of the plants do not impose strict limitations on the particle size of the chips.

The procurement organisation has at its disposal clear-cutting areas in which ample branches and tops have been left as logging residue. Stemwood has been harvested by multi-purpose machines which leave accumulations of slash in small bunches. As the cost of harvesting slash to the road side is lower than that of small-sized wood the procurement organisation produces the fuelwood from the residues in the areas worked by the multipurpose machines. However, when necessary whole trees may also be chipped. The work sites are scattered and the long-distance transport trip is 60 km on average.

Slash is hauled to the landing by the same forwarder as hauls the other timber assortments from the logging area. A multi-spiked grapple is installed temporarily in the loader for handling of the slash.

Chipping is done by a truck-mounted slash chipper or crusher (Fig. 18) with an adjustable screen for even particle size. Two 90 m^3 (loose measure) trucks with trailer are needed. One extra interchangeable trailer is also necessary. The equipment investment on chipping and long-distance transport is about 2,9 million marks.

The labour requirement and costs of the schedule are clearly smaller compared with stem-formed raw material sources. The difference is due primarily to the fact that no manual cutting work is necessary. The work supervision input is also small as purchasing and planning take place already in conjunction with the harvesting of stemwood.

	Manpower requirement, man-days/m^3	Work costs, marks/m^3
Work of the contractor		
Hauling of slash	0,022	32
Chipping	0,010	31
Hauling of chips	0,025	30
Work supervision	0,008	5
Total	0,065	98

The job-creating effect of the harvesting of slash in the schedule described here is only 65 man-days, i.e., 0,28 man-years per 1 000 m^3. The case would generate directly in the forest and transport phase a quantity of work corresponding to 11 man-years. This is, apart from work supervision, machine work performed by means of heavy equipment. Recovery of slash does not produce important silvicultural advantages.

Fuel obtained from slash is considerably cheaper than other forest chips. However, it may have the draw-back, especially during the winter, of a high moisture content. Moreover, in summer operations excessive amounts of sand and stones may occur. These may cause problems when chips are combusted by a small heating plant.

10. FUEL PROPERTIES OF FOREST CHIPS

10.1 Heating value of forest chips

The thermal energy of fuel depends on the chemical composition of the substance. A high carbon and hydrogen content means a high heating value, whereas oxygen has the contrary effect. The composition of green fuelwood is seen in Fig. 19.

In the complete combustion of wood oxygen combines with carbon producing carbon dioxide and with hydrogen producing water. At the same time 32,8 MJ of thermal energy per kg of burnt carbon and 142,2 MJ per kg of burnt hydrogen is released.

A part of the released thermal energy is, however, consumed in vapourising the water originally present in the wood and that formed in the combustion process. It is consequently not possible even in complete combustion to exploit this *calorimetric heating value* (higher heating value) of wood fully.

The heating value of wood is commonly expressed in fact as *effective heating value* (lower heating value). It indicates the thermal energy of wood released during combustion after deduction of the energy spent on vapourisation when the water cools down to its initial temperature retaining its vapour form. The effective heating value of wood is expressed in kilowatt-hours or megajoules (kWh = 3,60 MJ) or their multiples.

The differences between the heating values of wood species and fuelwood assortments arise in the main from the differences in the proportions of cellulose, lignin and extractives. Lignin has a higher heating value than cellulose. Resin and other extractives have a higher heating value than wood proper. It is for these reasons that the effective heating value of bark, branches and needles is slightly higher than that of bark-free stemwood, but the differences are not great (cf. Olofsson 1975).

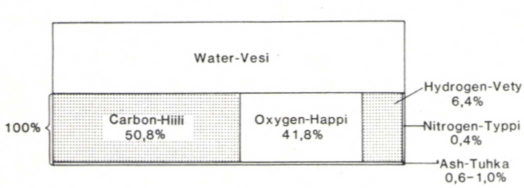


Fig. 19. Chemical composition of fuelwood.
Kuva 19. Polttopuun kemiallinen koostumus.

	Birch	Pine	Spruce
	Heating value of absolutely dry biomass, MJ/kg		
Stemwood	19,0	19,2	19,0
Bark of stem	22,3	19,4	19,8
Branches, excl. green matter	20,3	20,2	19,8
Needles		21,1	19,8

As the vapourisation of water consumes energy, water lowers the effective heating value of wood. The effect of water on the average effective heating value (W_{eff}) of Finnish tree species in bark-free stemwood can be seen in the following formula in which the weight of wood refers to the true weight with water included.

$$W_{eff}, \text{MJ/kg} = 19{,}06 - 0{,}215\ M$$

M = moisture content on a green weight basis, %

Table 17 shows the heating value of the most common fuelwood assortments used as raw material for fuel chips, calculated per kg of absolutely dry wood. The heating value is highest in slash as it contains abundant lignin- and resin-rich branch wood, needles and bark.

As fuelwood is bought and measured as a rule in volume units it is vital to know the effective heating value of wood also per cubic metre. The basic density of wood serves as a conversion factor from weight units to solid volume units. It denotes the dry matter of wood in kilograms per solid cubic metre (kg/m^3) when the volume of wood is measured on a green weight basis. Thanks to high basic density the heating value of a solid volume unit is highest for birch and for spruce slash. Needles, though their heating value per kg is high on account of

Table 17. The effective heating value of fuel chip wood in megajoules per kilogramme of absolutely dry wood (Hakkila 1978).

Taulukko 17. Eräitten polttopuulajien tehollinen lämpöarvo absoluuttisen kuivaa puukiloa kohti laskettuna (Hakkila 1978).

Assortment *Puutavaralaji*	Species *Puulaji*	Moisture content, % — *Kosteus, %* 0	20	40	60
		Heating value MJ/kg — *Lämpöarvo MJ/kg*			
Whole-trees from sapling stands					
Taimistojen pienkokopuu	Pine—*Mänty*	20,5	19,8	18,8	16,8
	Spruce—*Kuusi*	19,6	19,0	18,0	16,0
	Birch—*Koivu*	19,6	19,0	18,0	15,9
Whole-trees from thinnings					
Harvennusten pienkokopuu	Pine—*Mänty*	19,6	19,0	18,9	15,9
	Spruce—*Kuusi*	19,2	18,6	17,6	15,5
	Birch—*Koivu*	19,0	18,4	17,4	15,4
Slash excl. needles					
Hakkuutähde neulasitta	Pine—*Mänty*	20,4	19,8	18,7	16,6
	Spruce—*Kuusi*	19,7	19,1	18,1	16,0
	Birch—*Koivu*	19,7	19,1	18,1	16,0
Slash incl. needles					
Hakkuutähde neulasineen	Pine—*Mänty*	20,5	19,9	18,9	16,8
	Spruce—*Kuusi*	19,8	19,2	18,2	16,2
Sawmill slabs *Sahausjäte*	Softwood *Havupuu*	19,2	18,6	17,6	15,6

extractives, reduce because of their low basic density the heating value per solid cubic metre of slash chips (Table 18).

A comparison is made in the last vertical column of Table 18 between the heating value of a solid cubic metre of wood and a ton of fuel oil when the moisture content of wood is 40 % on a green weight basis. For instance, a solid cubic metre of birch whole-tree chips corresponds to 0,203 ton of oil equivalent (toe). For alder, which is a considerably lighter wood, the effective heating value per solid cubic metre of whole-tree chips equals 0,158 ton of oil.

The water of wood is vapourised in the first phase of the combustion process. After drying wood begins to gasify and four-fifths of the dry matter of wood burns in gaseous form. In the final phase of the process the rest of the dry matter burns as fixed carbon at a velocity dependent on the supply of oxygen.

The flame temperature does not always rise to a sufficiently high level especially if the wood is moist. Combustion is then incomplete, and in addition to carbon dioxide and water vapour carbon monoxide and hydrocarbons also originate.

No burning system is capable of recovering in its entirety the energy amount shown by the effective heating value. Loss is caused primarily by the following factors:

— Emission gases escape unburnt.
— Emission gases carry heat with them.
— Incompletely burnt carbon is left among the ashes.
— Heat radiates and passes from he furnace to sites where it is not needed.

The *efficiency of combustion* shows the proportion of effective heating value recovered in reality. Efficiency depends not only on the properties of fuel but also on the furnace and its controls. Efficiency tends to be poorer for wood than for fossil fuels. Regulation of combustion is especially difficult when the fuel properties vary irregularly.

Heating plants operate at under-capacity for a considerable part of the year. Efficiency falls when the load diminishes. For this reason, and also because of the furnace start-ups and stops, *annual efficiency* is always poorer than with full-load operation using the same fuel. The annual efficiency of chip-fired heating plants is on average 73 %, partly because of over-capacity (Immonen & Seppälä 1984).

Table 18. The effective heating value of fuel chip wood in megajoules per solid m^3 (Hakkila 1978).
Taulukko 18. Hakepuun tehollinen lämpöarvo kiintokuutiometriä kohti laskettuna (Hakkila 1978).

