Developing technology for large-scale production of forest chips

Wood Energy Technology Programme 1999–2003

Pentti Hakkila, VTT Processes

Technology Programme Report 5/2003 | Interim Report

TEKES

Developing technology for large-scale production of forest chips

Wood Energy Technology Programme 1999–2003

Interim Report

Pentti Hakkila
VTT Processes

TEKES

National Technology Agency

Technology Programme Report 5/2003
Helsinki 2003

Tekes – your contact for Finnish technology

Tekes, the National Technology Agency, is the main financing organisation for applied and industrial R&D in Finland. Funding is granted from the state budget.

Tekes' primary objective is to promote the competitiveness of Finnish industry and the service sector by technological means. Activities are aimed at diversifying production structures, increasing productivity and exports and creating a foundation for employment and social well-being. Tekes finances applied and industrial R&D in Finland to the extent of nearly 400 million euros annually. The Tekes network in Finland and overseas offers excellent channels for cooperation with Finnish companies, universities and research institutes.

Technology programmes – part of the innovation chain

The technology programmes are an essential part of the Finnish innovation system. These programmes have proved to be an effective form of cooperation and networking for companies and the research sector for developing innovative products and processes. Technology programmes promote development in specific sectors of technology or industry, and the results of the research work are passed on to business systematically. The programmes also serve as excellent frameworks for international R&D cooperation. Currently, 45 extensive technology programmes are under way.

ISSN 1239-1336
ISBN 952-457-101-3

Cover: Oddball Graphics Oy
Page layout: DTPage Oy

Printers: Paino-Center Oy, 2003

Foreword

Finland is the world leader in utilisation of bioenergy. About 20 % of the primary energy is derived from wood-based fuels, a higher proportion than in any other industrialized country. Finnish forest industry has the central role in converting wood-based residues into heat and power.

However, meeting the challenges of the mitigation of climate change has lead to the commitment to double the use of the renewable energy sources by 2025, as compared to the situation in 1995. The main focus is on bioenergy. As all industrial wood residues are in use either as raw material or to produce energy, any increase must be based on the recovery of unutilised biomass in the forests: forest chips from logging residues and small-sized trees. The limiting factor is not the utilisation but rather the production of the fuel: the cost of production must be reduced, its supply must be reliable, and the quality of the fuel must be improved.

In Finland, technology development is among the main measures in obtaining the target. In 1999, the National Technology Agency Tekes established the five-year Wood Energy Technology Programme to develop efficient and competitive technology for the large-scale production of forest chips. As of November 2002, 35 research projects, 35 industrial projects and 15 demonstration projects had been initiated. Close collaboration between researchers and practitioners is typical of these projects. Joint projects have promoted the build-up of know-how and its transfer to practice. The competitiveness of forest chips has improved, and their use is growing.

As Finland is in the forefront of development, the new technology of wood fuel production and combustion has considerable export potential. Foreign scientists, practitioners and decision makers are interested in the state of the art. As most of the results of the programme are in Finnish, the dissemination of knowledge is severely restricted. This interim report of the programme therefore attempts to reach a wider audience of interested scientists, practitioners and organizations.

Tekes wishes to thank all the parties involved for their valuable contribution to the programme and to building a strong knowledge base in this area. Special thanks are extended to the Executive Board who has had the responsibility for supervising the programme and last but not least Programme Manager Professor Pentti Hakkila and his team from VTT Processes for the effective management of the programme.

Helsinki, December 2002

Tekes, the National Technology Agency

Summary

Finland is enhancing its use of renewable sources in energy production. From the 1995 level, the use of renewable energy is to be increased by 50 % by 2010, and 100 % by 2025. Wood-based fuels will play a leading role in this development.

The main source of wood-based fuels is processing residues from the forest industries. However, as all processing residues are already in use, an increase is possible only as far as the capacity and wood consumption of the forest industries grow. Energy policy affects the production and availability of processing residues only indirectly.

Another large source of wood-based energy is forest fuels, consisting of traditional firewood and chips comminuted from low-quality biomass. It is estimated that the reserve of technically harvestable forest biomass is 10–16 Mm^3 annually, when no specific cost limit is applied. This corresponds to 2–3 Mtoe or 6–9 % of the present consumption of primary energy in Finland. How much of this reserve it will actually be possible to harvest and utilize depends on the cost competitiveness of forest chips against alternative sources of energy.

A goal of Finnish energy and climate strategies is to use 5 Mm^3 forest chips annually by 2010. The use of wood fuels is being promoted by means of taxation, investment aid and support for chip production from young forests. Furthermore, research and development is being supported in order to create techno-economic conditions for the competitive production of forest chips. In 1999, the National Technology Agency Tekes established the five-year Wood Energy Technology Programme to stimulate the development of efficient systems for the large-scale production of forest chips. Key targets are competitive costs, reliable supply and good quality chips.

The two guiding principles of the programme are: 1) close cooperation between researchers and practitioners and 2) to apply research and development to the practical applications and commercialization. As of November 2002, the programme consisted of 35 research projects, 35 industry projects and 15 demonstration projects, inclusive of the completed ones. The participation of researchers and practitioners in joint projects has strengthened the research capacity and promoted networking amongst research organizations in the field of wood energy in Finland. Furthermore, researchers have been able to identify and meet the practical needs of the industry, and joint projects have facilitated the dissemination of research results to practical forestry, forest industry, energy enterprises and machine manufacturers.

During the first three years of the five-year programme, the use of forest chips increased from 0.5 Mm^3 to 1.3 Mm^3. The average increase was thus 270 000 m^3 per annum. If the official goal of the Action Plan for Renewable Energy Sources is to be achieved, an increase of 400 000 m^3 is required in each year of this decade.

The biomass resource exists. The combustion capacity of the present and planned heating and power plants is sufficient to absorb practically all competitively priced woody biomass available. As a result of the recent technological development, even stump and root wood can be used by large power plants equipped with modern fluidized bed technology.

Considerable progress is taking place in the technology of chip production, e.g. the successful CRL system based on bundling of residues and crushing at the plant. Nevertheless, the production of chips rather than combustion technology still remains the real bottleneck for the utilization of the bio-

mass potential of the Finnish forests. The main barrier is the high price of chips. Even worse, the fall in costs of production in the 1990s is supposed to reverse. Consequently, it is of great importance that the support for the research, development and commercialization of forest chip production technology should continue after the Wood Energy Technology Programme ends in 2003. For example, Tekes has recently expanded the scope to the small-scale production and combustion in a new sub-programme that will last till the end of 2004.

The parties involved in the forest chip business were interviewed in order to determine the constraints on growth. The survey indicates that many barriers remain, but that they are becoming less problematic. However, as the demand for forest chips increases, availability starts to cause concern. In addition to developing technology and reducing costs, non-technical barriers must also be addressed in order to encourage forest owners, forest machine entrepreneurs and chip producers.

Table of contents

1 Wood energy in Finland

Because of the harsh climate, high standard of living, long transport distances and the predominance of process-type industries, the per capita consumption of energy is in Finland high, 6 toe per annum. There are no deposits of fossil fuels, but the country is rich in forests. Therefore, energy management was based on wood longer than in most industrialized countries.

The area of productive forests is 20 Mha and the annual increment of stemwood 80 Mm^3. As the country is sparsely populated, the production potential of wood per capita is larger than in any other country in Europe.

Annual fellings are 12 m^3* per capita. In addition, the annual import of timber is 3 m^3 per capita. Altogether, the consumption of roundwood for various purposes is 15 m^3 per capita, while the corresponding average figure for the 15 EU countries is only 0.8 m^3.

The national economy of Finland is highly dependent on the renewable forest resource and the forest cluster built around the sustainable utilization of this resource. Forests are managed for the production of industrial raw material, but increasingly also as a source of clean renewable energy and for recreation. The forest cluster, including the concept of wood-based energy in its broad sense, is given a high priority in policy making.

1.1 Use of wood fuels

Despite the expansion of forest industries and the rapid decrease in the use of traditional firewood during the 1960s and 1970s, wood remains an important source of energy in Finland. While only 10 % of the annual removal of wood is *used directly for firewood*, much more energy is *derived indirectly from wood-based processing residues* from the forest industries.

Although the forest industries apply efficient technologies, a considerable part of the raw material is either unsuitable for end products or is just lost in processing. The proportion of *the energy component in the timber flow* of various forest industries is approximately:

- in sawmilling 15–25 % (sawdust, debarking and screening residue)
- in plywood manufacturing 40–50 % (log ends, waste from plies, dust, debarking and screening residue)
- in mechanical pulping 10–15 % (debarking and screening residue)
- in chemical pulping 50–60 % (lignin-rich black liquor, debarking and screening residue).

Almost 40 % of the wood raw material input of the Finnish forest industries therefore ends up as potential fuel, and practically none of this processing residue is left unutilized. When both the large-scale use of industrial process residues and small-scale use of traditional firewood are taken into account, some 35 Mm^3 wood equivalent or 46 % of the roundwood consumption is used for the production of energy (Figure 1). About 20 % of the total consumption of primary energy, corresponding to 6.2 Mtoe or 73 TWh, and 11 % of the electricity is derived annually from wood-based fuels (Figures 2 and 3). These shares are higher than in any other industrialized country.

*In this report m^3 refers to solid measure. When biomass is reduced to chips, 1 solid m^3 yields 2.5 loose m^3.

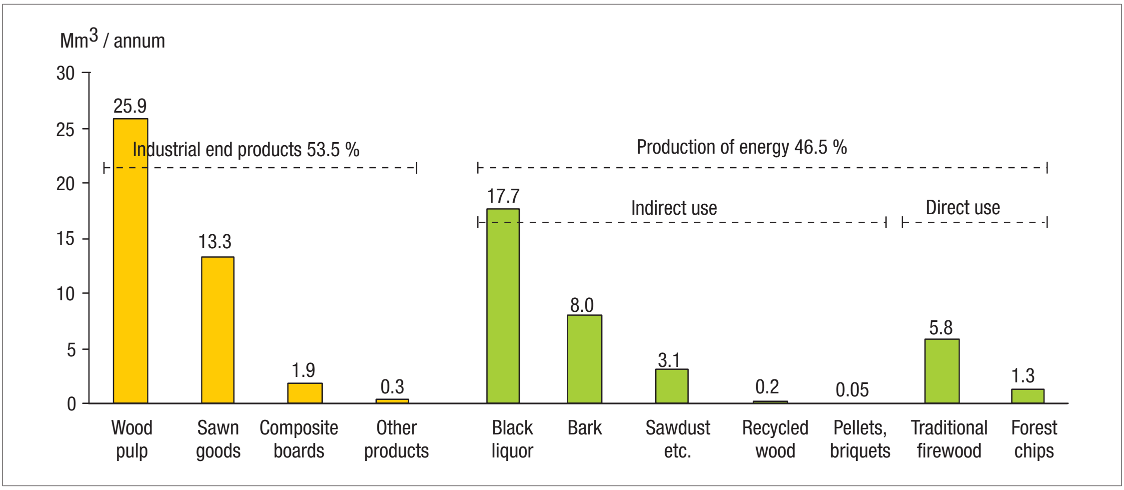

Figure 1. The end use of wood in Finland in 2001 (industrial end products, black liquor) or 2002 (solid wood fuels). Source VTT.

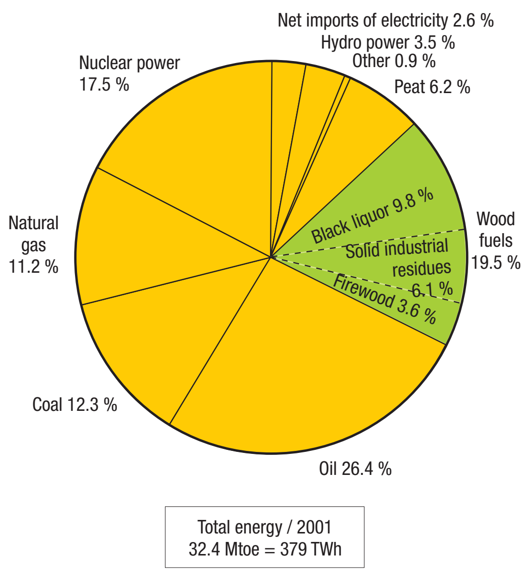

Figure 2. Total energy consumption by source in 2001. Energy statistics 2002.

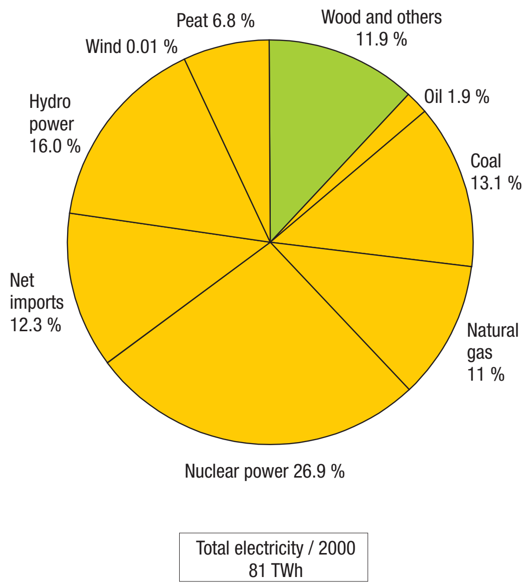

Figure 3. Production of electricity by source in 2001. Energy statistics 2002.

Three major sources of wood-based fuels can be identified: firewood used by farms and small-houses, black liquor from chemical pulping, and solid wood residues from all branches of forest industries, forestry and society at large. A considerable part of these solid wood residues, 14 TWh per annum, consist of bark from the forest industries, even though some 15 % of the original bark volume is lost when timber is cut with harvesters and lifted with grapple loaders on its way from stump to mill. An ongoing research project of the programme addresses the need to reduce the loss of bark during wood procurement.

Forest chips are still a minor product among the solid wood fuels. However, as indicated in Section 1.2, they will probably gain a significant role in energy production by the end of this decade.

1.2 Wood in the energy strategy

The objective of the Government's energy policy is to create circumstances that ensure the availability of energy, keep the price of energy competitive, and enable Finland to meet its international commitments with respect to emissions into the environment. As a Member State of the EU, Finland's obligation is to return the average greenhouse gas emissions in the years 2008–2012 to the level that prevailed in 1990, i.e. 76.5 Mt of carbon dioxide equivalent.

In 2001, the Government of Finland approved the National Climate Strategy which is aimed at reducing the greenhouse gas emissions. Renewable energy sources play an important role in the strategy. Implementation of *the Action Plan for Renewable Energy Sources* from 1999 (Figure 4), together with the Action Plan for Energy Conservation, account for about half of the targeted emissions reduction.

The goal is to bring an increase of 50 % in the annual use of renewable energy sources by 2010, when compared to the level of 1995. The share of renewable sources of the total consumption of energy would increase from 21 % to 27 % in 15 years.

As much as 90 % of the increase is to be derived from bioenergy. The increase will be composed of the following components:

	Increase by 2010 Mtoe/annum
Wood-based fuels from industrial processing residues	1.4
Fuels produced directly from forest biomass	0.9
Recycled fuels	0.5
Hydropower, wind power, heat pumps and solar energy	0.3
Total	3.1

Wood-based fuels thus play a dominant role in the Action Plan. The amount of additional wood fuels becoming available from industrial processes depends directly on the future growth of the forest industries. As a rule, using these by-products for energy is profitable, and the production technology is not a key issue.

According to the Action Plan, the second largest addition of renewable energy, i.e *0.9 Mtoe or 5 Mm³ wood fuel, is to be derived directly from low-qual-*

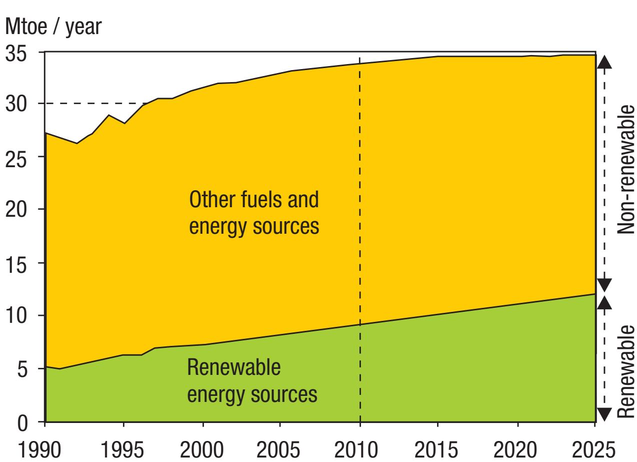

Figure 4. The total consumption of energy and the share of renewable energy sources up to 2025. Action Plan for Renewable Energy Sources 2000.

ity forest biomass. Here, the resource would enable an even higher increase than that outlined, and the availability of the biomass is not connected with future growth of the forest industries. Instead, a major barrier to the increased use of forest biomass as a source of renewable energy is its *poor price competitiveness* in respect to other fuels. Consequently, the development and commercialization of innovative forest fuel production technology is essential.

