Nordic Treasure Hunt

Extracting Energy from Forest Residues

Energy, Environment, Sustainable development

TECHNICAL RESEARCH CENTRE OF FINLAND
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Preface

The Kyoto Protocol on Climate Change and the EU's White Paper for a Community Strategy and Action Plan oblige the industrialized countries to substitute renewable energy sources for fossil fuels in order to reduce greenhouse gas emissions. In countries with large forest resources and well developed forest sectors wood is the primary source of renewable energy. The Nordic countries have significant experience and know-how in wood energy that coincides with the European Commission's ambitious targets for the use of renewable energy sources. In Denmark, Finland and Sweden, forest chips play an important role as an energy source.

The programme of the international wood energy workshop, entitled "Nordic Treasure Hunt: Extracting Energy from Forest Residues", consisted of six papers from Finland and five papers from leading experts from Sweden and Denmark. This seminar was focused on forest residues and its uses in the context of Nordic experiences and technologies. Competitiveness, costs and fuel quality as well as environmentally sound forestry were the key issues discussed. Some papers reported on recent research findings and progress, and some reviewed the past development and present status of large-scale production and use of forest chips. The seminar was organised in collaboration with the Finnish Wood Energy Technology Programme and the OPET Finland. In connection with the international programme, an annual seminar was held on August 29, 2000 at the Conference Centre in Jyväskylä, Finland.

The Tekes' Wood Energy Technology Programme 1999–2003 focuses on developing the production technology and improving the quality of forest chips from logging residues and small-sized trees. OPET Finland, a Finnish member of the European Network for the Organisations for the Promotion Energy Technologies, serves as a gateway to Finnish energy technologies and market actors, networking experiences from Finland to Europe and vice versa.

The Wood Energy Technology Programme, VTT Energy as the co-ordinator of the programme, and OPET Finland express their warmest thanks to all persons and institutions who kindly contributed to the seminar and the proceedings.

Pentti Hakkila and Satu Helynen
Wood Energy Technology Programme

Marjatta Aarniala
OPET Finland

Tekes, the National Technology Agency, established in 1999 a comprehensive Wood Energy Technology Programme to promote the development of technology for the production and use of forest chips. The target is to create techno-economic preconditions for increasing the use of forest chips to 2.5 million m^3 solid by 2003, i.e. fivefold in five years. Such a rapid growth requires improved procurement logistics, reduction of production costs, better quality of fuel, cofiring of forest chips with other fuels, and integration of the supply systems of industrial wood raw material and forest fuels. In August 2000, the programme consisted of a network of 20 research institute projects and 20 enterprise projects.

OPET Finland is a member of the OPET Network (Organisations for the Promotion of Energy Technologies). The OPET Network aims to promote the results of new energy technologies and their introduction in society. The Network operates under the fifth EU Framework Programme for Research and Development (1998–2002) as part of the Energy, Environment and Sustainable Development Programme. OPET currently includes over 100 partner organisations in 44 countries within the European Union, the candidate countries of Central and Eastern Europe and Cyprus, as well as Norway, Iceland and Israel. OPET Associates have also been established in key work regions such as the former CIS, Latin America, China, India and Southern Africa.

OPET Finland partners are National Technology Agency Tekes, Motiva Ltd and VTT Energy.

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Renewable energy sources in Finnish energy policy and climate change

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1. The Finnish Action Plan for Renewable Energy

The Action Plan for Renewable Energy Sources completed autumn 1999. The Action Plan was prepared by the Ministry of Trade and Industry, assisted by a large working group. A researcher team from the Technical Research Centre of Finland served as consultants during the preparation work.

The Action Plan has been compiled so as to be comprehensive. It encompasses all renewable energy sources available in Finland. In accordance with the Finnish Energy Strategy, the emphasis is on measures to increase the use of wood for energy and on measures to promote wind power. Similarly, measures have been proposed for promoting the use of recycled fuels as energy sources. The other types of energy discussed are small-scale hydropower, field biomass, solar power and heat pumps.

The points of departure for the Action Plan include – besides the Finnish Energy Strategy approved by the Government in 1997 – the Kyoto Protocol on climate change and the White Paper for a Community Strategy and Action Plan, “Energy for the future: Renewable sources of energy”, published by the European Union. National measures play a key role in achievement of the objectives set in the White Paper. The Action Plan for Renewable Energy Sources is a national programme in line with the White Paper of the European Union.

The Action Plan also serves the preparation of a national climate programme, for which various bodies – including the Ministry of Trade and Industry – must systematically analyse the aspects that are of importance for curbing greenhouse gas emissions.

The Action Plan sets objectives for the volume of renewable energy sources in 2010 and gives a prognosis on developments by 2025. The target set for the year 2010 is to increase the volume of energy generated using renewable sources by 50% when compared to the situation in 1995. This increase would be 3 Mtoe, which is about 1 Mtoe more than the trend based on the outline presented in the Finnish Energy Strategy (Figure 1 and Tables 1 and 2).

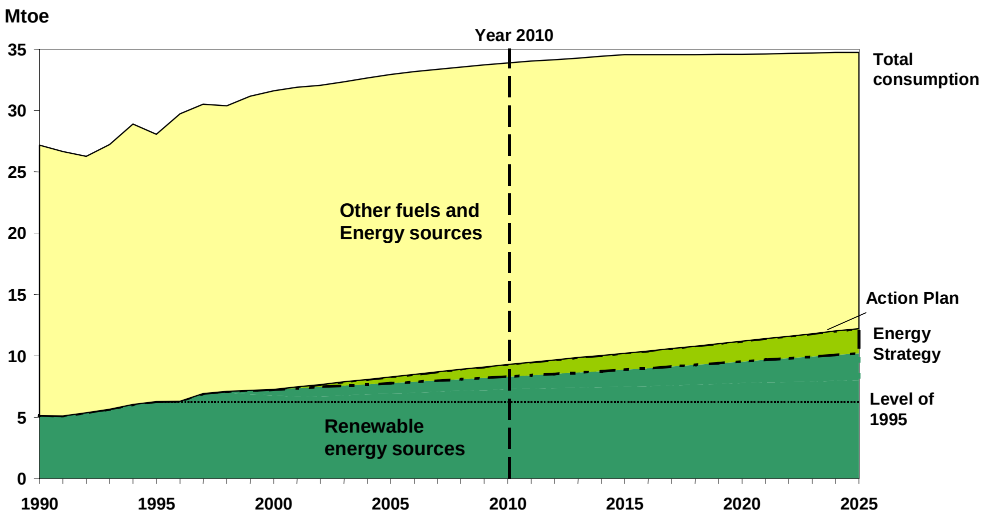

Figure 1. Renewable energy sources in proportion to total consumption.

The target set for 2025 is to double the use of renewable energy sources. These targets are demanding for a country like Finland, where the use of renewable energy sources is already high. In 1998, renewable energy sources accounted for about 23% of all energy consumption in Finland. Of this figure, 19% was wood energy and the rest mostly hydropower. This is the third highest percentage in the EU, and for bioenergy, the highest.

Table 1. Aims for renewable energy sources in Finland to year 2010 and vision to year 2025.

	Years Mtoe			Increase of RES from year 1995 to year 2010		Vision from increase from year 1995 to 2025	
	1990	1995	1997	Mtoe	%	Mtoe	%
BIOENERGY							
Industry	2,87	3,72	4,31	1,5	40%	3	80%
District heating	0,08	0,19	0,28	0,8	4-folds	1,5	8-folds
Firewood (households)	1,07	1,07	1,12	0,5	45%	0,75	70%
HYDROPOWER	0,92**	1,10**	1,03**	0,09	8%	0,17	15%
WIND POWER	0	0,0009	0,0014	0,09	100-folds	0,4	500-folds
SOLAR ENERGY							
PV	0	0,0001	0,0001	0,004	40-folds.	0,04	400-folds.
Solar heat	0	0,0002	0,0002	0,004	20-folds.	0,04	200-folds
HEAT PUMPS	0	0,01	0,03	0,1	10-folds	0,3	30-folds
TOTAL	4,9	6,1	6,8	3,1	50%	6,2	100%
Share of primary energy consumption, %	18,0	21,3	22,1		27*		35*
PEAT	1,34	1,78	1,99	Current use		Current use	

*based on the scenario of the Finnish Ministry of Trade and Industry issued in autumn 1998.
** includes also large scale hydro power.

Table 2. Increase of electricity production by renewable energy sources in Finland.

	Year 1995		Increased from 1995 to year 2010		Vision of the increase from 1995 to year 2025	
	TWh	MW_e	TWh	MW_e	TWh	MW_e
BIOENERGY						
Industry	6,2	2 000	3,5	500	10,5	1 500
CHP production in district heating	Included in previous	Included in previous	2,7	550	6,1	1 200
HYDROPOWER (<10 MW)	12,8**	2 200**	1,0	420	2,0	700
WIND POWER	0,01	6	1,1	500	5,1	2 000
SOLAR ENERGY						
Photo voltaics	0,001	1,5	0,05	40	0,5	500
TOTAL	**19**	**4 200**	**8,35**	**2 010**	**24,2**	**5 900**
Increase from 1995, %			40%	50%	120%	140%
Share of electricity supply %	27%		31%*		40%*	
PEAT	5,2	1 000				

*based on the scenario of the Finnish Ministry of Trade and Industry issued in autumn 1998.
** includes also large scale hydro power.

The main objective of the Action Plan is to enhance the competitiveness of renewable energy sources in relation to other energy sources. In the long run, the objective is to make renewables as competitive as possible on the open energy market, without any special supportive action taken by the State. The central measures listed in the Action Plan are development and commercialisation of new technology, and application of economic means, of which taxation and investment subsidies are the principal ones. In addition, measures are needed to abolish administrative barriers and to promote education, information, investigations and instructions.

It can be considered that the most important new promotion measure included in the Action Plan is large-scale demonstration support, which could be granted to one project once in three years. The support sum paid at once would be FIM 100–200 million. The last few years have shown that support of this type would be needed especially for putting new biofuel technology into use. The goal is to introduce this new support form into the State Budget of 2002.

For ensuring the competitiveness of renewable energy sources, it is necessary to continue energy tax schemes that have the same positive impact on renewables as the present tax schemes, which currently have a validity period of three years, owing to the notification of subsidies within the EU.

The Action Plan has been subject to a separate environmental impact assessment (EIA), in which the environmental impacts of the use of renewable energy sources and peat have been analysed in detail. The most notable impact is the reduction in greenhouse gas emissions. Following the intensified measures to be taken in accordance with the Action Plan, it is estimated that emissions of the principal greenhouse gas, carbon dioxide, can be cut by at least 2 million tonnes per year when compared with the outlook presented in the Energy Strategy. Further, thanks to the Action Plan, the use of waste for energy production, instead of taking it to refuse tips, will reduce methane emissions from tips by an amount corresponding to over one million tonnes of carbon dioxide per year.

Increased use of renewable energy sources may reduce greenhouse gas emissions considerably more than the figures presented above. In keeping with the nature of the Action Plan EIA, the Action Plan has been prepared as openly as possible.

To ensure that the objectives of the Action Plan are achieved, contribution by the State (tax subsidies, investment subsides and other forms of support) should be on average FIM 500 million (84 million €) per year for the next ten years. In 1998, the corresponding contribution exceeded FIM 300 million (50.5 million €). In addition, approximately FIM 200 million (33.6 million €) is currently used for funding research and development of energy production technology. To a greater extent than at present, this sum will be channelled to the development of renewable energy sources.

Although Finland is already the leading country in the industrialised world as concerns the use of wood for energy generation, the target set in the Action Plan for increasing the volume of renewable energy sources rests heavily on wood energy. Biofuels are estimated to account for about 90% of the increase in the use of renewable energy sources by 2010, as specified in the Action Plan. Of this, wood-based fuels in industry would account for about half, fuels obtained from forests would account for about 30%, while the remaining 20% would come from recycled fuels.

2. Current state of the preparation of the National Climate Programme

The Government is preparing a National Climate Programme for meeting the obligations specified in the Kyoto Protocol. The work is based on the programme of Paavo Lipponen's second Government, which says: "The Government will prepare and implement a national plan on how Finland will meet the goals of reducing greenhouse gas emissions, as agreed in the Kyoto Climate Convention. The obligations will be met so that the consequent measures do not impair the growth of economy and employment and help reduce Finland's public debt."

"Greenhouse gas emissions will be reduced in accordance with the international obligations set on Finland. Sectoral preparations will be compiled to make an action programme."

At this stage, reports from the various sectoral Ministries (Ministry of Trade and Industry, Ministry of Transport and Communications, Ministry of Agriculture and Forestry, and Ministry of the Environment) have been completed. At the next stage, these reports will be combined to make the final climate programme. The programme will be presented to the Government early in 2001, after which the Government will submit the programme as a report to Parliament in spring 2001.

Responsibility for compiling the National Climate Programme rests with the Ministry of Trade and Industry. The Ministerial Working Group "KYOTO", chaired by Minister Sinikka Mönkäre, steers the preparation of the programme.

Each Ministry has published its own report. However, it should be emphasised that these reports are still only the background material for Finland's National Climate Programme, which will be formulated under the supervision of the Ministerial Working Group towards the end of 2000.

The Ministry of Trade and Industry is responsible for the planning of energy policy measures, for assessment of the effects of these measures, and for their implementation. The plan for reducing emissions includes the following components: investigation of trends in energy production and consumption; calculation of emissions resulting from these trends; planning of actions (such as promotion of renewables, updating the energy conservation programme, changes in production structure, energy taxation, security of energy supply, etc.) and assessment of the effects of these actions; and a conclusion on the proposal for a comprehensive action plan. The emission calculations to be made by the Ministry will encompass all fuels and their future consumption trends and emission calculations, including the actions that have been planned, for instance, by the Ministry of the Environment, the Ministry of Transport and Communications and the Ministry of Agriculture and Forestry.

The Ministry of Transport and Communications is responsible for the planning and implementation of transport policy measures and for assessment of the effects of these measures.

The Ministry of the Environment is responsible for the planning of waste management and thereby for the planning and implementation of actions associated with methane emissions from refuse tips and from the cleaning processes of community waste waters. Recovery of methane gases for energy production is included in the overall development scenarios for the energy sector, drawn up by the Ministry of Trade and Industry. The Ministry of the Environment is also responsible for actions pertaining to energy consumption in buildings. Through community planning, the Ministry plays an important role in sectors such as energy use for transports or the prerequisites for building wind power plants.

The Ministry of Agriculture and Forestry is responsible for drawing up a plan concerning emissions from agriculture. Likewise, the Ministry is responsible for a plan pertaining to land use, changes in land use and development of forestry (sinks, including bog fields). These issues also fall within the administrative sphere of the Ministry of Trade and Industry (forest industry, use of forests, peat production).

The Ministry of Finance plays a key role when the focus is on the application of financial means of steering or on the economic and employment effects of the plans drawn up by other Ministries.

The impact that the actions have on society and on the economy will be evaluated when the comprehensive programme is compiled.

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National Climate Programme

- **National Climate Programme = NCP**
  - to meet the Kyoto target (± 0 %)
    - without impairing economic growth
    - -” - -” – increase of employment
    - promote decrease of public debt

  - Sectoral action plans (Ministries of Trade & Industry, Transport & Communications, Agriculture & Forestry and Environment) will be compiled to make an action programme, Min. of Trade & Industry is responsible

- **Timetable of NCP**
  - Sectoral action plans ready summer 2000
  - Compiling the NCP before end of 2000
  - NCP presented to Government early 2001
  - NCP as a report to Parliament spring 2001

MTI's sectoral action plan

- Promotion of the production structure of energy towards a balance with a lower carbon content
- Promotion of the energy market
- Promotion of the efficient use of energy and energy conservation
- Promote use of bioenergy and other indigenous energy sources
- Maintaining the high standard of energy technology
- Ensuring a sufficiently diversified and economical supply capacity of energy
- Maintain the security of supply in the energy sector

Role of technology development in promoting wood energy

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1. Introduction

The White Paper of the European Commission on renewable energy sources introduced a strategy to increase the use of renewable energy sources as an important action to reduce greenhouse gas emissions (EC 1997). The proposed goal is to double the use of renewable energy by 2010 compared to the level of 1995 (Fig.1). Totally, 80% of the increase is to be covered by bioenergy and less than one third of bioenergy is assumed to be wood-based fuels.

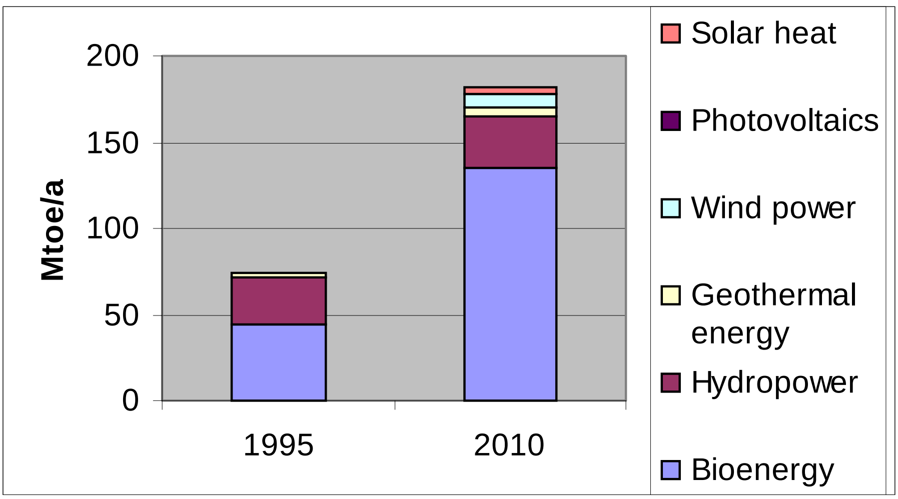

Figure 1. Goals for the increase of the use of renewable energy sources in the EU by 2010.

In Finland, the Action Plan for Renewable Energy Sources (MTI 2000) is aimed to increase the use of renewable energy by 50% by 2010 compared to the year 1995 (Fig.2). Compared to the White Paper of the EC, the suggested growth rate is slower, as the use of renewable energy is very extensive and a significant share of the potential resources and applications is already utilized. Some 90% of increase of renewable energy is to be covered with bioenergy that includes residues from forest industries (50%), forest fuels (30%) and some biobased waste materials.

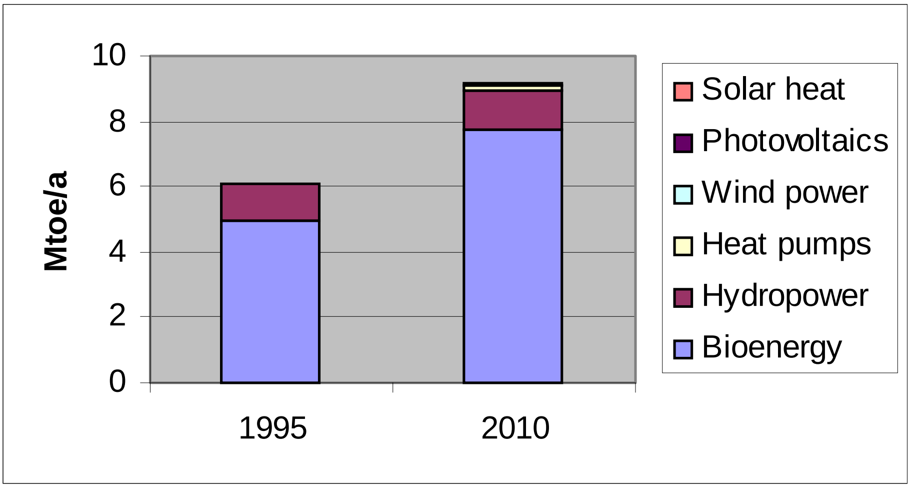

Figure 2. Goals for the use of renewable energy sources in Finland by 2010.

2. Competitiveness of renewable energy

The poor competitiveness of many renewable energy sources against conventional energy technologies based on fossil fuels is the main barrier of the increase their use. The development of some power production technologies is illustrated in Figure 3. The cost of electricity is shown as a function of the cumulative electricity production with selected technologies in the European Union 1980–1995. The experience curves of different energy technologies are typically straight lines in a double-logarithmic diagram. The progress ratio for each technology gives the price reduction after doubling of the cumulative production.

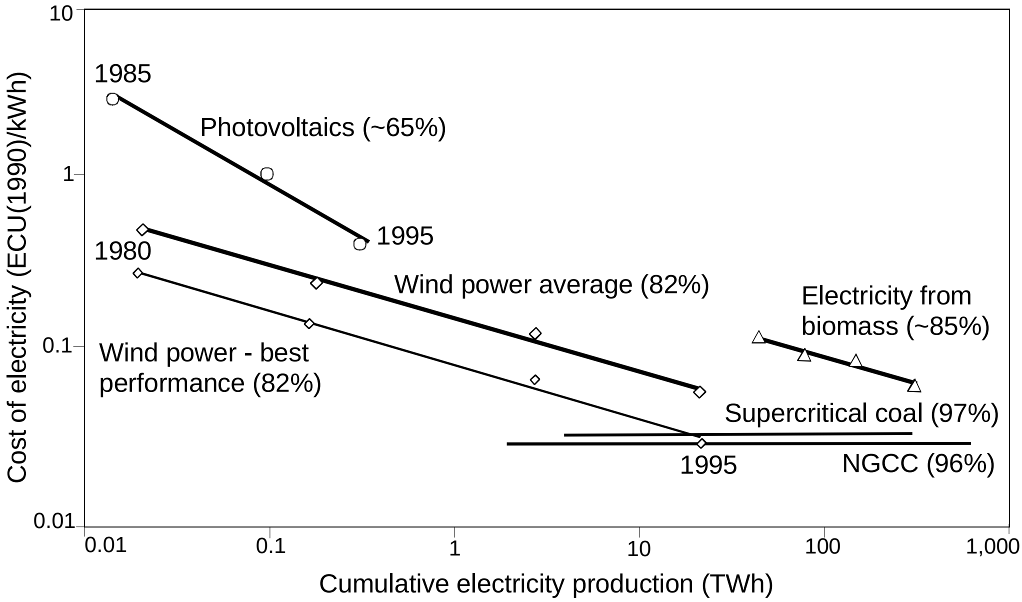

Figure 3. Some energy technologies for power production and their progress ratios in EU in 1980–1995. (IEA 2000).

The lowest costs are for large scale natural gas combined-cycle (NGCC) and coal-fired power plants which use high steam values and have high efficiencies. These well-established technologies have improved gradually, but cost reductions are relatively small, partly because of tightening of emission requirements. Of course, break-through of new technologies, such as integrated gasification combined cycle (IGCC) could still bring significant cost reductions.