Assortment *Tavaralaji*	Species *Puulaji*	Basic density, *Kuivatuoretiheys, kg/m³*	Moisture content, % — *Kosteus, %* 0	20	40	60	Toe/m³
			Heating value, MJ/m³ — *Lämpöarvo, MJ/m³*				
Whole-tree chips							
Kokopuuhake	Pine—*Mänty*	385	7540	7310	6920	6130	0,170
	Spruce—*Kuusi*	400	7430	7430	7020	6210	0,173
	Birch—*Koivu*	475	9040	8750	8270	7300	0,203
	Alder—*Leppä*	370	6810	6810	6430	5680	0,158
Slash chips excl. needles							
Hakkuutähdehake	Pine—*Mänty*	405	8250	8000	7590	6720	0,187
neulasittain	Spruce—*Kuusi*	465	9160	8880	8400	7450	0,207
	Birch—*Koivu*	500	9850	9550	9040	8020	0,222
Slash chips incl. needles							
Hakkuutähdehake	Pine—*Mänty*	395	8113	7872	7470	6628	0,184
neulasineen	Spruce—*Kuusi*	425	8424	8164	7731	6864	0,190
Unbarked saw mill slabs	Softwood						
Kuorellinen sahausjäte	*Havupuu*	415	7970	7720	7300	6470	0,179

The greater the moisture content of the wood, the lower is the efficiency in practice. Small furnaces in which it is more difficult to achieve a sufficient combustion temperature than in large ones react more sensitively to changes in moisture content. However, the effect of moisture is plant-specific and no universally applicable correlation can be postulated.

The optimal moisture content for combustion in medium-sized heating plants is generally 30—35 %. If the chips are very dry combustion can be too explosive. If this happens an increasing part of the thermal energy escapes into the atmosphere along with the gaseous emissions. Particulate emissions may occur concurrently.

When the moisture content rises to 50—60 % combustion begins to cause great difficulties and efficiency falls drastically depending on the furnace. Chips with this moisture content are classified at many heating plants already as unfit for use. When the moisture content exceeds 60—70 % the heating value of the wood does not suffice to maintain combustion.

Fig. 20 shows indicatively the share of the energy content of chips with varying moisture content recovered at a typical medium-sized heating plant when the furnace is run at nearly full load. Both energy and economy considerations require recourse to every meaningful expedient to keep the moisture content of fuelwood low.

10.2 Moisture content of forest chips

The moisture content of green wood is disturbingly high for combustion. It must be reduced in one way or another to achieve satisfactory efficiency.

	Moisture content of newly felled small-sized wood, %
Birch	40—50
Alder	45—55
Pine	50—60
Spruce	50—60

It is hardly possible in large-scale operations to lower the moisture content of chips. Wood must therefore be seasoned prior to chipping. The most effective and economical alternative is summertime transpiration drying. However, similarly to other seasoning methods, it has the drawback of dependence on weather conditions. Seasoning is minimal in a humid and rainy climate.

The lowest moisture content in transpiration drying, in good conditions under 30 %, is achieved by birch (cf. Hakkila 1962, Simola & Mäkelä 1976). Seasoning occurs in favourable circumstances in 2—4 weeks (Fig.

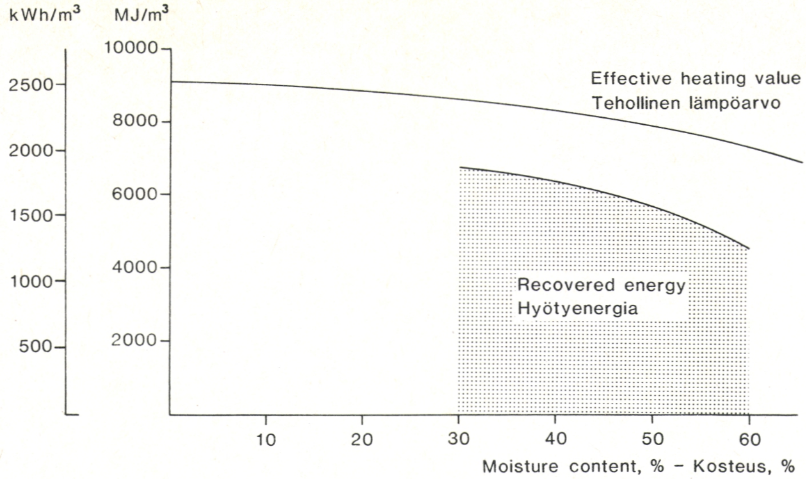


Fig. 20. Indicative example of the correlation between energy recovered from birch chips and the moisture content of the wood. Boiler efficiency has been assumed to be 80 % for a moisture content of 30 % and 70 % for a moisture content of 50 %.

Kuva 20. Suuntaa-antava esimerkki koivuhakkeesta talteen saatavan energian ja puun kosteuden välisestä riippuvuussuhteesta. Kattilan hyötysuhteeksi on oletettu 30 %:n kosteudessa 80 % ja 50 %:n kosteudessa 70 %.

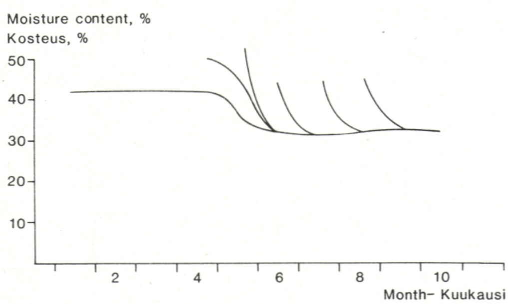


Fig. 21. Transpiration drying of birch trees felled at different times in an experiment conducted by the Forest Research Institute in 1960 (Hakkila 1962).

Kuva 21. Eri aikoina rasiin kaadettujen koivujen kuivuminen eräässä Metsäntutkimuslaitoksen kokeessa vuonna 1960 (Hakkila 1962).

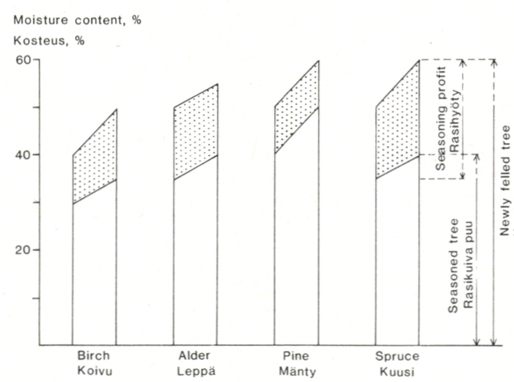


Fig. 22. Drying result for small-sized trees achieved by transpiration drying in favourable conditions.

Kuva 22. Rasimenetelmällä hyvissä oloissa saavutettava pienpuun kuivatustulos.

21). Pine seasons more slowly than other tree species.

When the relative humidity of the air rises with the onset of autumn the trees lying on the ground re-absorb moisture. They must therefore be hauled to the roadside and placed in high piles before the autumn rains.

Fig. 22 shows the result of transpiration drying in good conditions. However, fuelwood even when piled absorbs more moisture in the course of the autumn, and in wintertime snow and ice also become admixed with the chips.

Transpiration drying covers on average 41 % of all fuel chip production. It is used most commonly by the forest industry's procurement organisations. This is due partly to the easy applicability of the method to the

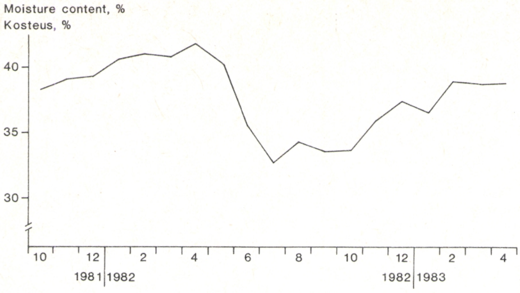


Fig. 23. Monthly variation of the average moisture content of forest chips according to measurements made at heating plants in 1981—1983.
Kuva 23. Metsähakkeen keskimääräisen kosteuden vaihtelu kuukausittain lämpölaitoksilla tehtyjen mittausten mukaan vuosina 1981–1983.

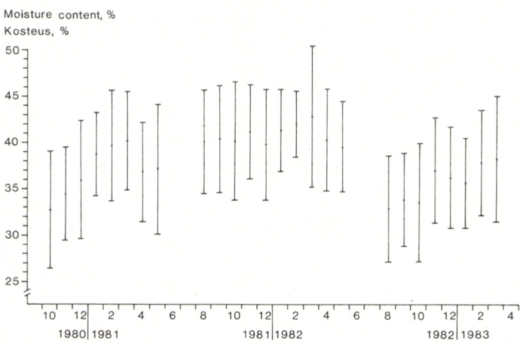


Fig. 24. Monthly variation of the moisture content of forest chips at the heating plant of the town of Virrat. The vertical lines show the standard deviation (s) between loads around the mean ($\bar{x}$).
Kuva 24. Metsähakkeen kosteuden vaihtelu kuukausittain Virtain lämpölaitoksella. Pystyviivat osoittavat kuormien välisen hajonnan (s) keskiarvon ($\bar{x}$) ympärillä.

felling-piling technique of whole trees.

Fig. 23 presents the variation of forest chip moisture content from October 1981 to April 1983 as the mean of several heating plants. The moisture content was 40 % on average in the winter and significantly lower in the summer.