The Government's aim is to make all forms of renewable energy economically competitive on the open energy markets. The following support measures are employed:

- *Energy taxation on fuels used for heat production*. A carbon-based environmental fuel tax was imposed in 1990. Wood-based fuels are free of the tax because of their carbon neutrality (Figure 5).
- *Support to electricity production*. A tax of 6.9 €/MWh is levied on electricity, whether domestic or imported, rather than on fuel input. If forest chips or wind are used for the production of electricity, the tax is refunded to the producer.
- *Aid for investments*. Financial aid can be granted to development and investment projects in order to promote the conservation of energy, to improve energy efficiency, to promote utilization of renewable energy, to improve the security of energy supply, and to reduce harmful impacts of the production and use of energy. For special equipment used in the production of forest chips, the investment aid is typically about 20 % of the costs. Projects involving innovative technology are given priority.
- *Support for the production of forest fuels*. When small-diameter fuelwood is harvested from young forest stands, a subsidy of about 5.5 €/MWh is paid to chip producers. The stands must meet specific silvicultural criteria. No direct support is awarded for the production of fuel chips from logging residues from late thinnings or final harvest.
- *Public financial support to development and commercialization of technology*. The National Technology Agency, Tekes is responsible for technology R&D funding. Tekes allocates annually 10 million euros to the RES sector. The Ministry of Trade and Industry gives financial support to demonstration projects.

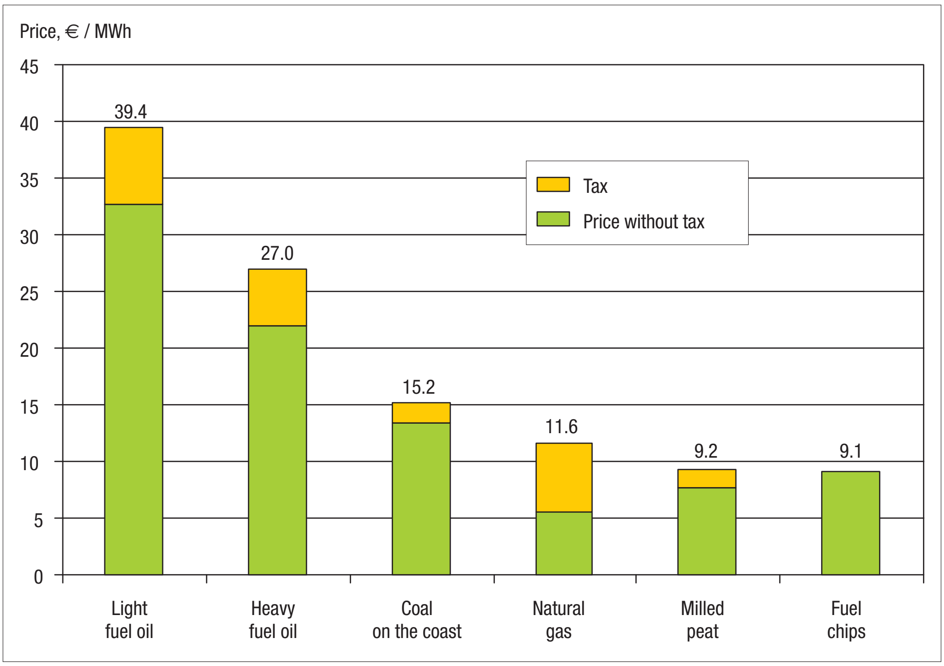

Figure 5. Consumer prices of different fuels in heat production in September 2002. VAT not included. Data from Energy statistics 2000.

2 The Wood Energy Technology Programme

The National Technology Agency Tekes is the main public investor in applied and industrial research and development in Finland. Renewable energies, an essential issue of subtainable development, is one of the key strategic areas. About 50 % of Tekes' funding is focused through technology programmes. Several of the programmes have dealt with bioenergy technology, focusing on areas such as production of fuels, combustion, conversion and environmental impacts (Figure 6).

The Bioenergy Research Programme (1993–1998) was aimed at the production, use and conversion of wood and peat fuels in 1993–1998. It was followed by *the Wood Energy Technology Programme* (1999–2003) that is focused on the development of technology for the large-scale production of forest chips.

The availability of forest biomass is not a limiting factor since the potential greatly exceeds the target. The capacity of heating and power plants also soon exceeds the target: new wood fuelled plants have been established and old plants have been modified to receive, handle and burn chips. The real limiting factor is the production of chips at competitive cost.

2.1 The targets of the programme

The ultimate target of the Wood Energy Technology Programme is to create favourable conditions

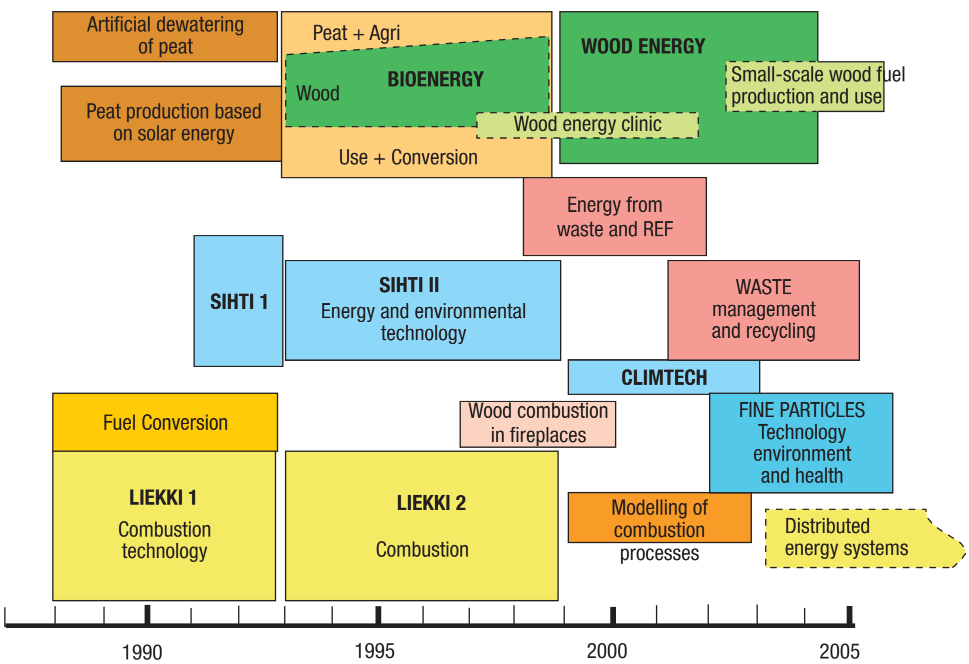

Figure 6. Tekes' programmes on bioenergy. The area of a rectangle indicates relative expenditure. Source Tekes.

of increasing the use of forest chips. Consequently, *the programme is aimed at developing the production technology and procurement logistics for forest chips*. The emphasis is on system development for large-scale operations in conjunction with combined heat and power production.

Preconditions for a rapid increase in the use of forest chips are the reduction of costs, improved quality of chips, and reliable delivery systems. Chips must also be produced by environmentally sound methods that support sustainable forest management. *The primary targets of the programme* are:

- to integrate energy production into conventional forestry and the procurement of industrial timber
- to develop production systems and procurement logistics for forest fuels
- to develop technology for comminuting, bundling, handling and storage of wood fuels
- to develop long-distance transport of chips, uncomminuted loose residues and composite residue logs
- to encourage the participation of forest machine and truck contractors in the wood fuel branch
- to develop quality control for forest chips and processing residues from the forest industries
- In 2002 the scope was expanded. A sub-programme was established for small-scale production and combustion of wood fuels.

The programme has set for itself an unofficial goal: increasing the annual use of forest chips from 0.5 Mm^3 in 1998 to 2.5 Mm^3 in 2003, i.e. a five-fold increase in five years. The target is ambitious, and it appears that it may not be possible to achieve it within the scheduled time. In 2001 the use of forest chips has reached 1.3 Mm^3.

2.2 The organization of the programme

The programme is composed of projects that typically last 1–3 years. There are three types of projects:

- *Projects undertaken by research institutes* address common and general needs. The results and know-how achieved are in the public domain. In research projects research organizations collaborate with industrial partners.
- *Projects dealing with product development*, i.e. industrial projects, are related to practical applications. They serve specific needs of a single company or company integrate. Examples include the development of a complete chip procurement system, a less corrosive combustion technique for chips rich in needles, or a chipper, bundler, feller-buncher for small trees, forwarder for biomass transport, and a special truck for forest fuels. An industrial project commonly includes a research component that requires co-operation with a research organization. The results and experience from company projects are not necessarily in the public domain.
- *Demonstration projects* are aimed to promote introduction and deployment of new technologies in forest fuel production and combustion. Funding is primarily investment grant-aid from the Ministry of Trade and Industry.

Several research organizations participate in the program: VTT Processes, The Finnish Forest Research Institute, Metsäteho Oy, University of Joensuu, University of Jyväskylä, University of Oulu, TTS Institute, and the Radiation and Nuclear Safety Authority of Finland. Each research institute project has an advisory board composed of researchers and practitioners from participating organizations. The board typically meets 2–4 times a year to discuss research needs, budget changes and major reports and to monitor the work programme. The industrial projects may also have such a board, but it is an internal company decision. A complete list of the projects of the programme is presented in Appendix 1. Table 1 shows the distribution of projects into major subject groups.

The programme is *coordinated by VTT Processes*. The coordinator participates in the meetings of the research projects and some of the industry projects. The coordinator also arranges annually an internal research seminar and a public annual seminar at which results are presented to interested researchers, practitioners and decision makers. Results are published annually in the yearbook of the programme.

Table 1. The projects of the Wood Energy Technology Programme by subject groups since 1999, as of September 2002.

Subject group	Research projects	Industrial projects	Demonstration projects
Planning and organization	5	4	
Production systems and techniques	4	15	15
Quality control, handling and use	11	9	
Impacts on forestry	6	1	
Small-scale production and use	3	5	
International cooperation	6	1	
Total	**35**	**35**	**15**

Tekes has invited *an executive committee* for the programme to direct the work. The Exco consists of representatives of the major market actors in the forest fuel area. The following organizations were represented at the end of 2002:

- Biowatti Oy (production and distribution of wood fuels)
- BMH Wood Technology (manufacturer of receiving and handling equipment etc.)
- Fortum Power and Heat Oy (production of electricity, heat etc.)
- Kvaerner Pulping Oy (manufacturer of fluidized bed boilers etc.)
- Ministry of Agriculture and Forestry (forestry policy)
- Ministry of Trade and Industry (energy policy, funding of new technology demonstrations)
- Forestry Development Centre Tapio (promotion of private forestry)
- Pohjolan Voima Oy (production of electricity and heat)
- Plustech Oy/Timberjack Oy (manufacturer of forest machines)
- Tekes (funding)
- Trade Association of Finnish Forestry and Earth Moving Contractors (forest machine contracting)
- UPM-Kymmene Oyj (forest industry, procurement of timber and wood fuels)
- Vapo Oy (production and distribution of peat and wood fuels)
- VTT Processes (programme coordinator).

The estimated total cost of the program is 35 M€, of which about 11.5 M€ will be provided by Tekes for research and development, and 4 M€ by the Ministry of Trade and Industry for demonstration projects. The majority of funding comes from enterprises for their own product development projects and public research projects in which industry participates. Research institutes also participate in funding.

The programme will end in 2003 except for the new sub-programme for small-scale production and use of wood fuels. This late extension of the programme will continue to the end of 2004.

3 The operating environment of forest chip production

Forestry, forest industries and the entire forest cluster in its broad sense are of considerable importance for the national economy of Finland. Consequently sustainability has long been the guiding principle of forest management.

The majority of the domestic timber is harvested from private forests, the average area of a forest holding being less than 40 ha. The predominance of non-industrial family forestry strongly influences the care and intensity with which the forests are managed and utilized. However, the fragmented nature of this form of ownership increases the cost of timber procurement and affects the requirements placed on forest machines with respect to their mobility from site to site and friendliness to the forest environment.

3.1 Management of forests

Thinnings are a standard silvicultural practice. In southern Finland, nearly all stands are thinned commercially from below twice or three times, and in northern Finland once or twice, during the rotation period. Commercial thinnings are preceded by a pre-commercial thinning, from which timber is not harvested because of the small tree size. A typical management regime is shown in Table 2. The production of biomass residues is highest in spruce stands due to the long crown of the trees.

The correct timing of silvicultural activities is essential for maintaining the vitality of the stand, to accelerate the diameter growth of the trees and to improve the physical conditions for future mechanized cuttings. However, where pulpwood is in over-supply, the precommercial and first commercial thinning phases are a problem. Compared to the final harvest, the productivity of work is low and mechanization more complicated.

Early thinnings are a particular challenge to forest owners, timber procurement organizations and machine manufacturers alike. Demand for small-sized wood and the presence of a well developed and disciplined wood procurement organization are preconditions for early thinning. This is why it is hoped that the use of low-quality residual biomass as a source of renewable energy will promote management of non-industrial forests in Finland.

Table 2. A typical management regime of a southern Finnish forest stand.

Treatment	**Stand age**	**Yield of timber**	**Biomass residues**	
	years	**m^3/ha**	**m^3/ha**	**toe/ha**
Precommercial thinning	10—20	—	15—50	3—9
1st commercial thinning	25—40	30—60	20—50	4—9
2nd commercial thinning	40—55	4—80	15—30	3—6
3rd commercial thinning	5—70	60—90	20—30	4—6
Final harvest	70—100	200—300	60—120	11—22
Total during rotation		**330—530**	**130—280**	**25—52**

Figure 7. Small-sized hardwood from early thinning (Courtesy of the Finnish Forest Research Institute).

Figure 8. Stump and rootwood of Norway spruce, uprooted for fuel with an excavator from a clear-cut area (Courtesy of UPM-Kymmene Oyj).

Harvesting the final timber crops from a regeneration cutting presents no problem. The demand for timber is sufficient, stumpage prices are high and the operations are fully mechanized. But regeneration by planting after the clear-cutting operation gives rise to concern, as the work has not been mechanized and there is a shortage of manual labour. The mechanization of planting is becoming a necessity, but it is technically very difficult under Finnish conditions. If the thick layer of logging slash could be removed from cut-over areas, conditions for rationalization would be improved.

The harvesting of unmerchantable forest biomass presents *an opportunity for promoting good forest management practices* in conjunction with early thinnings and regeneration cuttings. Such silvicultural benefits are not achieved through the harvesting of residues in later thinnings, where the remaining trees can efficiently utilize nutrients from the decomposing biomass. Therefore, the residues from later thinnings are not included in the harvestable energy potential of the Finnish forests, and later thinning operations are not included in the technology development of the Wood Energy Technology Programme.

3.2 The unutilized reserve of biomass

For silvicultural reasons, large quantities of *unmerchantable small-sized trees should be removed from young stands* even though there is no demand for this low-quality biomass (Figure 7). Another unutilized reserve, although offering less silvicultural incentives, is the *biomass residues composed of crown mass, unmerchantable stem parts and even stump-root systems from the clear-cutting areas* of mature forests (Figure 8).

It is difficult to estimate what proportion of the theoretical biomass reserve is actually harvestable. Technology is ultimately bound to the price development of alternative fuels, labour supply, environmental factors, etc. Figure 9 represents the upper limit of *the technically available biomass reserve*. The potential is reduced when a maximum cost limit is set.