Costs of solar and wind energy, and also electricity from biomass, show great learning rates. Costs have decreased rapidly because of new technological innovations and accumulated experiences within the industry when the sales of the systems have increased. The cumulative production of electricity from biomass is much greater than from solar and wind energy, but the costs have decreased more slowly.

The cost figures of bioenergy in Figure 3 do not refer to combined heat and power production which has presently much lower production costs in Scandinavian countries. CHP plants have a total efficiency of about 80%, whereas the efficiencies for conventional power-only production technologies are typically less than 35%. Other important cost factors within biomass-based power production are the capacity of the plant and of course the availability of low-cost biomass.

Finland can present long-term learning curves concerning the production and use of fuel peat. Since the late 1970's the cumulative production of fuel peat is 300 TWh, and the cost reductions of fuel have been remarkable (Fig. 4). Public RD&D investments have contributed to large energy research programmes in the field of peat production, and fuel producers and manufacturers have commercialized a wide variety of new harvesting methods and equipment.

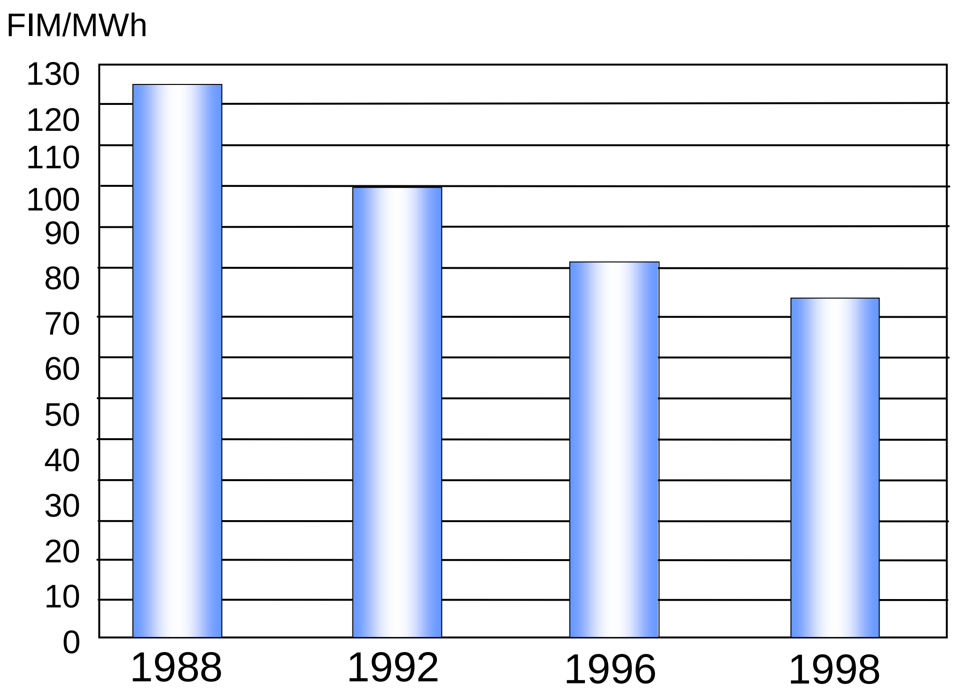

Figure 4. Production costs of fuel peat in Finland, years 1988–1998. 1 FIM = 0.17 €, 1 € = 5.94753 FIM.

Public funding of research, development and demonstration (RD&D) activities has been shown to be crucial to introduction of new technologies which have high risks for commercialization. Additionally, industry and public co-operation on RD&D is needed for a rapid commercialization of new technologies. Public funding is especially important in a transition phase when an established technology is replaced with a new one (Fig. 5).

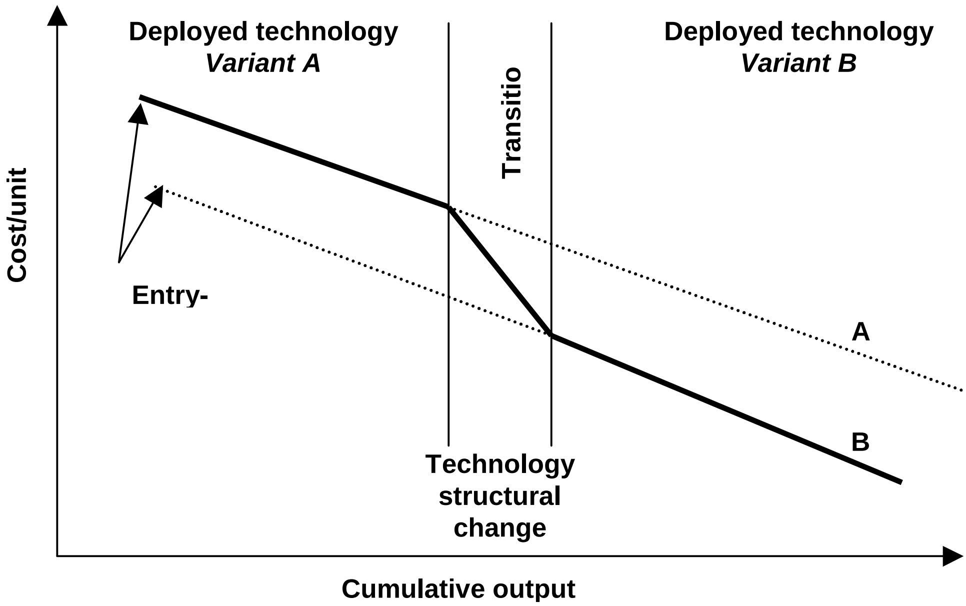

Figure 5. Technological structural change (IEA 2000).

3. Competitiveness of wood energy

Before the Wood Energy Technology Programme (1999–2003) was started in Finland, the main barriers of the increase of the energy use of forest chips were identified thoroughly. The main barriers included:

- High cost of forest chips
- Uneven and unpredictable variation of quality

- Low volume of production, and economy of scale is not fully benefited
- Uneven seasonal distribution of use at plants for heating purposes
- Unpreparedness of forestry organizations
- Shortage of experienced machine contractors.

The cost structures of different types of wood fuels were analyzed to focus the development efforts on key issues in view of cost reductions (Figure 5). Chipping and on-road transport to the plants are among the most important cost factors. Nevertheless, it was also observed that possible improvements should not be limited to incremental improvements of present systems or equipment but novel systems should also be created. Research projects of the technology programme were encouraged to have a broader perspective than an improvement of an existing chipper or other separate equipment.

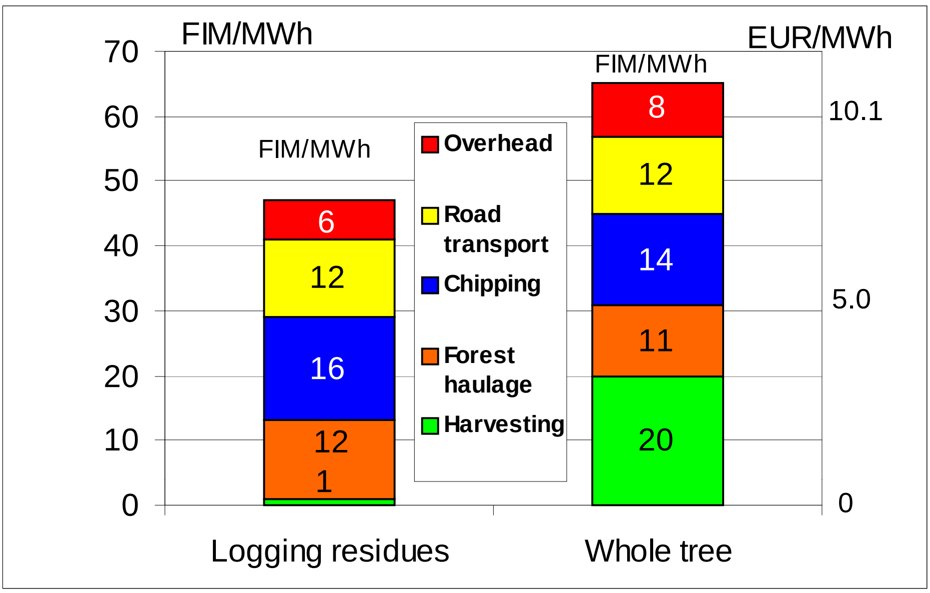

Figure 6. Cost structures of forest fuels.

Ways to further reduce the costs of chips were divided into the following categories:

- Integration of chip production (planning, harvesting, transportation, terminal operations) in the procurement of industrial wood
- Development of centralized fuel processing systems at terminals and at power plants
- Exploiting the existing infrastructure of peat production
- Development of on-road transport of forest fuels, both as chips and unchipped
- Development of the logistics of chip procurement (organizing, location of storage, handling of mixtures of several fuels in different production phases and at plants)
- Participation of self-employed forest owners in fuel production, especially from small-sized trees.

Integration of forest fuel production to other existing activities, such as the procurement of industrial wood and fuel peat, were assumed to give significant cost reductions. The recent cost reductions in the harvesting and transportation of conventional timber and fuel peat can then be fully exploited also in forest chip production. Integration gives the forest fuel procedures an opportunity to deploy existing equipment and procurement organizations, and profit from their experience and a larger scale of operations.

Recent cost reductions concerning forest fuels in Finland are presented by Pentti Hakkila and Ismo Nousiainen in this publication (p. 39–55).

4. Summary

The main barrier to the increased use of forest fuels has been and still is their poor economic competitiveness compared to fossil fuels, partly because the environmental and social benefits of wood energy are not taken into account. Therefore, further cost reductions are necessary. Experiences on intensive research, development and demonstration activities in the field of fuel peat, forest fuel and combined heat and power production (CHP) have shown in Finland that significant reductions are possible to obtain. In this process, close operation and networking of research organizations and industry, manufacturers, fuel producers and users, play an ever increasing role.

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Research on bioenergy in Sweden Present status and future plans

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Introduction

In 1998 the new energy policy decided by the Parliament in 1997 came into force. On the 1st of January a new national agency was established. The National Energy Administration, former NUTEK, is Sweden's national authority on issues regarding the supply and use of energy. The Administration was located in Eskilstuna (114 km west of Stockholm) as of September 1998.

The Administration's main task is to promote a safe, efficient and environmentally sustainable supply and use of energy. It does so by supporting research on renewable energy sources and technology procurement of energy-efficient products and by providing investment support for the development of renewable energy. The Administration also serves a supervising function as monitoring authority of the recently deregulated electricity market. The Department for Structural and Market Analysis provides analyses of the linkages between energy, the environment and economic growth. The annual turnover is SEK 1 billion (0.11 billion €) and the number of employees is approximately 160.

An energy research, development and demonstration programme aimed at an ecologically sustainable energy system was initiated on 1 January 1998 with an allocation of SEK 2 310 million (260 million €) over a seven-year period. The Swedish National Energy Administration is responsible for the implementation of the main part of the programme.

The total funding for energy research, development and demonstration in Sweden is SEK 2 500 million (287.7 million €) per year (1997). The sources of the funding are about one-third each from government, electricity companies and other industry, respectively.

1. Biofuels

Just over 15% of Sweden's total primary energy supply is classified as biofuels. During 1997, use of biofuels (principally wood and forest product residues such as black liquors, bark and sawdust) and peat amounted to about 8 Mtoe of which about 5 Mtoe is used internally in the forest industry for heat and some electricity production. Single-family houses use a stable 1 Mtoe off-forest fuels. In the district heating sector the use of biofuels and peat has almost doubled to about 2.2 Mtoe over the five years to 1997. Biofuels now meet more than 50% of the supply to the district heating grids. Wood fuels meet the main part of the market growth. Reducing costs of biofuels was established explicitly as an important objective in the 1997 energy policy legislation.

Use of biofuels for heat production is promoted by taxes on fossil fuels. Biofuels in CHP are promoted by investment aid. Investment subsidies for district heating grids indirectly promote the use of biofuels.

1.1 Present status of the energy administrations research related to forest fuels

At present the Swedish National Energy Administration run four research programmes closely linked to the production and capture of forest fuel:

System studies bioenergy (7 million SEK (0.8 million €) / year)

The programme runs between year 1998 and 2001. The major goal of the programme is to identify barriers within the bioenergy system and try to develop solutions that will bypass the barriers. So far promising development on techniques to compress harvest residuals and techniques to capture forest residuals in early thinnings have been studied. Life Cycle Assessment models evaluating bioenergy systems has also been created.

Drying of Biofuels (3 million SEK (0.34 million €) / year)

The programme runs between year 1996 and 2000. No continuation is planned due to lack of financing from external stakeholders. The programme aims at increase the knowledge of forced drying of biofuels. The programme has financed LCA-studies, studies on the optimisation of the drying process as well as fire and risk assessments.

Carbon Balances (5 million SEK (0.57 million €) / year)

The programme runs between year 2000 and 2004. The major goal is to contribute to the basis for a ”climate efficient” forestry and to a Swedish climate strategy. The programme has focused on the flux of CO2 on forestland. The programme also support studies of methane fluxes and the underlying processes of the CO2 fluxes.

Biofuels and the environment (8 million SEK (0.92 million €) / year)

The programme runs between year 2000 and 2004. The programme is a continuation of a more basic research programme. The goal of this second phase is to give authorities (Energy, Forestry and Environmental) as well as the industry a research supported basis for how to produce and use biofuels in a sustainable way. Focus is ash-circulation, intense “fuel” forestry and bio-diversity.

1.2 Future plans

Issues for the coming years will among others be:

System development

In spite the fact that the individual parts and actors of the bioenergy system may functioning efficient the competitiveness of bioenergy is judged by the system efficiency. It is a challenge in the coming year to promote the technical and economical development of the whole bioenergy system. The development will deal with logistics, environmental and logistic management systems, incentive structure etc.

Greenhouse gas and sustainability dimension of forest fuels

We need to very clearly establish the sustainability of the present use of forest fuel, but also demonstrate a possible sustainable intense production and use of forest fuels. This system may include a number of captures of forest fuels within one tree generation and include ash circulation as well as fertilising.

The forest fuel systems need also to be adjusted in order to preserve or enhance the carbon sequestration in the forest ecosystem.

Research co-operation with other countries

To be able to reach a critical mass of forest fuel research enlarged and deepened co-operation between the influential forest fuel countries seem increasingly attractive. The co-operation may include joint research programmes with regional calls for research projects. Co-ordination of research strategies with different countries focusing on different aspects of forest fuels may also be an attractive solution. The co-operating countries may co-ordinated their representation in the European Union and other institutions as well as jointly carried out analysis and reports.

European dimension of forest fuels

The forest fuel sector is not any longer a closed and national sector. To an increased extent forest fuel production and use is affected by the European Union in terms of standards, regulations, tax structures as well as European research programmes.

The forest fuel research must consider and relate to existing and planed international standards, regulation and tax structures. The ongoing and planned research will at times also be more or less directly connected to the political process. The research efforts therefore need in though competition with other renewables to promote forest fuel so that it will become a front runner in the conversion of the European energy system towards sustainability.

1.3 Other Swedish financiers

Below you find a list (not comprehensive) of a number of influential financiers of bioenergy research in Sweden.

Elforsk

Association of Swedish Power Producers), Sveriges Elleverantörer (The Swedish Electricity Suppliers) and Svenska Kraftnät (The Swedish National Grid).

Total funding for research and development from the electricity companies is SEK 700–800 million (80–92 million €) per year, of which SEK 100 million (11.5 million €) is spent through Elforsk. The total Elforsk funding, including Government contributions and other co-financing, amounts to SEK 220 million (25.3 million €) per year.

Elforsk's activities are organised in five programme areas, Hydropower, Thermal Power and Renewables, Transmission and Distribution, Utilisation, and Strategies and Systems. Projects on safety and environment issues are integrated in all the programme areas. Elforsk is not involved in work on nuclear power.

Värmeforsk

Värmeforsk is the co-operative body of the Swedish energy, process and manufacturing industry and of energy consultants for research and development of heat technology. Värmeforsk AB finances research programmes on construction technology, combustion technology and environment, materials, forest industry, and modern process control systems. Elforsk AB is responsible for the administration of Värmeforsk. The total annual budget of the Värmeforsk research, development and demonstration programmes is about SKr 27 million per year of which the Swedish National Energy Administration co-finances 40%.

MISTRA

The Swedish Foundation for Strategic Environmental Research , MISTRA, was established in January 1994 with a capital of SEK 2.5 billion (0.29 billion €). The capital in 1998 was close to SEK 4 billion (0.46 billion €). The income earned on the capital is used to support strategic environmental research.

MISTRA's budget for activities in 1998 amounts to SEK 300 million (34.5 million €). MISTRA supports strategic environmental research, i.e., research with a long-term perspective directed towards solving major environmental problems, and to the sustainable development of society.

Pulp and Paper Industry Institute

The Swedish Pulp and Paper Research Institute (STFI) is an institute for the development of the Swedish paper and pulp industry. The industry is highly energy intensive in all process steps. Energy related research has been organised in a programme over a period of three years, co-financed by STFI and the Swedish National Energy Administration. The programme ends in 1999, and discussions about future activities are currently under way.

Swedish District Heating Association

The Swedish District Heating Association promotes district heating and district cooling related research and development. Most district heating enterprises are members of the organisation. It is responsible for a main part of the industry research and development. The programme, focusing on hot water technology, comprises distribution technology, district heating central technology, measurement technology and systems technology. It covers research at universities as well as problem-oriented research. The Swedish National Energy Administration is co-financing these activities.

Energy Systems Studies

The programme is a Swedish National Energy Administration programme and aims at contributing to an ecologically and economically sustainable energy system. The programme is intended to describe and explain how the energy system functions and is affected by man, society, technology and environment. SEK 10 million (1.1 million €) per year, has been allocated to this programme over a period of three years.

Renewable energy – the Danish case pictured by policy, biomass and wind

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1. Policy

The main objective of the first Danish energy plan, Danish Energy Policy 1976, was to safeguard Denmark against supply crises.

The next plan, Energy Plan 81, continued to focus on limiting the national dependence on imported oil and due to the increasing unemployment rates high priority was given to socio-economic considerations. The plan boosted the development of the oil and gas fields in the North Sea considerably, and the nation-wide natural gas network was established. Following Energy Plan 81, the first subsidy schemes aimed at the exploitation of straw and chips were introduced, and biomass became a competitive fuel through increasing taxation of fossil fuels. The first chip-fired district heating plants were built and the consumption of wood-chips, straw and firewood in individual dwellings rose markedly.

The third energy plan, Energy 2000, is from 1990 and gives high priorities to environmental considerations. The plan is an ambitious attempt to increase the use of environmentally desirable fuels.

The fourth and latest plan, Energy 21, was introduced in 1996. A long-term objective in this plan requires that CO_2 emissions must be halved in 2030 compared with 1998. The CO_2 objective shall be achieved through energy savings, better exploitation of the energy resources and contributions from renewable energy sources amounting to 35 per cent of the gross energy consumption in 2030. Energy 21 assumes that renewable energy covers 12–14 percent of the country´s total energy consumption in 2005. The majority of this contribution is to come from wind power and biomass.

1.1 Legislation

In order to implement the activities suggested in Energy 2000 the Danish parliament passed the Heat Supply Act in 1990. This act gave the Minister of Energy wide powers to control the choice of fuel at district heating plants and decentralised CHP plants.

On the basis of this act a number of coal fired district-heating plants have been converted to natural gas-fired, decentralised CHP generation. In addition, some small district-heating plants not connected to the large district heating networks have been converted to use biofuels.

The Heat Supply Act was followed by two acts offering the prospective of subsidising the process of conversion to environmentally more desirable fuels. The two acts in question are:

- "State-Subsidised Promotion of Decentralised Combined Heat and Power and Utilisation of Biomass Fuels Act".

- Under this act, it is possible to grant subsidies of up to 50 per cent of the construction costs. In practice, subsidies have typically been in the range of 20–30 per cent of the construction costs.

- "State-Subsidised Electrical Power Generation Act", under which a subsidy of DKK 0.17 (€ 0.02) per kWh is granted for electrical power generation based on straw and chips. In addition the CO_2 tax of DKK 0.10 (0.013 €) per kWh is refunded in case of renewable energy, so actually private producers of electricity based on renewable energy receive a total subsidy of DKK 0.27 (€ 0.034) per kWh.

1.2 The Biomass Agreement

In 1993 the Danish Parliament made an agreement concerning increased use of biomass in the energy supply sector. A vital element of the agreement stipulates that the centralised electrical power utilities are obliged to buy 1,4 million tonnes of biomass per year including between 200 000 and 400 000 tonnes of wood chips and 1,0–1,2 million tonnes of straw. Originally, the aim should have been met in 2000, but under a new supplementary agreement from 2000 the time limit is extended to year 2005.

1.3 The electrical power reform

In 1993 the Danish Parliament made a framework agreement concerning an overall law reform for the electrical power sector. This reform ensures that the market for sale of electrical power will be opened completely by the end of 2002.

In order to ensure the competitiveness of renewable energy sources, a special market for “eco-friendly” electrical power will be opened at the same time in Denmark. The idea of the system is that a number of “eco-friendly” certificates corresponding to the electrical power generation for a certain period of time is awarded to e.g. biogas plants. The individual biogas plant can then sell power on the free market for electrical power while selling the certificates on a special market for “eco-friendly electrical power”.

The eco-friendly power is so called “high priority power”. This means that operators generating it have a guarantee that they can sell their product, even if there is a surplus of electrical power.

Consumers will be obliged to buy a certain amount of eco-friendly electrical power each year, but in practice the demand for the eco-friendly certificates will be found among the electrical power companies and parts of industry.

Thus, the certificates will replace the current system with grants for generation of electrical power at renewable energy plants. The purpose is to increase competition between the individual producers and renewable technologies. Wind turbines will be able to compete in this market, but it may be hard for expensive new technologies such as gasification of biomass, Stirling engines and the like.

In order to ensure appropriate development of these technologies, it will still be possible to award subsidies for research, development and construction. In addition, the authorities are considering the possibility of paying a supplementary price per kWh generated to less competitive technologies – at least for a certain period of time.

The final lay out of the market for eco-friendly electricity will be decided upon in this year.

2. Biomass

The export value of Danish biomass technology and know how in 1998 is approximately 0.7 billion Danish crowns (100 millions €) distributed on ovens for firewood 300 millions Danish crowns and CPH technology, chippers and the like 400 millions Danish crowns.

2.1 Wood

In Denmark an estimated 700 000 m^3 of solid content firewood is produced every year, approximately 400 000 m^3 of which comes from forestry. The rest comes from wood industry, gardens, parks and the like.

Wood chips are mainly produced in conifer thinning and only to a lesser extent on clear felling areas. In Denmark the importance of chips as a fuel has continued to increase over the past 20 years, and today approximately 300 000 m^3 solid fuel wood are produced each year.

All together wood chips and firewood constitutes 35 per cent of yearly total Danish cut, and it is expected to grow to 40 percent in two to three years time.