In addition to average moisture content, evenness of moisture is another important quality factor as irregular variation makes combustion control difficult and results in the lowering of efficiency. Fig. 24 shows the standard deviation of the moisture content of load-specific chip samples on either side of the mean for each month at the heating plant of the town of Virrat from September 1980 to

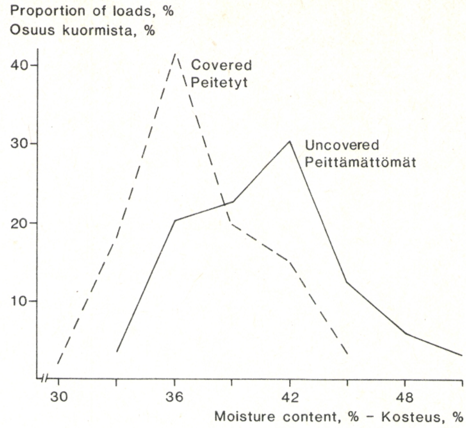


Fig. 25. Distribution by load of the moisture content of chips made in the winter from covered and uncovered whole-tree piles in an experiment (Uusvaara 1984).
Kuva 25. Peitetyistä ja peittämättömistä kokopuupinoista talvella tehdyn hakkeen kosteuden kuormittainen jakauma eräässä kokeessa (Uusvaara 1984).

March 1983 in a material consisting of 1 766 tractor loads of chips. The monthly standard deviation between the tractor loads is generally 5—6 moisture percent units around the mean.

With experience, increasing attention is being paid to the moisture content of forest chips as a cost factor. Transpiration drying, forest haulage in a sufficiently early phase, high and regular piles and the avoidance of snow in winter chipping suffice to keep the moisture content safely below 40 %.

Piles can be protected against rain also by means of tarpaulins which must be placed over the piles in August or at the latest at the beginning of September. In a recent study the moisture content of chips made from whole-tree piles covered in the autumn was 36,1 % during the following winter, whereas from uncovered piles it was 39,1 % (Fig. 25).

The costs of covering, including materials and work, accounts for 2—4 % of the total costs of forest chips. Covering with sufficiently thick paper or plastic tarpaulins seems to be motivated for piles which are to be chipped during the most severe winter season. At the same time as covering slows down the increase in the moisture content of wood, it also facilitates winter chipping (Uusvaara 1984). Covering has, however, been an exceptional measure so far.

10.3 Solid volume content and weight of forest chips

Forest chips are measured practically everywhere in terms of *loose volume* based on the load space of the chip vehicle. The measuring unit is loose (piled) cubic metre (m^3, loose).

The dry matter content of a loose cubic metre depends in the first place on the *basic density of the wood* which shows the dry mass of the solid volume unit (kg/m^3). The average basic density of the most important raw material sources of chips is presented in Table 18. The differences between fuelwood assortments are considerable. In contrast, the random variation within the fuelwood assortments is relatively small.

Secondly, the dry-matter content of a loose cubic metre depends essentially on the *solid volume content of chips* which shows the ratio between the dry masses of the loose volume unit and solid volume unit (m^3 solid/m^3 loose). The value 0,40 is generally used in Finland as the ratio of the solid volume content of chips. However, the ratio may in fact vary considerably depending on the quality of the raw material and the handling of the chips. Some of the most important factors affecting solid volume content are enumerated in the following.

— The *tree species* appears to affect solid volume content distinctly. The solid volume content is higher for alder and pine than for birch. The exceptionally great solid volume content of alder chips is shown in the following table and also in Kanninen's (1980) study in which it was as high as 0,49. The differences between the tree species are probably due in part to differences in the quantity of fine fractions.

	Study 1*	Study 2**	Study 3***
	Solid volume content of whole-tree chips at the heating plant		
Birch	0,389	0,386	0,39
Alder	0,484	0,458	..
Pine	0,421	0,444	0,44

* Kanninen, Uusvaara and Valonen 1979
** Uusvaara 1984
*** Metsola 1983

— *Particle size distribution* exerts an effect in that long over-sized particles and twigs lower the solid volume content. Needles and fines, on the other hand, in moderate quantities increase the solid volume content.

— The *blowing strength of the chipper and the method of loading* influence the solid volume content significantly. Chips blown through the discharge spout into the truck load are denser than chips dropped from a conveyor, a tipping tractor or the silo of the sawmill. There are also differences between chippers depending on their blowing strength. The following figures derive from an experiment in which four blow-loading chippers were compared (Kanninen, Uusvaara and Valonen 1979). The Algol prototype chipper had an especially effective blower.

Chipper	Solid volume content of chips
Trelan D 60	0,384
TT 1500 T	0,416
TT 1500 L	0,432
Algol (prototype)	0,483

— *Settling* in the course of transport increases the solid volume content of the chips. To settling contribute the initial solid volume content, possible freezing of the chips, length of the haul, evenness of the road, and the use of a trailer. The following tabulation shows that the settling of forest chips in a hauling truck is distinctly smaller than in a trailer (Kanninen, Uusvaara and Valonen 1979).

Distance, km	In truck	In trailer
	Settling, %	
1 – 15	1,8	
16 – 40	2,5	5,6
40 +	3,4	4,8

Settling is rapid to begin with but slows significantly already after a distance of 20 km (Uusvaara 1972). Hence, even forest chips, although their haulage trips are short, have time to settle almost as much as sawmill chips over long distances especially as the early distance must often be made over rough roads.

The commonly used 0,40 must be regarded as too rough a figure. On the basis of materials at the Forest Research Institute, the following solid volume contents by tree species at the heating plant are recommended:

	Solid volume content of chips m^3 solid/m^3 loose
Birch whole-tree chips	0,39
Alder whole-tree chips	0,46
Pine whole-tree chips	0,43

These figures can be used to calculate the average dry mass and heating value of the commonest whole-tree chip types per loose cubic metre (Table 19). It must be borne in mind, however, that the variation is great when the measuring unit is the loose cubic metre.

The heating value of a loose cubic metre is highest in birch, about 0,90 MWh in fairly dry (moisture content 40 %) seasoned whole-tree chips. The corresponding value for alder is 0,82 MWh/m^3 loose, and pine comes between birch and alder. These averages are,

Table 19. Average effective heating value of whole-tree chips per m^3 loose measure (measured at the plant).
Taulukko 19. Kokopuuhakkeen keskimääräinen lämpöarvo irtokuutiometriä kohti lämpölaitoksella.

Variable *Muuttuja*	Birch *Koivu*	Alder *Leppä*	Pine *Mänty*
Basic density, kg/m^3 *Kuiva-tuore tiheys, kg/m^3*	475	370	385
Solid vol. cont. of chips *Hakkeen tiiviys, m^3/i-m*	0,39	0,46	0,43
Moisture content of green wood, % *Kosteus kaatotuoreena, %*	45	50	53
Mass of chips, kg/m^3 loose *Hakkeen massa, kg/i-m^3:*			
Freshly felled wood *Kaatotuore hake*	335	335	350
Seasoned wood *Kuivahtanut hake*	310	280	275
Dry mass *Hakkeen kuivamassa*	185	170	165
Heating value, MJ/m^3 loose *Lämpöarvo, MJ/i-m^3*			
Freshly felled wood *Kaatotuore hake*	3160	2760	2790
Seasoned wood *Kuivahtanut hake*	3220	2940	3120
Heating value, kWh/m^3 loose *Lämpöarvo, kWh/i-m^3*			
Freshly felled wood *Kaatotuore hake*	880	765	775
Seasoned wood *Kuivahtanut hake*	895	820	865

however, not necessarily reliable in individual cases. Pricing that is fair and stimulates efforts to improve quality is possible to achieve only by weight scaling and moisture content sampling.

10.4 Effect of chip properties on the operation of the heating plant

High plant investment costs strain the profitability of forest chips as fuel. The greatest part of them relates to the chip handling and storing system. The more advanced the automation the higher are the equipment costs. Without automation, on the other hand, a larger work force is needed and that is a heavy cost factor especially for small plants.

The operating reliability of a heating plant depends essentially on the chip-handling equipment. The operations of especially the following devices are critical:

— Chip receiving equipment
— Chip silos and hoppers
— Chip conveyors
— Furnace feeders with their automatic control devices

The sensitivity of the handling equipment to disturbances is frequently the result of unnecessarily complex systems or incorrect dimensioning. Disturbances concern generally the variation of chip properties and they lead to an increase in the need of a substitute fuel (oil). As long as the fuel is blameless the equipment functions well, but it is hardly possible to keep forest chips reliably within a narrow quality requirement range. It is thus imperative in equipment planning to guard against splinters that do not come up to quality requirements.

Important factors are high moisture content of chips including snow and ice, particle size and especially over-sized and fine materials, green matter and impurities. The aim must naturally be homogeneous and clean chips, but costs rise with demands. For instance, the costs of stem chips at the heating plant are nearly 10 % higher than those of whole-tree chips.

It is possible in most chippers to regulate the nominal particle size by changing the position of the knives or anvils, the number of the knives, the velocity of the feeding device or screen constructions. The average target length is generally 30—40 mm. However, chips have in reality often been shorter than the target.

Plant size, MW	Target Average chip length, mm	Real
0,5 - 1,0	34	27
1,1 - 5,0	40	30
All	37	29

Average particle size may be of significance for controlling the air required for combustion. Variation of average size is, however, no major disturbing factor in practice.