Depending on the criteria employed, the technically harvestable biomass reserve is estimated to be 10–16 Mm^3 or 22–35 % of the theoretical potential, i.e. of all above- and below-ground biomass

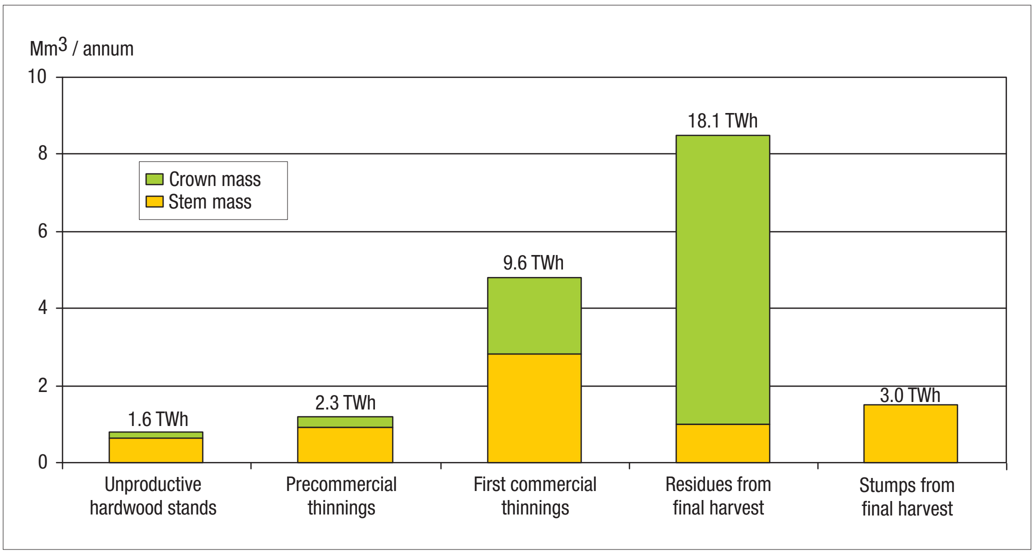

Figure 9. An estimate of technically harvestable residual biomass from conventional forestry in Finland. No maximum cost limit applied.

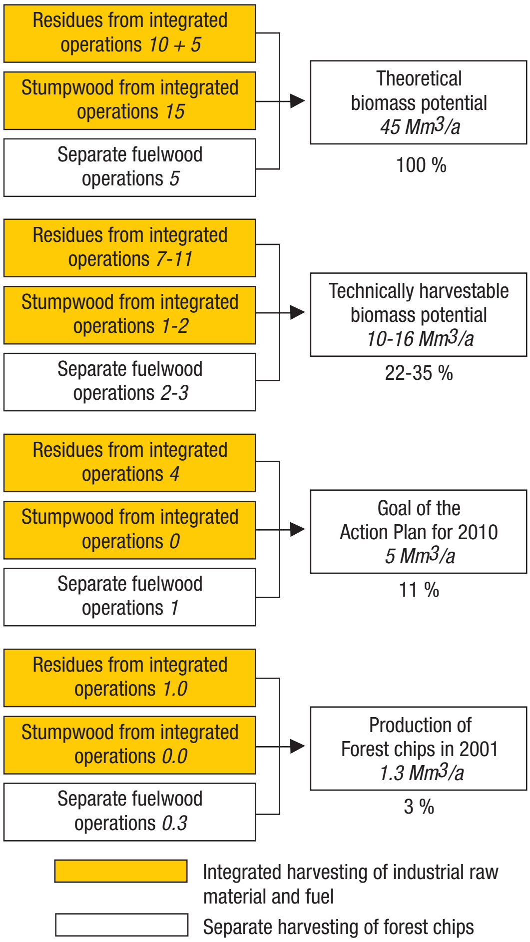

Figure 10. The biomass reserve of the Finnish forests.

residues from a hypothetical annual stemwood removal of 70 Mm^3. The official goal of the Action Plan for Renewable Energy Sources is equal to 11 % of the theoretical potential (Figure 10).

3.3 The procurement of industrial timber

Environmental, ecological and multiple use considerations place increasing constraints on logging in Finland. The procurement organization has to deal with both delivery sales and stumpage sales. About 85 % of domestic roundwood is purchased from private, non-industrial forest holdings.

Three large forest industry companies, Stora Enso Oyj, UPM-Kymmene Oyj and Metsäliitto-Yhtymä are responsible for the procurement of more than 80 % of all commercial timber. They operate nationwide and perform their wood procurement through special *forestry departments, that contract the implementation of procurement to independent entrepreneurs*. Cutting and off-road haulage are included in a single logging contract, whereas secondary transport is subject to a separate contract. A contractor typically owns 1–4 forest machines or trucks.

The technology of wood procurement is based exclusively on *the mechanized cut-to-length system*. Both the delimbing and cross-cutting of stems are carried out with one-grip harvesters at the stump. An exception is early thinnings where cutting is still commonly performed with a chainsaw. Timber is transported to the landing with load-carrying forwarders. Road transport is performed with seven-axle truck+trailer units with 60 t maximum allowable weight. Timber procurement in Finland is carried out by 1500 single-grip harvesters, 1700 forwarders and 1400 timber trucks.

Over 7000 m^3 of timber is produced and delivered to mills annually per employee in the procurement organizations. The machine technology used is reaching its limits, and the emphasis in system development is therefore shifting to logistics, information technology, environmental quality, timber quality and the harvesting of residual biomass.

This, then, is the operating environment in which the future production of forest chips will take place. The integration of fuel production with the procurement of conventional timber is a natural solution. In addition, independent contractors and their networks will be needed to produce forest chips, primarily from young thinning stands for local heating plants. There the level of integration is low and so the biomass more easily accessible to entrepreneurs operating independently of the large timber procurement organizations.

3.4 Utilization capacity of wood fuels

Two alternative combustion technologies are available for the large-scale conversion of forest biomass to heat and electricity. The traditional *grate combustion* method is competitive when boiler capacity is less than 5–20 MW. A new type of rotating grate boiler is also suitable for wet biomass, such as debarking residues from sawmills.

Larger plants employ *fluidized bed combustion* (FBC) technology. In FBC boilers, fuel is fed into a fluidized bed of hot sand, which is circulated by a stream of high velocity air from below. Combustion takes place either in a bubbling fluidized bed (BFB) at low air velocity, or in a circulating fluidized bed (CFB) at a higher air velocity As the bed material is massive relative to the amount of fuel, the combustion process is effectively stabilized and control of burning and pollutant formation is greatly facilitated.

The FBC technology was originally developed for the combustion of non-homogenous biofuels with difficult properties such as uneven particle size and high moisture content. The following advantages are achieved:

- Ability to burn low-grade fuels and on-line fuel switching
- Reduction of harmful emissions such as NO_x and SO_2.

A wide range of fuels can be accommodated with high efficiency: wood chips, bark, peat, sludge, industrial and municipal waste, coal, oil and natural gas. The FBC technology is therefore employed in new large plants, and a considerable number of traditional grate boilers and pulverized peat and coal boilers have been converted to fluidized bed technology. This has significantly *increased the potential for using biofuels in Finland*.

In *heating plants* where forest fuels are used for separate heat production only, 85–88 % of the energy content of the fuel is recovered. Typically, heating plants are small (Figure 11). In *condensing power plants* designed for separate electricity generation only about 40–45 % of the input energy is recovered in the form of electricity, while the remaining heat is lost in cooling water and flue gases. *Combined heat and power (CHP) production or cogeneration* is a single process by a back-pressure power plant. Power is generated as in a condensing plant, but heat is recovered and used in an industrial process or for district heating of a nearby community. Under conditions of a high all-year demand for heat it is often possible to achieve good fuel efficiency and a high product value by combining power and heat production.

CHP plants have an overall efficiency of 85–90 %. About 20–30 % of the energy input is converted to electric power and 55–70 % to heat. CHP plants are responsible for 33 % of the electricity supply and 75 % of the district heat in Finland. Almost all large towns use CHP for district heating. These plants are usually large, but the co-generation technology is now being scaled down for plants with an electricity output of only 5–10 MW.

As CHP technology is already widely employed in Finland, the possibilities to expand the overall capacity are limited. However, where an old plant is being replaced, it may be feasible to shift from fossil fuels to biofuels, even though the total capacity does not grow.

Pohjolan Voima Oy alone has recently invested 620 M€ to biomass CHP plants with a total capacity of 559 MW_e and 1038 MW_{th}. By 2010, approximately 3000 MW new electricity generation capacity will have been installed to meet the growth in energy demand or to replace old plants. A significant portion of the new capacity will employ CHP technology and cocombust peat and wood fuels (Figures 12 and 13). The share of forest chips in these plants will entirely depend on their cost competitiveness and availability. It is obvious that *the limiting factor is not the utilization capacity but rather the production capacity of forest chips*.

Figure 11. Ekotuli heating plant at Tikkakoski (Courtesy of Vapo Oy).

Figure 12. A view of the wood fuel yard of the 550 MW_{th} Alholmens Kraft CHP plant. Receiving and crushing station for CRL bundles on the right side. Pulpwood piles on the background (Courtesy of E.V.A.).

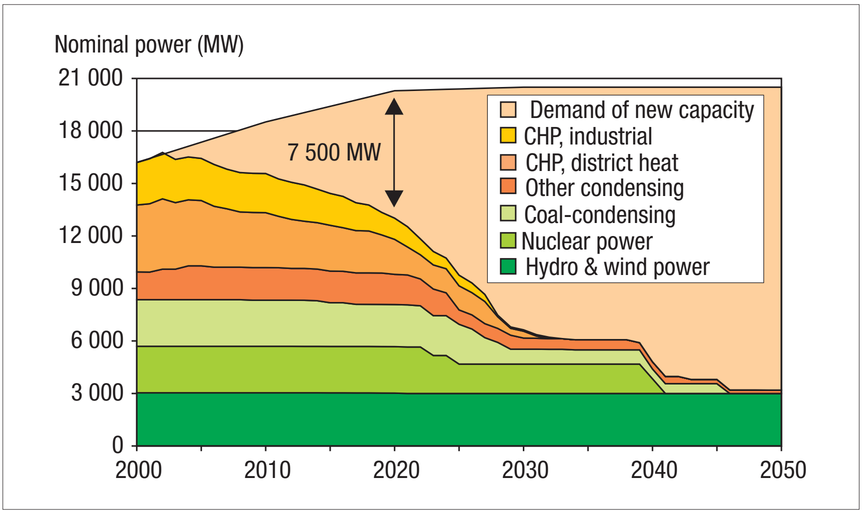

Figure 13. Estimated shutdown schedule of the present electricity generating capacity and demand for new capacity in Finland. Source VTT.

3.5 Cocombustion of wood and peat

Peatlands cover one third of the land surface of Finland. A half of this peatland area is in natural state, while the other half has been drained for forestry. About 1.4 % of the area is earmarked for peat extraction. The total area of the extraction fields is currently about 40 000 ha. Nationwide the growth of peat far exceeds the harvest.

As there are no fossil fuels in Finland, *peat is an important source of indigenous energy.* In fact, Finland is the world leader in the technology of peat production and combustion. Vapo Oy annually produces over 20 Mm^3 and Turveruukki Oy about 2 Mm^3 loose peat fuel. In addition, more than 200 small producers operate locally. Some 90 % of the production is milled peat and 10 % sod peat.

Before the global energy crises in the 1970s peat was scarcely used at all, but when the Government intensified the support to technology development in the 1980s, an epoch-making change took place. In 2001, the consumption of fuel peat corresponded to 2.0 Mtoe or 6 % of the total consumption of primary energy. It is used mainly in back-pressure power plants for combined production of heat and power, but heat is the only product in small plants. About 18 % of district central heating and 5 % of electricity is generated from peat.

As an indigenous fuel, peat improves the energy self-sufficiency of Finland, where its production creates much-needed jobs in rural areas. The price of fuel peat is quite stable and competitive. Fuel peat has good storage properties, and its supply is secured as the inventory is large enough for a year's consumption.

Large plants burn peat mainly in fluidized bed boilers at atmospheric pressure. They are typically multifuel boilers that also utilize other solid fuels, such as bark, sawdust, forest chips or coal. It follows that in these plants *fuel peat competes with wood fuels*. On the other hand, *peat and wood fuels also complement each other.* In large plants, the following benefits may be gained from the co-firing of wood and peat:

- The use of more than one type of fuel helps to reduce the transport distances and costs.
- In a peat fuelled plant, emissions of CO_2 and sulphur are reduced when peat is partly replaced by wood.

- Corrosion problems caused by alkalis and chlorine from needle-rich forest chips can be reduced when the chips are co-fired with peat.
- Peat has a rather constant moisture content, whereas forest chips tend to be too moist during the winter when the demand for energy is highest. Mixing chips and peat keeps the average moisture content of fuel stable.
- The inferior storage properties of wood chips prevent a plant from keeping large inventories. Peat, on the other hand, is easy to store, and it can be used for securing the fuel supply.

In large plants, fuel supply can seldom be based on wood alone. For example, the world's largest biofuelled power plant, Alholmens Kraft in Pietarsaari on the western coast of Finland, uses a 50/50 mixture of wood and peat with 10 % of the total energy derived from forest chips. The capacity of the plant is 240 MW_e power, 100 MW_{th} process steam for a pulp and paper mill, and 60 MW_{th} district heat.

The combined use of wood and peat puts special requirements on the supply logistics, receipt and mixing the fuels at the plant. Several projects of the Wood Energy Technology Programme have addressed this problem area.

4 Technology for large-scale chip production

4.1 System development

A prevailing feature of the programme is *system approach*. A forest chip production system consists of a sequence of individual operations performed to process biomass into commercial fuel and transport it from source to plant. The main phases of chip procurement are purchase, cutting, off-road transport from stump to roadside, comminution, measurement and secondary transport from roadside to mill. The system offers the organization, logistics and tools to control the process.

The efficiency of a procurement system is highly dependent on both the environment and the infrastructure in which it is operating. Economic, social, ecological, industrial and educational factors, as well as local traditions, also have an effect. Consequently, no single production system is optimal in all countries or in all conditions within a given country. Under Finnish conditions, the operating environment of forest chip procurement is characterized by the following attributes:

- The majority of the forests belongs to private non-industrial owners, the size range of holdings being typically 20–200 ha. This means small average sales volumes, cramped landing areas at nearby road sides, and frequent shifting of machines from site to site. These drawbacks increase the cost of transactions and the scaling of biomass, decrease the operational availability of machines and so *place considerable demands upon control of large-scale chip procurement*.
- Up to 90 % of harvestable biomass potential is linked to the harvesting of industrial roundwood (Figure 10). The production of forest chips must therefore be *integrated with the existing timber procurement*, but the degree of integration may vary.
- All logging machines and timber trucks are owned by independent contractors. *The production of forest chips rests on private contractors* and the profitability of their enterprises.
- The Finnish forests belong to the Pan-European Forest Certification System (PEFC). *Good forest management practices* are essential also for the production of forest fuels.
- *The demand for chips varies seasonally*, especially in smaller heating plants. It is highest in the winter and lowest in the summer, which causes fluctuations in employment. In large CHP plants, the demand for chips is more stable.
- Only small plants can base their fuel supply exclusively on forest chips. To secure fuel availability, to reduce the costs, and to level out quality variation, *larger plants burn forest chips mixed with bark, sawdust, peat or coal*. To keep the fuel mixture constant, chip arrivals at the plant must be strictly scheduled. This requirement complicates the logistics of forest chip procurement.

Compatibility of equipment

The integration of forest chip production with the procurement of roundwood opens up possibilities for cost savings. It is feasible to use the existing transport equipment for forest biomass when possible. However, due to differences in handling properties and destinations, special equipment is also needed.

Forest machine contractors harvest over 40 Mm^3 of roundwood annually. Delivery sales by self-employed forest owners included, timber truck contractors correspondingly haul 55 Mm^3 of roundwood. The Nordic cut-to-length system is the only technology employed when harvesting timber for the forest industries. The equipment used by different contractors is compatible, allowing organizational flexibility.

Unfortunately, *little machine compatibility has been achieved* in the procurement of forest chips, although the annual production is not yet much more than 1 Mm^3. The lack of compatibility is because the logging conditions vary considerably from the early uncommercial thinning of young stands to the final harvest of mature stands, and because the technology is still new. Several alternative production systems are in use, and each system employs special equipment that is not necessarily compatible with other systems. *Poor compatibility increases the commercial risks* for contractors and plants when they invest in new equipment, and it may result in underemployment and unnecessary shifting of harvesting machines and trucks from one site to another.

Alternative systems

A forest fuel production system is built around the comminution phase. The position of the chipper or crusher in the procurement chain largely determines the state of biomass during transportation and, consequently, whether subsequent machines are dependent on each other. Comminution may take place at the source, at the road side or landing, at a terminal, or at the plant where the chips are to be used. Four alternative production systems have been studied in the Wood Energy Technology Programme (Figure 14).