Chip production equipment has been improved considerably in recent years, but logistics are still a problem in Danish forest chip production. The absolutely predominant part of the Danish harvesting of wood chips is obtained by thinning in immature stands. In practice, the thinning trees are felled during winter (in order to reduce the danger of stump infection by fungus) and hence dry at the place of felling for four to six month. By this method, the following is achieved:

- Evaporation of approximately 50 percent of the moisture content of the trees.

- Shedding of needles and a number of thin branches before the trees are fed into the chipper.

The chipping is done on strip roads in the stand. The off-road hauling is done by a tractor equipped with a high tipping trailer following the chipper thereby enabling it to continue chipping while the tractor carries the chips to the roadside. Road transport is normally done by means of container trucks which with a container on the tractor and one on the trailer can transport approximately 80 m^3 loose volume at a time.

The total operation: The chipping, the off-road hauling, the loading in containers and the trucking must run smoothly without delays or break downs in any of the involved sub-operations. Logistics are hence difficult and research efforts to solve this problem are done.

Chipping of whole trees involves an increased use of the forest ecosystem compared to conventional timber harvesting. This may have consequences connected with the following two aspects:

- Chipping increases the removal of plant nutrients from the area, since a major proportion of the nutrient-rich parts (needles, branches, and bark) are removed.

- A great proportion of organic material is removed, which may reduce the humus content of the soil and thereby its capacity to support wood production.

Wood pellets are made on the basis of wood waste from industry. Production levels have reached 200 00 tonnes per year, but the market is growing rapidly.

Today Denmark has a wide wood pellet distribution network, which has grown after several large oil companies have entered the market.

2.2 Straw

Only 1 million tonnes of the straw produced in Denmark (7 million tonnes) is used for energy purposes. Straw is more difficult to process than wood because there is a higher risk of corrosion and slagging problems. On the other hand, the price is normally lower than the price for chips and wood pellets.

The use of straw at CHP plants is expected to increase particularly much in the years to come, as the electrical power companies are obliged to buy at least 1 million tonnes of straw per year as from 2005.

The development in the number of straw- and wood chip-fired district heating plants in Denmark between 1981 and 2000 has resulted in a total number of 120 plants. The number of straw-fired plants has levelled out, but the number of chip-fired plants is still increasing.

2.3 Energy crops

So far, the growing of special crops for energy generation purposes has been unattractive due to (1) to small yields combined with to high growing and harvesting costs (2) the large excess amount of straw and chips.

3. Wind

Danish wind turbines have a market share of half the world market with a turnover of some 12 billion Danish crowns (1.5 billion €). 83% export 1994–1999 the wind industry has been growing at a rate of some 40 per cent per annum, and growth rates around 20 percent per year are foreseen for the first decade of the new century.

3.1 History

A major reason behind the leading Danish role in manufacturing modern wind turbines is a long historical tradition. In Denmark is the use of wind energy for electricity generation 100 years old. In the 1890s **Poul la Cour,** a meteorologist, inventor, and folk high school principal, started experiments converting classical windmills to DC electricity generation. In aerodynamics la Cour pioneered the use of an electrical operated wind tunnel and patented a mechanical device to stabilise the torque (power output) of wind turbines.

La Cour gave courses in wind energy for Danish “wind electricians”. Some old students later built a number of both two-and three-bladed wind turbines for the F.L.Smidth engineering company, mostly during World War II.

After World War II the interest in wind energy waned. But in the early 1950s a retired chief engineer, **Johannes Juul,** took up his old interest in wind energy, acquired during one of la Cour´s courses in 1903. Juul built a number of experimental machines and was the first to connect a wind turbine with an AC generator to the electrical grid.

1956 Juul built the 200 kW Gedser wind turbine, which became a pioneering design for modern wind turbines. The Gedser machine ran without any major maintenance for 11 years, and acted later as test machine for NASA, which needed measurement results for a new ambitious U.S. programme for construction of large wind turbines. To day it has become a museum piece in the Danish Electricity Museum.

3.2 Present day industry

The present day Danish wind energy industry had a rather humble infancy in the 1970s. Technical interested people, who based their designs on scaled down versions of the Gedser machine, pioneered most projects. The maximum power output was 10–15 kilowatts. There was a considerable interest in these designs, so one of the pioneers, **Riisager,** managed eventually to build a series of some 30 machines.

Having noticed the success of companies like Riisager´s, some manufacturers of agricultural machinery (e.g. Vestas, Nordtank, Bonus, and later Micon) quickly realised the commercial possibilities of the rapidly growing turbine manufacturing sector. With their superior engineering knowledge, these companies quickly came to dominate the Danish wind turbine market, and later the world market. Today, these companies are all on the "top ten" list of manufacturers world-wide.

In 1999 the Danish wind turbine companies supplied turbines with a rated capacity of some 2240 megawatts, equivalent to two large nuclear or coal-fired power stations per year.

Wind energy today covers 12 per cent of Danish electricity consumption. In the latest scenario (1996) the Danish Ministry of the Environment and Energy has set a target of 16 per cent by 2003 and the long term targets are set even higher (40–50 per cent).

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Forest chips in Finland – use, experiences and prices

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1. The first appearance of fuel chips in the 1950s

During and right after World War II, practically no fuel other than wood was available in Finland. Procurement of firewood for space heating in rural and urban areas, industrial purposes and vehicle fuel was a critical and extremely demanding task. The consumption of traditional firewood exceeded 20 million m^3 solid per annum, providing employment to some 130 000 cutters and 125 000 horse drivers during the winter season.

When oil again became available, the use of firewood started to decrease radically, as the production and use of traditional firewood required a great deal of manual labor. Unfortunately, there was virtually no alternative use for the hardwood growth of 12 million m^3 solid/a, which did not meet the quality requirements for saw and veneer logs.

The decline in fuelwood use endangered the management of young forests, since the demand for small-sized wood is an essential precondition of silvicultural thinnings. Small-sized wood was to be made more attractive as a fuel through automation of handling. Consequently, a large-scale research and development programme was launched in the mid-1950s. The efforts were focused on fuel chips, a new and rather unknown concept.

Unbarked sawmill slabs, small under-sized softwood stems, and hardwood that did not meet the quality requirements for saw or veneer logs were potential sources of fuel chips. Since no technology existed on the production of chemical pulp from birchwood, excellent raw material was abundantly available for chipping. However, feeding systems for boilers were underdeveloped and required chips of high quality. Stems had to be carefully delimbed by hand and stored for drying before size reduction. Chipping was carried out with light farm tractor-driven equipment. Since hydraulic cranes did not yet exist, feeding of wood to chippers took place by hand. The scale of operations was small with transport distances from the forest to plant typically less than 30 km.

The peak use was achieved in 1963, when the number of chip-fired boilers in Finland was about 400. The consumption of chips was some 150 000 m^3 solid per annum, a half of which was produced by Vapo (the State Fuel Centre). Among the largest users were several garrisons of the Finnish Defence Forces whose main motive was the development of technology for domestic fuels for conditions of crisis.

Cheap oil and the simultaneous broadening of the raw material base of the pulp industries to birch wood broke the basis of fuel chip business in the mid-1960s. The production and development of chipping equipment stopped, and it became difficult to find funding for research. The use of chips thus collapsed because:

- The price of oil decreased radically

- Particle board and fiberboard mills were built which used small-sized wood

- Birch wood and sawmill slabs became sought-after raw material for sulfate pulp.

2. Temporary revival of interest in the 1980s

By 1970 a large number of chip-fired boilers had been replaced or converted for the use of oil. Fortunately, the Defence Forces had continued to use fuel chips to maintain the know-how. Other than a number of garrisons and farms, only a few chip-fired boilers remained. The technology was preserved, but development had stagnated.

Two subsequent global energy crises first quadrupled the price of oil in 1973–1974 and still doubled it in 1978–1979. Even worse, the availability of oil was no longer secure. The Government of Finland developed its first energy policy programme, the main goal of which was to secure the availability of energy in accordance with the needs of national safety and commercial and industrial life. Principal means of the policy were the conservation and promotion of national energy self-sufficiency.

The main achievement of the programme was sophisticated technology for large-scale energy production from peat fuel. This part of the programme was so successful that Finland became a world leader in peat technology. In addition, the use of fuel chips revived, although peat was a considerably cheaper fuel when available.

At this time the equipment employed for the harvesting and trucking of conventional timber was now far more advanced and efficient than 20 years before. Farm tractors had been largely replaced by forest tractors equipped with hydraulic cranes. Chippers had become heavier and were also equipped with hydraulic cranes. These developments were of great importance since it now was possible to feed undelimbed trees and even logging residues into chippers. Delimbed material could be replaced by cheaper sources of biomass. The cost of production was reduced, but the quality of chips suffered.

The technology of fuel chip production developed greatly. Forwarder-mounted terrain chippers and truck-mounted landing chippers were introduced, and the off-road transport of logging residues was solved with forwarders. However, bunching of logging residues to facilitate the loading of forwarders or feeding of terrain chippers remained a problem.

Due to investment aid for heating plants and the reduction of chip costs, the use of forest chips started to rise in the early 1980s. In 1982, altogether 102 heating plants of 0.5–10 MW capacity, 13 heating plants of over 10 MW capacity, and thousands of farms were using forest chips. A typical size of a forest chip-fired plant was 2–3 MW. Among the users were 60 district heating plants, 17 garrisons, 9 school buildings, 8 industrial plants, 5 hospitals, and 4 dairies. A common economic problem was under-utilization of capacity, especially during the summer season.

In 1982, the consumption of forest chips by the above mentioned 115 heating plants was 393 000 m^3 solid. In addition, the forest industries used 126 000 m^3 solid forest chips for fuel and another 127 000 m^3 for the production of sulfate pulp and particle boards. The total output of commercial forest chips, farm use excluded, was thus 646 000 m^3. Vapo, local forest management associations and the forest industries were the major producers.

The primary source of forest chips was unmerchantable small-sized trees, either delimbed or undelimbed. As the consumption of fuel chips increased, the forest industries occasionally felt concerned about the possible use of good quality pulpwood as fuel. In reality, the primary source of forest chips was under-sized trees with or without branches, and only Vapo still reduced a major proportion of its chips from pulpwood-sized hardwood. The use of chips from logging residues occurred on a very small scale, and it was only restricted to the forest industries.

The growth was limited primarily by the high cost of production: 60 FIM/MWh (10 €/MWh) at the plant for chips from logging residues, 70–80 FIM/MWh (11.8–13.5 €/MWh) for whole-tree chips and 80–90 FIM/MWh (13.5–15.1 €/MWh) for chips from delimbed stems. The nominal prices paid in the early 1980's were actually higher than those paid for similar chips two decades later.

The success of forest chips was largely dependent on the high oil price. When the oil price started to decline, forest chips were no longer competitive. As the availability of oil seemed to be secured again, the Government and industry interest faded. Even the Defence Forces, who had been using fuel chips for more than 20 years to maintain technical know-how, substituted cheaper oil for chips by the end of the 1980s. The use of forest chips for fuel was reduced to about one third of the level of 1982. The use of whole-tree chips as industrial raw material was stopped completely due to quality and cost reasons. Chip contractors could not employ their equipment and skills, and machine manufacturers could no longer find markets for their products.

3. New coming of forest chips in the 1990's

By the early 1990's, the use of forest chips had shrunk to about 180 000 m^3, i.e. one third of the record level ten years previously. The future looked almost hopeless, until the society interest gradually increased once again. This time the development had very little to do with the price of oil. It was a result of epochal changes in economic life and, on the other hand, an alarming global climate change:

- The annual increment of Finnish forests had improved exceeding the consumption of timber by 15–20 million m^3 solid. The demand for small-sized wood was insufficient and the thinning targets of young plantations could not be met.

- Rapid mechanization of cutting work with single-grip harvesters resulted in severe unemployment for forest workers. A harvester replaced ten chainsaw operators, who could not find compensating work in the forests or elsewhere.

- The CO_2 emissions from fossil fuels were found to warm up the global climate. Mitigating this harmful greenhouse effect required limiting the use of fossil fuels and replacement of them with renewable energy sources.

In this situation the Ministry of Trade and Industry started to advance the use of wood and peat for energy. The importance of wood energy in the national economy and management of environment was recognized, and the use of forest chips slowly started to rise again. In 1995 the total use of forest chips for fuel was 260 000 m^3 solid.

It was of utmost importance that the forest industries took up a very positive attitude and an active role in the development. This made it possible to integrate the procurement of industrial timber and fuel chips, so as to reduce the costs and improve the logistics and reliability of operations. However, this development meant a shift of interest from small-sized thinning wood to logging residues from final harvest. Consequently, benefits to the management of young forests and employment were reduced, but it became possible to decrease the cost of chips through fully mechanized procurement systems. Behind the favorable cost development of fuel chips from logging residues are the following facts:

- As long as timber was cut motor-manually, bunching of residues was not possible. Cutting of timber from regeneration areas was mechanized in the late 1980's and early 1990's with one-grip harvesters. The working techniques of a harvester can be adapted for bunching the logging slash at a low cost.

- Due to technical development and competition between forest machine enterprises, the logging cost of conventional industrial timber was reduced by over 20% and trucking cost by almost 30% during the first half of the 1990s. This general trend was reflected in the cost of chip production from logging residues, as the same machine entrepreneurs and organizations were responsible for the procurement of timber and fuel chips.

- Research and development of new technology was once again active. The Ministry of Trade and Industry and Tekes carried out the massive Bioenergy Research Programme from 1993–1998.

- The increased use of forest chips by forest industries and power plants made it possible to employ efficient equipment and systems.

- Procurement logistics was improved through integration of operations and the learning process.

The Bioenergy Research Programme was followed by the Wood Energy Technology Programme of Tekes (National Technology Agency) in 1999, coordinated by Finntech Finnish Technology Ltd Oy and VTT Energy. The goal of this ongoing five-year programme is to help to raise the use of forest chips to 2.5 million m^3 solid by 2003 (Figure 1). In the long term, the Action Plan for Renewable Energy Sources of the Ministry of Trade and Industry aims to raise the annual production of forest chips to about 5.2 million m^3 by 2010. The goal of the National Forestry Programme approved by the Government of Finland is 4–4.5 million m^3 solid forest chips by 2010.

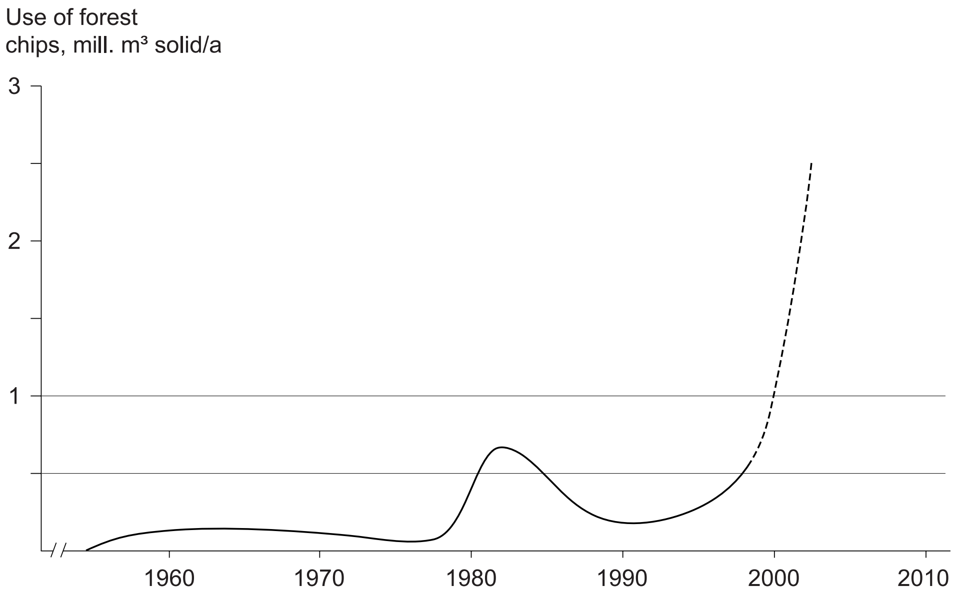

Figure 1. The use of forest chips in Finland in 1960–1999 and the goal (dashed line) for 2003 of the Wood Energy Technology Programme.

4. The present use of forest chips

The Finnish Statistical Yearbook of Forestry provides a comprehensive annual overview of wood consumption in the country. However, the statistics ignore the use of forest chips which are composed mainly of residual stemwood and crown mass being used primarily by a large number of heterogeneous plants outside the traditional forest sector.

The Wood Energy Technology Programme is currently surveying the use of forest chips in Finland in 1999. The first stage of the study was to list the users and their addresses. The number of users is growing, but concurrently some plants may stop burning forest chips for various reasons. No up-to-date list of users currently exists.

The user list was collected initially from the existing data bases of VTT Energy and the Finnish Forest Research Institute and completed through telephone interviews with 250 local Forest Management Associations and other relevant actors. Valuable information about forest chip-fired plants was received from all the major chip producers other than Vapo. Plants whose annual use of forest chips was more than 250 m^3 solid (625 m^3 loose), independently of the size of the plant, were included. Altogether, 150 such plants were identified.

The survey does not include small-scale use in farms and buildings. Neither does it include the operations of small heat enterprises, the number of which was estimated by the Work Efficiency Institute at about 80, the average size of chip boiler being 0.3 MW. It is roughly estimated that these missing small-scale users consumed some 180 000 m^3 solid of forest chips in 1999.

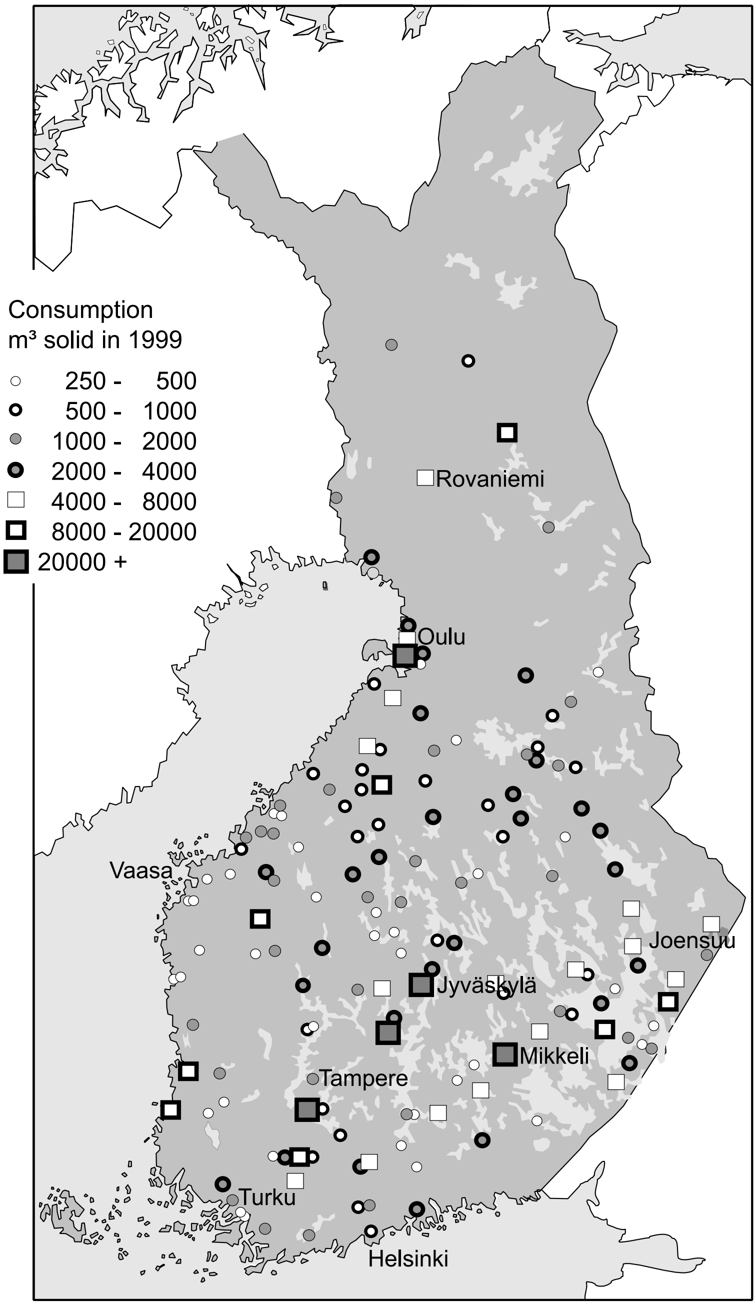

Figure 2. The location of forest chip-fired heating and power plants in Finland in 1999. Minimum use of a plant 250 m³ solid per annum.

Few consumers exist in the sparsely populated northern half of Finland. In the southern half of the country they are widely spread and rather evenly distributed (Figure 2). However, as forest biomass is available abundantly, forest chips are typically harvested from within a short radius of the plant, leaving a large part of the forests even in the south in a zero zone with regards to forest chip demand. The consumption is shown in Table 1.

Table 1. Consumption of forest chips in Finland in 1999.

	Use of forest chips	
	m^3 solid/a	%
Heating plants	273 000	36
CHP plants:		
- Forest industries	109 000	15
- Other CHP plants	185 000	25
Plants using more than 250 m^3/a, total	567 000	76
Estimated small-scale use	180 000	24
Total	747 000	100

Heating and power plants and forest industries combust forest chips typically mixed with other fuels such as peat, wood and bark residues from forest industries, and coal. The forest chip-fired heating and CHP plants (forest industries excluded) actually produced more heat from industrial wood and bark residues. In fact, forest chips consisted only one fourth of their total use of wood-based fuels. An even more important source of energy for them was peat. Therefore, mixing and cofiring of forest chips with other solid fuels play an important role in the Wood Energy Technology Programme.

In Figure 3 the results of the 1999 survey are compared with an earlier study by the Finnish Forest Research Institute. The total consumption (small-scale excluded) had doubled in four years from 258 000 m^3 solid to 567 000 m^3 solid. It is important to notice that the growth was based primarily on chips from logging residues. In addition, some growth occurred in the category of other wood sources, which contains mainly chips made from rotten spruce from southern Finland or residual stemwood from Russia. Practically no growth took place in chips reduced from small-sized trees, but a remarkable shift from delimbed stems to whole trees occurred inside this category.

The majority of ongoing research projects deals with technology designed for logging residues from final harvest rather than small trees from young stands. This is because the principal fund raiser, the forest industries, is interested mainly in the logging residues due to their lower cost of harvesting and flexible integration in the procurement logistics of conventional timber. Although the production of fuel chips from small trees in young thinning stands enjoys substantial financial support from the society, the cost tends to remain too high to make them a competitive fuel. To improve the effectiveness of small-tree chipping as a silvicultural tool, research on small-tree technology should be strengthened.