Over-sized particles and twigs may cause clogging in the gratings of the receiving devices and silos, bridging in the silos, clogging and breaks in the unloaders and conveyors and disturbances of the automatic control devices.

Stokers in particular are sensitive to twigs and large particles. The thinner the stoker the more easily it is clogged. The diameter of the stokers of heating plants varies from 10 to 60 cm. Experience of dog or scraper conveyors is for the most part positive.

Problems caused by over-sized particles and twigs can be reduced by making the conveyors sufficiently wide, avoiding long moving distances, and through correct coating and shaping of the silos. It is possible at larger plants to place a simple disc screen at the head of the handling system.

Fine material even when abundant constitutes a minor problem compared with over-sized particles. It may slide below the grate or cause clogging so that the air required for combustion is distributed unevenly in the chip bed. More unusual disturbances are clogging of the stoker feeder, disturbance of the photocells that function as sensory organs and the problems caused by particulate emissions.

Green matter accelerates the deterioration of chips. Consequently, it increases the danger of energy loss, mould dust and spontaneous ignition if chips are stored for longer than 2—3 weeks. When profuse as in slash chips produced in the winter, green needles may also increase freezing and bridging and clog conveyors and the grate.

An *excessively high moisture content* lovers the effective heating value of chips and above all the boiler efficiency so that the share of recoverable effective energy is diminished. When the moisture content varies irregularly, control of combustion meets with difficulties. A high moisture content is harmful also to the flow of chips and leads thus to bridging, especially if moist chips freeze. Freezing of chips may prevent the start up of the silo discharge.

Exceptionally low moisture content results in too rapid combustion and lowers boiler efficiency. Very dry chips may catch fire before the boiler. Too fierce combustion may also cause excessive particulate emissions in the environment.

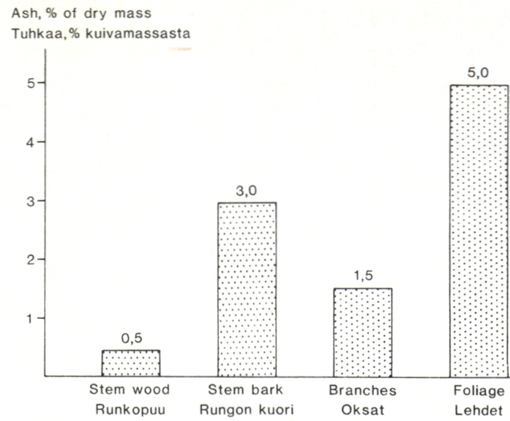


Fig. 26. Proportion of pure ash in the dry matter of different parts of small-sized wood as the mean of four tree species (Hakkila and Kalaja 1983).

Kuva 26. Puhtaan tuhkan keskimääräinen osuus pienpuun eri osien kuivamassasta neljän puulajin keskiarvona (Hakkila ja Kalaja 1983).

10.5 Ash residues from forest chips

The ash content of wood is low compared with other solid fuels. The melting point is so high that clinkering hardly occurs at all. The main exception is stump and root wood with their abundant soil materials.

The ash content of bark-free small-sized wood is only 0,5 %. The ash content of bark is 3 % on average, that is six-fold compared with wood proper. Ash is particularly abundant, about 5—6 %, in the leaves or needles of birch, alder and spruce (Fig. 26).

The content of pure ash in fuel chips made of small-diameter whole trees is 0,9—1,6 %, depending on the tree species, when all branches with leaves are included. The ash content of chips made of delimbed stems is 0,7—1,0 %.

An average of 3—5 kg of pure ash is left behind from one solid cubic metre of fuel chips depending on the tree species and degree of delimbing (Table 20). Because sand and charcoal also remain as impurities among pure ash, quantity of ash residues that originate at a heating plant is naturally greater.

The properties of heating plant ash depend on fuel and also on the furnace, controls and ash separation apparatus. If, for instance, the grate is small and it is necessary to use high air pressure in combustion, the carbon content of fly ash increases.

Table 20. The amount of pure ash in m^3 of freshly-felled small-sized trees (Hakkila and Kalaja 1983).

Taulukko 20. Puhtaan tuhkan määrä vastakaadetun pienpuun kiintokuutiometriä kohti (Hakkila ja Kalaja 1983).

Source of fuelwood *Polttopuulähde*	Birch *Koivu*	Alder *Leppä*	Pine *Mänty*	Spruce *Kuusi*
	Ash, kg/m³ — *Tuhkaa, kg/m³*			
Delimbed stems *Karsittu ranka*	3,1	3,3	2,7	3,9
Whole trees, excl. leaves *Kokopuu lehdittä*	3,7	4,0	3,0	4,9
Whole trees, incl. leaves *Kokopuu lehtineen*	4,6	4,6	3,2	6,1

Samples collected by the Finnish Forest Research Institute indicated that the ash residues of chip-fired heating plants contained an average of 62 % of soluble pure ash. The corresponding share in the bark ash of forest industry companies was 55 % and in the fly ash of large power plants using milled peat 37 % (Fig. 27).

As ash contains a great many nutrients and trace elements necessary for trees, field crops, livestock and human beings it should be recycled. Ash lacks nitrogen which evaporates into the atmosphere during combustion, but it contains abundant phosphorus, potassium, calcium (Fig. 28) and trace elements.

The power plant ash could be used in farming as a soil improvement agent and fertiliser, especially for soils suffering from high acidity and a low level of trace elements. Ash can be used in fields as a soil neutraliser equal to ground limestone and its spreading can be carried out by the equipment of lime-spreading contractors.

Recycling of ash to the forest would serve to diminish the danger which improved recovery of wood biomass imposes on the nutrient balance of forest soil. In forestry ash should be spread preferably on nitrogen-rich peat lands. However, recycling to swamps is difficult for the time being in the absence of a serviceable prime mover. There are already in use forwarder-mounted prototype devices to spread ash residues of the forest industry's bark-fired power plants.

The problem of recycling requires of ash producers attention to the following points:

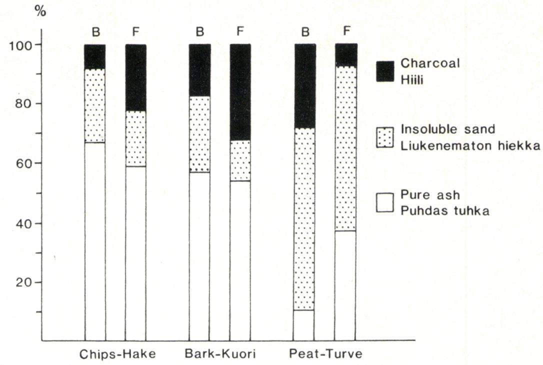


Fig. 27. The proportion of charcoal, sand and soluble pure ash in different power plant ashes (B = bottom ash, F = fly ash) (Hakkila and Kalaja 1983).

Kuva 27. Hiilen, hiekan ja liukenevan puhtaan tuhkan osuus erilaisissa voimalatuhkissa (B = arinatuhka, F = lentotuhka) (Hakkila ja Kalaja 1983).

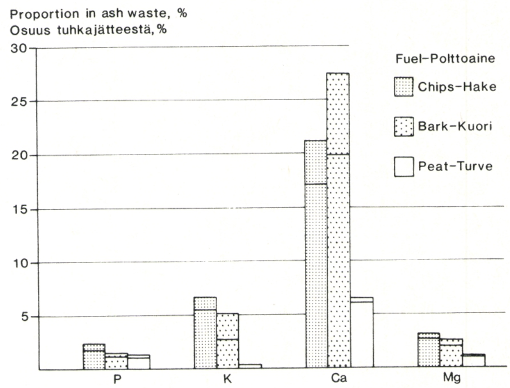


Fig. 28. The proportion of main nutrients in the ash waste of heating plants tired with chips, bark and milled peat. The lower part of the column represents all the ash waste and the whole column charcoal-free ash waste (Hakkila and Kalaja 1983).

Kuva 28. Pääravinteitten osuus haketta, kuorta ja jyrsinturvetta polttavien lämpölaitosten tuhkajätteessä. Pylvään alaosa edustaa kaikkea tuhkajätettä ja koko pylväs hehkutettua hiiletöntä tuhkajätettä (Hakkila ja Kalaja 1983).

— Wood and bark ash should be kept separate from the ash of fossil fuels. The last-mentioned is worthless as a soil improvement agent and fertiliser and contains moreover harmful heavy metals.
— Ash must for cost reasons be as completely burnt as possible.
— Ash must not be so hot when the vehicle is loaded that it might cause a fire risk in the forest.
— Ash must be cooled with the smallest possible amount of water. If the moisture content of ash exceeds 30 % spreading is difficult especially in winter conditions.
— Ash must be stored in such a way that it is easy to load and does not cause serious dust problems.

Loading ash onto a forwarder-mounted spreading unit.

Spreading ash from a strip road with a forwarder.

11. FOREST CHIP PROCUREMENT COSTS

11.1 Cost level of forest chips

The true cost level of forest chips made of delimbed stems averaged approx. 170—190 marks/m^3 in 1982. The cost level of whole-tree chips was 155—175 marks/m^3, or nearly 10 % lower (Table 21).

The forest industry produces chips at lower cost than other organisations mainly thanks to the effectiveness of the cutting phase. This is due to the recovery of trees with branches, the use of the felling-piling method and employment of professional forest workers who work at piece rates.