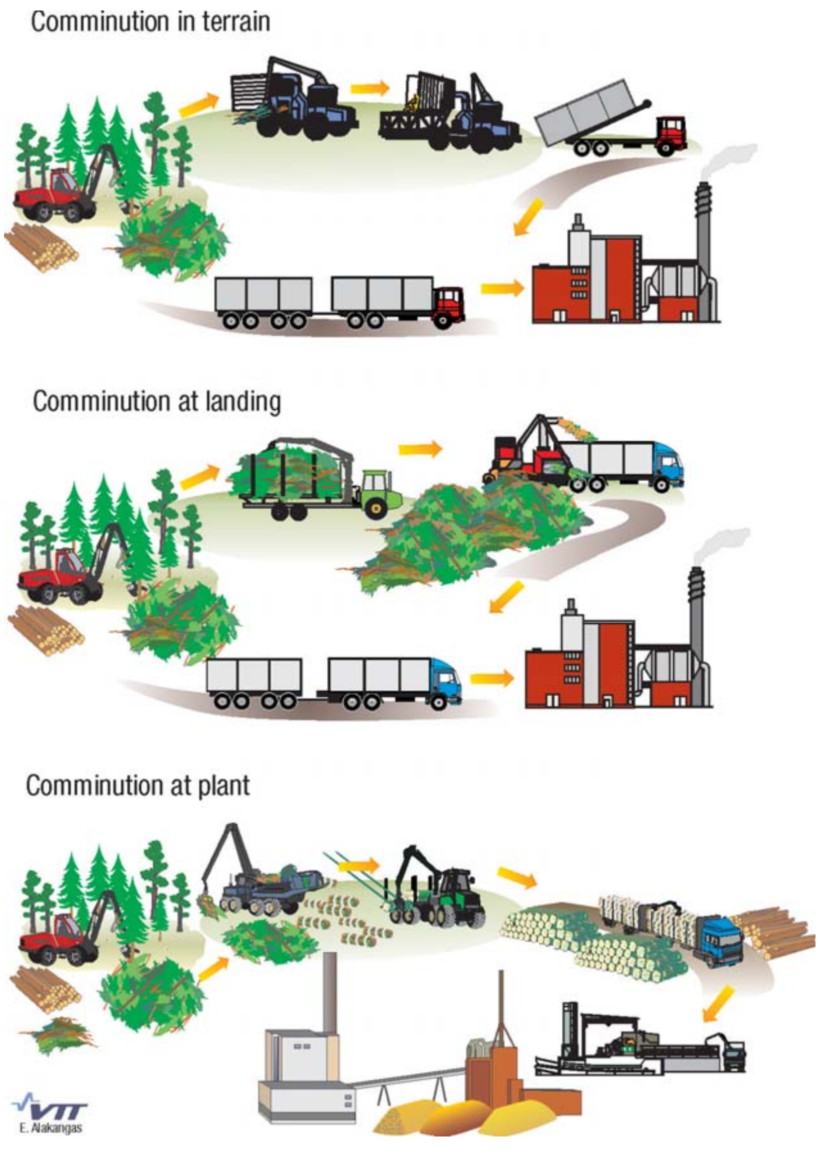

Figure 14. Alternative systems for the production of forest chips. Source VTT.

Comminution at the source, or in the terrain, requires a highly mobile chipper suitable for cross-country operations and equipped with a tippable 10–20 m^3 chip container. The chipper moves in the terrain on strip roads and transfers the biomass with its grapple loader to the feeder of the chipping device. When the chipper container fills up, the load is hauled to the road side and tipped into a truck container, which may be on the ground or on a truck trailer (Figure 15).

As a single machine carries out both the comminution of biomass and the off-road transport of chips, the cost of shifting machines from site to site is reduced, and smaller logging sites become commercially viable. The use of containers weakens the interdependence between the chipper and the truck, although it is not entirely removed. Large landing areas are not needed, but a level and firm site is necessary for the truck containers.

For off-road operation, the chipper must be as light as possible, although its strength and stability may suffer. Even so, terrain chippers tend to be too heavy for use on soft soils, while use of crushing equipment in terrain is out of question. A terrain chipper requires flat and even ground and, because of its small load size and slow speed, its range is less than 300–400 m. Snow causes problems in the winter and results in an increased moisture content of chips, unless the terrain chipper operates at a landing.

When large volumes of forest fuels are produced, the terrain chipping system becomes difficult to control. At present, the role of the system is diminishing.

Comminution at a landing is performed in smaller operations with farm tractor-driven chippers and in large-scale operations primarily with heavy truck-mounted chippers or crushers. The biomass is hauled with forwarders to the landing and bunched onto 4 to 5 m high piles. This facilitates operation in difficult terrain and in winter conditions and allows longer off-road hauling distances. The forwarder operates independently of the chipper. The comminuted biomass from the chipper is blown directly into a 100 to 130 m^3 trailer truck, a process that makes the system hot and vulnerable, i.e. subsequent machines are dependent on each other. A wider landing area is required than in the alternative systems because of the large road-side inventories of biomass and the simultaneous presence of the chipper and the truck.

To avoid the system from over-heating, the *truck-mounted chipper and chip truck* can be replaced by a *single chipper truck* (Figure 16). This blows the chips directly into its own containers and then hauls the load to the plant. As the chipper truck is equipped with its own chipping device and crane, load capacity suffers and the operation radius around the plant is reduced.

Landing chippers do not operate off road and can therefore be heavier, stronger and more efficient than terrain chippers. If the biomass, such as stump and root wood, is contaminated by stones and soil, it is possible to use crushers that are more tolerant instead of chippers (Figures 17 and 18).

The close linkage of comminution and trucking results in waiting and stoppages and thus reduces the operational availability. On the other hand, the landing chippers are reliable and their technical availability is rather high. The system has so far kept its position as the basic solution of large-scale procurement of forest chips.

Comminution at a terminal or plant means that road transportation of the biomass takes place before the size reduction. The biomass is transported to the terminal or plant in the form of undelimbed tree sections, whole small-trees, loose logging residues or bundles. Low bulk density restricts the operation radius, unless the biomass is bundled.

At large plants, comminution can be performed with efficient stationary crushers at low cost. At satellite terminals or smaller plants, the use of transportable chippers or crushers is more feasible, although the productivity of comminution is lower and the cost higher.

Figure 15. Pika Loch 2000 terrain chipper (Courtesy of S. Pinomäki Oy).

Figure 16. TT-97 RMS chipper truck (Courtesy of Biowatti Oy).

Figure 17. Truck-mounted Giant chipper comminuting logging residues at a landing (Courtesy of LHM Hakkuri Oy).

Figure 18. Trailer-mounted Diamond tub grinder crushing stump and root wood at a landing (Courtesy of UPM-Kymmene Oyj).

Figure 19. Timberjack 1490D residue bundler in a clear-cutting area (Courtesy of Timberjack Oy)

Figure 20. Off-road transport of residue bundles with a conventional forwarder (Courtesy of Timberjack Oy).

Comminution at the plant, based on the *bundling of logging residues* and crushing of bundles with stationary equipment, has been one of the key areas of technological development in the Wood Energy Technology Programme. In this system, logging residues are compressed and tied into 60–70 cm diameter, 3 m long bundles or *composite residue logs* (CRL) (Figure 19). A bundle of green residues weights 500 kg and has an energy content of about 1 MWh. Bundles are transported to the road side using a conventional forwarder (Figure 20) and on to plant with a conventional timber truck. About 65 bundles or 30 tons form one truck load. Whether it will be necessary, for safety reasons, to equip the truck with rear and side walls, is still an open question.

Efficient process control

The CRL technology is still new and has considerable development potential. Although it was introduced in Finland as recently as in 2001, many of the major producers of forest chips have already started to employ it. The rapid success of the system is a consequence of the recent development of bundling techniques and the *many indirect advantages*:

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

4.2 System building components

As a chain is as strong as its weakest link, *identifying and solving problem areas play a key role in system building*. This typically requires the development of new machines, but it may also require new working techniques and work organization. Although the system approach is the principle of the programme, some projects focus on narrower topics aimed at developing and demonstrating solutions for bottlenecks in a system.

The efficiency of comminution is one of the key areas. *Efficiency is understood in its broad sense*: high output, flexible adjustment in the system, reliability, good product quality, and minimum harmful environmental impact. Among the comminution equipment developed and studied are the Pika Loch 2000 chip harvester of S. Pinomäki Ky, capable of tipping its load from 4.2 m height directly onto a truck trailer; the truck-mounted Giant chipper of LHM Hakkuri Oy, capable of producing even-sized chips from different kind of loose and bundled biomass; the farm tractor-mounted TT-97 RMT drum chipper and the TT-97 RMS chipper truck from Heinola Sawmill Machinery for carrying out both road-side chipping and chip transport; a two-phase crusher prototype; and the 1490D residue bundler of Timberjack Oy.

The programme has also participated in the development and demonstration of the Timberjack 720 and 730 multi-tree feller heads for the mechanization of small-tree harvesting from early thinnings; the Valtra farm tractor-based residue forwarder with enlargening load space from Metsäenergia Ky (Figure 21); the farm tractor based, load-compacting HavuHukka residue forwarder from Vapo Oy for transporting residues from source to satellite terminal (Figure 22), and a forwarder-based prototype combi-machine developed by Antti Varis for collection and hauling logging residues and simultaneously preparing the site for regeneration.

Figure 21. A Valtra farm tractor-based residue forwarder with enlargening load space (Courtesy of TTS-Institute).

Figure 22. The load-compacting HavuHukka forwarder for transporting residues from logging site to satellite terminal (Courtesy of Vapo Oy).

Machine development is frequently accompanied by method development, including aspects such as work techniques and adjustments in the procurement system. As machine contractors are usually paid by piece rate, measuring the performance may become a source of friction in the procurement system. Measuring unprocessed biomass is difficult, and for a low-value product the cost of measurement must be kept low. Therefore, *methods for the measurement of biomass must be developed*. One of the research projects concerned with adding crown mass estimation to the computerized stem volume measurement of a one-grip harvester, based on the diameter and taper of the stem. Another project concerned a simple estimation method for determining the performance of a forwarder in the off-road transport of logging residues from stump to road side. In the CRL system, measurement problems have been solved in an ideal way, as the volume and energy content of a bundle is sufficiently constant and the bundler produces cost-free real-time information about the number of bundles.

4.3 Assessing cost factors of chip production

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

The cost factors of forest chip production are not known sufficiently. When the Wood Energy Technology Programme was established, this lack of elementary knowledge was recognized as a serious shortcoming from the view point of technology development. The effect of factors such as stand conditions and hauling distances should be known for a number of reasons:

- to identify the most advantageous stands for chip production
- to estimate the change in the cost when the demand for chips increases or quality requirements of the fuel are tightened
- to focus on the key problems in machine and method development
- to collect relevant material for practitioners for decision making.

The effect of cost factors associated with the operating environment depends on the scale of operation, the technology applied, the source and quality requirements placed upon the biomass. At the end of the fourth year of the programme, cost factor information is only available for logging residues from final harvest, whereas cost studies on small-tree harvesting from early thinnings are still in progress. Examples of the results are presented below:

- The cost of recovery depends on the yield of biomass per hectare. The recovery of logging residues from the final cut of mature spruce stands is typically 20 % of the recovery of roundwood. For pine, the corresponding figure is not much more than 10 %. Halving the recovery raises the cost of off-road transport by 10 %. The cost of harvesting is thus lowest in spruce-dominated stands, and the availability of forest fuels is best in regions where spruce is the dominating species.
- The proportion of foliage in logging residues from mature stands in 30 % for spruce and 20 % for pine. The cost of chips increases if the residues are left to season on the site so as to improve the quality of fuel and reduce the loss of nutrients from forest soil through defoliation. The cost increase is caused by reduced biomass recovery, the delay in the harvesting schedule, and accompanied logistical disadvantages.
- If a plant's demand for logging residues increases, the average cost of procurement increases as well, because the operations must be extended to less favourable stands and at greater distances. Figure 23 shows how the average cost of biomass at plant (cost of comminution excluded) increases with growing demand. Considerable regional differences result from differences in the structure of forests and species dominance. Furthermore, a plant with a coastal location has to operate within a semicircular procurement area, whereas plants in the interior typically operate within a circular procurement area.

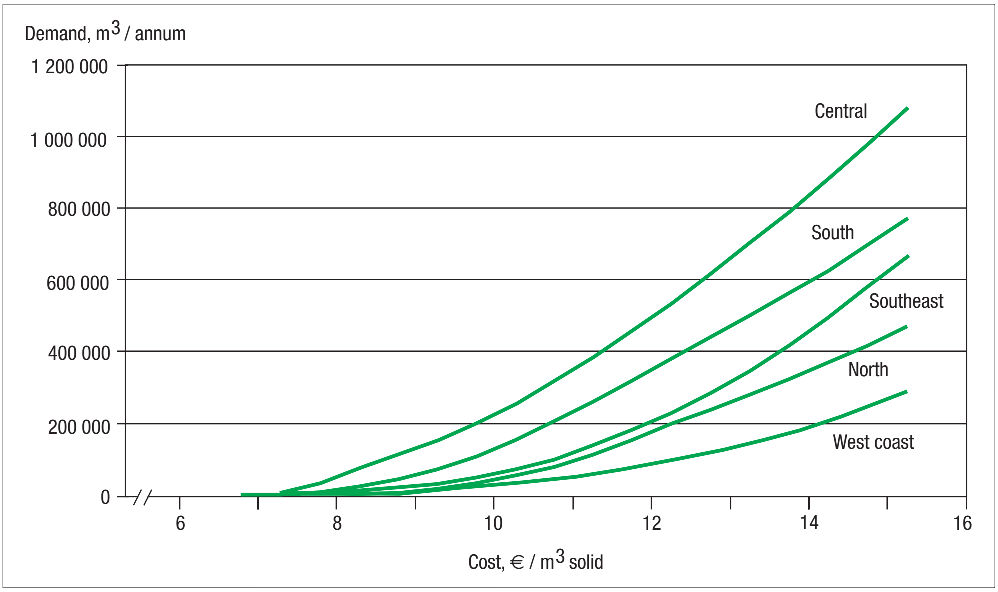

Figure 23. Effect of a plant's demand for logging residues on the average cost of transportation in different regions of Finland. Cost of comminution excluded. Source VTT.

- The small size of timber sales from private forest holdings is a serious cost factor. Proper timing and coordination of operations with neighbouring holdings could increase the harvestable fuel in a region by more than 10 % and reduce the average costs by 4 to 6 %.

4.4 Truck transport of forest chips

Truck transport is the largest single cost factor in the procurement of logging residue chips, constituting up to one third of the total cost at the plant. As the use of forest fuels grows, the average distance and the cost of transport will also grow further.

At present, forest biomass is delivered to the plant mainly in the form of chips. Most of the trucks used for hauling forest chips were originally designed for operating on better roads and for other materials such as sawmill chips, sawdust, debarking residues and peat. They are not ideal for use on forest roads and cramped landing sites. The *unsuitability of trucks strains the productivity* because of slower driving speed, increased waiting times and under-utilization of load capacity. Drivers of these trucks are often unaccustomed to side roads and therefore reluctant to use them. Consequently, shortage of trucks is not uncommon.

Along with the increase in the use of forest chips it has become necessary, but also easier, to employ special trucks for forest chips or even uncomminuted residues, and to develop efficiency by means of advanced logistic control of transport. The following topics have been studied in the programme:

- Compaction of chips to increase bulk density in conjunction with loading from the chipper. Compared with blowing, a belt conveyor equipped with a mechanical ejector was found to compress the load volume by up to 15 %.
- Truck transport of uncomminuted loose residues (Figure 24) and residue bundles.
- Logistics of forest fuel transport. The use of an internet-based, general-purpose logistics control system applying mobile terminals was studied. Among the aspects investigated were vehicle control and terminal logistics, navigation of vehicles, and work planning and instruction delivery by internet to mobile terminals.

There is considerable *development potential in the logistics control system* (Figure 25). The advantages mentioned by the participants of the project

Figure 24. Loading uncomminuted logging residues onto a special truck+trailer unit (Courtesy of Metsäteho Oy).

Figure 25. Internet-based logistics control systems help to reduce the cost of chip procurement and improve the reliability of fuel supply (Courtesy of Biowatti Oy).

under consideration are "paper free truck cabin", decreased need of cellular phone calls, and GIS/GPS supported navigation. Technology should be developed further to support the whole business process of the truck entrepreneur so that the information needed in planning, operative work and invoicing could be monitored by the system.

4.5 Control of fuel quality

The quality of forest chips is dependent upon the source of the biomass and the techniques employed for comminution, handling and storage. Consistent particle size, as well as low contents of moisture, foliage and ash each improves the efficiency and economy of combustion. However, *different boilers demand different fuel properties*. The larger the plant, the more tolerant it usually is of random variations in fuel properties, mainly because large boilers employ the fluidized bed technology. Even so, knowledge of fuel properties and careful control of quality are essential to the operational reliability and efficient combustion of all boiler systems. *The most important single quality factor is the moisture content* of chips, as it affects the heating value, storage properties and transport costs of the fuel. Moisture content is thus a direct cost factor, and it is taken into account in the pricing of fuel. An excessive moisture content results in a price reduction, while a low moisture content may bring a bonus.