5. The price of forest chips

In the survey, the present users were asked to name the technical and economic barriers preventing them from increasing the share of forest chips in their fuel palette. The barriers were in order of importance as follows:

1. High cost of chips
2. Lack of procurement organization or insecurity of deliveries
3. Technical problems of reception and handling of chips at the plant
4. Insufficient boiler efficiency
5. Unsatisfactory quality of chips.

Although the Government's taxation policy favors renewable sources of energy such as forest chips, by far the most important barrier for all users continues to be the high cost of chips. Therefore, most of the present projects aim to research procurement cost reductions, either directly or indirectly.

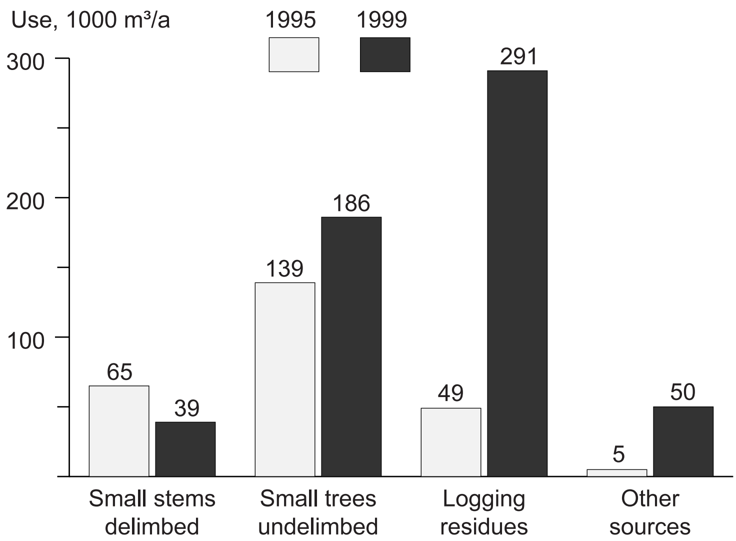

Figure 3. The sources of forest chips in 1995 and 1999. Small-scale use excluded.

Unlike in Sweden, Finland does not have a permanent system for monitoring the price development of forest chips, but a comprehensive study of prices has been performed earlier for the years 1982, 1995 and now for 1999. Figure 4 shows that not only real but even nominal prices have radically decreased in the last two decades: the average price of forest chips at heating plants (forest industries and large CHP plants excluded) was 85 FIM/MWh (14.3 €/MWh) in 1982 but only 66 FIM/MWh (11.1 €/MWh) in 1995 and 53 FIM/MWh (8.4 €/MWh) in 1999. This favorable trend is a result of the following factors:

- Development of logging and transport equipment and procurement systems

- Development of procurement logistics through education and experience

- Growth of the scale of operations

- Shift from more expensive delimbed stems to cheaper whole trees and further to logging residues as the source of fuel.

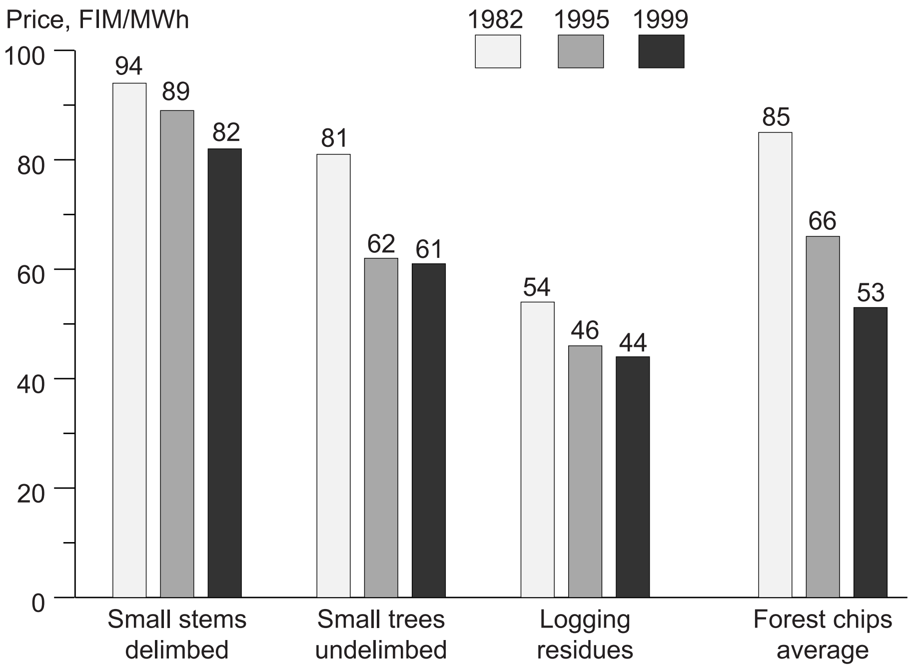

Figure 4. The development of the prices of forest chips at heating plants. VAT excluded. (1 FIM/MWh = 0.17 €/MWh.)

Price differences between the various types of solid wood fuels started to level out during the second half of the 1990s. The price of bark and saw dust increased as a result of increased demand, and the price of chips from delimbed stems decreased due to reduced demand. The prices of chips from whole trees and logging residues seemed to decrease slightly, but the change was not significant (Table 2). It is obvious that further price reductions will be slow, particularly because the average trucking distances will grow, profitability of the forest machine and truck enterprises is poor, and land owners have stumpage expectations.

Table 2. Average prices of wood fuels paid by heating plants in 1995 and 1999. VAT excluded.

Source	1995		1999		Change
	FIM/MWh	€/MWh	FIM/MWh	€/MWh	%
Industrial residues:					
Bark	32	5.4	38	6.4	+19
Sawdust	33	5.6	36	6.1	+11
Chips	44	7.4	43	7.2	-2
Forest biomass:					
Delimbed stems	89	15.0	82	13.8	-8
Whole trees	62	10.4	61	10.3	-2
Small trees, average	88	14.8	65	10.9	-26
Logging residues	46	7.7	44	7.4	-4
Forest chips, average	64	10.8	53	8.9	-17

Heating plants less than 10 MW in size still prefer chips to small sized trees. This is partly a result of municipal ownership, as the municipalities give a strong emphasis towards social impacts such as job opportunities and silvicultural benefits. Small-tree chips are also thought to be of better quality which is especially important for small plants: they are generally drier, they contain less foliage and they have a more even particle size distribution. Unfortunately, this means higher priced chips. For 0.5–1 MW heating plants the average price of chips was 73 FIM/MWh (12.3 €/MWh) , whereas for over 10 MW plants the price was only 48 FIM/MWh (8.1 €/MWh) (Table 3). The price paid by the forest industries and large power plants was not studied in this respect, but it is estimated that the total value of commercial forest chips used in Finland in 1999 was FIM 55–60 million (9.3–10.1 million €) (small-scale use excluded).

Table 3. The source and average price (VAT excluded) of forest chips of heating plants by size class in 1999.

Source of forest chips	0.5–1	1–5	5–10	10+	Forest industries
	Plant size, MW				
	Proportion, %				
Delimbed stems	60	16	15	17	0
Whole trees	33	54	82	33	10
Logging residues	3	15	3	48	90
Other	4	15	0	2	?
Total	100	100	100	100	100
	Price, FIM/MWh (€/MWh)				
All forest chips	73 (12.3)	58 (9.8)	53 (8.9)	48 (8.1)	?

Small plants also suffer from another disadvantage compared to the large CHP plants. Their demand for heat fluctuates seasonally, and their overall annual efficiency is somewhat weaker. However, the efficiency has increased due to improved equipment, experience and quality control of chips (Figure 5).

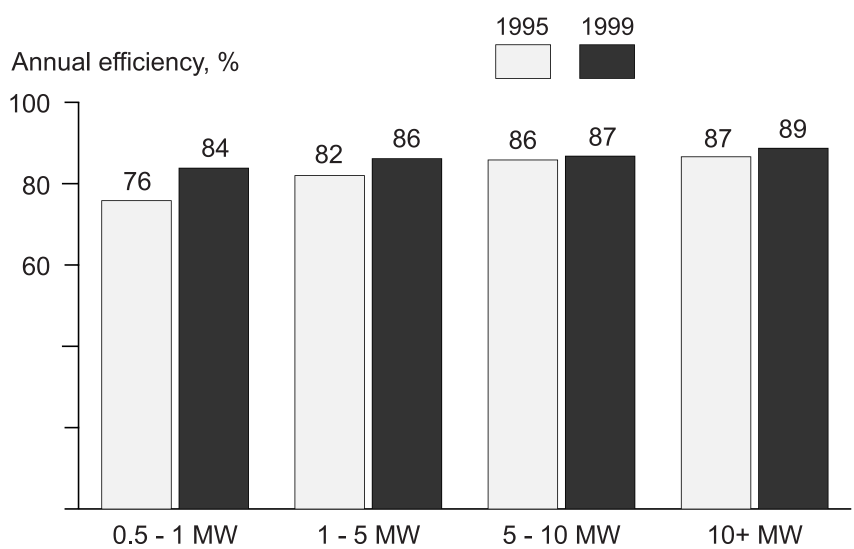

Figure 5. The annual efficiency of forest chip fired heating plants in 1995 and 1999 by size class.

The quality of chips is a cost factor, since good and even quality means better heating value, better efficiency in combustion and reliable operation. The most important quality factor of forest chips is the moisture content which affects the heating value of fuel and the efficiency of combustion. A problem is that the moisture content of chips is highest during mid-winter when the peak demand for heat is highest. In 1999, the monthly average moisture content of forest chips used by heating plants was quite satisfactory at 41% (Figure 6). However, the good result was partly a result of a very dry summer. Furthermore, the moisture content was higher in forest chips used by the forest industries.

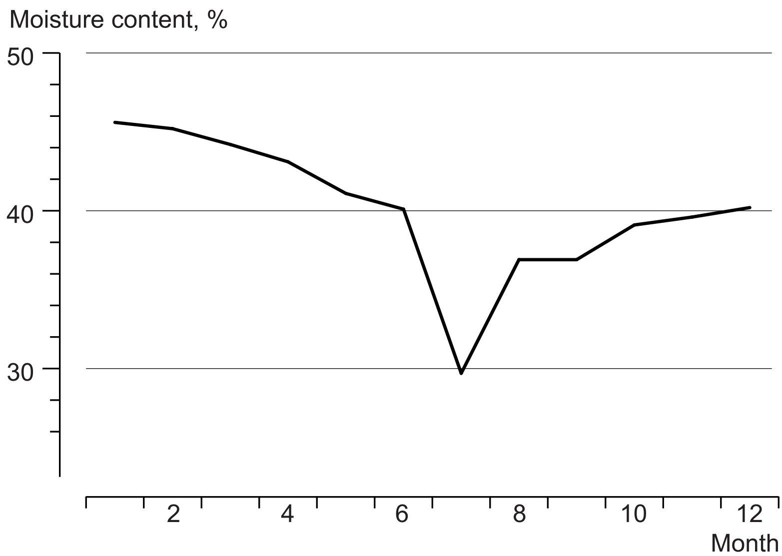

Figure 6. Variation on the average moisture content of forest chips as delivered to heating plants during 1999.

6. Prospects for the near future

The use of forest chips is increasing, although the increase is presently restricted to chips made from logging residues from the final harvest. In 2000 and 2001 the increase will take place mainly in large CHP plants of power and forest industry companies. In addition, a large number of new smaller users are expected to appear. Dozens of new heating plants have recently received investment aid from the Ministry of Trade and Industry to adapt their technology for forest chips and other wood fuels. On the other hand, according to the survey, few of those heating plants which presently use forest chips are going to expand their use.

The forest industries are today actively involved in the development and building up of procurement systems for forest chips, simultaneously giving great emphasis to the integration of timber and fuel production. The interest of forest machine and truck contractors is growing as well, and the machine constructors see the production of forest chips again as an attractive and fledgling area of business. However, as the interest of large producers is mainly in logging residues rather than small trees, the impact of fuel chip production on rural employment and management of young forest plantations remains smaller than earlier anticipated.

Still, the profitability of the production and use of forest chips remains weak. The need for research and system development remains high. Since Finland's international obligations and the Action Plan for Renewable Energy of the Ministry of Trade and Industry require the increasing use of renewable energy, the promotion of the use of forest chips will be continued. Among the means available are taxation, investment aid and financial support to research, development and demonstration projects.

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Forest chips in the energy strategy of UPM-Kymmene

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1. Forest chips in the energy strategy of UPM-Kymmene

The use of wood based energy is increasing rapidly. It year the amount of logging residues is pretty 1 million m^3 solid and the nation target for year 2003 is to rise the amount 2,5 times. UPM-Kymmene has even higher goal. We intend to increase more than 2,5 times in the same time period. It is obvious that we are the biggest player in logging residues business. A lot of work is needed to reach those targets.

The CO_2 emission, Climate Change matter, is big issue for globally acting company as UPM-Kymmene. Looking is as an challenge for us, we from the energy point of view see three choices: energy efficiency, power supply and fuel options. We are carrying out energy efficiency audits and implementing action to improve efficiency, rearranging our power supply by increasing the share of CO_2 free power and increasing the use on rewable fuels.

The use of heat resources (fuels and heat) mills in Finland in 1999 was 21,6 TWh. Over 65% of total heat energy was covered by renewable fuel or energy. Black liquor and bark are dominating. The use of logging residues was nearly 200 GWh. We have to notice the actions for logging residues started in 1997. The goal for year 2000 is 400 GWh and aim is to broke 1 000 GWh limit in next few year time.

The biggest logging residues user is Kaipola and Valkeakoski is close to same amount. Rauma and Jämsänkoski started to use logging residues in 1999. This year the new users of logging residues are Pietarsaari, Kuusanniemi and Kajaani. The new biomass power stations to Pietarsaari, Jämsänkoski and Kuusankoski will start up 2001 and 2002. After these investments are in full stream the use of logging residues is expected to be at the level of 1 500 GWh. This means annually 2 million m^3 of wood chips and 20 000 transport lorries. At that stage the importance of wood chips is remarkable and is a great challenge for the whole supply chain.

We have and will be testing or evaluating all the methods to produce wood chips. The methods are following:

- Chipping on site
- Chipping on roadside
- Chipping at the power station
- Integrated harvesting and thinning
- Chipping at the terminal.

The development work has been carried out as both in nations projects and own ones. The contribution of Tekes has been furthering. The real work to produce wood chips has been a lot by learning though trail and error. All the production methods have good and bad features, so it seem that there would not be one only production method, but they all are effective under specific conditions.

The forest nutrition matter is also very important. There has been going on studies and the interdependence is becoming clear. From sustainable developments point of view the wood based fuels ashes should be circulated back to forest. Also those studies are on going.

Combustion properties of wood chips has caused problems in some fluidized-bed boilers. The problems have been the bed agglomeration, deposits and corrosion in the superheaters. It case of UPM-Kymmene the wood chips are co-combusted with bark, sludge and peat. By knowing the different properties of fuels and phenomenon in combustion, it is safe to burn wood chips.

Experiences of control of moisture content are also going on. To get the full benefit of logging residues as a fuel the control of moisture is essential. During the winter period it is vital to deliver low and constant low moisture content logging residues to the power plant. So by understanding the drying process at summer time, you also have to able to maintain that low moisture content during autumn rains and when the snow cover the surface.

The cost of wood based fuels has to be competitive to be able to increase their use. Taxation is therefore very crucial for this whole logging residues business. Because we are making long term commitments, also taxation and other way to lead to the right direction has to be predictable.

Employment and self-employment possibilities to countryside are obvious by producing logging residues. To reach that target all parties, who are involved, has to be active. The training for people producing logging residues is vital and also that they are aware of the properties, which are expected from good quality logging residues. They also have to be able to make needed investment and run that business in profitably way to ensure reliably delivery in a long run.

To summarise the main point of this presentation. The production of logging residues is:

- a challenging task
- a lot of work to be done
- an excellent opportunity to reduse CO_2 emissions
- new employment possibilities.

European wood-fuel trade*

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Abstract

This paper discusses research carried out during the 1990s on European wood fuel trade at the Department of Forest Management and Products, SLU, in Sweden. Utilisation of wood-fuels and other biofuels increased very rapidly in some regions during that period. Biofuels are replacing fossil fuels which is an effective way to reduce the future influence of green house gases on the climate. The results indicate a rapid increase in wood-fuel trade in Europe from low levels and with a limited number of countries involved. The chief products traded are wood pellets, wood chips and recycled wood. The main trading countries are, for export, Germany and the Baltic states and, for import, Sweden, Denmark and to some extent the Netherlands. In the future, the increased use of biofuel in European countries is expected to intensify activity in this trade.

Keywords

Bio-energy markets; international trade; wood energy; EU energy policy; policy instruments; wood fuel; market development, bioenergy, wood-fuels.

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1. Introduction

Traditionally, wood-fuels have been used in the same geographical region in which they were produced. In more recent years, this pattern has changed in northern Europe by the large-scale use of biofuels for district heating and a vast supply of recycled wood and forestry residues. The trade situation has therefore developed as a result of means of control on waste and energy. Sea shipments allow for bulk transports of biofuels over long distances at low cost. This paper focuses on this development in trade from a Swedish perspective.

Imports of recycled wood-fuels and other biofuels have increased very fast during the past few years, mainly because of the high taxes on fossil fuels, a well developed burning capacity for solid fuels in some countries, i.e. Sweden, and new more extensive waste legislation in some other European countries, i.e. Germany and the Netherlands. One example is the combination of the recycling system "der Grüne Punkt" for packaging in Germany which produces a great deal of fibre, on the other hand the CO_2 taxes and investment support for biofuelled boilers and CHP plants in Sweden, which creates a demand.

Another example of wood-fuel trade is the low-cost production of green chips and densified fuels in the Baltic states and its effect on the Swedish and Danish and other wood-fuel markets. There are also imports from North American fuel pellet producers to Swedish district heating plants. This development has been facilitated by the stronger biofuel purchasing power that Swedish and other Nordic heating plants have in relation to competitors from outside the Nordic region. A condition for wood-fuel trade is that the transport system is based on low variable costs for freights between regions.

The trade in biofuels in the EU is regulated according to an EU protocol (EEG No 259/93) that divides waste into three main categories: green, yellow and red. The waste that is listed as green is free for trade between countries, and examples are tall oil, wood pellets, uncontaminated demolition wood, green wood chips, peat, and rubber tires. For import from the yellow list, the importer must be registered with authorities; this type of waste consists of products contaminated by arsenic or other hazardous substances. The importer must also have a certificate from the end user concerning destruction of the waste. Red waste is the most risky, and imports require permission from authorities.

The industrial use of wood-fuels is strongly dependent on the prices of competitive fuels, i.e., fossil fuels, and is also affected by policy instruments. Fuels are traded on an international market while energy policies up to now have mainly been national. The expected common energy policy of the European Union, stated in the EU white paper, will have an important influence on biofuel trade.

2. European wood-fuel trade

Wood-fuel trade is a fast growing activity in Europe, although it is still now being carried out in low quantities and with the involvement of a limited number of countries. A description of the situation in different parts of Europe is reported below.

<u>Nordic countries</u>

Sweden has experienced a massive development of district heating systems during the last 20 years. Mainly as a result of the taxation system with a carbon dioxide tax, wood-fuels compete successfully on this market with fossil fuels and other untaxed biofuels.

Imports basically help in replacing fossil fuels and a study, which is a follow-up of a 1993 trade study (Nutek, 1993), examines the driving forces for increasing biofuel trade in Europe and analyses the Swedish trade in biofuels (Vinterbäck & Hillring, in print). In 1997, imports accounted for about one fourth of the total biofuel consumption in Swedish district heating (Table 1), an increase three times projected in the earlier study (Nutek, 1993). Of this, quite half was classified as wood-fuels.

Table 1. Imports of biofuels (untaxed fuels) to Sweden 1992, 1995 & 1997.

	1992	1995	1997
Biofuels (PJ)	2–4	11–15	20–32
Approximate share of wood-fuels (%)	20 (estimated)	33–45	44–62

Source: Vinterbäck & Hillring, (in print).

During the past 20 years, Swedish market wood fuel prices have decreased, while consumption has increased dramatically. Production costs dominate the cost/price structure, as the physical access to wood-fuels vastly exceeds the demand.

Beside Sweden, Denmark and Finland also have a substantial burning capacity in the district heating markets, which could be the base for an integrated market for biofuels in the Baltic sea area.

Western Europe

As legislation such as landfill fees, which give rise to subsequent material recycling, has been introduced in several European countries, more or less closed-loop recycling systems have been developed. Germany is a leading country in this area, where recycling systems are producing substantial material flows, some of which consist of recycled wood. The amount of recycled wood fibre in Germany is estimated at 15 million tonnes annually (equal to 200 PJ; Lang, 1999).

The particleboard industry in Germany uses secondary wood processing residues as market prices are low since the energy generation is the only competitor (Frühwald, 1999). These residues are excellent for direct energy generation, but bulky transport is expensive. A better solution for energy generation is densification to briquettes or pellets which would reduce transportation costs. Another problem associated with secondary processing residues is the frequent contamination with glues, paints, overlays (including PVC) etc. Such contamination sometimes causes problems in other material cycles, although it is not a severe restriction for energy generation as long as problematic substances such as PVC or wood preservatives are minimised and combustion is carried out in large-scale boilers.

As an example, the landfill fee in Hamburg for railway sleepers is 800 DM/tonne and for demolition wood 200 DM/tonne. It is thus now more interesting to export both qualities to, e.g. Sweden. As off the year 2005, material that contains more than 5% organic matter will not be permitted at all to be deposited in landfills in Germany. In addition, new energy-taxes are underway in Germany, which could make local combustion more interesting.

The Netherlands is an example of a potential importer of biofuels and have a very low potential of wood-fuels from primary production in forest operations (Nutek, 1993). However, recycling systems and landfill fees gives a large potential of recycled fuels and waste for domestic use or export.

Central and Eastern Europe

With the development of recycling legislation, infrastructure, and consumer awareness, the countries of Central and Eastern Europe are approaching the higher recycling rates of some Western European and North American countries. This increased recycling will also increase the supply of recovered wood fuels for energy generation (UN-ECE Timber Committee, 1999).

A second increasing source of wood fuels comes from the forestry and forest industry sector. This is already a strategic resource, and with today's increasing production of primary products, by-products that may be used for energy generation will also become more easily available. Estonia is a good example of the development of forestry where economic growth in the sector has been nearly 20% annually the last five years (Kosenkranius, 1999).

The wood fuels may then be utilised domestically or exported. To support domestic use, programmes for technology transfer and investment support have been carried out by different countries and organisations. One example is the Swedish program for environmentally adopted energy systems in the Baltic Region and eastern Europe (UN-ECE Timber Committee, 1999).