The lack of a reliable chipper has previously been an obstacle to the production of chips from slash. This limiting factor is now receding thanks to machine development work. The use of slash chips is confined, however, presently only to the forest industry which recovers slash from its own clear-cutting areas harvested with multipurpose machines.

The forest industry uses large-sized equipment in its slash harvesting operations. Due to the low stumpage price, small work supervision requirement and low interest expenses, the cost level is essentially lower than for stem and whole-tree chips (cf. Vehmas, Hakala and Ritala 1983).

	Cost level of slash chips procured by the forest industry marks/m^3 loose	marks/m^3 solid
Stumpage price	2,50	6,80
Haulage of slash	11,00	27,70
Cost at road side	13,50	36,50
Chipping	12,00	30,00
Hauling of chips	10,50	28,40
The above together	36,00	94,90
Work supervision	3,50	9,50
Other overheads	0,50	1,40
Interest costs	1,00	2,50
Grand total	41,00	108,30

Table 22 shows the average cost level of forest chips in marks per megawatt hour according to heating value. Birch chips are more economic than pine and especially alder because of the high heating value. Cheaper than all the stem chip and whole-tree chip assortments, however, are slash chips the cost level of which is 60 marks/MWh.

The cost level varies with logging technical conditions, supply and demand, labour force factors, the effectiveness of organisation etc. Fig. 29 shows the cost frame within which the different forest chip assortments were placed in 1982 with minor exceptions.

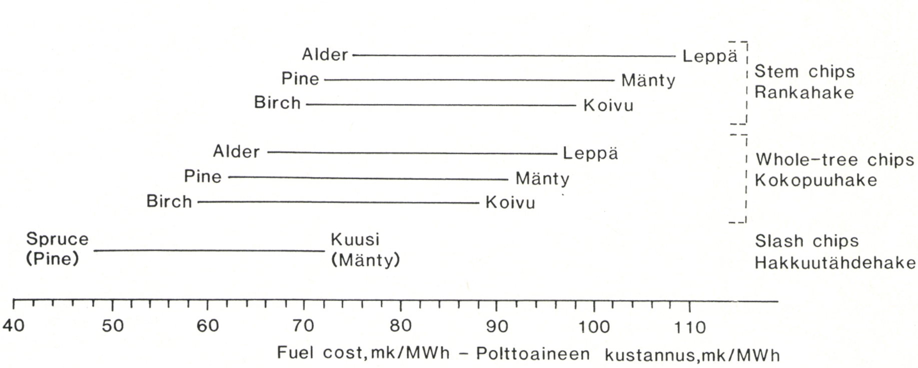


Fig. 29. The cost level of forest chips at a heating plant (mk/MWh) at the end of 1982.
Kuva 29. Eri metsähakelajien kustannustaso lämpölaitoksella (mk/MWh) vuoden 1982 lopussa.

Table 21. The cost level of forest chips made from whole trees and delimbed stems in 1982 (De = delivery sales, St = stumpage sales).
Taulukko 21. Karsimattomasta kokopuusta ja karsitusta rangasta tehdyn metsähakkeen kustannustaso vuonna 1982 (De = hankintakaupat, St = pystykaupat).

Cost factor *Kustannuserä*	Forest industry *Metsäteollisuus* De	 St	Forest man. assoc. *Mh.yhdistys* De	 St
	Cost of chips, mk/m^3 *Hakkeen kustannus, mk/m^3*			
STEM CHIPS — *RANKAHAKE*				
Stumpage price *Kantohinta*		17		24
Cutting of chip wood *Hakepuun teko*		55		105
Hauling of chip wood *Hakepuun ajo*		21		25
Cost at road side *Kustannus tien varressa*	85	93	116	154
Chipping *Haketus*	27	27	27	27
Transport of chips *Hakkeen ajo*	26	26	21	21
Total of the above *Edelliset yhteensä*	138	146	164	202
Supervision *Työnjohto*	13	16	13	16
Other overheads *Muut yleiskulut*	4	4	4	4
Interest *Korkokulut*	5	6	7	10
Grand total *Kaikki yhteensä*	160	172	188	232
WHOLE-TREE CHIPS — *KOKOPUUHAKE*				
Stumpage price *Kantohinta*		16		
Cutting of chip wood *Hakepuun teko*		40		
Hauling of chip wood *Hakepuun ajo*		22		
Cost at road side *Kustannus tien varressa*	79	78	103	
Chipping *Haketus*	27	27	27	
Transport of chips *Hakkeen ajo*	26	26	22	
Total of above *Edelliset yhteensä*	132	131	152	
Supervision *Työnjohto*	13	16	13	
Other overheads *Muut yleiskulut*	4	4	4	
Interest *Korkokulut*	5	5	6	
Grand total *Kaikki yhteensä*	154	156	175	

11.2 Cost structure of forest chips

The costs of forest chips are grouped in Table 23 differently from the usual way. Direct wages including social security outlays account for 40—50 % of the total forest chip costs. In addition, wages are included indirectly in machine costs (machine purchase price, spares, maintenance) and in miscellaneous costs which include insurance, various travel expenses, the machine contractors' profit, etc.

Distribution of costs gives decision-makers additional information for the following planning tasks when the advantages of chips are compared with imported fuels for the locality's economy.

— The income formation created by the procurement of forest chips in the own commune and outside it.
— The expected price development of forest chips depending on possible changes in costs of wages, machines or fuels.
— Domestic input of forest chips compared with other domestic and imported fuels (cf. Kupari 1983). Foreign cost sources in Finnish conditions are represented by about a half of machine depreciation, most of fuels and lubricants and approximately a fourth of the maintenance and repair costs, in other words, in all 10—15 % of the total costs of forest chips.

Table 22. The cost of forest chips in marks per megawatt hour (effective heating value) by tree species. Moisture content 40 % in whole tree chips and 50 % in slash chips.
Taulukko 22. Metsähakkeen lämpöarvon mukainen kustannus puulajista riippuen. Kosteus kokopuuhakkeessa 40 % ja hakkuutähdehakkeessa 50 %.

Assortment *Hakelaji*	Heating value — *Lämpöarvo* MWh/m^3 solid MWh/m^3	 MWh/m^3 loose MWh/i-m^3	Cost *Kustannus* Mk/MWh
Stem chips: *Rankahake:*			
Birch—*Koivu*	2,25	0,88	82
Alder—*Leppä*	1,74	0,80	90
Pine—*Mänty*	1,95	0,84	85
Whole-tree chips: *Kokopuuhake:*			
Birch—*Koivu*	2,30	0,90	73
Alder—*Leppä*	1,78	0,82	80
Pine—*Mänty*	2,00	0,86	76
Slash chips: *Hakkuutähdehake:*			
Pine—*Mänty*	1,96	0,73	60
Spruce—*Kuusi*	2,03	0,75	59

12. THE JOB-CREATING EFFECT OF THE PROCUREMENT OF FOREST CHIPS

Use of unmerchantable residual and small-sized wood as fuel for heating plants creates sorely needed jobs in rural districts. The job-creating effects can be classified as follows:

— The immediate job-creating effect of the heating plant while it is being erected. It consists partly of the manpower requirements in the manufacture of equipment and partly of those in construction and installation work.
— The permanent jobs of the heating plant. Here a manpower requirement of 2,6 man-years on average per 1 000 tons of oil equivalent arises for domestic fuels (Toropainen 1982). This equals nearly 0,5 man-years per 1 000 m^3 of small-sized wood consumed.
— The permanent jobs in the forest offered by chip procurement.
— The indirect jobs that originate and which are estimated to be 0,9 times that of direct jobs as regards the building phase and 1,3 times as far as permanent jobs are concerned (Toropainen 1982).

Table 23. Cost structure of forest chips from stumpage sales in 1982.
Taulukko 23. Pystykaupoilla hankitun metsähakkeen kustannusrakenne vuonna 1982.

Cost factor *Kustannuslaji*	Whole-tree chips *Kokopuuhake*	Stem chips *Rankahake*
	Proportion, % — *Osuus, %*	
Stumpage price *Kantohinta*	12,9	11,4
Direct wage costs: *Välittömät työpalkat:*		
Forest workers *Metsurit*	21,3	33,0
Machine operators *Koneen kuljettajat*	11,6	8,6
Foremen *Työnjohtajat*	9,2	7,1
Others *Muut*	1,2	1,0
Wages, total *Työpalkat yhteensä*	43,3	49,7
Machine costs: *Konekustannukset:*		
Depreciations *Pääoman poistot*	11,9	9,7
Interest (12 %) *Pääoman korko (12 %)*	4,4	3,6
Fuels and lubricants *Poltto- ja voiteluaineet*	5,7	5,5
Maintenance, repair *Huolto ja korjaus*	9,0	8,4
Machine costs, total *Konekustannukset yhteensä*	31,0	27,2
Interest on procurement cost *Hankintakustannusten korko*	3,1	3,3
Miscellaneous — *Muut*	9,7	8,4
Grand total — *Kaikki yhteensä*	100,0	100,0

The manpower requirement of different harvesting methods varies greatly. To mention an example, the productivity of forest owners' work is considerably lower in delivery sales than it is with stumpage sales carried out by professional forest workers. Cutting of delimbed stems requires double the manpower needed for the felling-piling of whole trees.