The moisture content of fresh biomass must be reduced to obtain the full energy potential. Moisture is a critical fuel property, especially in the winter time (Figure 26), as a reduction in the moisture content occurs only during the summer. Maintaining the reduced level of moisture during the autumn rains requires careful planning and timing of operations. During recent years, the procurement organizations have managed greater control of the moisture content, and truck loads of fuel with an excessive 55–60 % moisture content are no longer common. Nevertheless, energy is still lost because biomass arrives at the plant with an excess of moisture.

Forest chips that contain *high quantities of needles may cause combustion problems* because of their

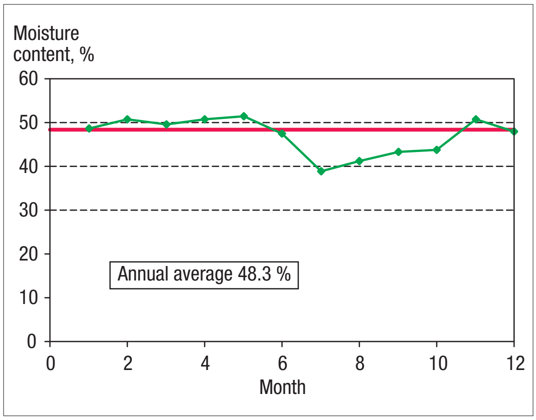

Figure 26. Seasonal variation of the moisture content (green mass basis) of forest chips arriving at plant in 2000. Average of several plants. Source VTT.

high contents of alkali metals and chlorides. Depending on the combustion conditions, the alkali metals can be oxidized or they can form sulphates or chlorides. If only wood chips are burned, the sulphur content is low and chlorides are formed. The chlorides tend to be condensed on heat transfer surfaces of the boiler causing the risk of high-temperature corrosion. If the sulphur content of the fuel is increased, e.g. by mixing peat with chips, sulphates are formed instead of chlorides, and the risk of corrosion is avoided. Unless the needle problem in combustion is solved, forest chips cannot be allowed to contain a high needle content, which means friction in the logistics and increased costs. Therefore, this topic is given considerable emphasis in the program.

Examples of the projects dealing with the *quality improvement of forest chips* in the Wood Energy Technology Programme, as well as *quality aspects of industrial processing residues*, are:

- quality control of logging residues and small diameter trees by means of seasoning
- critical properties of wood fuels in respect of power plant availability
- chemical changes in wood fuels during storage and thermal drying, and the effects of the changes on fuel properties, occupational health hazards and emissions during storage
- flue gas emissions from cofiring by-products from the plywood and particle board industries

- boiler corrosion in conjunction with the cocombustion of wood and sludge
- improving the combustion properties of bark: reduction of moisture content prior to storage, removal of impurities, and optimizing storage
- use of forest chips in large fluidized bed boilers
- improving the particle size of chips through chipper development
- suitability of small-diameter wood for pulping, and setting of boundaries between pulpwood and fuelwood.

4.6 Receiving and handling forest chips

Wood fuels differ from peat and coal in respect of their handling properties, such as particle size, particle size distribution, bulk density, moisture content and fluidity. Differences also occur amongst the wood fuel. For example, forest chips and debarking residues behave differently as fuels.

Modern boilers, fluidized bed boilers in particular, make possible the efficient use of non-homogenous forest fuels, and to cocombust them with other fuels. In large plants, *forest chips are often blended with bark and peat* to homogenize and standardize the mixture.

Receiving, handling, mixing and feeding are problematic where the plant is not prepared for the special properties of chips and chip truck. As these operations are an essential function of a forest fuel production system, they are given an important position in the Wood Energy Technology Programme. The following topics are being addressed:

- Development of inbound logistics of arriving chip trucks in order to reduce the time used for queing and unloading.
- Adjusting plants designed for peat trucks unloading sidewards to accept chip trucks unloading backwards.
- Making a homogenous mix from a variety of fuels. Mixing is usually performed at the receiving station of the plant, but it may take place also in conjunction with intermediate fuel storage when loading or unloading fuel silos.
- Adjusting handling equipment, such as disc screens and conveyors, to cope with chips containing over-sized particles, impurities and excessive moisture.
- Developing comminution of forest biomass with high-capacity stationary crushers at the plant.

When old technology is replaced, or a greenfield plant is built to use forest chips, *participation of the forthcoming chip procurement organization in the planning phase is necessary.* Since the mid 1990s, a large number of heating and CHP plants have been refitted with the technology required to use forest chips. This has greatly increased the utilization capacity of forest fuels in Finland. It has been learned by experience, that *due consideration must be given to the differing properties of forest chips* and the specific demands of the forest fuel procurement system. Otherwise, the fluency of fuel deliveries, reliability of fuel feeding and the quality of fuel may suffer.

4.7 Impacts of biomass removal on forestry

The fundamental rationale for the promotion of forest energy is the reduction of greenhouse gas emissions, i.e. the protection of the environment. It follows that the *production must be in agreement with sustainable forestry.* Although the Wood Energy Technology Programme is primarily aimed at developing new technology for forest chip production, the impacts on the ecosystem and forestry can not be ignored.

Studying the effects of intensive biomass removal requires long-term biological experiments and permanent sample plots in forests. This is beyond the scope of short-term technological projects. However, credibility of the system development presupposes that its impacts are taken into account and evaluated. The goal must be prevention, or at least the minimization of possible harmful effects.

The greatest concentration of plant nutrient elements occurs in the parts of the tree, such as foliage, where essential life processes take place. It is thus inevitable that the extraction of crown mass means an increase in nutrient loss from the forest; more in fact than the increase in biomass yield would suggest. In comparison with conventional stem-only harvesting, each percentage increase in biomass recovery from crown mass with foliage incurs increased nutrient losses amounting to 2– 3 % for pine, 3–4 % for spruce, and 1.5 % for leafless hardwoods. Yet, particularly in managed forests, *crown mass represents such a large proportion of the fuel potential that large-scale bioenergy production would not be feasible without it* (Figure 9).

Yield studies show a decline in growth after crown mass removal. However, scientific experiments carried out in Finland and other Nordic countries do not correspond to the every-day practice in the following respects: crown mass has been completely removed from the experimental stands, which would never be achieved operationally; the growth loss caused by 4 m wide strip roads in thinnings has not been taken into consideration; and in the control plots representing stem-only logging, residual biomass has been distributed manually evenly across the whole site in an ideal way, which is not the real case in mechanized cutting operations. Results from scientific experiments only seldom include allowances for the differences between experimental treatments and actual harvesting practices, thus causing confusion among forest owners.

Even though the results may be exaggerated, the problem is real enough. The programme sees *the control of nutrient loss* to be an important aspect of the development of harvesting techniques. The following possibilities occur:

- No technology is able or intended to remove all crown mass from the site. For example, the salvage of logging residues from the final harvest, irrespective of the system applied, extracts only some 70 % of the crown mass.
- Summertime transpiration drying is an effective way of achieving the simultaneous reduction in moisture content and partial defoliation in small whole trees and logging residue heaps on the site. However, the flow of fuel from the logging site to the energy plants slows down, and the recovery of biomass is reduced.
- In small-tree operations, especially in young pine stands, topping the trees means compromising the principle of whole-tree logging, but it reduces effectively the loss of nutrients. If a 3 m top from a pine tree is left on the site in an early thinning, needle recovery is reduced by 52 % but the overall recovery of whole-tree chips is reduced by only 8 %.
- Nutrient loss caused by intensive biomass recovery can be counteracted by *the recycling of ash*, the loss of nitrogen excluded. A precondition of feasible ash recycling is proper ash management at the plant. Cofiring of biomass with fossil fuels, municipal waste or peat results in diluting the nutrient content of ash and is therefore a serious constraint to recycling. So far, the programme has not developed ash recycling technology. But to assure the safe handling, storage and use of ash, an ongoing project is developing tools to predict the radioactivity of wood ash. A life cycle analysis of wood fuel use has also been carried out.

The negative effect of biomass removal on forest growth can be largely reduced by these means. From the viewpoint of the forest owner, possible *growth losses should be weighted against the silvicultural benefits* achieved:

- Precommercial thinnings, the Achilles' heel of the Finnish forestry, are encouraged. Tending young stands results in the increased growth of industrial timber.
- The removal of logging residues from regeneration areas improves the productivity and quality of site preparation and planting. A cost saving of € 100/ha may be achieved.
- The removal of logging residues and stumps creates favourable conditions for the mechanization of planting. About 80 000 ha are reforested each year in Finland by manual planting, but a serious shortage of forest labour is becoming an insurmountable barrier. The effect of biomass removal on the conditions for mechanized planting is being studied in the programme.

5 Use of forest chips

Biofuels play an important role in Finland's energy and climate strategies. One of the targets is to raise the annual consumption of forest chips to 5 Mm^3 by 2010. To direct the energy policy, decision makers need information about development trends and barriers constraining the implementation. This information is also useful for directing the Wood Energy Technology Programme, because the primary task is to create technical opportunities for the increased production of forest chips.

5.1 Monitoring the use

The Finnish Forest Research Institute regularly publishes reliable statistics on forestry and forest industries in the Statistical Yearbook of Forestry. The statistics include detailed information on the consumption of wood by the forest industries. However, use of forest and industrial wood residues for the production of energy has not been monitored. Since such statistics were found necessary for directing research, the Wood Energy Technology Programme carried out a survey on the use of forest chips in 1999. In 2000, *the Finnish Forest Research Institute started to monitor the consumption of solid wood fuels*. Statistics for the previous year are now published in every April.

Excluding small-houses and farms, the use of solid wood fuels in 2001 was 12.4 Mm^3 or 23 TWh. More than a half of the total amount consisted of bark. The relative role of forest chips was still modest (Figure 27).

A considerable part of industrial processing residues is used directly at source, so that the fuel never enters the market. On the other hand, *forest chips is typically a commercial product*. The proportion of forest chips in the total volume of commercial

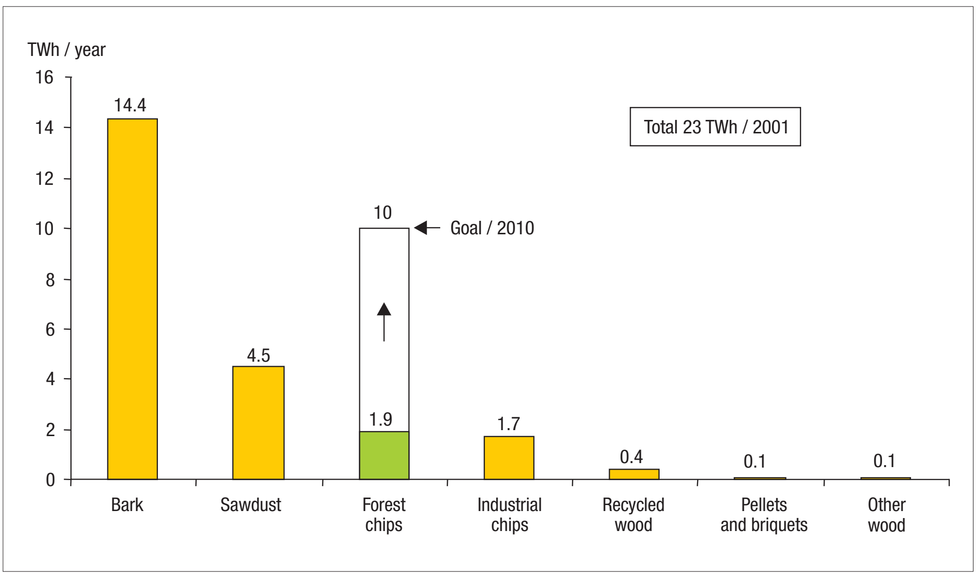

Figure 27. Use of solid wood fuels at heating and power plants in 2001. Small-scale use excluded. Data from the FFRI.

wood fuels is thus much higher. Furthermore, as the market price of forest chips is higher than that of bark and sawdust, its share of the value of the wood fuel markets is even greater. The following figures do not include the use of wood fuels in small-houses and farms:

	Share of forest chips, %
Volume of all solid wood fuels	8
Volume of commercial solid wood fuels	16
Value of all solid wood fuels	12
Value of commercial solid wood fuels	23

The total value on forest chip trade was 17 M€ or 23 % of wood fuel markets to consumers other than small-houses and farms in 2001. The aim is to raise the production fivefold by 2010. This will mean that in the future *forest chips will be the primary article in the markets for unrefined wood fuels*.

Due to the low energy density and high cost of transport, wood fuel markets are usually local. Only two companies specializing in biofuel production operate nationwide: Biowatti Oy and Vapo Oy. In addition, UPM-Kymmene Oyj has integrated large-scale forest chip production in the procurement of industrial roundwood, but chips are procured mainly to power plants owned by the company itself or Pohjolan Voima Oy.

5.2 Users of forest chips

Again excluding small-houses and farms, 645 consumers of wood fuels were identified in 2001. At least 307 of them used forest chips, exclusively or in a fuel mixture. Figure 28 shows the primary users of forest chips. Consumption is largest in central Finland and smallest in sparsely populated northern Finland. New plants keep appearing on the map, and many of the present users are increasing their consumption.

Traditionally, small-houses and farms use considerable quantities of fuelwood for heating. In 2001, the figure was 6 Mm^3. Most of this was firewood, but 0.38 Mm^3 chips from delimbed stems or undelimbed whole trees was also consumed.

Earlier, forest chips were mainly used for heat production. However, excluding small-scale use, presently the combined production of heat and power is more important. *The growth is fastest in cogeneration*, which is in agreement with the Finnish energy policy goal (Figure 29).

The source of forest chips is of importance when considering impacts on forestry, integration of operations, machine selection, job opportunities and fuel quality. In the mid 1990s, the main source was early thinnings. Since then, *the technological development has been rapid concerning logging residue chips* but slow with respect to small-tree chips. The former has become more competitive and its use has increased rapidly, whereas *the use of small-tree chips has more or less stagnated* (Figure 30). The programme is currently trying to stimulate the development of small-tree technology.

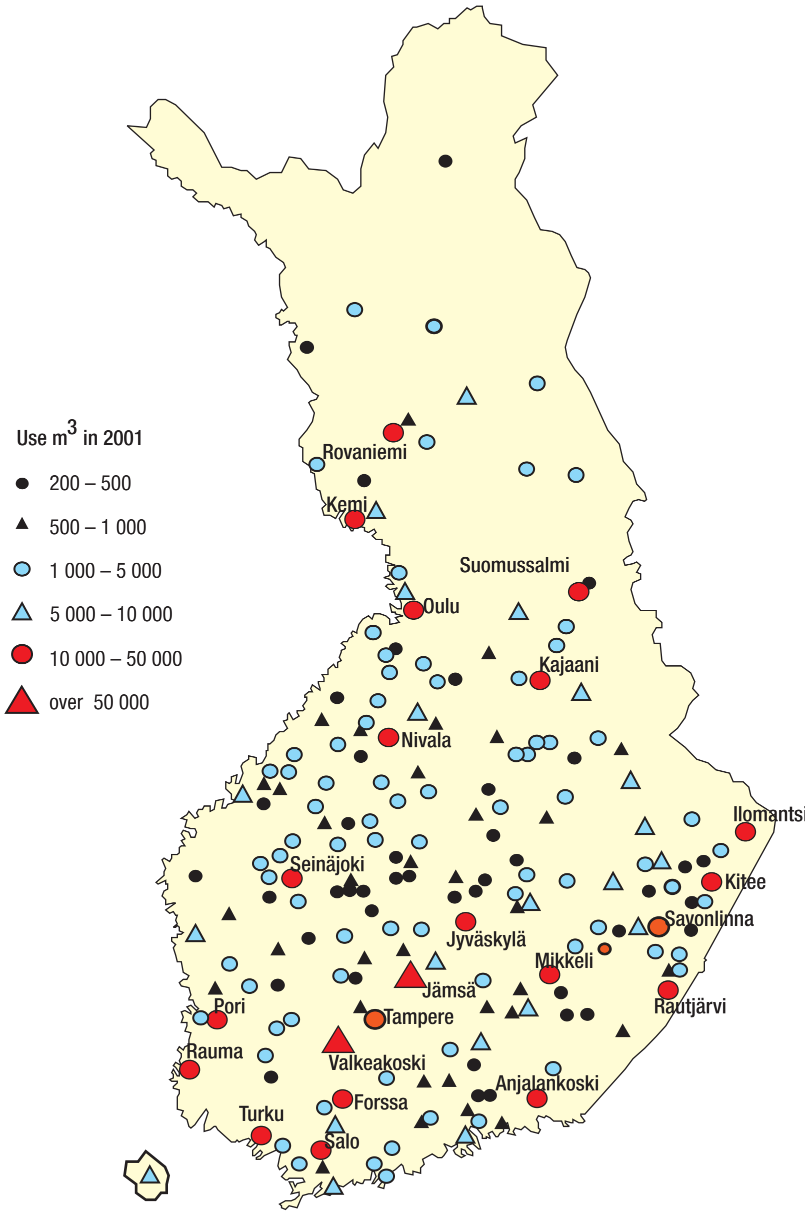

Figure 28. The heating and power plants using forest chips in 2001. Small heat entrepreneurs excluded. Data from FFRI.