New export possibilities may also be investigated, an example being the export of densified and other biofuels from countries in the Baltic region to some western or Nordic European countries, i.e. Sweden and Denmark or the Netherlands.

Southern Europe

Biofuel use in southern Europe is limited. There are high market potentials especially for electricity production, but wood resources are generally rather small. However, there are some countries with a large wood-fuel use, i.e. France, and other countries with fairly large unused resources of wood-fuel, i.e. Italy (Nutek, 1993). However, many Mediterranean countries completely lack an infrastructure for the harvesting and utilisation of wood-fuels.

In general, biofuels from the agricultural industry has a high potential in the region (Nutek, 1993). Industrial residues, such as those in the olive oil industry, have been traded to northern Europe, but this trade is not expected to increase significantly.

Projects to utilise renewable energy resources are being carried out in many regions and the domestic use of biofuels is predicted to increase in the area. Special initiatives have been taken to meet the overall goal to fulfil international agreements on climate change.

3. Discussion and conclusions

The largest forest resources in Europe are found in the north and the east while the population is concentrated to the central, southern and western parts. Beside regional trade, the current situation gives flows of raw materials of forest-based products from north/east to central/south/west. Most of the recycled material is produced in the latter region.

Energy taxes have proved to be a very powerful policy instrument for the development of the current burning capacity for solid biomass fuels, which in turn has developed a wood-fuel market. These two factors, together with the expansion of the recycling policy in European countries and the well developed district heating networks in some countries have been the main driving forces for the development of biofuel trade.

With correct pricing, biofuel trade gives opportunities for future supply to a harmonised European (and North American) market as more wood-fuels will be developed to commercial energy sources in different regions.

The development of recycling systems and production of wood-fuel for energy generation has been very rapid in some eastern and central European countries. However, there is a great need for a continued exchange of information, technology and expertise in many areas such as legislation and policy matters to ensure a continued successful implementation of recycling and wood energy systems.

The wood fuel trade is expected to increase in the future due to an increase in the use of biofuels. New energy policy for the European Community, international agreements to reduce greenhouse gases, new strategies aiming at renewable energy in some leading energy companies, and new international standards for biofuels and waste are the driving forces for this trend. Increased interest in utilisation of biofuels will result in more efficient system solutions and efficient technology for future development of the market.

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Cost factors of fuel chip production

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Abstract

The volume forest chip production is assumed to grow substantially in Finland in coming five years. The aim has been set to increase the use of forest fuels five fold compared to recent value, which is about 0.5 million m^3 solid annually. As a result, larger areas will be harvested and majority of this increase is assumed to be logging residues.

It is essential to take carefully into account all cost factors related to forest fuel harvesting. These include site-based cost factors, such as site and stand conditions as well as road network and available equipment for harvesting and long distance transportation. Operating and information systems and human factors play an important role behind tangible cost factors.

An important factor is the scale of operation. Harvesting machinery is expensive and thus the annual output considerably affects the costs. In addition, the greater the share of the potential fuel supply recovered, the higher the cost of procurement. This is due to longer transport distances and the need to operate on less favourable sites. This paper presents some findings of selected cost factors in forest fuel procurement. The effects of storage human factors are highlighted.

1. Introduction

Wood is considered to be a local fuel. Nevertheless, it has to compete on global energy markets with other sources of energy. Therefore, procurement of forest fuels calls for cost effective harvesting and transport practices since forest biomass is scattered on a large geographic area. Economically acceptable transport distance for forest fuel is a fraction of the one for oil due to its low energy density. As a result, the raw material must be gathered from an area the radius of which is typically less than 100 km. Knowledge on cost factors associated with harvesting and transport of forest fuels is essential as procurement systems are designed and operated for forest fuels. Mechanization of forest work has promoted the development of cost effective harvesting machinery and methods for wood fuel procurement. Consequently, forest fuels are currently becoming competitive especially in Nordic countries.

2. Machine characteristics as cost factors

Machine characteristics define the uppermost limits for the machine performance in varying environment and organization. Characteristics of the off-road machines can be classified in two main classes according to vehicle mobility (balance, driving speed, steerability, hauling) and material handling capacity (load capacity, loading, unloading and processing capacity).

Balance or stability is perhaps the most important factor effecting on an off-road machine's performance (Terrängsmaskinen 1981). Stability effects on driving speed, steerability, drawbar pull, ability to move uphill and downhill, and load handling. Driving speed defines the transport performance of the vehicle together with the load capacity. By off-road vehicles the driving speeds are typically very low, only some kilometers per hour, due to the uneven ground surface and slopes.

Load capacity effects strongly on the productivity, since output of each work cycle equals to the load volume (Figure 1). Limits for load capacity are set by the gross mass of the machine which effects on the vehicle mobility and rut formation. Large load volume causes problems when the machine has to drive on narrow skid trails or forest roads in uneven terrain.

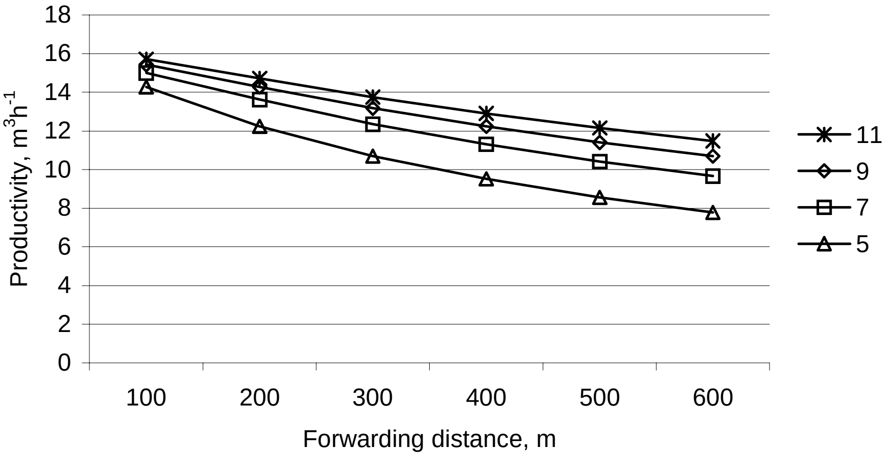

Figure 1. Effect of load size on forwarding capacity of logging residues.

Hauling capacity describes the ability to overcome forces resisting the movement of the machine. Friction, slope and rut formation counteract hauling capacity. Engine and load volume effect on the counter forces of hauling capacity. Steerability depends on the dimensions of the machine, steering system (front wheel steering/frame steering), power transmission system, wheels and controls. Material handling capacity defines how fast a machine can load and unload material. Loading and unloading speed can be defined as the function of movement speed and controllability of the crane.

3. Work site conditions as cost factors

The productivity of energy wood harvesting is affected by work site factors such as the terrain, the method used for harvesting the industrial roundwood prior to or simultaneously with recovery of wood fuel, distance to landing, and the amount of potential fuel at the logging site. In addition, the total amount of wood fuel to be recovered per site affects the need to move machinery from site to site.

In work studies the work is broken into elements in order to get a more detailed view of the work cycle. Different elements require different inputs of a worker or a machine. Furthermore, separate elements are affected by different work site factors.

4. Human factor

Relation of labor and machine costs effects on the optimal mechanization degree of wood harvesting in certain conditions. In industrial world the cost of labor is so high that mechanization is a must. Education level at the country effects on the selection of appropriate mechanization degree and technology. Usually, high education level correlates also with the overall labor cost in a certain country. The share of labor costs is in industrialized countries typically less than 30% of the total hourly cost of a machine unit. In countries where labor costs are low, lower mechanization level is feasible. In Russian Karelia manual cutting is less expensive than mechanized cutting by Nordic single grip harvester even in final fellings. In Finnish Karelia manual cutting can be competitive only in first thinnings. This difference resulted mainly from the difference in wage level in Russian and Finnish Karelia (Sikanen et al. 1996).

In addition to the work site factors, the machine operator has a significant effect on the productivity of the machine. Factors affecting the operators performance are his/hers effort, skills, physical and psychic capacities and motivation to perform the work (Harstela 1993). Also the culture and wage system effect on operators motivation (Gullberg 1995). Independent entrepreneurs seem to be more motivated to run the machine effectively than hired operators.

The flow of information in logging organization has a great effect on the actual costs of operation. As a by product or additional information in many time studies it has been found that machines and trucks use a great share of their working time in unessential operation. For instance, because the location and conditions of a certain storage of logging residues has not been known precisely enough, truck and a chipper may use several hours by searching the storage. If the trafficability of the forest road has not been investigated well enough, the combination vehicle (truck with a trailer) can not turn in the end of the road, or it gets stuck in the snow. My estimation is, that these human induced surplus costs can ruin the whole economy of harvesting.

5. Storage of wood as a cost factor

The quality of energy wood affects fuel costs in several ways. Impurities such as stones, metals and sand can damage chipper blades requiring more frequent replacements or sharpening. Dull blades impair chipper productivity and result in undesired particle size of chips. Blade costs are USD 0.4–0.8 per m^3 for green logging residues without impurities. Normal blade cost is USD 0.8–1.2 per m^3. Dry residues cause 10–20% higher blade costs and impurities among the material can raise the blade cost up to USD 2 per m^3.

The moisture content of wood affects the cost of transport. The more water there is in the material, the less fuel is transported. Furthermore, high and erratic moisture content causes problems for combustion process control. Reducing the moisture content calls for storage of the material either on the site, at landings, at terminal or at the plant. Storing promotes the heating value of the material, especially when the storage involves providing protection from rain. In the case of tree sections the value of the wood material increased by 12% during storage. This could have been more but storage can also cause considerable raw material losses (Brunberg et al. 1998). For instance, the storage of spruce material can lead to 20–30% losses due to defoliation. As a result, recovery rate at the site diminishes. Thus, the radius for procurement area increases raising the cost of trucking. In the chipping phase, dried logging residues are much more difficult to process and the productivity of a chipper diminishes by 20% compared to fresh material. As a result, storage and drying may raise the total cost (per dry tonne) of harvested and transported material by 5–15%.

6. Conclusions

The profitability of wood fuel procurement can be increased by efficient targeting of harvesting operations to stands where the conditions are favorable for energy wood recovery. Running of operations in an optimal way calls for knowledge of the factors influencing procurement costs. Furthermore, information on how each system works under different conditions is required when selecting machinery for different conditions.

The scale of operations has a major impact on procurement costs. Large boiler plants must purchase wood over a wide geographical area. The areal availability of wood fuels varies depending on the structure and management practice of the forests and the shape of the procurement area. Storage of material can reduce the moisture content of wood fuel. This increases the calorimetric value of the harvested material. On the other hand, it often leads to material losses and increased costs in the procurement chain. Therefore, a careful examination of availability, need for storage and price of wood fuel should precede a decision to build a chip-fired plant.

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Cofiring of wood - fuel handling and cocombustion*

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Abstract

New types of solid biofuels are penetrating into the fuel market. Solid biofuels are initially being utilised in existing power plants. At the moment the typical method is cofiring or cocombustion. Especially, the handling and feeding of the new fuel types into the boiler is often problematic, because of the variation in particle size, flow and handling properties, heat value, density, chemical composition and ash behaviour. The lack of available design parameters or planning instructions for handling operations of the new fuels is obvious. It is therefore necessary, to develop and promote the cofiring of biomass in different existing plants and new power plants. This presupposes in most cases retrofits to FB or grate boilers and a separate gasifier connected to the main boiler or new boilers. Demonstration plants, the development of facilities and equipment and research work are most important in this field.

1. Introduction

One of the actions in the White Paper [1] on renewable energy is to promote the cofiring of biomass with fossil fuels. Cofiring is widely used in the Nordic countries and is also spreading to the rest of Europe. The total number of

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biomass cocombustion plants in Europe is estimated at approx. 150 [2]. In most cases biofuels are mixed before feeding into the boiler, but also separate fuel feeding lines and dosing systems are being developed depending on the further process. The cofiring project is included in the European bioenergy – net-work-AFB-Net and is partly financed by ALTENER programme and co-ordinated by VTT Energy. The participating organisations are Centrales AgrarRohstoff-Marketing- und Entwicklungs-Netzwerk (C.A.R.M.E.N. e.V.), Germany, Centro da biomassa para a Energia (CBE), Portugal, Danish Centre for Landscape and Planning, Institut Technique Européen du Bois Energie (ITEBE), France, KOBA s.r.I., Italy, Swedish University of Agricultural Sciences, Dept. Forest Management and Product (SLU), The Austrian Energy Agency (EVA) and VTT Energy, Finland.

2. Methods

Information on the fuel procurement, handling and feeding of different biomasses in existing cofiring plants (20 in total) was gathered and analysed. The eight participating organisations have contributed to this research. This survey has been carried out according to a specified schema [3].

Each country has selected and evaluated those power plants, which have technical possibilities to start biomass cofiring and pass on the information and experience gainede. The evaluation and analysis consists of the following parts: Fuel procurement, handling and feeding technology at the power plant, Detailed examination of the fuel handling system and Fuels and fuel characteristics.

Each partner has made an evaluation by visiting the plant interviewing the plant managers, maintenance personnel and fuel producers and collecting the above-mentioned information. The results have been reported as followed: New fuel (mixtures), cofiring systems, methods and technology, Cofiring experience in fuel procurement and fuel handling, mixing and feeding of different type fuels and conclusions and recommendations.

3. Results

The plants/boilers represent various size classes and combustion technologies: thermal effect less than 1 MW up to over 300 MW with biomass, fluidised beds (CFB and BFB types), several types of grate boilers, gasifiers and pulverised fuel boilers. Most of the plants are industrial or municipal CHP (combined heat and power) plants, but units producing only electricity (condensing power plants) are also included.

The biofuels include wood residues from industry and forestry, agricultural residues (straw, vineyards residues, oil pressing residue etc.), short rotation forests (coppice, willow) and waste based fuels. In most cases the biomass is mixed with main fuel and the mixture is fed into the boiler. Separate biofuel feeding takes place in a gasification process.

Technically and commercially the most feasible process solutions are fluidised bed boilers (new and retrofits), which are typical in Finland and Sweden, mixing of biomass with coal in large condensing power plants (Germany), grate retrofits and gasification connected to a coal fired boiler (Austria, Finland). In addition there is a modern waste-burning power plant equipped with a sophisticated control system (Italy) and new wood- and straw-fired CHP plants with effective fuel receiving and mixing system (Denmark).

Some results concerning these process and systems are presented in the following chapters.

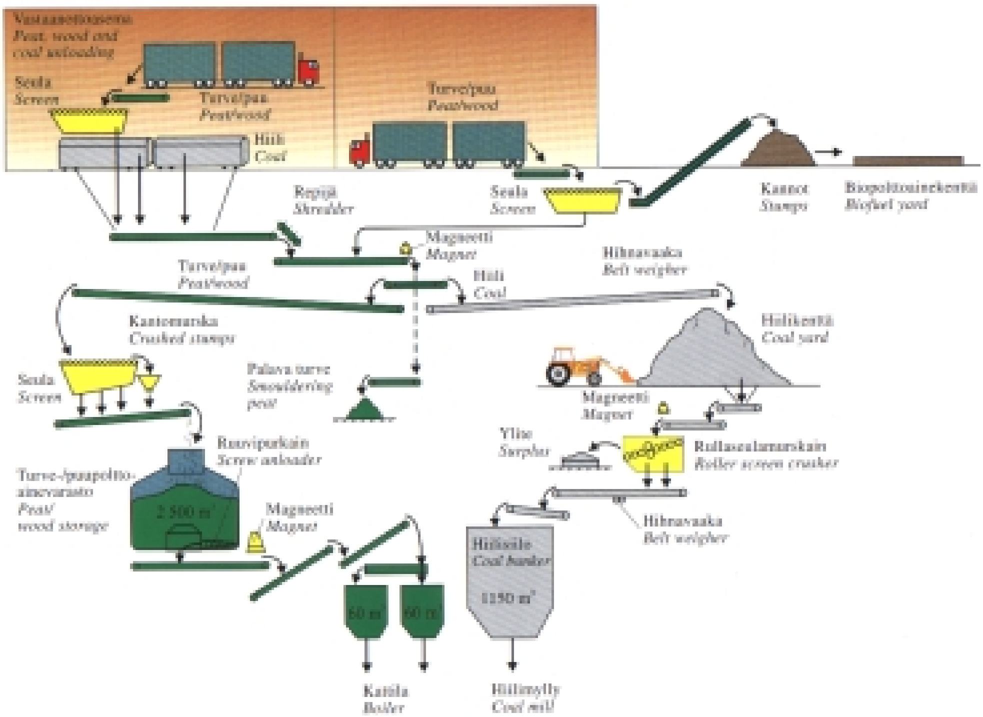

Figure 1. Fuel handling system at a 300 MW cocombustion (retrofit) BFB boiler, where the proportion of wood fuel has been increased to 20% – the Fortum Rauhalahti CHP plant in Finland.

3.1 Fluidised bed process

Fluidised bed (CFB and BFB) combustion is flexible for the different fuel types (energy density), variation of moisture content and particle size. However, in order to achieve good boiler efficiency and a stable process and production it is necessary to mix and homogenise the separate fuels and to control the fuel (energy) flow into the boiler. These actions require screening and crushing of over sized particles at some stage, mixing fuels at the receiving station and/or in the intermediate storage and adjustable feeding conveyors for silo discharge and near the boiler. In the Nordic countries, for example in the several boiler conversions have been made from pulverised coal-fired-, grate boilers and even old recovery boilers to BFB boilers. At the same time the fuel variety has changed, but the existing handling and feeding systems are still utilised. The handling and feeding lines are normally designed for one fuel type, in most cases especially in Finland for peat fuels. This has emphasised the importance of fuel quality control and the effective mixing of different fuels. The fuel homogenisation takes place in the delivery and/or at the receiving station and in the intermediate storage of a power plant. At the moment there are also many plans to make separate feeding lines for the new wood fuels. Figure 1 presents a typical existing fuel handling system, where the fuel mixing takes place mainly at the receiving station. Also the silo loading and unloading systems (discharge conveyors) are utilised to achieve the desired fuel mixture.

3.2 Grate boilers

The a grate combustion is the traditional method of using wood fuels. The analysis includes two power plants utilising wood as the main fuel: one in Sweden and the other in Denmark.

The Swedish 55 MW CHP boiler utilises bark, sawdust, logging residues, willow (Salix) and wood pellets. The fuels are mixed in a large rectangular intermediate storage. There were some initial start-up problems with the fuel handling system, but there has not been any unscheduled shut down for five years now. Some fouling problems have been detected in the super-heater area of the boiler. An excessively large proposition of Salix chips is thought to be the cause of the problem. Tests are still being carried out to find the optimum propositions of the feed.

The Danish wood-fired CHP power plant has a vibrating grate and its fuel effect is 17.3 MW. Bigger particles drop onto the grate and smaller ones burn in a suspension. The fuel consists of forest wood chips, chips from whole trees, dry wood waste from industry (sawdust) etc. The fuel mixing takes place using two parallel crane lines. These lines provide fuel to two different hoppers, which are usually filled with different types of fuel (Fig. 2). By controlling the feeding rates of the stoker dischargers a sandwich layer with two different kinds of fuels is made on the belt conveyor leading into a feeding bin for the boiler. So far there is not yet any extensive operating experiences. The plane screens have been replaced with disc screens.

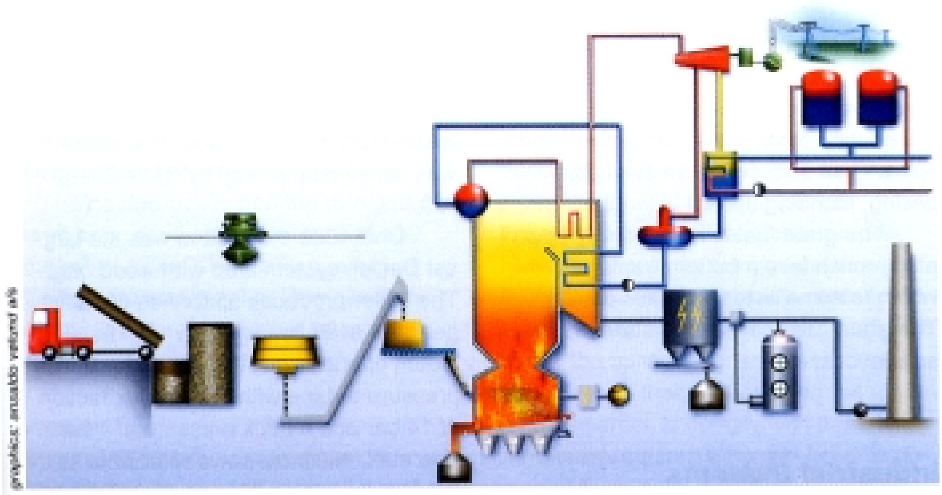

Figure 2. Schematic diagram of the CHP -plant at Assens Fjernvarme in Denmark.

3.3 Cofiring in coal boilers

Cofiring was tested in Germany in two separate power plant (pulverised coal and grate combustion). The aim of the tests was to clarify the feasibility of the permanent cocombustion of biomass in a power plant and to determine possible modifications. Fuel for the first power plant, Kraftwerk Schwandorf (condensing power plant 280 MW_{th},) was dry pellets of straw, cereals and different grasses (hay) from landscape management. The pellets (10% of heat energy demand) were mixed with coal using a wheel loader and conveyed using a normal feeding line into the coal mills. The mixture was injected into the combustion chamber. Waste wood was also tested. The pellets caused dust emissions: it is necessary to improve the mechanical strength of pellets and to premix with brown coal at the coal storage. Hardly any additional slagging was observed during short-term tests. However, the long-term tests (a week) showed an increased slagging tendency. Wood tests succeeded well and waste wood has been co-fired in one unit since June 1999.

In the second plant (CHP power plant of Würzburg) wood chips (beech and coniferous wood) were tested as a substitute fuel. The test period lasted six weeks in one boiler (grate combustion, 89.5 MW_{th}) at a maximum 25% share of biomass for the total fuel demand. The mixing took place after the feeding bunkers (silos) using two balance belt conveyors. The receiving and handling of the chips succeeded without problems, although excessively large wood chips caused some clogging in dosing.

In Austria two large-scale demonstration projects were also realised for the cofiring of biomass in coal-fired condensing power plants. One was at St. Andrä power plant (124 MW_{el}), which involved the installation of a moving combustion grate (2 x 5 MW) integrated at the bottom end of the coal boiler hopper (Fig. 3). The other was at Zeltweg power plant (137 MW_{el}), where biomass is gasified in a separate gasification reactor (10 MW), working on the principle of a circulating fluidised bed (CFB). The product gas is led at a high temperature to the coal boiler, where it is burned together with coal. Also in Finland there is a gasification unit (60 MW), which is in continuous operation. It uses wood fuel and waste-derived recovered fuel (RF) and is connected to a coal-fired main boiler (Fig 4).