Table 24 presents orienting manpower requirement figures. They are the averages of various stand conditions, equipment solutions, hauling distances and other factors. For instance, some farm tractors are equipped with a hydraulic loader while others lack it. Or, on the other hand, the chip haulage trip of, say, farm tractors is shorter than that of trucks with a full trailer. Manpower requirement figures are consequently difficult to compare but it is possible to estimate on their basis the total work of forest chip procurement.

With work supervision included, roughly 130 000 work days were spent on the procurement of 393 000 m^3 of forest chips for heating plants in 1982. Although procurement is on the whole year-round activity, the jobs it provides in the forest, contrary to the operations of the heating plant, last only a part of the year. Fuel chip wood is cut primarily in the summer and off-road haulage takes place at the end of the summer and in the autumn. Chipping and chip haulage, on the other hand, are concentrated in October-April. The volume of work is converted into work years of 230 days in Table 25.

Productivity of man-work including work supervision and long-distance transport in the procurement of forest chips is an average of 3 m^3 per work day. This is only a half of the productivity of the procurement of industrial wood.

The forest chip procurement of heating plants corresponded to the direct manpower requirement of 565 years in 1982. Nearly two-thirds of it consisted of the cutting of fuel chip wood by power saw and one-third of various types of machine work and work supervision. The direct labour requirement offered by heating plants was correspondingly about 190 man-years. The indirect effect is 1,3-fold (cf. Toropainen 1982), i.e., 980 man-years in 1982.

	Work opportunities arising from combustion of forest chips by heating plants, man-years in 1982
Direct jobs:	
At the forest end	565
At the heating plant	190
Direct jobs, total	755
Indirect jobs, total	980
Permanent jobs, total	1735

Table 24. Work consumption in certain phases of harvesting of forest chips in man-days per solid m^3 and megawatt hour.
Taulukko 24. Työn menekki miespäivinä hakkeen kiintokuutiometriä ja megawattituntia kohti eräissä metsähakkeen hankinnan työvaiheissa.

Work phase *Työvaihe*	Work method *Työmenetelmä*	Work consumption — *Työmenekki* Man-days/m^3 *Miespäivää/m^3*	Man-days/MWh *Miespäivää/MWh*
Cutting of chip wood *Hakepuun teko*			
	Forest owner, delimbed stems *Hankintatyö, rankana*	0,285	0,141
	Forest worker, delimbed stems *Metsurityö, rankana*	0,204	0,101
	Forest worker, whole trees *Metsurityö, kokopuuna*	0,102	0,050
Hauling of chip wood *Hakepuun ajo*			
	Forest owner, farm tractor *Hankintatyö, maatal.tr.*	0,050	0,025
	Contractor, forwarder *Urakoitsijatyö, metsätr.*	0,022	0,011
Chipping — *Haketus*			
	Contractor work *Urakoitsijatyö:*		
	Light chipper *Kevyt hakkuri*	0,038	0,019
	Medium-sized chipper *Keskiraskas hakkuri*	0,025	0,012
	Heavy chipper *Raskas hakkuri*	0,010	0,005
Transport of chips *Hakkeen ajo*			
	Contractor work *Urakoitsijatyö:*		
	Farm tractor *Maataloustraktori*	0,035	0,017
	Truck-cum-trailer *Täysperävaunuauto*	0,020	0,010
Planning, supervision *Suunnittelu, valvonta*		0,029	0,014

Table 25. Direct work opportunities arising from the production and transport of forest chips for heating plants in Finland in 1982.
Taulukko 25. Lämpölaitosten metsähakkeen hankinnan tarjoamat välittömät työtilaisuudet vuonna 1982.

Work phase *Työvaihe*	Amount of work in 1982 *Työmäärä v. 1982* Man-days *Työpäiviä*	Man-years *Työvuosia*
Cutting of chip wood: *Hakepuun teko:*		
Forest owners *Metsänomist. hakintatyö*	54 000	235
Professional forest workers *Metsurityö*	29 200	127
Hauling of chip wood: *Hakepuun ajo:*		
Farm tractor drivers *Maataloustraktorityö*	5 900	26
Forwarder drivers *Metsätraktorityö*	5 300	23
Chipping: *Haketus:*		
Tractor and truck drivers *Traktori- ja autohakkurityö*	8 800	38
Transport of chips: *Hakkeen ajo:*		
Farm tractor drivers *Maataloustraktorityö*	6 300	27
Truck drivers *Kuorma-autotyö*	9 000	39
Planning, supervision etc. *Suunnittelu, valvonta y.m.*	11 400	50
Work at the forest end, total *Metsäpään työ yhteensä*	129 900	565

Covering a pile with a plastic tarpaulin.

A whole-tree pile covered for mid-winter chipping.

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TIIVISTELMÄ

Metsähake lämpolaitosten polttoaineena Suomessa

Tutkimuksen tausta

Suomessa käynnistyi vuosina 1980—82 kaikkiaan 95 yli 0,5 MW:n lämpölaitosta, jotka käyttävät metsähaketta pää- tai lisäpolttoaineenaan. Vaikka maallamme on pitkäaikaiset perinteet polttohakkeen käytössä, lämpölaitosten kiivastahtinen rakentaminen ja metsähakkeen hankintatoiminnan nopea laajeneminen eivät aina sujuneet kitkatta. Ajantasaisen tutkimustiedon ja varmatoimisten esimerkkitapausten puuttuessa jouduttiin usein turvautumaan ennalta kokeilemattomiin laite- ja menetelmävaihtoehtoihin.

Koska polttohakkeen hankinta ja jakelu ovat usein avainasemassa lämpölaitosten kannattavuuden ja toiminnan luotettavuuden kannalta, SITRAn kotimaisten polttoaineiden alueellisen hyväksikäytön projekti teki vuoden 1982 alussa päätöksen käytössä olevien hankintaketjujen toimivuutta, kustannuksia ja sovellutusalueita selvittelevästä tutkimuksesta. Tavoitteena oli luoda sekä myönteisten että kielteisten kokemusten pohjalta eri oloihin parhaiten soveltuvia metsähakkeen hankinnan toimintamalleja. Työ tehtiin SITRAn toimeksiannosta ja valvonnassa Metsäntutkimuslaitoksen metsäteknologian tutkimusosastolla metsäenergiakysymyksiä tutkivan PERA-projektin osana.

Tutkimuksen ensimmäisessä vaiheessa kartoitettiin metsähaketta polttavat yli 0,5 MW:n lämpölaitokset, joita vuoden 1982 päättyessä oli metsäteollisuuden voimaloita lukuun ottamatta 115. Näistä otettiin yksityiskohtaiseen tarkasteluun 60 laitosta, joista kussakin haastateltiin hankintaorganisaation edustajaa, haketusurakoitsijaa sekä lämpölaitoksen päivittäiseen käyttöön osallistuvaa henkilöä.

Tulokset antavat kuvan lämpölaitosten hakehuollon edellytyksistä ja ongelmista, hankintatekniikasta sekä vuosien 1982—83 vaiheessa vallinneesta kustannustasosta. Ne on julkaistu suomenkielellä SITRAn kotimaisten polttoaineiden alueellisen hyväksikäytön projektin tutkimusraportissa nro 33 (Hakkila 1984).

Koska Suomi on metsähakkeen polttoainekäytössä edelläkävijä, taitotietomme herättää kiinnostusta laajalti myös ulkomailla. Tästä syystä Metsäntutkimuslaitos julkaisee tutkimuksen päätulokset SITRAn myötävaikutuksella myös englanninkielisinä.

Metsähakkeen saantimahdollisuudet

Metsähakkeen polttoainekäyttöä edistettäessä lähdetään edellytyksestä, että polttohake tehdään markkinakelvottomasta pienpuusta ja metsätähteestä. Näin rajaten on tarjolla oleva korjuukelpoinen biomassareservi 15,3 milj m^3/a, mutta osa siitä voidaan samanaikaisesti katsoa myös massa- ja levyteollisuuden potentiaaliseksi raaka-aineeksi. Reservi on noin 20-kertainen nykykäyttöön verrattuna, ja metsähakkeen tuotantopotentiaalin odotetaan olevan vielä ensi vuosikymmenen lopullakin selvästi käyttöpotentiaalia suuremman.

Pääosa lämpölaitosten metsähakkeesta tehdään karsitusta tai karsimattomasta pienpuusta. Leimikkokohteita ovat verhopuuston poisto kuusentaimiston päältä, vajaatuottoisen lehtipuuston avohakkuu sekä nuoren metsän ensiharvennus. Keskimääräisessä pystykaupalla myydyssä leimikossa on pinta-ala 6 ha sekä hakkuukertymä 41 m^3/ha ja 245 m^3/leimikko. Avohakkuualoilta saatavan hakkuutähdehakkeen käyttö rajoittuu pienemmistä kustannuksista huolimatta toistaiseksi vain metsäteollisuuden voimaloihin.

Pystykaupoin ostetuissa hakepuuleimikoissa on kuitupuun mitat täyttävän puutavaran osuus VAPOlla 60 % ja muilla organisaatioilla keskimäärin 21 %. Vastaavaa tietoa ei ole saatavissa hankintakauppojen hakepuusta, mutta kuitupuuosuus lienee siinä pienempi.