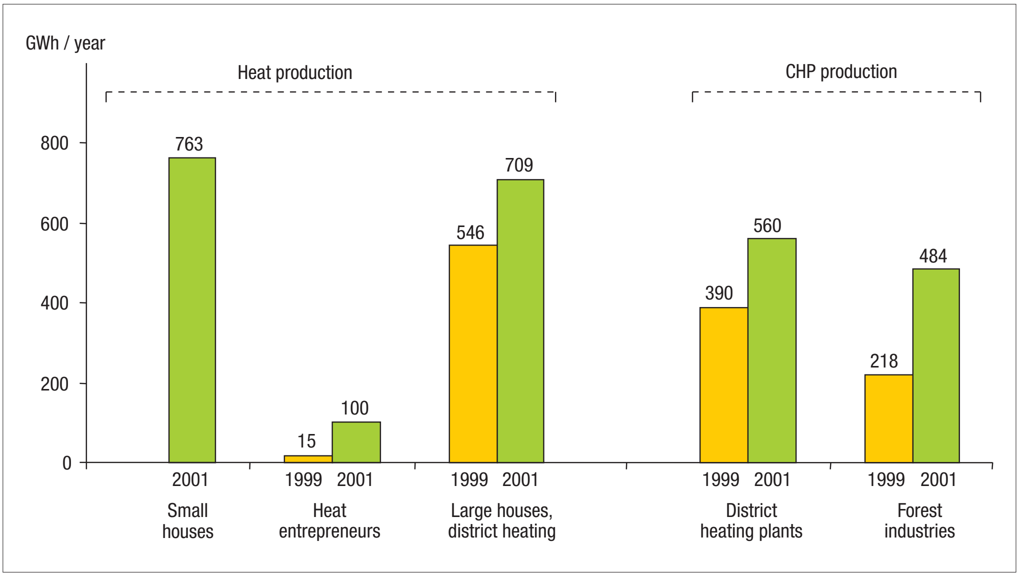

Figure 29. The users of forest chips in 1999 and 2001. GWh equals to 500 solid m³ wood. Data from VTT Processes and the FFRI.

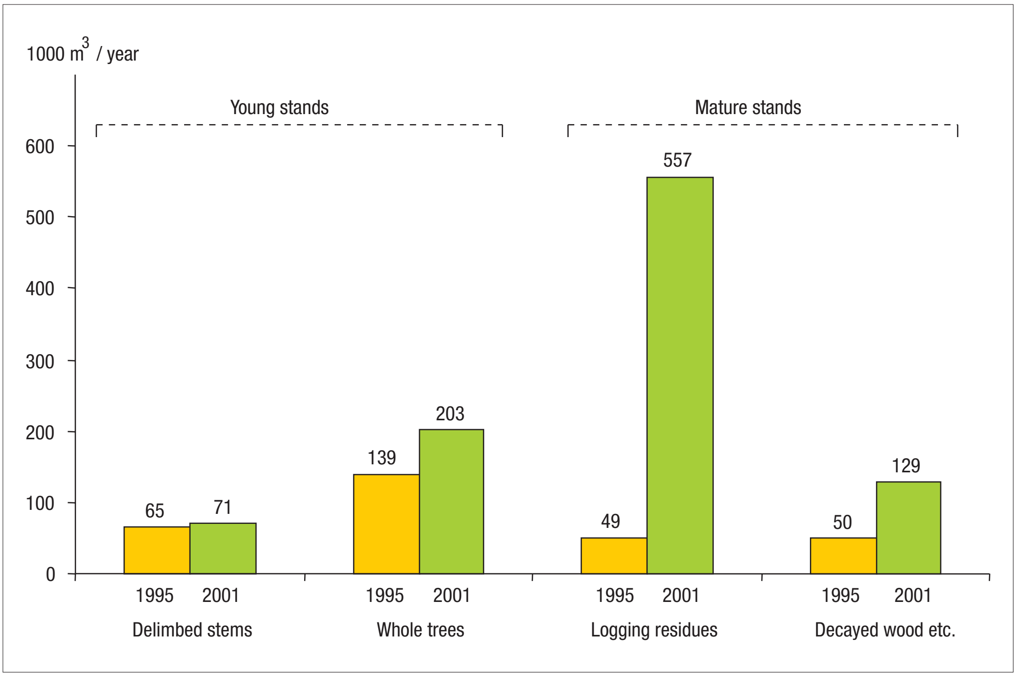

Figure 30. The sources of forest chips in 1995 and 2001. Small-scale use excluded. Data form the FFRI.

5.3 Driving forces

Figure 31 shows the development in the use of forest chips since the late 1950s. In the early days of fuel chip technology *the driving force was tending of young forests*. When birch became a pulpwood species in the 1960s, the demand for low-quality hardwood improved and the urgent silvicultural incentive for forest chip production almost disappeared.

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

The deep economic depression of the early 1990s as well as the mechanization of timber harvesting *aggravated rural unemployment*. With the consequent reduction in the demand for wood from thinnings, attention again shifted to forest fuels. Simultaneously, society began to pay notice to issues related to climatic change, especially the CO_2 emissions from fossil fuels. Gradually *the global environmental threat became the prevailing driving force of forest fuels*. So far, the rationale seems to be lasting, and so the industry is in a safer position than before when investing in know-how, machine construction and utilization of the forest biomass.

During 1999–2001, the average growth rate in the production of forest chips was 270 000 m^3 per annum; a fast enough rate to allow introduction of new production technology, but not fast enough to allow mass-production of equipment. Without mass-production the technology is doomed to remain expensive.

The official goal of forest chip production will require increased growth rates. From 2002 on, the annual increase should be 400 000 m^3 each year of this decade. As the biomass potential of the Finnish forests and the utilization capacity of the heating and CHP plants are sufficient, the most critical factor is the production of chips. The following chapter deals with current constraints on production.

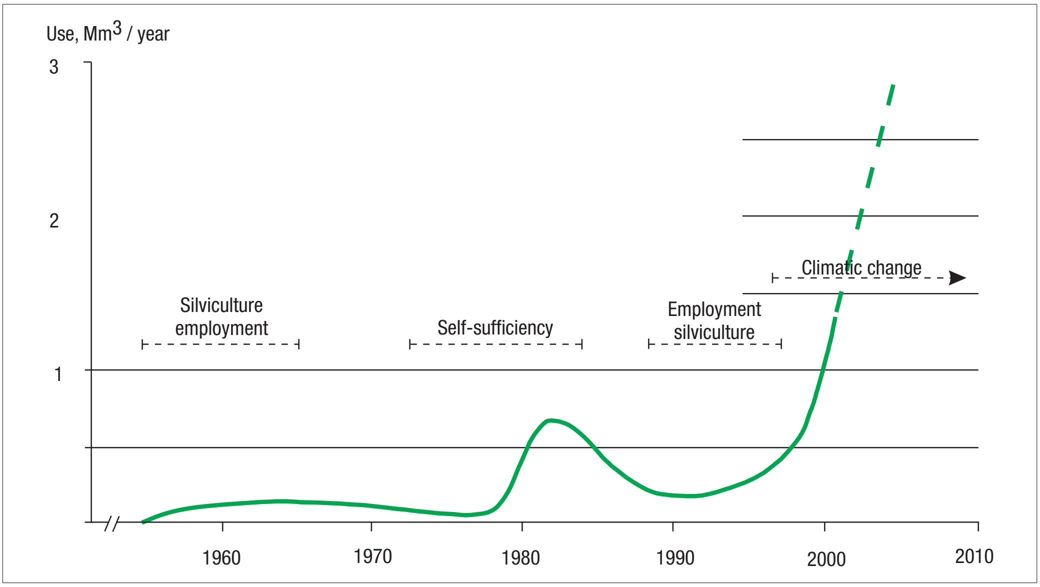

Figure 31. Use of forest chips since the mid 1950s. Data from VTT Processes and the FFRI.

6 Constraints on forest chip production

The large-scale procurement of forest chips from heterogenous biomass from dispersed forest holdings is logistically demanding. The procurement organization has to solve a large number of economical, technical, institutional, silvicultural and ecological problems. The first section of this chapter deals with the high cost of forest chips. The second section identifies other, predominantly non-technical barriers that may require institutional rather than technical solutions.

6.1 The high cost of forest chips

The problem of forest fuels is that their *use is beneficial to the national economy, but it is not necessarily profitable business*. To improve the competitiveness of forest fuels, either the cost of other fuels must be increased or the cost of forest chips must be reduced. The key goal of the Wood Energy Technology Programme is to develop technology for reducing the cost of chips.

A considerable cost reduction took place during the 1990s as a result of a number of factors and changes in the operating environment:

- Timber harvesting was fully mechanized. Harvesters reduced the cost of logging and laid a foundation for the cost efficient recovery of logging residues.
- Due to improved employment and two-shift work, the operating cost of forest machines and timber trucks was reduced.
- The maximum total weight of timber trucks was raised to 60 tons thereby lowering the cost of on-road transportation.
- Costly small-tree chips were partly replaced by logging residue chips.
- Increased chip demand led to the deployment of more efficient chippers, and they could be used to their full capacity. The economy of scale helped to reduce the costs.
- Intensive research and development efforts and practical learning refined the technology and logistics of chip production.

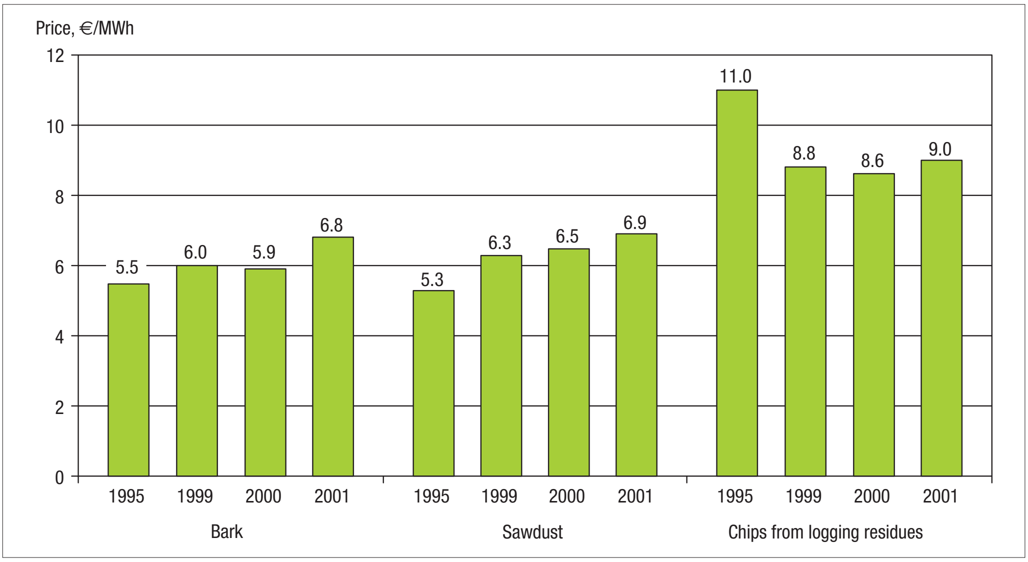

Figure 32. The price of solid wood fuels at plant in September 2002, excluding VAT. Data from VTT Processes and the FFRI.

Figure 32 shows the price development of wood fuels at the plant since the mid 1990s. *The price of bark and sawdust increased* due to growing demand, whereas *the price of forest chips decreased* because of the reasons listed above. However, the trend in forest chip price is changing. A 5 % increase occurred in 2001, and the increase seems to continue.

The price of forest chips in Finland is 25–30 % lower than in Sweden. Due to the high energy taxes on fossil fuels in Sweden, the sovency of wood-fuelled heating plants is considerably better. However, *cost pressures are accumulating* in Finland as the demand grows:

- On-road transport is the largest single cost item in the procurement of logging residue chips. Hauling distances grow with demand.
- It is currently possible to concentrate biomass recovery at sites with the best technical conditions for extraction. Meeting the growing demand requires the extension of operations to less favourable sites.
- Requirements for reducing the share of foliage on site through seasoning slow down the fuel flow and hinder the logistics.
- Contrary to the Swedish practice, usually no stumpage price is paid to the forest owner. The growing demand creates stumpage expectations among forest owners.
- Profitability of the machine and truck enterprises is weak, and they have difficulties in purchasing modern technology. Weak profitability also prevents new entrepreneurs entering the profession.

Knowing average prices is not enough for directing research or making decisions. In reality, *the variation of production costs is wide*. Figure 33 shows an indicative example of the cost structure of forest chips from two alternative sources of biomass when comminution takes place at the road side. In both cases, the cost of comminution and transport is roughly the same. A radical difference occurs in cutting. For logging residues from final harvest only little cost has to be allocated to cutting, whereas in small-tree operations in young thinning stands cutting is by far the highest single cost factor.

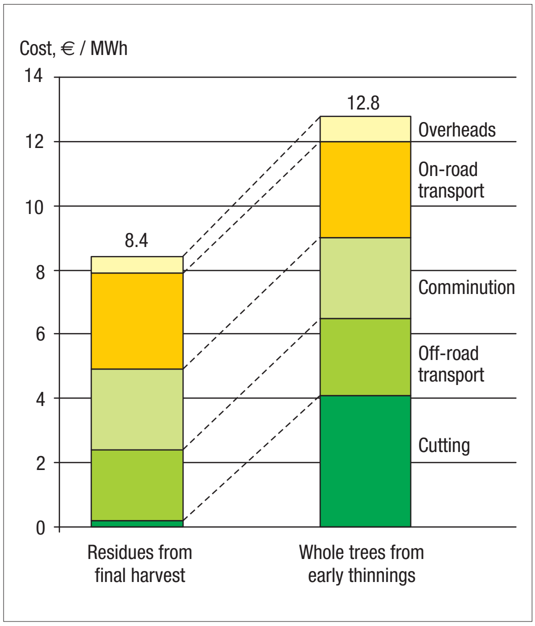

Figure 33. A typical cost structure of forest chips from logging residues and small whole trees. Cost at the plant excluding VAT. No stumpage included.

The cost burden of cutting makes small-tree chips uncompetitive even when efficient whole-tree harvesting is employed. Since the thinning of young plantations is a critical link in the Finnish forest management schedule, the production of forest chips is subsidized from public funds. The production support helps to reduce the costs of whole-tree chips almost to the level of logging residue chips, but support is available only for young stands meeting strict silvicultural criteria.

Consequently, only a modest increase has taken place in the production of small-tree chips despite the financial support. The Wood Energy Technology Programme encourages research and development in this field. Among the small-tree topics being studied are the following items: development of mechanized felling and off-road transport, determination of the cost factors, concentrating harvesting operations, drying during storage, and assessing the effect of small-tree operations on local employment and economies.

6.2 Non-technical barriers

The Wood Energy Technology Programme is aimed to remove or lower technical barriers by means of machine, methods and systems development. However, there are also many non-technical barriers to production. Although not within the scope of the programme, these barriers need to be considered when technology is developed. With respect to policy making, *it is important to be aware of all the constraining factors, both technical and non-technical*. Therefore, 15 specialists from different sectors of forestry, forest chip production, power plant management and machine construction were interviewed to identify problem areas. The main findings of that investigation are reported in Table 3 and below.

Secondary importance in integrated operations

Finnish society strongly supports the use of residual forest biomass as a source of renewable energy. All major actors are in agreement concerning the goals of climate and energy policies. However, the common good as such is not necessarily a sufficient incentive for all actors. They must also achieve personal benefits. The production of forest fuels therefore tends to be given only a secondary position in integrated operations:

- Lack of stumpage discourages the participation of forest owners. The benefits they achieve are indirect. Those who do not realize the long-term effects of improved silviculture, remain passive.
- The production of forest fuels may be experienced in timber procurement organizations as an unnecessary burden. In addition to high-value timber, the organization has to start harvesting low-value biomass that is basically a free commodity. High-value products enjoy a priority position in transport schedules and when crowded landing areas are divided between sawlogs, pulpwood and residue piles.