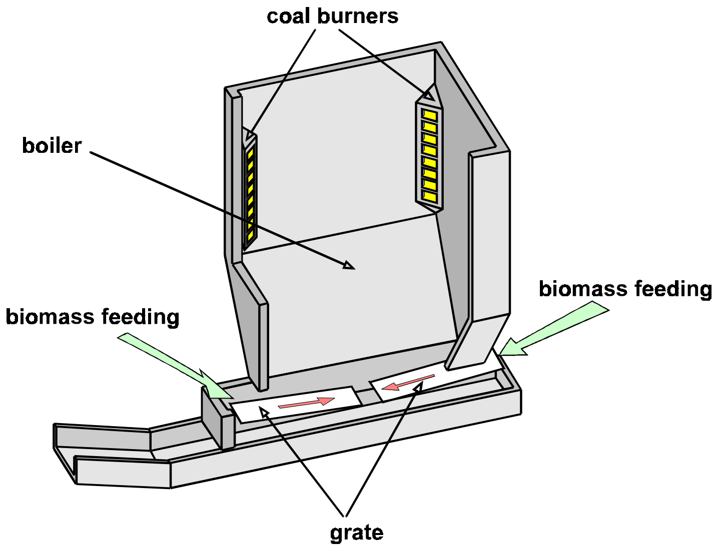

Figure 3. Integrated biomass grate at St. Andrä power plant in Austria.

The combustion of biomass on a grate integrated into the furnace of a coal boiler requires sufficient free space below the boiler. The advantages are no pre-drying and no excess connecting ducts. In addition, no gas cleaning and cooling are needed. A typical operation problem is the handling of biomass with the high ratio of impurities like stones and metals in the available fuels, which may disturb and interrupt the conveying path. By cutting the oversized particles to a maximum length of 300 mm with a shredder, the problems are solved and the conveying line works properly.

The gasifier at Zeltweg power plant can be seen as a fuel preparation unit that always operates together with the thermal power plant and substitutes for a proportion of the coal (3%). The system is almost fully automated, so the main personnel costs are incured only in connection with feeding of the biofuel system only. In Austria during the hot commissioning phase extensive tests of the plant with combustion operation were carried out no problems were found. In Finland Lahden Lämpövoima Ltd´s Kymijärvi CHP- power plant gasification project demonstrates the direct gasification of wet biofuel in an atmospheric CFB gasifier and the cofiring of hot, raw and very low calorific gas directly in an existing coal-fired boiler (350 MW_{th}). The unit has been in continuous operation since the beginning of 1998. Last year (1999) a total 340 GWh (110,000 t) of the wood and recycled fuel were utilised. So far the main experiences have been positive: reduced emissions, availability (81% first year) and negative effects on the operation of the main boiler are minimal. The fuel handling may cause problems. Separate receiving and handling lines for different fuel fractions would be recommended.

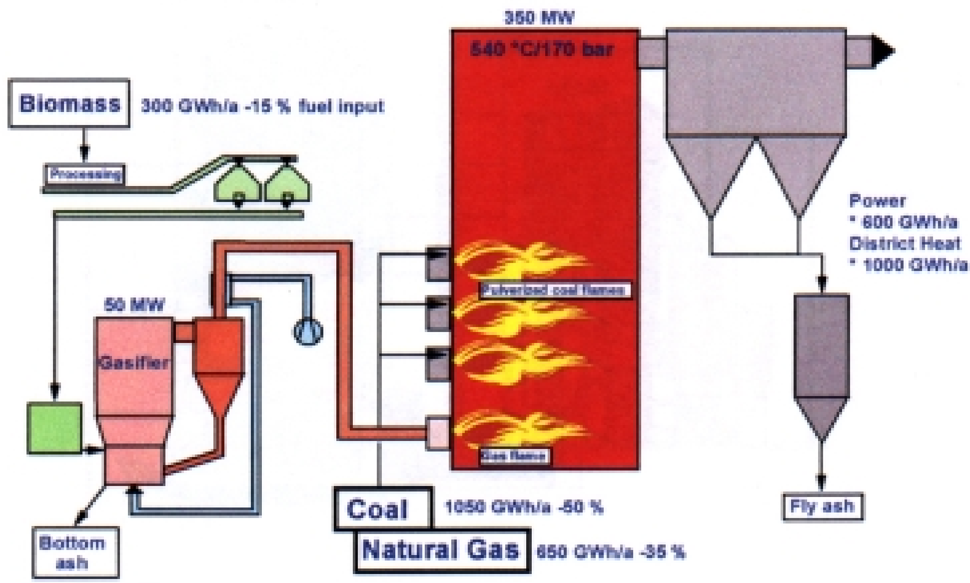

Figure 4. CFB Biomass gasification system in Lahti, Finland.

3.4 Cofiring in waste incineration plants

The analysis includes one modern CHP waste incineration plant (Termoutilizzatore) in Brescia, Italy. The boiler´s thermal effect is 2 x 88,3 MW (stoker grate). The nominal capacity of the two combustion lines is 2 x 23 t/h. The main fuel is municipal solid waste, industrial (non-hazardous) waste and dried sewage treatment sludge. Cofired solid biomass consists of olive pressing, wine production and wood residues and poultry dejections. Waste is transported to the plant with pressing waste lorries (approx. 200/d). Waste unloading takes place in a closed negative pressure hall and tipping drops waste material into the bunker. The storage capacity (waste bunker) is 30 000 m^3. The bunker is equipped with two cranes. The first crane piles the material and the second discharges and moves the material into the combustion hopper. This system is used for homogenising of the waste feed into the boiler. The feeding and movement of waste on the grate and the air supply are controlled by infrared cameras. According to operational experience particle sizing (crushing) at the receiving station and a direct feeding line for fine materials into the feed hoppers would be needed.

4. Discussion

The plant reviews present typical methods of cofiring biomass and also differences between individual countries. The effect of the structure of energy production, demand and consumption on the biomass cofiring can be clearly seen. New renewable fuels have penetrated the market in most countries. The main method of utilising these biomass fuels is cofiring. At first it is also the most economic way of rapidly utilising biofuels.

In the Nordic countries the pulp and paper industry has a very strong influence on the use of biomass energy and cofiring. The large forest resources also provide many saw mills, and their by-products like bark and saw dust are used for energy production. The lack of fossil fuels and the cold climate have emphasised the effective use of indigenous fuels, mostly based on biomass. The situation has also created very sophisticated boiler technologies, skilled equipment manufacturers and CHP solutions.

In Central Europe cofiring of biomass takes place with coal and in smaller units mixing different, mostly wood-based materials and residues. There are very interesting solutions for cofiring in the big coal-fired boilers. In many cases they are still trials, but some of them, e.g. the gasification technology, are technically feasible and will soon be commercially competitive. Also the mixing of biomass with coal seems very interesting and tests should be extended.

In southern Europe, cofiring takes place mostly using agro-biomass fuels in smaller units. Also waste-based materials are utilised. There are also very specialized combustion solutions.

Cofiring is used for the following reasons:

- In the Nordic countries the forest industry harvests wood raw material for production of pulp or timber. Wood residues from debarking-, and delimbing are already available at the plant (cost effective).

- In many cases disposal by burning is the only cost-effective and environmentally sound way of waste treatment currently available. A new and promising way of meeting these goals and to utilise waste as energy is to apply cocombustion or gasification of different fuels and wastes. This assumes that the waste material composition is known i.e. waste material for fuel purposes has passed through the source separation and pre-treatment process.

- New environmental regulations and taxation of fossil fuels have recently aroused greater interest in the use of biomass and wood residues in energy generation.

- European countries, especially the Nordic countries, have developed technologies for wood raw material and wood fuel production, combustion and gasification.

- In cocombustion even small amounts of biomass could substitute for fossil fuels. The best case is if the boiler is already designed or retrofitted for cocombustion. An alternative solution could be a biomass-fuelled gasifier connected to an existing coal-fired boiler.

The main problems in cocombustion and gasification are the following:

- The lack of accurate design parameters and planning instructions for handling, conveying and feeding.

- Mixing of different fuels; the properties of biomass are not homogenous and they can vary in a wide range.

- Feed control and accurate measurements.

- When using energy crops like straw and reed canary grass the alkali metal contents can cause problems in cocombustion and gasification.

- Using different biomass fuels with coal and waste needs more control and advanced handling technology in the plants.

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Cofiring of wood cocombustion*

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Abstract

The objective of this study was to determine safe combustion conditions in circulating and bubbling fluidised-bed boilers for wood chips produced by different forest harvesting chains. The optimal mixing ratios for typical and commonly used forest chip qualities, as well as for mixtures of chips and other fuels, under steam temperatures typical of circulating and bubbling fluidised-bed boilers are also determined. Emissions are also reviewed. The combustion and

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co-firing properties of fuels produced by different forest chains, and their suitability were studied first in VTT's test facilities and later in industrial-scale power plant boilers. The formation of alkaline and chlorine compounds and their effect on boiler fouling were studied by deposit probes in the test facilities. Deposits and phase changes in their compounds and corrosion risks are analysed by SEM-EDX. Utilisation of logging residue chips can cause deposition on heat exchanger surfaces and corrosion due to chlorine of wood ash. The harmful formation of alkaline and chlorine compounds on boiler surfaces could be prevented by co-firing sulphur-containing fuel.

1. Introduction

This research project is included in the Finnish Wood Energy Technology Programme, which focuses on developing the production technology and improving the quality of forest chips from logging residues and small-sized trees. In 1998, energy use of forest chips in Finland amounted to 0.5 million solid m^3. The target of the Programme is to reach 2.5 million solid m^3 by 2003. Potentials of increasing the use of forest chips are largely related to large power plants, which use forest chips in co-combustion with bark, sawdust, peat, recovered fuel and fossil fuels. The best available technique for co-firing of these kinds of fuel is fluidised bed combustion (FBC).

In Finland, indigenous sources of primary energy are hydropower, wood-based by-products of industrial processes, firewood and peat. The percentage of wood consumption in Finland's total consumption was 20% in 1999, Figure 1. (1)

Grate boilers have been traditionally used for small scale wood combustion, while FBC is most commonly used in boilers with thermal capacity greater than 5 MW. By using FB techniques and co-combustion it is possible to achieve high power plant availability and combustion efficiency with low emissions.

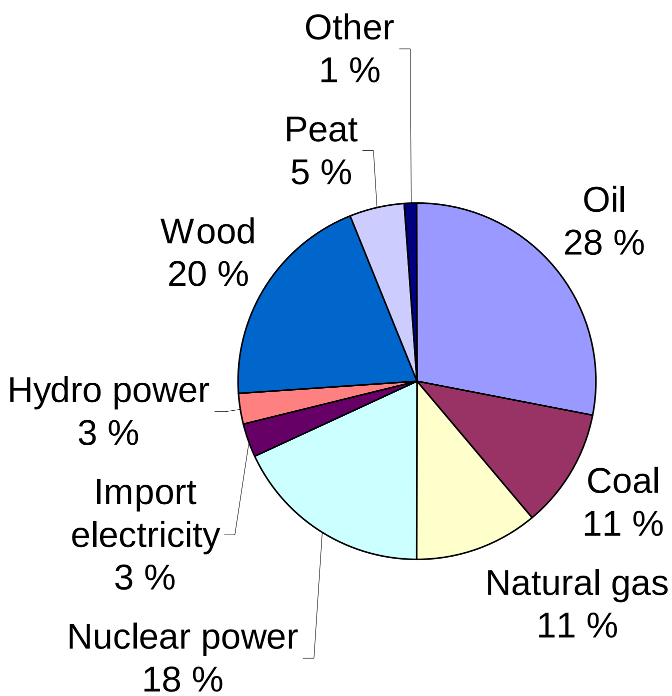

Figure 1. Energy sources in Finland in 1999. (1)

2. Background and targets of research

Increase in the use of wood is possible only by increasing the combustion of forest chips in large boilers of industrial and municipal CHP plants. The size of fluidised-bed boilers designed for solid biofuels has been successfully increased, the biggest circulating fluidised bed (CFB) boiler of 550 MW_{fuel} being under construction in Pietarsaari for Ahlholmens Kraft. This plant will burn annually 1 million m^3 of wood fuels, the share of forest chips being significant.

The aim of this project was to determine safe combustion conditions for typical and commonly used forest chip types and their mixtures with other fuels, starting with FB and CFB laboratory test equipment and later at power plants.

In Finland, forest chips are co-combusted with other wood fuels, bark, peat, coal, sludges and other waste materials. The use of wood offers environmental advantages over fossil fuels. Sulphur dioxide emissions can be reduced, as the sulphur content of wood is very low and the alkaline ash of wood can bind sulphur dioxide formed from other fuels (2, 3). Furthermore, carbon dioxide released from wood combustion is bound in growing biomass, and hence increasing wood use does not increase the total carbon dioxide emissions (4).

Branches, foliage, and bark of trees contain more ash than stemwood, and nutrients and trace elements are concentrated in these parts more than in the stemwood. The use of forest chips increases the amount of phosphorus, sodium, potassium and chlorine in the boiler. Alkalis, phosphorus and chlorine contribute to the formation of detrimental melts and to their condensation as corrosive deposits on superheater surfaces. Formation of detrimental deposits is reduced, when wood is co-combusted with a sulphurous fuel. The vaporised alkaline metals of wood ash are bound in sulphur, the amount of alkaline chlorides in deposits is reduced or these are not formed at all, and chlorine is released as HCl to flue gases.

Composition of deposits and their injurious effects on material have been measured and studied successfully in VTT Energy by small scale deposition propes. Baxter (5) has used similar type of probe in pulverised fuel combustion at Sandia National Laboratory. Present research method for deposit formation on superheater surface has been proved to be usable also at full scale power plant boilers. For this purpose, VTT Energy has developed a special corrosion probe in Technology Programme: Materials for Energy Technology (KESTO).

Co-combustion of solid biofuels with fuels that contain sulphur and, in larger amounts, silicate-based ash reduces agglomeration of bed material. Nordin (3) has reported that bed sand sintered in the combustion of energy crop. When coal was added, no sintering was observed. Consequently, fuel mixing can be used as a method preventing bed agglomeration.(6)

3. Combustion experiments with fb and cfb laboratory equipment

3.1 FB-test facility

Combustion tests were carried out in VTT Energy's fluidised bed test facility of 13–15 kW fuel capacity. The height of the FB reactor is 4.1 m, diameter of bed 0.16 m and diameter of freeboard 0.23 m. The temperature levels in the reactor can be maintained with separately controlled heaters in bed and freeboard areas. The bed area and two zones of the freeboard can be cooled down with air or water if necessary. It is possible to adjust combustion conditions similar to those prevailing in full-scale FB boilers.

3.2 CFB-test facility

CFB combustion tests were carried out with VTT Energy's circulating fluidised bed test facility of 40 kW fuel capacity. The CFB reactor consists of an air/water-cooled fluidised bed refractory lining (ceramic) combustor. The temperature levels in the reactor can be maintained with electrical heaters, cooling system and by feeding combustion air in right proportions. The amounts of primary air and secondary air fed from three levels are adjusted and measured by thermal mass-flow meters.

Due to the 8-m rising height a sufficient residence time is also achieved at high flue-gas velocity.

3.3 Tested fuels

Four different grades of chips were used in the test runs, Table I. The storage time of logging residue chips ranged 0–1.5 years, and their chlorine content was 0.04%. In co-combustion, two peat grades of 0.16% and 0.41% sulphur content were used, Table 1. The fuels were dried and ground to the particle size suitable for the test equipment (<4 mm). The fuels were moistened to 30–40% moisture content prior to the test.

Table 1. Fuel characteristics and compositions.

	Whole tree chips	Logging residue chips 1–3	Milled peat 1–2
Wood grade, mainly	Pine	Spruce	-
Storage time (a)	n. 2	0–1.5	-
Ash content (wt-%), 815 °C	0.64	2.17–4.2	4.76–5.78
LHV in dry matter (MJ/kg)	19.3	19.4–19.9	20.9–22.0
C-content (wt-%)	51.2	51.0–52.1	54.7–56.5
H-content (wt-%)	6.05	5.19–6.13	5.34–5.59
N-content (wt-%)	0.17	0.56–1.04	1.55–1.73
O-content (wt-%)	41.9	33.8–38.8	30.4–33.0
S-content (wt-%)	0.01	0.05–0.1	0.16–0.41
Cl-content (wt-%)	0.01	0.04	0.03–0.05

The ash fusion determination for the fuels indicated that the softening, hemisphere and fluid temperatures of whole-tree chip ash were about 100 ºC higher than those of logging residue chip ash 1 and 2, Table 2.

Table 2. Fusion characteristics of fuel ashes.

		Whole tree chips °C	Logging residue chips 1 °C	Logging residue chips 2 °C
Oxidising atmosphere	S	1240	1160	1140
	H	1300	1230	1190
	F	1350	1240	1230
Reducing atmosphere	S	1200	1140	1140
	H	1300	1240	1180
	F	1330	1245	1220

S = softening, H = hemisphere, F = fluid, WTC = Whole tree chips, LRC = Logging residue chips, MP = Milled peat

3.4 Experiments and emission results

FB experiments

Average conditions and flue gas compositions of FB experiments are presented in Table 3. Air distribution between primary/secondary/tertiary air was 50/30/20. Experiments were carried out with wood fuels, and peat was mixed with wood in some experiments. The NO contents of flue gas were less than 100 ppm. The highest SO_2 contents, 144 ppm, were measured when peat was used as an additional fuel. The SO_2 contents of wood fuels were very low.

Table 3. Test conditions with the FB test equipment.

Fuel	Milled peat 1–2 %*)	O_2 %	CO ppm	NO ppm	SO_2 ppm	T_{av} °C
Whole tree chips	-	3.7	15	78	2	864
Logging residue chips 1	0–50	4.2–5.1	11–208	63–95	1–144	827–881
Logging residue chips 2	0–50	4.3–4.7	21–158	58–95	1–31	829–879
Logging residue chips 3	0–20	5.0–6.1	5–7	73–80	0–15	874–900

Test duration 0.5–5 hours, *) on dry basis

CFB experiments

Combustion conditions of CFB experiments are presented in Table 4. Combustion air can be fed from four different points, i.e. primary air feed, and secondary air feeds separately adjusted from three heights. Air distribution in the CFB experiments was at first 50/30/20/0, but was readjusted to 50/10/10/30 to minimise the NO content. After the change the NO contents dropped by about 100 ppm. The SO_2 contents of flue gas were lower for the CFB test equipment than for the FB equipment.

Table 4. Test conditions with the CFB test equipment.

Fuel	Milled peat 1–2 %*)	O_2 %	CO ppm	NO ppm	SO_2 ppm	T_{av} °C
Whole tree chips	-	6.1–6.4	4–10	177–307	0–4	896–913
Logging residue chips 1	0–50	4.7–6.3	7–38	140–241	0–75	866–897
Logging residue chips 2	0–20	5.8–6.5	4–15	225–265	0–1	867–922
Logging residue chips 3	0–20	4.9	5–8	138–151	2–16	884–886

Test duration 0.5–5 hours, *) on dry basis

4. Results

4.1 Bed material analysis

The risk of bed agglomeration usually grows as the amount of alkaline metals (sodium and potassium) or iron increases (7). Salts formed from biomass may cause sticky partially molten coatings of ash on bed material particles.

When logging residue chips 1 or 2 were burned in the test equipment, the particle size of the bed material grew as particles adhered to each other. When peat was added, this phenomenon disappeared. This kind of agglomeration can be studied with a scanning electron microscope combined with an energy dispersive X-ray microanalyzer (SEM-EDX).(8) Agglomerated particles were coated with material that comprised mainly calcium and potassium together with some phosphorus. Figure 2 shows the X-ray maps for a typical agglomerate. An agglomerate from CFB experiment is shown as a back scattered electron image (BEI) with 300× magnification. The material between the sand particles is suggested to be potassium calcium silicates.

No chlorine or sulphur containing deposits were found on the surfaces of bed particles adhered to each other. Previous studies have indicated that these do not affect bed agglomeration (9). Nordin (3) has observed bed sand sintering when combusting solid biofuels. Similarly to the present study, he found that Si, K, Ca and Al accumulated in bed sand as agglutinative substances when energy crop was burned. When the same biofuel was co-combusted with coal, no sintering was observed.

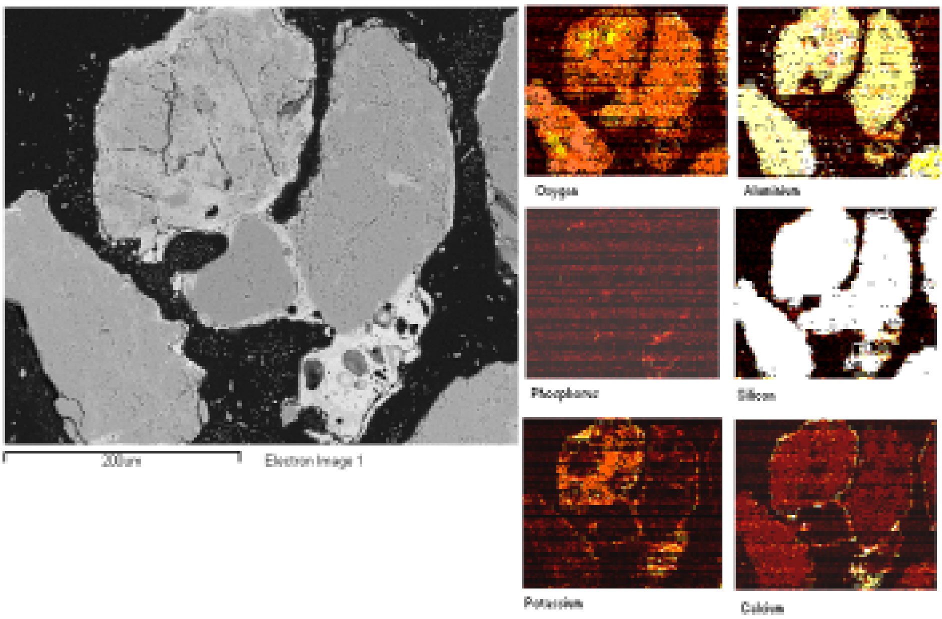

Figure 2. An agglomerate of bed material in CFB -experiment (logging residue chips 1) as a BEI-image. In the X-ray maps the sintering material formed around the bed particles contains potassium calcium silicates. Average temperature of CFB was 870 °C.