Metsähakkeen polttoainekäyttö

Vuoden 1982 päättyessä 0,5—10,0 MW:n lämpölaitoksia oli yhteensä 102. Ne käyttivät vuodessa 1310 m^3 (3300 i-m^3) haketta kutakin tehomegawattia kohti. Tämä vastaa keskimäärin 2850 tunnin huippukäyttöaikaa metsähakkeella. Vajaakäyttö aiheutuu lähinnä laitosten ylimitoituksesta, sisäänajovaiheen teknisistä ongelmista sekä erityisesti kesäajan vähäisestä lämmöntarpeesta. Pääosa lämpölaitoksista oli valmistunut vuosina 1980—82 ja tutkimusajankohtana niin ollen paljolti vasta aloittelemassa täysmittaista toimintaa.

Yli puolet metsähaketta polttavista 0,5—10,0 MW:n käyttöpisteistä on kunnallisia kaukolämpölaitoksia. Merkittäviä käyttäjiä ovat myös puolustusvoimain varuskunnat, meijerit, oppilaitokset ja sairaalat.

Metsähaketta polttavia lämpölaitoksia on pienpuuvarojen ja nimenomaan koivun runsaudesta johtuen erityisen paljon Pohjois- ja Keski-Pohjanmaalla, mutta myös Jyväskylän ja Joensuun ympäristössä on useita käyttöpisteitä. Lounais-Suomessa metsähakkeen polttoa rajoittavat vähäisemmät pienpuuvarat ja esimerkiksi ulkomaisen hiilen edullisuus, Etelä-Pohjanmaalla muun muassa turpeen hyvä kilpailukyky ja Lapissa ja Kainuussa taas asutuskeskusten harvalukuisuudesta johtuva pieni käyttöpotentiaali.

Metsähaketta käytetään paitsi energian tuotantoon jossain määrin myös teollisuuden raaka-aineena. Kaupallisen metsähakkeen kokonaiskäyttö ilman pienkuluttajia oli vuonna 1982 yhteensä 646 000 m^3 (1 613 000 i-m^3). Siitä ohjautui 20 % sulfaattimassa- ja lastulevyteollisuuden raaka-aineeksi, 20 % metsäteollisuuden polttoaineeksi ja loput 60 % eli 393 000 m^3 lämpölaitosten polttoaineeksi. Viimeksimainittujen metsähakkeesta toimitti VAPO 31,4 %, metsänhoitoyhdistykset 18,8 %, metsäteollisuus (pääasiassa Osuuskunta Metsäliitto) 18,4 % ja muut organisaatiot 31,4 %.

Metsähakkeen polttoainekäyttö on lisääntymässä myös metsäteollisuudessa. Erityisesti tämä koskee monitoimikoneella korjattujen avohakkuualojen oksa- ja latvustähteestä tehtyä hakkuutähdehaketta.

Metsähakkeen hankinnan järjestely

Metsähakkeen hankinnasta nykyisin vastaavat organisaatiot toimivat hyvin, ja niitten varaan voidaan rakentaa vaikeuksitta paljon suurempienkin hakemäärien hankinta. Ei näytä olevan erityistä tarvetta uusien hakeorganisaatioitten luomiseen.

Hakepuu ostetaan puoliksi pysty- ja puoliksi hankintakaupalla. Puolihankintakauppoja, joissa metsänomistaja vastaa hakepuun teosta ja kasauksesta traktoriuran varteen, tehdään hyvin vähän. Viimeksi mainittu vaihtoehto näyttäisi kuitenkin tarjoavan mielekkään vaihtoehdon metsätilanomistajille.

Metsähakkeen hankinnan vaatima työnjohtopanos on suuri, keskimäärin 2,9 miespäivää 100 m^3 kohti. Tämä aiheutuu lähinnä kauppaerien pienuudesta, hakkuutyön alhaisesta tuottavuudesta, kuuman korjuuketjun toiminnallisesta haavoittuvuudesta, mittausongelmista sekä uuden korjuutekniikan sisäänajovaiheen hankaluuksista ja menetelmäkehittelystä.

Toimitusten tasaisuudella ja jatkuvuudella on kustannusten kannalta tärkeä merkitys. Kesällä useimmat lämpölaitokset keskeyttävät toimintansa tai polttavat pienen lämmöntarpeen vuoksi vain öljyä, jolloin haketoimitukset seisahtuvat. Metsähakkeen heikon säilyvyyden ja puskurivarastointimahdollisuuksien puuttumisen vuoksi myös haketus ja hakkeen kuljetus on keskeytettävä vastaavasti, vaikka juuri kesäaikana olosuhteet ovat haketuksen kannalta edullisimmillaan. Toimitusten painopiste on sydäntalvessa, jolloin työolot ovat vaikeat.

Hakepuun teko ja metsäkuljetus

Hakkuutyön tuottavuutta voidaan parantaa merkittävimmin siten, että luovutaan pienpuun karsimisesta ja haketetaan puut oksineen. Erityisesti metsäteollisuus on järkeistänyt korjuuta tältä pohjalta, joka lisää samalla myös leimikon biomassakertymää. Työ tapahtuu silloin tehokkaimmin siirtely-kaatomenetelmällä, jossa moottorisaha varustetaan pystyasentoisen kaatosahauksen mahdollistavalla kaatokahvalla. Seuraavat luvut osoittavat, että hakkuutyön tuottavuus kohoaa kokopuun siirtely-kaatotekniikkaa käyttäen jopa kaksinkertaiseksi rankamenetelmään verrattuna.

	Karsitun rangan teko	Kokopuun siirtely-kaato
	Hakkuutyön tuottavuus, m^3/päivä	
Aikapalkkaus	2,9	4,2
Urakkapalkkaus	4,9	9,8

Hakkuutyö tulee korjuuteknisistä syistä keskittää kesäaikaan, jolloin myös kuivuminen on tehokkainta. Kesäaikainen rasiinkaato mahdollistaa puun elävän latvuksen haihdutustoiminnan hyväksikäytön, kun puut jätetään muutaman viikon ajaksi levälleen tai pieniin taakkoihin kasattuina hakkuupalstalle.

Hankintakaupoissa puut kuljetetaan tien varteen yleensä maataloustraktorilla, joka on varustettu peräkärryllä ja yhä useammin myös kuormaimella. Pystykauppojen hakepuu kuljetetaan pääasiassa metsätraktorilla. Keskimääräinen tuotos nähdään seuraavista luvuista.

	Kuorman koko, m^3	Tuotos m^3/päivä
Maataloustraktori	3,6	26
Metsätraktori	5,6	50

Haketus ja hakkeen kuljetus

Suurin osa hakkureista on maataloustraktorikäyttöisiä. Markkinoilla on myös metsätraktorisovitteisia järeitä palstahakkureita sekä suuria tuotantomääriä varten rakennettuja autosovitteisia järeitä varastohakkureita. Lisäksi on valmistettu muutama hinattava omalla moottorilla varustettu järeä varastohakkuri.

Vaikka lämpölaitoksia palvelevat hakkurityypit on kehitetty vasta 1970-luvun lopulla tai 1980-

luvun alussa, monet niistä ovat saavuttaneet erinomaisen toimintavarmuuden. Konerikot vievät keskimäärin vain 5 % työmaa-ajasta, ja pääosa siitäkin aiheutuu käyttökoneen ja kuormaimen häiriöistä.

Kun puskurivarastoinnin mahdollisuudet ovat käytännössä vähäiset, hakkureitten kapasiteetti joudutaan mitoittamaan talvikauden huipputarpeen mukaan. Seurauksena on vajaakäyttö suurimman osan vuodesta. Sydäntalvella, jolloin valon puute muutoinkin vaikeuttaa haketusta, työtä joudutaan tekemään kahdessa ja joskus jopa kolmessakin vuorossa. Vain 47 % hakkeesta syntyy yksivuoroisella työtahdilla.

Hakkurin kuljettajan työmaa-ajasta kuluu 40 % muuhun kuin varsinaiseen haketukseen. Hakkurien työsaavutukset jäävät niin ollen käytännössä huomattavasti pienemmiksi kuin niille ilmoitetut tehotuntituotokset. Keskeytyksiä aiheutuu lähinnä hakeajoneuvojen odotuksesta, hakkurin siirroista työmaalta toiselle, huollosta, konerikoista ja lepotauoista. Useat urakoitsijat, joilla hakkurin käyttökoneena on maataloustraktori, parantavat traktorin työllisyyttä hoitamalla samalla ajoneuvolla myös hakkeen kuljetuksen.

Myös itse haketustyössä sattuu tuotosta alentavia keskeytyksiä. Yleisimmät häiriötilanteet aiheutuvat torven tukkeutumisesta, puitten jäätymisestä, pinojen päällä olevasta lumesta sekä terien kulumisesta. Välittömien teräkustannusten osuus on 8 % hakkurin kokonaiskustannuksista.