It is of great importance that forest owners and their forest management associations, as well as machine and truck entrepreneurs, and the staff of the timber procurement organizations, each learn to *appreciate forest fuel as a natural and relevant product of sustainable forestry.* The CRL system with its many indirect advantages (section 4.1) has been found to significantly raise the status of forest fuel production in organizations.

Lack of stumpage price

If the production goal (5 Mm^3) of forest fuels is achieved, in 2010 forest chips will consist of about 8 % of the total annual wood yield (60 Mm^3) from the Finnish forests and 10 % of the total cost of harvesting and secondary transport. If the average stumpage price of forest biomass rises from the present zero level to, say 2 €/m^3 solid, it will mean less than a 1 % increase in the total stumpage sum paid to all forest owners. The stumpage price of forest biomass is thus more a matter of principle.

Table 3. Trends in the barriers to the large-scale use of forest chips in Finland. *= barrier, **= major barrier, ***= very serious barrier.

Barrier	1995	2002
Excessive cost of chips	***	**
Uncertain chip supply	**	*
Shortcomings in receiving and handling	**	*
Unsuitability of boiler for chip combustion	**	*
Unsatisfactory quality of chips	**	*
Shortage of contractors	*	*
Availability in proportion to demand	*	**

At the present level, only about 10 % of the technically harvestable logging residues are recovered. Acquiring the possession of such a modest fraction of the potential is not an essential problem for the procurement organizations. However, problems may arise when there is a considerable increase in demand. The 2010 goal implies that 30–50 % of the technically harvestable potential is to be recovered and utilized. If a large majority of forest owners do not realize the silvicultural benefits of residue extraction by then, the availability of forest chips may be at risk. As yet, no systems analysis has been made of Finnish forestry as a producer of renewable energy taking into account the effects of fuel production on the long-term availability of conventional industrial timber.

Weak participation of forest management associations

The promotion of private forestry in Finland rests primarily with forest management associations (FMA). The private forest owners pay a compulsory fee to the local association, which is the prime mover in the management and timber trade of private forestry. Their contribution is also of utmost importance from the viewpoint of forest fuel production. In particular, the FMAs' role is essential in the large-scale production of fuel from young thinning stands, an area where the large wood procurement organizations normally do not operate.

Although there are exceptions, the participation of forest management associations in the production of forest fuels has been disappointing. Their primary goal has been the tending of young stands rather than the extraction of low-value biomass. The simple thinning operation becomes much more demanding if the small trees felled are to be recovered for energy.

Forest management associations should be encouraged to co-operate with a network of forest machine and truck contractors to jointly procure forest chips for one or several local heating plants (Figure 34). Three projects of the Wood Energy Technology Programme were aimed at the development and testing of such an organization in order to improve the safety and credibility of small enterprises as a distributor of local wood fuel. Forest management associations should also take advantage of the possibility to facilitate stand establishment in conjunction with residue harvesting (Figure 35).

Weak profitability of machine and truck enterprises

In the Finnish system, the production of forest chips is based entirely on independent machine and truck enterpreneurs. Profitability is weak, however, and the profession has a poor image. Many problems have to be solved:

- For forest chips to be competitive against alternative fuels such as peat, the price must not exceed a given level. The price of fuel chips is actually at lower level than in any other country in the EU. Low profitability of contracting makes it difficult to replace equipment, and it does not motivate new entrepreneurs to the business.
- Many of the special machines such as chippers are constructed by the entrepreneurs themselves. This lack of standardization reduces the size of manufacturing series, and so keeps the prices of new equipment high.
- Several alternative production systems are in use. The absence of a standard system creates a risk when investing in a specific technology.
- There is a shortage of experienced machine operators. The first driver course specifically designed for fuel chip procurement was started at the end of 2002.
- Seasonal fluctuation in the demand of chips causes problems for the employment of drivers and machines.

Nevertheless, forest machine entrepreneurs consider chip production an important and developing sector that is being monitored and studied carefully. Its *growth potential is probably greater than that of the conventional timber harvesting* during the next ten years. Therefore, the Trade Association of Finnish Forestry and Earth Moving Contractors is participating in the project work and is presented on the executive committee of the programme.

Figure 34. Timberjack 770 harvester equipped with the accumulating Timberjack 730 feller head for small-tree operations (Courtesy of Timerjack Oy).

Figure 35. A forwarder equipped with an enlargening load space for off-road transport of logging residues and with a disc scarifier for simultaneous site preparation. A prototy-pe constructed by Antti Varis (Courtesy of the Forest Centre of North Karelia).

Lack of buffer storage

Fuel supply must be reliable and credible. Oil, coal and peat supplies are supported by large reserve supplies, but for wood fuels this practice does not exist. Wood fuels are produced daily as a by-product from timber harvesting and wood processing. Storage is difficult due to low energy density and rapid loss of dry matter.

The user of forest chips needs to be sure that fuel supply is not endangered under any conditions. The larger is the share of forest chips in the fuel supply, the more important it is that the quantitative and qualitative conditions of the contract are met. But problems may occur in conjunction with:

- national or international crises
- business cycles in the forest industries
- severe frosts and periods of long rain
- labor conflicts
- breakage of equipment.

In Finland, *large energy plants co-fire wood fuels typically with peat*. If the availability of wood fuels declines, the share of peat in the mixture can be increased. However, if the power plant is involved in certificate or emission trade, shifting temporarily from wood fuels to peat may be problematic.

The Wood Energy Technology Programme is currently studying how the buffer and reserve storage of wood fuels could be improved:

- In which physical state should the biomass be stored?
- What velocity of circulation is needed to prevent the biomass from deteriorating?
- Where should the biomass inventories be located?
- Is the production system sufficiently elastic if the demand suddenly changes?
- What are the additional costs and cost savings from buffer storage?

Weak demand for special equipment

Forest chips is not a common fuel in Europe. The annual production is about 4 Mm^3 in Sweden, 1 Mm^3 in Finland and 0.4 Mm^3 in Denmark. Small-scale use excluded, the total production in Europe is probably 8 Mm3. Sweden has been the pioneer, but during the last few years Sweden's use of forest chips stagnated due to abundant availability of residues from sawmilling, large-scale imports of recycled wood, and increased use of pellets. The growth rate has been fastest in Finland, and is currently 270 000 m^3 per annum.

It follows that *the market for special equipment remains small*. In some cases, a forest machine entrepreneur may find it cheaper to assemble a chipper or other equipment for himself, tailored for his specific needs. The development and manufacturing of machines is further complicated by the variety of logging conditions from young thinning stands to clear-cutting sites. Moreover, the goal is to perform transportation with conventional vehicles whenever possible,

As long as several incompatible systems are employed for the procurement of relatively modest amounts of forest chips, the manufacturing series remain small and the cost of machines high. It is therefore desirable that not so many different systems be used in the future. In Finland, a step to this direction is the introduction and rapid acceptance of the system based on centralized comminution of CRL bundles.

Literature used

Action Plan for Renewable Energy Sources. 2000. Ministry of Trade and Industries. Publications 1/2000.

Alakangas, E. (ed.) 2000. Puuenergian teknologiaohjelman vuosikirja 2000 (Yearbook 2000 of the Wood Energy Technology Programme). VTT Symposium 205. Espoo.

Alakangas, E. (ed.) 2001. Puuenergian teknologiaohjelman vuosikirja 2001 (Yearbook 2001 of the Wood Energy Technology Programme). VTT Symposium 216. Espoo.

Alakangas, E. (ed.) 2002. Puuenergian teknologiaohjelman vuosikirja 2002 (Yearbook 2002 of the Wood Energy Technology Programme). VTT Symposium 221. Espoo.

Energy Statistics 2001. 2002. Statistics Finland. Helsinki.

Finnish Statistical Yearbook of Forestry 2001. Finnish Forest Research Institute. SVT Agriculture, forestry and fishery 2001:52.

Hakkila, P., Kalaja, H. & Nousiainen, I. 2000. Use and prices of forest chips in Finland in 1999. VTT Energy.

VTT Energy. 2001. Energy visions 2030 for Finland. Edita. Helsinki.

Ylitalo, E. 2002. Puupolttoaineen käyttö energiantuotannossa vuonna 2001 (Use of wood fuels for the production of energy in 2001). SVT Maa-, metsä- ja kalatalous 2002:15.

Appendix 1

The projects of the Wood Energy Technology Programme

Planning and organization

Cost factors and large-scale procurement of logging residues PUUT01 *
Antti Asikainen
The Finnish Forest Research Institute
P.O.Box 68, FIN-80101 Joensuu
Tel. +358 13 251 4042
Fax.: +358 13 251 4567
E-mail: antti.asikainen@metla.fi

Energy wood procurement in connection with conventional wood procurement PUUT02 *
Pekka Mäkinen
The Finnish Forest Research Institute
P.O.Box 18, FIN-01301 Vantaa, Finland
Tel. +358 9 857 05345
Fax.:+358 9 857 05361
E-mail: pekka.makinen@ metla.fi

Estimation of the amount of logging residues in a harvester's data system PUUT03 *
Pertti Harstela
University of Joensuu
P.O.Box 111, FIN-80101 Joensuu, Finland
Tel. +358 13 251 3625
Fax.: +358 13 251 3590
E-mail: pertti.harstela@joensuu.fi

Wood fuel harvesting conditions in first thinnings PUUT04 *
Matti Sirén
The Finnish Forest Research Institute
P.O.Box 18, FIN-01301 Vantaa, Finland
Tel. +358 9 857 05339
Fax.: +358 9 857 05361
E-mail: matti.siren@metla.fi

Development of chip production from young forests – PUUT28
Kari Hillebrand
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 611
Fax. +358 14 672 597
e-mail: kari.hillebrand@vtt.fi

Distinction between energy wood and industrial wood PUUY11 *
Hannu Kivelä
Jaakko Pöyry Oy
P.O.Box 4, FIN-01621 Vantaa
Tel. +358 9 8947 2501
Fax. +358 9 879 7031
E-mail: pekka.kivela@poyry.fi

Networked contractors in chip production PUUY15
Tomi Salo
Koneyrittäjien liitto ry
Sitratie 7, 00420 Helsinki
Tel. +358 9 5600 124
Fax. +358 9 5630 329
E-mail: tomi.salo@koneyrittajat.fi

Determining the performance in forest haulage of logging residues PUUY22
Kaarlo Rieppo
Metsäteho Oy
P.O.Box 194, FIN-00131 Helsinki
Tel. +358 9 132 5237
Fax.: +358 9 659 202
E-mail: kaarlo.rieppo@metsateho.fi

Prefeasibility study of e-business application for the energy wood markets PUUY23 *

Jaakko Jokinen
JP Management Consulting (Europe)
P.O. Box 4, FIN-01621 Vantaa
Tel. +358 9 894 71
Fax. +358 9 879 7031
E-mail: hannu.kivela@poyry.fi

Production systems and techniques

Production of mixed fuels at the terminal PUUT05 *

Arvo Leinonen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä, Finland
Tel. +358 14 672 677
Fax.: +358 14 672 597
E-mail: arvo.leinonen@vtt.fi

Developing a two-stage crusher for comminution of forest biomass PUUT12 *

Arvo Leinonen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 677
Fax.: +358 14 672 597
E-mail: arvo.leinonen@vtt.fi

Development of chip procurement, short-distance haulage and storage of wood chips PUUT13 *

Teuvo Rasimus
Occupational Adult Education Centre of Savonlinna Town
Telakkatie 9, FIN-57230 Savonlinna, Finland
Tel. +358 15 575 8236
Fax.: +358 15 575 8290
E-mail: teuvo.rasimus@akk.savonlinna.fi

Development of transportation economy and logistics of forest chips PUUT20

Tapio Ranta
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 611
Fax. +358 14 672 597
E-mai: tapio.ranta@vtt.fi

A method for thinning young stands PUUY01 *

Jarmo Hämäläinen
Metsäteho Oy
P.O.Box 194, FIN-00131 Helsinki, Finland
Tel. +358 9 132 5224
Fax.: +358 9 659 202
E-mail: jarmo.hamalainen@metsateho.fi

Wood fuel production based on chipping at plant PUUY02 *

Antti Korpilahti
Metsäteho Oy
P.O.Box 194, FIN-00131 Helsinki, Finland
Tel. +358 9 132 5242
Fax.: +358 9 659 202
E-mail: antti.korpilahti@metsateho.fi

Special chipper for industrial usage of the forest residues PUUY03 *

Tommi Lahti
LHM-Hakkuri Oy
Lahdentie 231, FIN-41290 Kangashäkki, Finland
Tel. +358 400 656 045
Fax.: +358 14 216 128
E-mail: tommi.lahti@energiat.inet.fi

Production of fuels from logging residues PUUY04 *

Seppo Paananen
UPM-Kymmene Oyj
P.O.Box 32, FIN-37601 Valkeakoski, Finland
Tel.+358 204 163 818
Fax.: +358 204 163 839
E-mail: seppo.paananen@upm-kymmene.com

Tractor-operated drum chipper PUUY05 *

Ari Melkko
Heinolan Sahakoneet Oyj
P.O.Box 24, FIN-18101 Heinola, Finland
Tel. +358 3 848 4206
Fax.: +358 3 848 4202
E-mail: melkko.ari@heinola.troponor.fi

Technology for forest chips production at the terminal PUUY06 *

Jaakko Silpola
Vapo Oy
P.O.Box 22, FIN-40101 Jyväskylä, Finland
Tel. +358 14 623 5644
Fax.: +358 14 623 5707
E-mail: jaakko.silpola@vapo.fi

Clinic for wood fuel technologies PUUY07

Dan Asplund
Jyväskylä Science Park Ltd
P.O.Box 27, FIN-40101 Jyväskylä, Finland
Tel. +358 14 4451 112
Fax.: +358 14 4451 199
E-mail: dan.asplund@jsp.fi

Forest biomass as a real choice of the renewable energy PUUY12

Arto Timperi
Plustech Oy
P.O.Box 306, FIN-33101 Tampere
Tel. +358 0204 80 4683
Fax. +358 0204 80 4690
E-mail: arto.timperi@fi.timberjack.com

Development of a new all-terrain chip harvester PUUY13

Sakari Pinomäki
Sakari Pinomäki Ky
Pinotie 3, FIN-33470 Ylöjärvi
Tel. +358 3 3480 700

Trailer combination for transportation of logging residues PUUY14 *

Jaakko Silpola
Vapo Oy Energy
P.O.Box 22, FIN-40101 Jyväskylä
Tel. +358 14 623 5644
Fax. +358 14 623 5707
E-mail: jaakko.silpola@vapo.fi

Bundler for logging residues PUUY16 *

Fredrik Pressler
Biowatti Oy
Revontulentie 6, FIN-02100 Espoo
Tel. +358 01046 585 07,
Fax. +358 01046 694 298
E-mail: fredrik.pressler@metsaliitto.fi

Design and manufacture of chipping equipment PUUY18 *

Jorma Issakainen
Kesla Oyj
Kuurnankatu 24, FIN-80110 Joensuu
Tel. +358 13 682 841
Fax. +358
E-mail: jorma.issakainen@kesla.inet.fi

Bundling system for large scale utilization of forest energy PUUY19 *

Juha Poikola
Pohjolan Voima Oy
P.O.Box 40, FIN-00101 Helsinki
Tel. +358 050 3133 278
Fax. +358 9 6930 6335
E-mail: juha.poikola@pvo.fi

Combining forest residue transportation and soil preparation PUUY21

Timo Hartikainen
Oy FEG – Forest and Environment Group Ltd
Sirkkalantie 17, FIN-80100 Joensuu
Tel. +358 13 2637 417
E-mail: timo.hartikainen@feg.fi

Development of a two-stage crusher for comminution of forest biomass – Phase II PUUY31

Heikki Paalanen
Joutsan Konepalvelu Oy
Kangasniementie 13, FIN-19650 Joutsa
Tel. +358 14 880 8100
Fax. +358 14 880 8120
E-mail: heikkipa@joutsankp.fi

Quality control, handling and use

Utilisation of wood from early thinnings PUUT06 *

Raimo Alén
University of Jyväskylä
P.O.Box 35, FIN-40351 Jyväskylä, Finland
Tel.+358 14 260 2562
Fax.: +358 14 602 501
E-mail: raimo.alen@jyu.fi

Processing of debarking residues into fuels PUUT07 *

Risto Impola
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä, Finland
Tel: +358 14 672 542
Fax.: +358 14 672 597
E-mail: risto.impola@vtt.fi