During the experiments, samples were taken from the CFB circulating material and from bed sands at one-hour intervals. The composition of the samples was analysed with XRF to study the accumulation of different substances in circulating material and in bed sand. In Figure 3 the same circulating material samples as in Figure 2 were analysed with XRF. It may be concluded that the XRF analysis supports the observations made with SEM-EDX. Figure 3 shows that the calcium, potassium and phosphorus contents increase during the experiments. The magnesium and manganese contents also grow slightly.

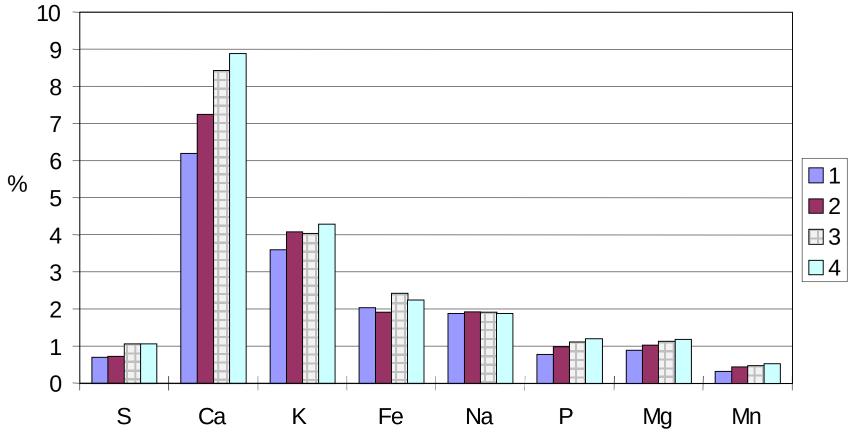

Figure 3. Change in the composition of CFB circulating material according to samples taken at one-hour intervals (1–4 h), logging residue chips 1, average temperature in the CFB test equipment 870 °C.

When burning logging residue chips with the FB test equipment, the time series of bed sand samples indicated accumulation of same substances (Figure 4) as in the circulation material of CFB (Figure 3). When peat was added, the accumulation decreased (Figure 5). Only the potassium and calcium contents increased during the experiment, but not as much as when burning pure logging residue chips. In FB bed sand samples, sulphur was found only in very small contents, while the sulphur content of CFB circulating material ranged 0.5–1%. Sulphur is concentrated more probably in fine particles.

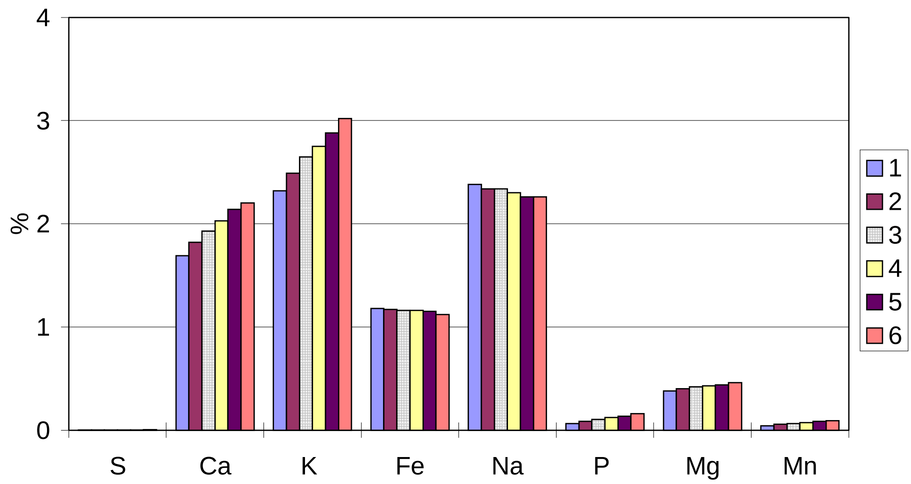

Figure 4. Change in the composition of FB bed material according to samples taken at one-hour intervals (1–6 h), logging residue chips 1, average temperature in the FB test equipment 881 °C.

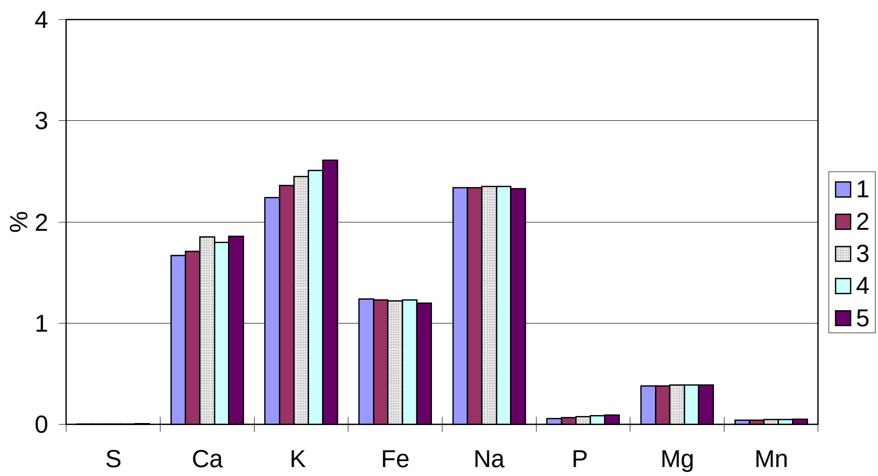

Figure 5. Change in the composition of FB bed material according to samples taken at one-hour intervals (1–5 h), 50% logging residue chips 1 + 50% peat 1, average temperature in the FB test equipment 873 °C.

In the experiment with whole-wood chips, when bed agglomeration was not found, the particle size of the bed material with sieve analysis was 0.276 mm. In the experiment with logging residue chips the bed agglomerated and the average particle size increased to 0.351 mm.

4.2 Composition of depositions

During the experiments, deposit formation was studied with a cooled probe inserted into the hot gas flow. In the FB experiments the probe was located in an intermediate channel after the reactor and prior to particle separation. The temperature of the probe was kept at 480 °C. The deposit of sample rings from the probes was analysed with SEM-EDX. In the experiments with logging residue chips 1 the fly ash material was deposited mainly on the incoming side of the probe. The material consisted of calcium and magnesium oxides. Some alkaline metal silicates were also found. It was found that in the combustion tests with logging residue chips some amounts of potassium and sodium chlorides were deposited around the sample ring, Figure 6.

When combusting the mixture of peat and logging residue chips (ratio 1:1) in the FB reactor it was found that the amount of chlorides was reduced in the deposition. The deposited material consisted of calcium, sulphur and aluminium silicates, Figure 7.

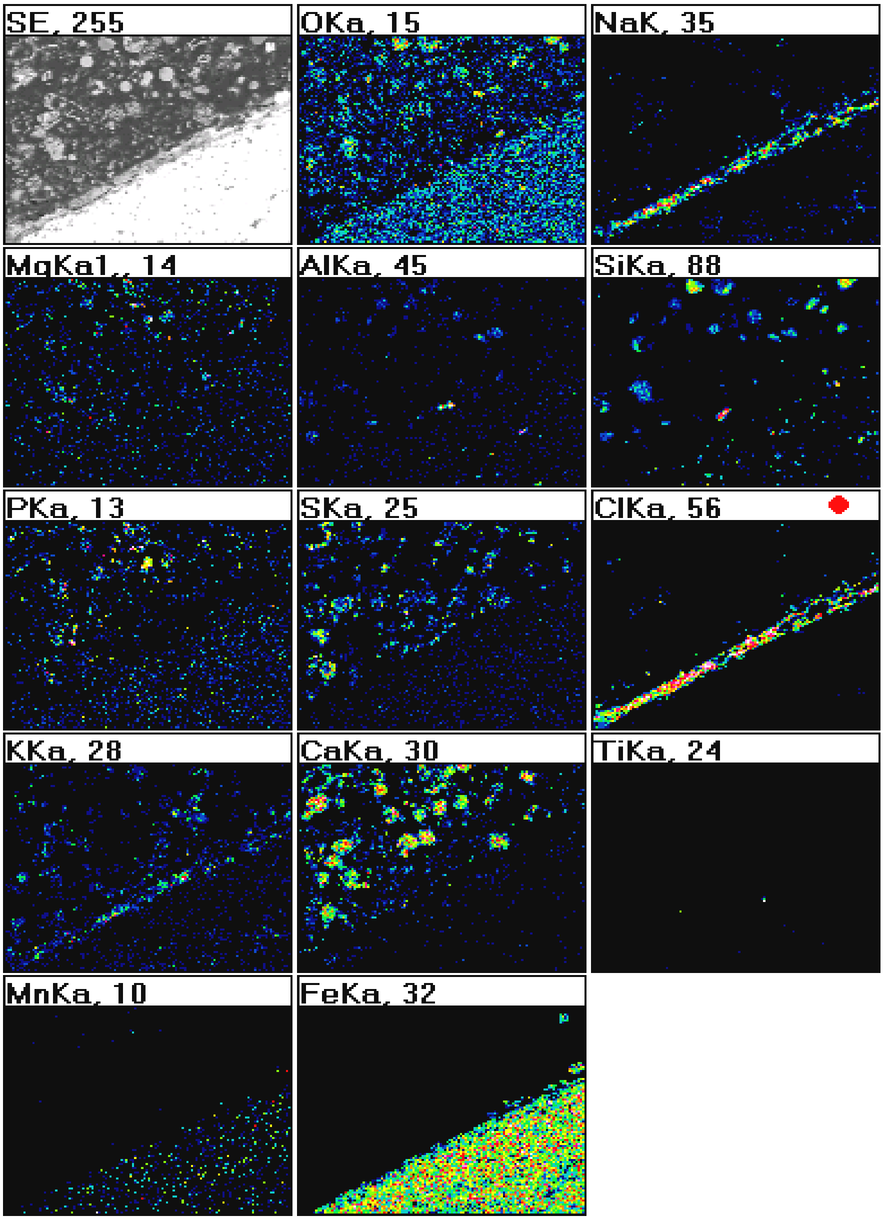

Figure 6. X-ray maps from the probe (cross-section) in the FB reactor (BEI-image, magnification 650X). The average temperature of the reactor was 881 ºC and of the probe was 480 ºC. Fuel: logging residue chips 1. Potassium chloride and sodium chloride deposits were 2–3 µm thick.

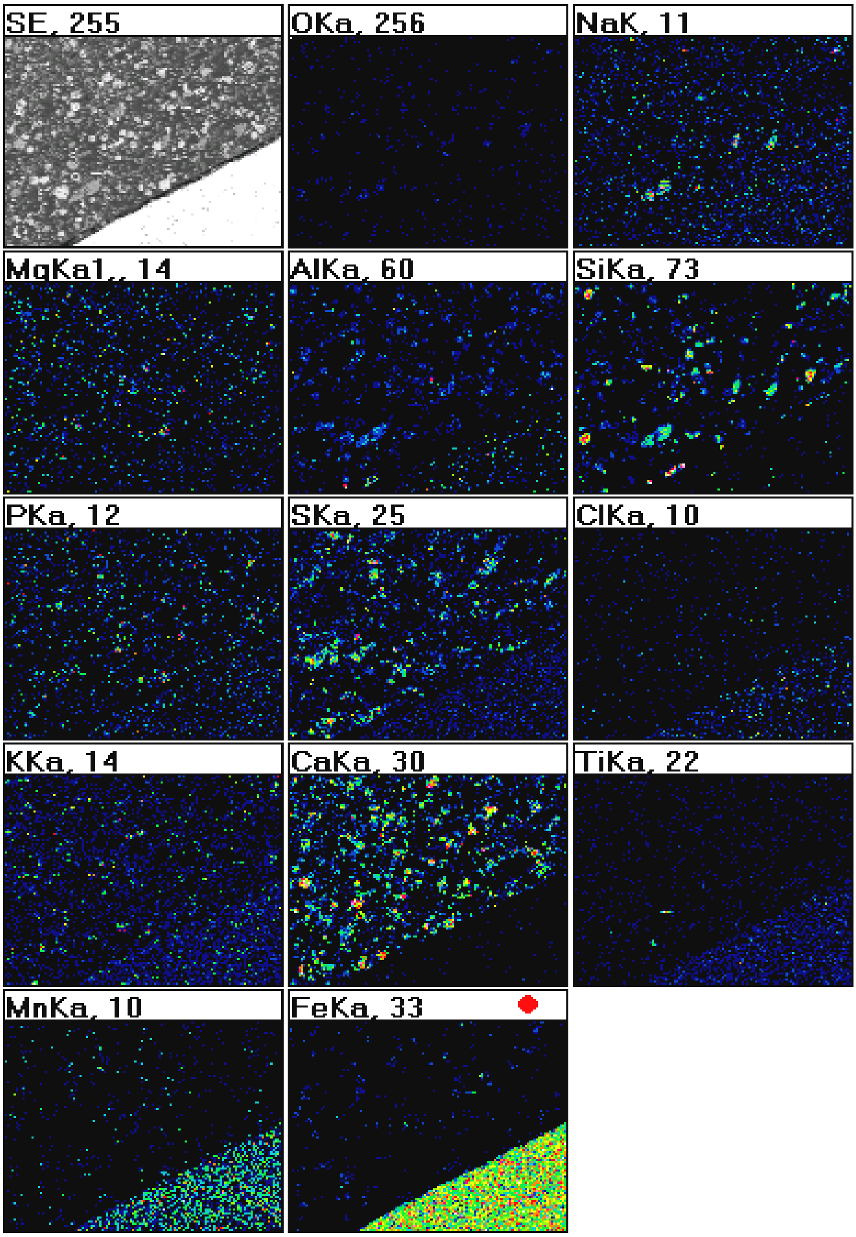

Figure 7. X-ray maps from the probe (cross-section) in the FB reactor (BEI-image, magnification 330X). The average temperature of the reactor was 873 ºC and of the probe was 480 ºC. Fuel: 50% logging residue chips 1 + 50% peat 1. The potassium chloride and sodium chloride deposits have disappeared.

4.3 Interaction between HCl and SO_2

The HCl contents of flue gas were determined in the flue gas prior to cooling with FTIR in FB reactor. The HCl content of flue gas increased, when peat was mixed with wood fuel, Figure 8. The peat grades contain 0.16% and 0.41% sulphur, which binds the alkaline metals of wood ash. As a consequence, binding of chlorine in alkaline metals is reduced, and the amount of detrimental compounds on superheater surfaces is reduced. More and more chlorine is released as HCl along with flue gas. This was also seen in these experiments.

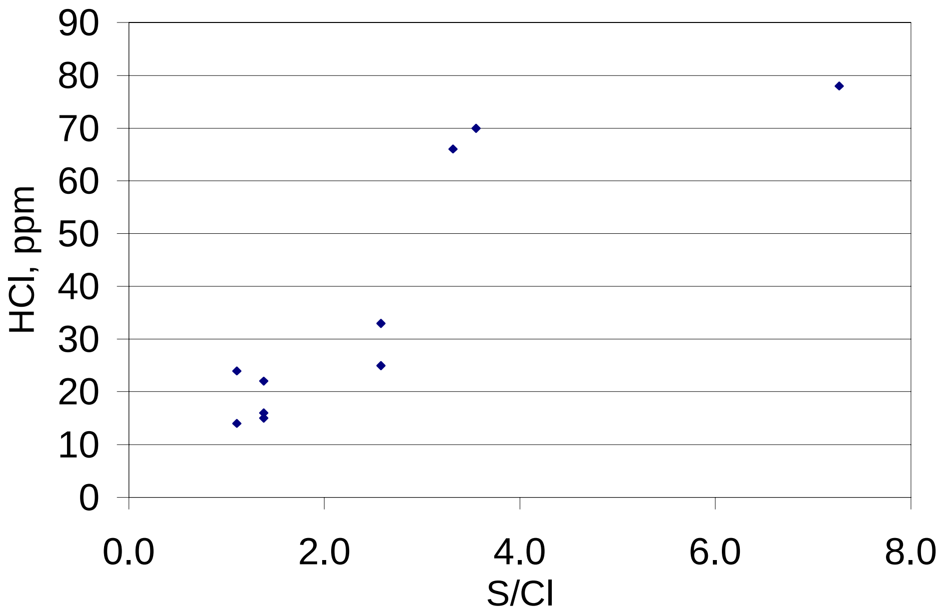

Figure 8. HCl contents of flue gas with different S/Cl ratios in the FB experiments. FTIR, dry flue gas.

4.4 Phase equilibrium calculations

The risk of bed agglomeration was found to be higher when combusting logging residue chips than when combusting whole tree chips. The tendency to agglomerate reduced when peat was mixed with logging residue chips. These trends are apparently related to the amount of fused phases wetting bed particles and to the mechanical strength of bonds formed by different fused phases between bed particles. The last mentioned factor is dependent on the viscosity of the fused phase. This viscosity is very low for fused inorganic salts and insufficient in binding bed particles. Sulphate, carbonate or chloride-rich fused phases do not cause any significant risk of bed agglomeration. In the combustion of logging residue chips, alkaline metals are released at high temperatures. These reduce the fusion temperature of small ash particles in the bed. The alkaline, calcium and aluminium rich silicate fused phases wet large sand particles. When silica (SiO_2) is dissolved from sand particles in the surrounding fused films, the viscosity of the film and the formation risk of stable sand agglomerates increases. Phosphorus may have a significant role in bed agglomeration, i.a., as phosphoric oxide, like silica, forms slag (10). On the other hand, even a small amount of phosphoric oxide reduces the fusion temperature of quartz close to the operation temperature of the bed. Phosphorus increases sharply the diffusion rate of silica in alkaline silicate fused phases (10). Calcium oxide binds phosphorous anhydride to high-fusing compounds.

Phase equilibrium calculations were carried out to study to which extent results of combustion experiments can be explained by the principles presented above. Small amounts of calcium, phosphorus and alkaline metals and an excess amount of silica (SiO_2) were added to the compositions presented in Table I. The result of calculations was clear. In relatively high alkaline/sulphur ratios, an alkaline silicate fused phase is formed in the bed and part of chlorine is as hydrogen chloride, part as gaseous alkaline chlorides. In relatively small alkaline/sulphur ratios and with sufficiently high oxygen potentials alkaline metals are bound to fused or solid sulphates, which do not cause agglomeration of bed particles. There is no alkaline silicate fused phase present in the bed. Chlorine was mainly in the gas phase as hydrogen chloride. Depending on mixture ratios and oxygen potential, phosphorus is in the gas phase and as phosphates of alkaline metals or calcium. When aluminium was added to the model mixture, in addition to alkalis, calcium and phosphorus, the situation complicated essentially. As alkali-aluminium silicates are very stable, no significant amounts of alkalis were bound to sulphates with any composition ratios. In all calculated cases, there was fused alkali-aluminium silicate present in the bed. Chlorine was present as hydrogen chloride. Under these conditions, sulphur was present in gaseous as sulphur compounds or was bound to calcium compounds, if the model mixture contained tolerably much of calcium. These results may explain the trends of agglomeration and enrichment with different fuel mixtures observed in the experiments, i.a. Figures 4–5. The calculation results also indicated that the risk of bed agglomeration or the form of chlorine occurrence in mixtures of wood, chips and different peat grades cannot in general be concluded from the sulphur/chlorine ratios and sulphur/alkali ratios of the fuel mixture.

The phase equilibrium studies of the bed give a satisfactory explanation for the effect of peat combustion on the quality of deposits in the probe, found in the experiments. The alkaline metals released in the combustion of logging residue chips react with chlorine and hydrogen chloride producing alkali-chloride vapours in flue gases. These vapours then condense on the cooled probe in the intermediate channel. It is known today that initial oxidation of low-alloy steel is accelerated significantly in the presence of alkaline chlorides at as low as 450 ºC (11). Hence, there is a risk of superheater corrosion. Depending on the fuel and on the chemistry of the bed, the alkalis are bound in sulphates and/or silicates. Mixing of peat with the logging residue chips reduced the condensation of alkaline chlorides in the intermediate channel or eliminated it, Figure 7, as chlorine occurred mainly as hydrogen chloride in the flue gases. The risk of superheater corrosion may still exist, because hydrogen chloride may, depending on the SO_2/HCl-ratio in flue gases, transform mixed sulphates to alkali chlorides in deposits (12). Case-specifically, the theoretical sulphur dioxide content of flue gases may be nil, or on the contrary, the flue gas may contain significant amounts of sulphur trioxide. Hence, the corrosion risks of boiler heat exchange surfaces and secondary surfaces should be determine case-specifically.

5. Conclusions

Alkaline metals and phosphorus-containing phases are deposited on the surfaces of bed particles in the combustion of logging residue chips. These phases adhere bed particles to each other and increase their size. Despite of the low chlorine content (0.04%) of the fuel mixture, chlorine was enriched in the deposit probe having surface temperature 480 °C. When sulphur-containing peat is added to the fuel mixture, the bed particles do not adhere and chlorine does neither enrich in the deposits. The sulphur of peat binds alkaline vapours to sulphate, which does not cause bed agglomeration even in fused form. Chlorine occurs as hydrogen chloride in flue gases. Hydrogen chloride does not condense in the area of superheaters and does neither cause such a risk of corrosion as the same amount of chlorine as alkaline chlorides. The results of phase equilibrium calculations indicated that in general any conclusions cannot be drawn from the risk of bed agglomeration or from the form of chlorine occurrence in mixtures of wood, chips and different peat grades on the basis of sulphur/chlorine or sulphur/alkali ratios in the fuel mixture. The laboratory tests indicated that it would be favourable to co-combust at least 10–20% of peat, depending on its sulphur content, with logging residue chips. This reduces bed agglomeration and problems involved. The amount of detrimental alkaline chlorides is also reduced. When peat was mixed with logging residue chips in the test equipment runs, calcium, potassium and phosphorus were also accumulated in the bed sand. It may be necessary to remove coarse layer from the bed to prevent agglomeration. The chemical composition of deposits and bed material can be evaluated efficiently by pilot-scale experiments and SEM-EDX analyses of bed material. Presented research method for deposit formation on superheater surface has been proved to be usable also at full scale power plant boilers.

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Practical experiences of large-scale use of forest fuels in Sweden

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1. The use of biofuel in Växjö

The city of Växjö was the first city in Sweden to use wood-chips as fuel for district heating in a large scale. This was done in 1980 and the capacity was 30 MW_{th}.

Växjö was also the first city in Sweden to use wood chips as fuel for combined heat and power production in a cogeneration plant. This was in 1983 and the capacity was 47 MW_{th} and 18 MW_e. Both these projects were done as reconstruction of existing oil-fired boilers.

In 1997 we took into operation a complete new cogeneration plant, 104 MW_{th}, specially constructed for biomass fuels. Since 1997 we also have built 3 biofuel boilers for local district heating net in the size between 1–4 MW_{th}. All this plants are own and operated by a company own by the common – Växjö Energi AB called VEAB.