Maataloustraktorikäyttöisten hakkureitten keskimääräinen päivätuotos vastaa todellisuudessa vain runsaan 3 tunnin jatkuvaa haketusta. Poikkeuksen muodostavat VAPOn haketusterminaalit, joilla vastaava luku on 4,5. Käyttöasetetta voitaisiin nostaa työmaakeskityksillä, huolellisella suunnittelulla, puskurivarastoinitimahdollisuuksia parantamalla sekä ennen kaikkea tarpeettoman tehokkaita koneita välttämällä.

Lämpölaitosten metsähake saadaan ainakin nykytilanteessa lyhyiltä, keskimäärin 23 km:n kuljetusetäisyyksiltä. Mikäli toimitusmäärät ovat suuria, halvimpaan kustannustasoon päästään etenkin pitkillä matkoilla perävaunullisella kuorma-autolla. Lämpölaitosten hakkeen tarve ei ole kuitenkaan läheskään aina riittävä mahdollistaakseen järeän kaluston käytön.

Vuonna 1982 kuljetettiin 33 % lämpölaitosten hakkeesta perävaunullisilla ja 26 % perävaunuttomilla kuorma-autoilla, joista osa oli varustettu haketuksen ajaksi maahan laskettavilla vaihtolavoilla. Kaikkiaan 41 % lämpölaitosten metsähakkeesta, muun muassa metsänhoitoyhdistysten välityksellä tapahtuvat toimitukset, tuli perille traktorikuljetuksena.

On tarkoituksenmukaista, että sama urakoitsija vastaa sekä haketuksesta että jatkokuljetuksesta. Milloin molemmat tehtävät hoidetaan vielä samalla traktorilla, työketjun kitkatekijät vähenevät.

Metsähakkeen polttoaineominaisuudet

Lämpölaitokset käyvät huomattavan osan vuodesta vajaakuormalla, jolloin hyötysuhde laskee. Tästä syystä sekä myös kattilan käynnistyksien ja pysähdyksien vuoksi vuosihyötysuhde on aina heikompi kuin samalla polttoaineella täydellä kuormalla ajettaessa. Kiinteitä kotimaisia polttoaineita käyttävien lämpölaitosten keskimääräinen vuosihyötysuhde on osaksi ylimitoituksenkin takia vain 73 % (Immonen ja Seppälä 1984). Mitä kosteampaa puu on, sitä pienemmäksi hyötysuhde jää käytännössä. Kosteuden vaikutus on kuitenkin laitoskohtainen, eikä yleispätevää riippuvuussuhdetta voida esittää.

Pienkäyttöä lukuun ottamatta hakkeen kosteuden alentaminen on haketustapahtuman jälkeen käytännössä tuskin enää mahdollista. Keskisuurten lämpölaitosten tarpeita varten puu on näin ollen kuivatettava jo ennen haketusvaihetta. Tehokkain ja taloudellisin vaihtoehto on tuolloin kesäaikainen rasimenetelmä. Alhaisimman kosteuden — hyvissä olosuhteissa alle 35 % — saavuttaa rasissa koivu. Mänty kuivuu rasissa kaikkia muita puulajeja hitaammin. Rasipuut tulee ajaa tien varteen mahdollisimman korkeille varastopinoille ennen syyssateita.

Lämpölaitosten metsähakkeen kosteus on talvikaudella keskimäärin noin 40 % ja kesällä merkittävästi alempi. Kuormien välinen kuukausittainen hajonta on yleensä 5—6 kosteusprosenttiyksikköä keskiarvon ympärillä. Epäsäännöllinen vaihtelu vaikeuttaa polton säätelyä ja johtaa hyötysuhteen alenemiseen.

Yleisesti käytettyä hakkeen tiiviyslukua 0,40 on pidettävä liian karkeana. Puulajeittainen vertailu johtaa yhteisellä suhdeluvulla harhaiseen koivua suosivaan lopputulokseen. Metsäntutkimuslaitokseen useissa eri yhteyksissä kertyneitten aineistojen pohjalta suositellaan käytettäväksi seuraavia puulajeittaisia kokopuuhakkeen tiiviyslukuja: koivu 0,39, leppä 0,46 ja mänty 0,43.

Kokopuuhakkeen saapuessa lämpölaitokselle sen keskimääräinen kuivamassa on koivulla 185, lepällä 170 ja männyllä 165 kg/i-m^3. Lämpöarvo on vastaavasti 0,895, 0,820 ja 0,865 MWh/i-m^3, kun kosteus on 40 %. Vaihtelu on kuitenkin suuri, minkä vuoksi mittauksen ja hinnoittelun tulisi perustua kuivamassan punnitukseen.

Lämpölaitosten suunnittelussa ei ole otettu riittävästi huomioon metsähakkeessa aina esiintyviä ohjearvojen vastaisia ylimittaisia kappaleita ja oksanpätkiä, jotka aiheuttavat ongelmia erityisesti siiloissa, purkaimissa, kuljettimissa ja käsittelylaitteitten automatiikassa. Koska jyrkkä vaatimus tasaisesta palakoosta nostaa kohtuuttomasti metsähakkeen tuotantokustannuksia, hakkeen varastointi- ja käsittelylaitteet tulee suunnitella ja mitoittaa siten, että myös kokopuuhakkeen käyttö on mahdollista. Ketju- ja kolakuljettimet ovat osoittautuneet ruuvikuljettimia varmatoimisemmiksi.

Metsähakkeen hankintakustannukset

Karsituista rangoista tehdyn metsähakkeen todellinen kustannustaso oli vuonna 1982 yleis- ja korkokulut mukaan luettuina keskimäärin 170—190 mk/m^3. Kokopuuhakkeen kustannustaso oli vastaavasti 155—175 mk/m^3 eli lähes 10 % alhaisempi.

Hakkuutähdehakkeen orastava käyttö rajoittuu toistaiseksi metsäteollisuuden voimaloihin. Kustannustaso on vähäisen kantohinnan, hakkuuvaiheen puuttumisen, pienen työnjohtotarpeen ja pienten korkolukujen ansiosta oleellisesti alhaisempi, vuoden 1982 päättyessä keskimäärin 108 mk/m^3.

Metsäteollisuus hankkii hakkeen muita organisaatioita hieman alhaisemmin kustannuksin etenkin hakepuun tekotyön tehokkuuden ansiosta. Tämä perustuu puitten talteenottoon oksineen, siirtely-kaatomenetelmän yleisyyteen sekä urakkapalkkauksella työskentelevien, työnsä hyvin hallitsevien ammattimetsureitten käyttöön.

Lämpöarvon mukaan laskettuna kokopuuhakkeen kustannus on puulajista riippuen 70—80 mk/MWh, rankahakkeen vastaavasti 80—90 mk/MWh. Korkean lämpöarvonsa vuoksi koivu on muita puulajeja edullisempaa, mutta erot eivät ole kovin suuria. Kaikkia ranka- ja kokopuuhakelajeja edullisempaa, 60 mk/MWh, on kuitenkin monitoimikonetyömailta saatu hakkuutähdehake.

Kokopuuhakkeen kustannuksista koostuu 13 % kantohinnasta, 43 % välittömistä työpalkoista sosiaalikuluineen, 31 % konekustannuksista, 3 % hankinta-ajan korosta ja 10 % muista kustannuksista.

Metsähakkeen kokonaiskustannuksista on 85—90 % kotimaista alkuperää. Ulkomaisten kustannuslähteitten osuus on siis vain 10—15 %.

Metsähakkeen hankinnan työllistävä vaikutus

Miestyön tuottavuus on työnjohto ja kaukokuljetus mukaan lukien metsähakkeen hankinnassa keskimäärin 3 m^3 työpäivää kohti. Tämä on vain puolet teollisuuspuun hankinnan tuottavuudesta.

Lämpölaitosten metsähakkeen hankintaan, jonka kokonaismäärä oli 393 000 m^3, käytettiin vuonna 1982 työnjohto mukaan luettuna noin 130 000 työpäivää. Vaikka hankinta kokonaisuutena pyöriikin ympärivuotisena, sen tarjoamat työtilaisuudet — päinvastoin kuin ehkä lämpölaitoksen toimet — kestävät vain osan vuotta. Hakepuun teko tapahtuu ensisijaisesti kesäkaudella ja metsäkuljetus loppukesällä ja syksyllä. Haketus ja hakkeen kuljetus taas painottuvat lokahuhtikuulle.

Vuonna 1982 lämpölaitosten metsähakkeen hankinta vastasi 565 vuoden välitöntä työpanosta, josta lähes kaksi kolmannesta muodostui hakepuun teosta moottorisahalla ja yksi kolmannes erilaisesta konetyöstä ja työnjohdosta. Kun myös lämpölaitosten työpaikat ja toiminnan välillinen merkitys otetaan huomioon (vrt. Toropainen 1982), työllistävä kokonaisvaikutus voidaan vuosityöpaikoiksi muunnettuna arvioida seuraavaksi.

	Työvuosia
Välitön työllistävä vaikutus	
Metsäpäässä	565
Lämpölaitoksella	190
Välillinen työllistävä vaikutus	980
Yhteensä	1735

Lämpölaitosten metsähake hankittiin suunnilleen 10 000 ha:n alalta. Koska kysymyksessä oli puutavara, jolle ei ollut tarjolla muuta käyttöä, voidaan toiminnan metsänhoidollisen vaikutuksen katsoa kattavan vastaavan alan.

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