Fluidised bed combustion of forest chips in big power plants PUUT08 *

Markku Orjala
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 534
Fax.: +358 14 672 596
E-mail: markku.orjala@vtt.fi

Quality management of wood fuels PUUT09 *

Kari Hillebrand
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä, Finland
Tel. +358 14 672 675
Fax.: +358 14 672 597
E-mail: kari.hillebrand@vtt.fi

Upgrading fuel by-products from wood-processing industry PUUT15 *

Raija Kuoppamäki
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 540
Fax.: +358 14 672 598
E-mail: raija.kuoppamaki@vtt.fi

Enhancement of back-pressure power production in pulp and paper mills PUUT17

Pekka Ahtila
Helsinki University of Technology
P.O.Box 4100, FIN-02015 TKK
Tel. +358 9 451 3618
E-mail: pekka.ahtila@hut.fi

Improving fuel quality and chipping capacity by developing chipping technique PUUT18 *

Veli Seppänen
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 611
Fax. +358 14 672 596
E-mail: veli.seppanen@vtt.fi

Receiving and handling systems for wood fuels PUUT19 *

Risto Impola
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel- +358 14 672 542
Fax. +358 14 672 597
E-mail: risto.impola@vtt.fi

Effect of wood fuels on power plant availability PUUT24

Markku Orjala
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 534
Fax. +358 14 672 597
E-mail: markku.orjala@vtt.fi

Flue gas emissions from cofiring of by-products from plywood and particle board industries PUUT25 *

Raili Vesterinen
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 574
Fax. +358 14 672 598
E-mail: raili.vesterinen@vtt.fi

Chemical changes of wood fuels in storing and drying PUUT29

Leena Fagernäs
VTT Processes
P.O. Box 1601, FIN-02150 Espoo
Tel. +358 9 456 5453, Fax. +358 9 460 493
E-mail: leena.fagernas@vtt.fi

Developing storage, material flow equalising and boiler feeding systems for solid biofuels PUUY08 *

Antti Nurmi
BMH Wood Technology
P.O.Box 32, FIN-26101 Rauma, Finland
Tel. +358 2 831 5236
Fax.: +358 2 822 1327
E-mail: antti.nurmi@bmh.fi

Further development of atmospheric CFB gasification technology PUUY09 *

Matti Hiltunen
Foster Wheeler Energia Oy
P.O.Box 66, FIN-48601 Karhula, Finland
Tel. +358 10 393 3335
Fax.: +358 10 393 3309
E-mail: matti_hiltunen@fwfin.fwc.com

Multifuel handling and feeding (MF2) PUUY10 *

Timo Järvinen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä, Finland
Tel. +358 14 672 692
Fax.: +358 14 672 597
E-mail: timo.jarvinen@vtt.fi

Oy Alholmens Kraft Ab's development programme for solid biofuel procurement, receiving, storage and advanced adjustment system for boiler PUUY20 *

Juha Poikola
Pohjolan Voima Oy
P.O.Box 40, FIN-00101 Helsinki
Tel. +358 050 3133 278
Fax. +358 9 6930 6335
E-mail: juha.poikola@pvo.fi

Development of hopper discharging control PUUY24 *

Esko Saarela
Raumaster Oy
Nortamonkatu 32, FIN-26100 Rauma
Tel. +358 2 8377 4231
Fax. +358 2 8223 801
E-mail: esko.saarela@raumaster.fi

The effect of cocombustion of wood and sludges on boiler corrosion PUUY28

Juha Räsänen
Varenso Oy, Energy services
PL 169, 78201 Varkaus
Puh: +358 2046 32 704, gsm: +358 4074 61 220
Fax. +358 2046 32 122
juha.rasanen@storaenso.com

On-line measuring of moisture content and quality of wood fuels PUUY29

Sauli Jäntti
Merinova Oy
P.O. Box 810, FIN-65320 Vaasa
Tel. +358 6 282 8200
Fax. +358 6 282 8299
E-mail: sauli.jantti@merinova.fi

Receiving and handling system for loose and bundled forest residue PUUY32

Antti Nurmi
BMH Wood Technology Oy
P.O. Box 32, FIN26101 Rauma
Tel. +358 2 831 5236
Fax. +358 2 822 1327
E-mail: antti.nurmi@bmh.fi

Development of screening technology in small power plants and heating plants PUUY34

Ossi Rissanen
ST-Tekniikka Ltd
Yrittäjäntie 6, 63700 Ähtäri
Tel. +358 6 5337901
E-mail: st-tekniikka@st-tekniikka.fi

Impacts on forestry

Effects of logging residue removal on forest regeneration PUUT10 *

Timo Saksa
The Finnish Forest Research Institute
FIN-77600 Suonenjoki, Finland
Tel. +358 17 513 8300
Fax.: +358 17 513 068
E-mail: timo.saksa@metla.fi

Environmental aspects of wood energy PUUT11 *

Helena Mälkki
VTT Processes
P.O.Box 1604, FIN-02044 VTT, Finland
Tel. +358 9 456 6442
Fax.: +358 9 456 6538
E-mail: helena.malkki@vtt.fi

The effects of intensified biomass recovery on forest PUUT14 *

Juha Nurmi
The Finnish Forest Research Institute
P.O.Box 44, FIN-69101 Kannus, Finland
Tel. +358 6 874 3219
Fax.: +358 6 874 3201
E-mail: juha.nurmi@metla.fi

Wood energy and greenhouse gases PUUT22 *

Sampo Soimakallio
VTT Processes
P.O.Box 1606, FIN-02044 VTT
Tel. +358 9 456 5808
Fax. +358 9 456 6538
E-mail: margareta.wihersaari@vtt.fi

Radioactivity of wood fuels and ash – implications to the use of ashes PUUT23

Virve Vetikko
Radiation and Nuclear Safety
Authority of Finland
P.O.Box 14, FIN-00881 Helsinki
Tel. +358 9 759 884 35
E-mail: virve.vetikko@stuk.fi

Effect of slash and stump removal on soil preparation and planting PUUT32

Pertti Harstela
The Finnish Forest Research Institute
Juntintie 40, FIN-77600 Suonenjoki
Tel. +38 17 5138
Fax. +358 17 513 068
E-mail: pertti.harstela@metla.fi

Environmentally sound afforestation of cut-away peat harvesting areas by fixing it up as a new carbon sink and controlling the impacts PUUY17 *

Pirkko Selin
Vapo Oy Energy
P.O.Box 22, FIN-40101 Jyväskylä
Tel. +358 14 623 5752
Fax. +358 14 623 5707
E-mail: pirkko.selin@vapo.fi
Small-scale production and use

Small-scale production and use

Survey of the R&D needs of small scale use of wood fuels PUUT26 *

Heikki Oravainen
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 532
Fax. +358 14 672 597
E-mail: heikki.oravainen@vtt.fi

Distribution, handling and quality improvement of wood fuels in small-scale use PUUT30

Ari Erkkilä
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 684
Fax. +358 14 672 597
e-mail: ari.erkkila@vtt.fi

Customer-oriented network trade and logistics of firewood PUUT34

Lauri Sikanen
The Finnish Forest Research Institute
P.O.Box 68, FIN-80101 Joensuu
Tel. +358 50 3788 235
Fax.: +358 13 251 4111
e-mail: lauri.sikanen@metla.fi

Palax 450 firewood processor PUUY26

Jaakko Viitamäki
Ylistaron Terästakomo Oy
P.O. Box 32, FIN-61400 Ylistaro
Tel. +358 500 365
E-mail: jaakko.viitamaki@terastakomo.fi

Quality control of wood pellets in small-scale distribution and handling PUUY27

Seppo Tuomi
TTS-Institute (Work Efficiency Institute)
P.O. Box 13, FIN-05201 Rajamäki
Tel. +358 9 290 41280
Fax. +358 9 290 41285
E-mail: seppo.tuomi@tts.fi

Production process for chopped firewood PUUY30

Kalle Kärhä
TTS-Institute (Work Efficiency Institute)
P.O. Box 28, FIN-00211 Helsinki
Tel. +358 9 2904 1424
Fax. +358 9 6922 084
E-mail: kalle.karha@tts.fi

Next generation sauna stove PUUY33
Pertti Harvia
Harvia Oy
Teollisuustie 1 – 3, FIN-40950 Muurame
Tel. +358 14 331 4000
Fax. +358 14 331 4090
E-mail: pertti.harvia@harvia.fi

Small-scale fluidised bed boiler invention for new business PUUY35
Kari Hiltunen
Forestfire Oy
Varastokatu 14, 00580 Helsinki
Tel. +358 9 7269 9541
E-mail: kari.hiltunen@nic.fi

International projects

Competitivity of new bioenergy technologies – IEA/Bioenergy PUUT16 *
Yrjö Solantausta
P.O.Box 1601, FIN-02044 VTT
Tel. +358 9 456 5517
Fax. +358 9 460 493
E-mail: yrjo.solantausta@vtt.fi

Cocombustion of solid biofuels and coal PUUT21
Veli-Pekka Heiskanen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 533
Fax. +358 14 672 596
E-mail: veli-pekka.heiskanen@vtt.fi

Technology transfer on biofuels between USA and Finland PUUT27
Arvo Leinonen
VTT Prosessit
PL 1603, 40101 Jyväskylä
Puh. (014) 672 677, Fax. (014) 672 597
E-mail: arvo.leinonen@vtt.fi

Maximum biomass use and efficiency in large-scale cofiring – PUUT31
Anne Suomalainen
VTT Processes
P.O. Box 1603, FIN- 40101 Jyväskylä
Tel. +358 14 672 521
Fax. +358 14 672 597
E-mail: anne.suomalainen@vtt.fi

Quality determination of Far Eastern wood fuels PUUY25
Dan Asplund
Jyväskylä Science Park
PL 27, 40101 Jyväskylä
Tel. +358 14 4451 112
Fax. +358 14 4451 199
E-mail: dan.asplund@jsp.fi

Preparation of new bioenergy projects for the 6th Framework programme of European Commission PUUT33
Kai Sipilä
VTT Processes
PL 1601, 02044 VTT
Tel. +358 9 456 5440
Fax. +358 9 460 493
E-mail: kai.sipila@vtt.fi

Special studies

Instructions for harvesting logging residue chips PUUJ01 *
Tage Fredriksson
Puuenergia ry
Soidinkuja 4, FIN-00700 Helsinki, Finland
Tel. +358 9 156 2247
Fax.: +358 9 1562 433
E-mail: tage.fredriksson@tapio.mailnet.fi

Survey on utilisation of forest chips PUUJ02 *
Pentti Hakkila
VTT Processes
P.O.Box 1604, FIN-02044 VTT, Finland
Tel. +358 9 456 6672
Fax.: +358 9 456 5000
E-mail: pentti.hakkila@vtt.fi
http://www.vtt.fi/virtual/afbnet/

The role of wood energy R&D and utilisation in EU PUUJ03 *
Pirkko Vesterinen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä, Finland
Tel. +358 14 672 715
Fax.: +358 14 672 749
E-mail: pirkko.vesterinen@vtt.fi

Possibilities to use stumps as fuel – Preliminary study PUUJ04 *

Ari Erkkilä
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 684
Fax. +358 14 672 749
E-mail: ari.erkkila@vtt.fi

Effects of wood fuels on operational costs of power plant PUUJ05 *

Jouni Hämäläinen
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 529
Fax. +358 14 672 749
E-mail: jouni.hamalainen@vtt.fi

Production costs of wood pellets in conjunction with different energy systems PUUJ06 *

Martti Flyktman
VTT Processes
P.O.Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 539
Fax. +358 14 672 597
E-mail: martti.flyktman@vtt.fi

Wood chip production from thinnigs PUUJ07

Tage Fredriksson
Puuenergia ry
Soidinkuja 4, FIN-00700 Helsinki
Tel. +358 9 156 2247
Fax. +358 9 1562 433
E-mail: tage.fredriksson@tapio.mailnet.fi

Survey on forest chip quality PUUJ08

Risto Impola
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 542
Fax. +358 14 672 749
E-mail: risto.impola@vtt.fi

Buffer storage of wood fuels PUUJ09

Tapio Ranta
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel. +358 14 672 722
Fax. +358 14 672 749
E-mail: tapio.ranta@vtt.fi

Feasibility of fuel drying on power plants PUUJ10

Martti Flyktman
VTT Processes
P.O. Box 1603, FIN-40101 Jyväskylä
Tel.. +358 14 672 521
Fax. +358 14 672 597
E-mail: anne.suomalainen@vtt.fi

Demonstration projects

Off-road transport of logging residues and a container for fuel chips PUUD1 *

Occupational Adult Education Centre of Savonlinna Town

A trailer for transportation of uncomminuted logging residues PUUD2 *

Kuljetusliike Hakonen ja Pojat

Bundling machine for logging residues PUUD3 *

Ris-Esset Ab Oy

Terminal chipping of forest biomass PUUD4 *

Vapo Oy Energia

GIANT chipper for logging residues PUUD5 *

Kotimaiset Energiat Ky

TT-1310RML –drum chipper PUUD6 *

Tmi Hake-Energia Kari Vainikka

Long-distance haulage of logging residues PUUD7 *

Vapo Oy Energia

Chipper container truck PUUD8 *
Biowatti Oy

Bundler for logging residues PUUD9 *
Konepalvelu Hölrin Oy

Drum chipper TT-1310 RML PUUD10 *
Hakeyhtymä Kankaanmäki

Terrain chipper tipping directly to truck PUUD11 *
Biowatti Oy

Crusher at end-user facility PUUD12 *
Oy Alholmens Kraft Ab

Bundler for logging residues PUUD13
Tmi Matti Sadeharju

Bundler for logging residues PUUD14
H & H Ala-Korpi

GIANT chipper for logging residues PUUD15
Kotimaiset Energiat Ky

T = research project
Y = industrial R&D project
J = other project
D = demonstration project

Projects marked with a star (*) have been completed.

Tekes' Technology Programme Reports

5/2003	Developing technology for large-scale production of forest chips. Wood Energy Technology Programme 1999–2003. Interim Report. 53 p.
4/2003	Code Technology Programme 1999–2002. Final Report.
3/2003	VÄRE – Värähtelyn ja äänen hallinta -teknologiaohjelma 1999–2002. Loppuraportti. 90 s.
2/2003	Kenno – Kevyet levyt -teknologiaohjelma 1998–2002. Loppuraportti.
1/2003	FFusion Technology Programme 1999–2002. Loppuraportti.
14/2002	Technology and Climate Change. CLIMTECH 1999–2002. 258 p. Sampo Soimakallio, Ilkka Savolainen (eds.)
13/2002	Avautuneet sähkömarkkinat ja jätteiden energiakäyttö – lainsäädännöllä synnytettyinä markkinoina. TESLA- ja Jätteiden energiakäyttö -teknologia-ohjelmien arviointiraportti. 62 s. Mervi Rajahonka, Lasse Kivikko, Mikko Valtakari, Matti Pulkkinen
12/2002	Information Technology and Electric Power Systems, TESLA Technology Programme 1998–2002. Final Report. 80 p.
11/2002	Informaatiotekniikka sähkönjakelussa, TESLA-teknologiaohjelma 1998–2002. Loppuraportti 102 s.
10/2002	Kilpailukykyä yritysten toimintatapoja kehittämällä – GPB-, ProBuild- ja Laatu-ohjelmien arviointi. Arviointiraportti 44 s. Mikko Valtakari ja Mervi Rajahonka
9/2002	Energiateknologiayritykset liiketoimintaympäristön murroksessa. Materiaalit energiatekniikan palveluksessa, KESTO-teknologiaohjelma 1997–2001. Arviointiraportti. 31 s. Lasse Kivikko
8/2002	Materials for Energy Technology, KESTO Technology Programme 1997–2001. Final Report. 128 p.
7/2002	Materiaalit energiatekniikan palveluksessa, KESTO-teknologiaohjelma 1997–2001. Loppuraportti. 128 s.
6/2002	Water Services 1997–2001. Evaluation and Final Report. 132 p.
5/2002	Pigmentit paperin raaka-aineena 1998–2001. Loppuraportti. 87 s.
4/2002	Global Project Business, Kansainvälinen liiketoiminta 1998–2001. Loppuraportti.
3/2002	ETX – Electronics for the Information Society 1997–2001. Final Report. 387 p.
2/2002	Evaluation of Finnish R&D Programmes in the Field of Electronics and Tele-communications (ETX, TLX and Telectronics I) Evaluation Report. 95 p.
1/2002	TLX Telecommunications – Creating a Global Village 1997–2001. Final Report. 200 p.

Julkaisujen tilaukset: www.tekes.fi/Julkaisut