When the first reconstruction to biomass fuels was done in 1980 the aim was to create a safe energy – supply in case of oil – crises in the world. The oil price was much lower than the price for wood chips why the government supported both the costs for the reconstruction and the additional cost for the fuel compared with the oil price.

The aim was to demonstrate how to reconstruct a typical oil-fired hot-waterboiler for district heating from oil-firing to firing with wood-chips which are a domestic fuel with great potential in Sweden. The result was used to make plans for a rapid reconstruction of a great number of equal boilers in many city's in Sweden.

Afterwards it is a bit funny that the first forestry company we asked to deliver the fuel said, ”There are no such fuel so we think you can't fulfil the project”. The actual volume was about 20 000 MWh. (Today we use 500 000–600 000 MWh and the capacity of fuel in our area is much bigger than so.)

In any case, we got our fuel and operated the boiler. The capacity was reduced from 50 MW to about 30 MW_{th} but this was expected.

In the autumn of 1980 the war between Iran and Irak started and the oil-price increased dramatically. Since the oil-price suddenly was twice as high as the price for wood-chips we used this fuel as much as possible.

In those days everybody tried to substitute the oil whit other fuels. The common sense was to use coal, which was much cheaper than oil and is produced all over the world in contrast to oil.

Even we studied the coal but we saw that it would take several years to get the necessary allowances because it was a hard resistance against the coal in many city's. Since we got a good experience of woodchips firing and thought that it would be easier to get a rapid decision by this fuel.

When we proposed the commonal council to accept a reconstruction of our oilfired cogeneration plant we got the necessary decisions very rapidly and was in operation only 14 months after that.

This rapid decision made that the economy for biomassfuels was equal to the economy by coalfiring since we expected several years of delay to get the necessary decisions for coal.

We had also got a competence in firing woodchips and we found it was a good fuel. The economy of the woodchips firing was very good until the oil-price sunk in the years around 1985. At that time it has been more profitable for us to change back to oil again but we believed that if we stopped the deliveries of biomassfuels, it would be very difficult to start up them again. We believed that in the long run the biomass-fuels would be most attractive.

In 1991 we got a new tax-system in Sweden when the CO_2-tax on fossil fuels were introduced together with sulphur-tax and changed common energy-tax. These taxes together with a successively lower price of biomass fuels gave very good economy to use these fuels for heating purposes.

The government in Sweden also decided to give subsidises to them who built biofuel fired cogeneration plants so the company VEAB build such a plant which was in operation in the autumn 1996. The capacity is 104 MW_{th}. The new co-generation block is also equipped with ammonia-injection to reduce the NO_x-emissions. There is also installed a so called slip-catalysor which will reduce the ammonia-emissions but has a very small direct influence on the NO_x-emissions. VEAB also built local district-heating net with boilers in three smaller villages in the commone. Also these are fired by biomass-fuels.

We can say that during these years we have had different aims but we reached them by using the same solution – use more biomass-fuels.

In the very beginning the safe fuel supply was most important together with the aim to reduce the sulphur-emissions. In about 1990 the CO_2-problem was focused and our owner, the Växjö common have taken the decision to be a CO_2-free city. In this our company have an important and active part.

We are now expanding our district heating-net were we replace oil and electricity by biomass based district heating. It is also an aim in Sweden to reduce the use of electricity since the parliament decided top stop two nuclear-plants. This was the reason for giving us subsidies to build our new co-generation plant.

We pay for the biomass fuels in proportion to the effective heating value. This means that the energy needed for the evaporation of the moisture content in the fuel is free of cost for us, the buyer.

2. Flue gas condenators

Two of our boilers are equipped with flue-gas condensators. One of them is connected to the biomass fired hot water boiler and one is connected to the 104 MW steam boiler for the new co-generation block. The flue-gas condensors will of course influence the possibility to use the district-heating load us a base for producing electricity in the cogeneration-blocks but the economic result of this has been good since the price of electricity has been very low during the latest years.

Flue-gas condensing increase the capacity of the boilers with 15–25%. Flue-gas condensing decrease the fuel costs even for the produced electricity since even the flue-gases from the fuel used for this propose will be cooled in the flue-gas condensor.

3. Possibilities in the future

If the price for the electricity will increase in the future we will, by a calculated level, stop the flue gas condensors and maximize the production of electricity. If the price of electricity will be high enough, we are prepared to install a gas-turbine with an exhaust-boiler which will feed the existing steam-turbine that means a combined cycle. The gas-turbine can be fired by light oil, natural gas or gasified biomass fuels.

The strategy for environmental questions for VEAB is to take initiative and fulfil what we believe in even if it not stated in the law and rule by the authorities. This means that we have to be competent enough to make the necessary conclusions.

It is also necessary to get a good economy and a safe technology to create a confidence from our owner, the Växjö common and from our customers. Until now we have succeed in these aims.

Today we got the mission from our owner the common to find a way to produce fuel for vehicles based on biomass fuels. We will do our very best!

4. Fuel market

In the very beginning many people were worry about if there should be enough biomass-fuels available. Today we can see that the consumption has increased rapidly and the price has been lower. One part of this is a market in function, one part is the technical development and one part is the import of biomass-fuels including wood residues from foreign countries to the cities by the coast.

The most of the fuel is sawdust, bark and other residues from the wood-industry. A decreasing part is branches and treetops from the timber felling area.

5. Problems by firing wood in a CFB-boiler

Even though VEAB has used pure wood, that is no waste qualities or high mineral species as *salix* there have been some difficulties commonly related to the mineral content of the ashes.

- Bed particle agglomeration – an adhesion of bed particles probably initiated by the mineral content of the wood ash. The effect of this is defluidisation of the bed. Often concerned as an interaction between calcium, potassium and silica, with melting points corresponding to that of the furnace.

- Deposits in the separator. The most severe are those in the return legs from the separator to the furnace, at worst causing blockage of these, which has resulted in unplanned shot down of the boiler. There have also been deposits on the sloped wall in the separator, these has later fallen down into the return legs and make the blockage even worse.

- Deposits on the over superheaters in the furnace, the so-called wing wall, causing working environmental problems at the revision. This is supposed involving the same mechanism as the agglomeration possibly as an effect of reducing atmosphere.

- Deposits on the fuel injectors building up high stalagmites, that fall down when being too high. The result is blocking of the primary air nozzles at the bottom, which causes defluidisation of the bed. This is a phenomena occurres intermittent and then not on all four injection points to the same extent.

- Deposit on the superheaters exchangers initiating high temperature corrosion. Sandvik 2 has obvious signs of this though there has been no indications of high chloride content in the fuel - as in waste or high chloride peat.

- Corrosion/erosion of the air preheaters. Because of the high moisture content and low inlet temperatures of the air, there has been condensation on the air tubes, resulting in damages.

The most of the problem mentioned above are today solved or so much less than they don´t influence the availability of the boiler. We will this season try to mix some peat in the biomass fuel to got less problem by deposits.

Technology of fuel chip production in Sweden

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1. State of the art

Exact statistics is poor over volumes and methods for forest fuel handling in Sweden. A SkogForsk survey where all main players during the season 1996/97 was interviewed showed a utilisation of approximately 6 TWh of primary forest fuel. 4,4 TWh logging residues from clear cuts, 1 TWh rotted wood mainly from clear cuts and 0,7 TWh extracted in thinning operations.

Forest fuel handling is today dominated by a few large companies like, Södra Skogsenergi, Sydved Energileveranser, Naturbränsle, SCA Norrbränslen, Stora Enso, Assi Domän and SÅBI. These companies have contracts with end users and handle both primary forest fuels, bi-products and other energy assortments. For the forest operations and truck transport entrepreneurs are hired.

Recent interviews with production managers at the larger forest fuel companies shows that final felling still is the source for the absolutely dominating volume of logging residue. An attempt to approximate the different methods in final felling based on these interviews from summer 2000 shows that:

- 80 (or more) % is chipped at roadside or in a large pile close to the roadside
- 10% is chipped directly on the clearcut in the piles produced by the harvester
- 10% (or less) is transported uncomminuted to terminal or heating plant
- Collection of fresh, green, material is rare

- 10–25% of chipped material is transported to a terminal for storage, storage time approximately 6 months
- Average worksite is 250–400 m^3 loose in southern Sweden
- Average transport distance is 60–75 km, forest to end-user
- Landowner is payed 0–15 SEK/m^3 loose (0–1.7 SEK/m^3 loose)
- Profitability is close to zero.

1.1 Typical operations

In a typical operation tops and branches are left in fuelwood piles to dry on the cutover during the spring and early summer. Subsequently the residues are generally forwarded to the landing, or to a place on the cutover close to the landing where the residue piles are covered over with paperboard to keep the moisture content down. The position of the pile should be high, windy and sun exposed.

Comminution is done by chippers mounted on forwarders. The comminution takes place during winter season just before the material will be used at the heating plant. The 60–75 km truck transport, is done by container rigs, three containers on a truck and each container with a volume of approximately 35 m^3. Mainly to secure deliveries during winter and though period 10–25% of the chipped material is placed at terminal. Storage time on the terminal is probably 4–6 months or more. Transport from terminal to end-user is taken care of by conventional cellulosa-chip trucks

During late summer and early autumn chipping can take place in the small piles left on the cutover by the harvester. Chipping directly on the cutover during this period slows down the flow of chips during a period with low demand from the end-users. The operation gives the advantages to keep the entrepreneurs operating during this period, possibilities to reach a high quality fuel without forwarding and piling with paper coverage to the same or even lower cost compared to conventional operations.

It seems that the increase of central comminution (at terminal or end user) which was discussed a couple of years ago hasn't taken place. On the contrary has chipping at landing or close to the landing increased since 1996/97.

For example decided Stora-Enso recently to shift from a system where uncomminuted material was transported with large bulk trucks to terminals, to conventional chipping at roadside. The terminals was placed in a grid in the eastern part of Stora-Ensos operational area (west of Gävle).

Some reasons why the terminal based system is going back might be:

- Higher costs
- Problems to keep control over quality at large terminals
- Problems to find suitable terminals due to noise and smell
- Low forest fuel activity in central and northern Sweden where terminal based systems are more favourable due to winter conditions.

1.1.1 The transport system

Transport of fuelwood assortments occurs mostly by truck. The Swedish vehicles has a length of 24 m and a gross vehicle weight of 60 tonnes. The dominating technique for transporting wood chips is a container rig. On the vehicle, three containers are placed, each of which has a volume of 35 m^3, it gives a payload of 35 tonnes. In general, nine containers are used in a system for preparation and transport to the heating plant or storage site. It takes about 45 min to load three containers and 25 min to unload them.

The normal vehicle for transporting unchipped logging residues consists of a purpose built loading space of approximately 145 m^3 (truck + trailer). To increase the degree of compaction of the unchipped logging residues the truck can be equipped with a heavy-duty crane with double-acting lift cylinders. The load can also be compacted by the heavy crane on an independent loader.

Train transport of by-products is used. During the autumn of 2000 a new transport system is launched by Naturbränsle. The company will transport bi-products from longer distances to the region of Mälardalen.

2. Low profitability - big need to intensify rationalisation

The increasing consumption of wood fuel by district heating plant in recent years has led to intensified activity. However, since the prices available for wood fuel have not risen, ways of increasing efficiency of old systems and new methods for simpler and more cost-effective handling of wood fuel are obviously of great interest.

The first step that needs to be taken to reduce wood-fuel handling costs is to refine and improve the existing technology and, not least, to develop sound logistics. Another way in which substantial savings could be made would be to minimize storage of wood fuel and also to optimize the storage process itself.

The quality of the fuel, of course, is always in the spotlight. Fundamental requirements for cost-effective handling of wood fuel are careful harvesting, to avoid picking up contaminants, and assisting drying of the wood after forwarding by piling the residue in an open, airy and sunny location, and covering the piles properly with paperboard.

It is also essential to select the right sites, ie, those containing plenty of wood fuel, and avoiding small sites where the cost of moving machinery would constitute too high a share of the total production costs.

So in addition to the rationalization of conventional logging systems, interesting developments are taking place when it comes to compacting the logging residue on the site.

The absence of technology for compacting logging residue in the woods has long been felt. The first breakthrough occurred in 1995, with the introduction of the Bala Press baler. Thereafter, Fiberpac and Wood Pac unveiled equipment capable of compressing the logging residue into cylindrical bales, known as composite residue logs (CRLs) – a form welcomed by loggers, who have been accustomed to handling logs for more than 100 years.

2.1 Composite residue logs (CRLs)

Two companies, Fiberpac and Wood Pac, have launched systems for compacting logging residue from final felling into cylindrical bales known as *composite residue logs (CRLs)*. The CRLs have a diameter of roughly 0.75 m and a length of three metres. They weigh between 400 and 600 kg and have an energy output in excess of 1 MWh. The compaction units, which are mounted on medium-duty forwarders, weight 6–7 tonnes.

The technology is attractive because systems that enable logging residue to be compacted on the site can reduce the cost of wood fuel delivered free to the end user. CRLs can be handled as roundwood throughout the handling chain: conventional forwarders and roundwood haulage rigs can be used and CRLs also facilitate efficient haulage by rail – an important consideration for the future should there be a substantial rise in the demand for wood fuel.

The CRL systems are still under development and several problems remain to be solved. Carrying CRLs on roundwood haulage rigs may require the use of netting or solid side boards to prevent material falling off during transit; in addition, further studies need to be made of the consequences of storing compacted reside and to find an efficient means of chipping CRLs.

Studies on the Fiberpac 370 and Wood Pac units have pointed to productivity of 20–30 CRLs per productive (G_{15})[1] hour and approximately 15 CRLs per hour, respectively.

[1]*Productive (G_{15}) hour = Hour of productive machine time including downtime not exceeding “15" minutes per occasion.*

Figure 1. The Fiberpac 370 weighs approximately 6 tonnes and can be mounted on a medium or heavy-duty forwarder.

*Figure 2***.** *Wood Pac mounted on a Rottne forwarder. Compaction chamber consists of 8 cylinders and is topfeeded.*

CRLs can be extracted efficiently by conventional forwarders – it is even possible to load the CRLs crosswise to increase the payload; moreover, they can be extracted at half the cost of loose, uncompacted residue.

Similarly, conventional roundwood rigs can be used for secondary haulage of CRLs, although problems with needles and twigs falling from the load can occur, requiring it to be contained by means of netting and/or thin side boards on the rig.

The use of a large mobile or stationary chipper at the heating plant could achieve a cost saving of two-thirds compared with conventional chipping in the woods. Chipping, however, still constitutes a bottleneck in the system and intensive work is therefore in progress to find the best technology for chipping the CRLs.

Figure 3. A conventional roundwood rig can accommodate some 66 CRLs – 15 per stack on the trailer and 10 or 11 per stack on the truck. A pulpwood bolt is placed on either side at the bottom of each stack to prevent the load from overhanging the load-securing devices.

Large drum chippers can achieve high levels of productivity and low chipping costs. The problem with this machinery, however, is that it is highly sensitive to contaminants, resulting in low availability and expensive repair costs. One solution could be to use crushers, which are more tolerant of contaminants. Work to find the right machinery that can deliver high productivity at a low cost is therefore under way.

Figure 4. A Bruks 1004 CT drum chipper mounted on a dumper-truck chassis. This chipper has a capacity of 200,000 m^3 (solid) over an eight-month season and assuming a mechanical availability of 60%.

In collaboration with Raida Jirjis at the Swedish University of Agricultural Sciences, SkogForsk has studied the effects of storing CRLs. The first study of Fiberpac CRLs, which were stored from August 1998 until February 1999, found no change in the moisture content when the stacks were covered by paperboard but a 5% increase when left uncovered. The volume of chips from each CRL was 1.4 m^3, corresponding to an energy output of 0.7 MWh/m^3 for green CRLs and 0.82 MWh/m^3 for brown ones. The University formed the view that storage had not given rise to fungal spores in quantities likely to constitute a health hazard on chipping and also judged the risk of biomass losses to be moderate, particularly for brown CRLs. To and Wood Pac units, new studies have been started, the findings of which will be reported by the University in autumn 2000.

Compared with the cost of conventional chipping systems, our calculations indicate that the costs incurred in the CRL system are comparable or slightly lower. However, such comparisons require a measure of caution, since the differences between the systems are highly dependent on the haulage distances involved. A major advantage of the CRL system is that the same handling and administrative routines can be used as in conventional roundwood logging.

Table 1. Comparison of costs (SEK/m^3 (loose) and SEK/MWh) in the CRL system and a conventional chipping system.

	SEK/m^3 loose (€/m^3 loose)			
	Chips	€/m^3 loose	CRLs	€/m^3 loose
Forwarding	21	2.4	8	0.9
Fiberpac			19–26	2.2–3.0
Moving between sites	2	0.2	2	0.2
Miscellaneous (roads, rejects, etc.)	6	0.7	2	0.2
Covering of stacks in the woods	3	0.3	0	0
Chipping	35	4.0	10–15	1.2–1.7
Subtotal	67	7.7	41–53	4.7–6.1
Haulage	(75 km), 23	2.6	(30 km), 10	1.2
To terminal	5	0.6	10	1.2
Terminal to heating plant (50 km)			10	1.2
Operational costs, SEK/m^3 loose	**95**	**10.9**	**71–83**	**8.2–9.6**
MWh/m^3 loose	0,88	0.1	0,8	0.1
Operational costs, SEK/MWh	**108**	**12.4**	**89–104**	**10.2–12.0**

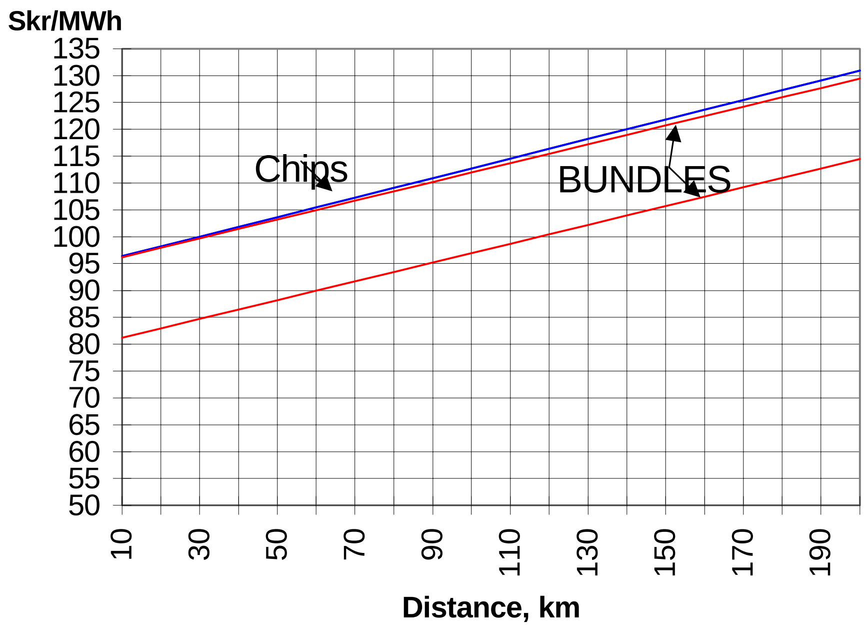

Figure 5. Comparison of operational costs (Skr/MWh) in the CRL system and a conventional chipping system. The costs in the CRL system apply to a haulage distance of 30 km from the woods to the terminal. The X-axis denotes the distance from terminal to end user (CRLs) and from the woods to end user (chipping system).

2.2 Integrated harvesting of roundwood and logging residues - a visionary system

One direction that development work could take to devise cost-effective systems for wood-fuel harvesting would be to integrate roundwood and wood-fuel harvesting (Integrated system). An analysis of this technique is described by Dan Glöde, [3]. The integrated system consists of a single-grip harvester equipped with a compressing unit that is fed with residues directly from the delimbing process. The idea is that by integrating the harvest of timber and collection of residues the operations can be done on the same occasion instead of at two separate times, and also that specific machinery for taking care of residues can be avoided. The conclusion is that the cost of forest fuel can be decreased by developing a machine for simultaneous harvest of timber and logging residues. If such machine can maintain the productivity at the timber harvest, the system–cost can be decreased by more than 20% compared to today's systems.

2.3 Small trees from pre-commercial thinnings

The volume of logging residues from thinnings is quite small today. However with an increasing demand for forest fuel assortments together with changes in silviculture regimes interest increases to collect logging especially from precommercial thinnings.

The annual backlog of cleaning or precommercial thinning in Sweden is some 50,000 ha. Unless this is dealt with, we shall soon be facing serious problems when it is time for securing a suitable return from first or commercial thinnings. One way that additional revenue could be generated from these neglected or uncleaned stands would be to harvest wood fuel by means of a multitree-handling felling head, with chipping of the felled trees.

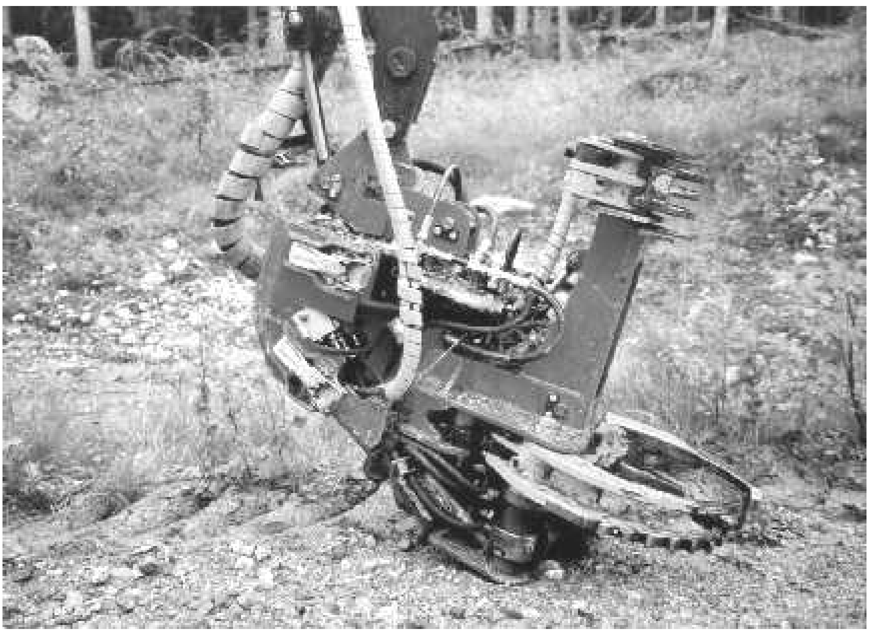

Figure 6. The EnHar unit – an accumulating or multitree-handling head for felling and baling.

SkogForsk's studies on the Timmek EnHar multitree-handling felling head have found that the unit could be a viable option but that improvement of both the technology and the operating methods is needed.

An interesting path that Timmek is exploring is the development of a method of baling thin stems. As in the baling of logging residue, this could simplify handling in the subsequent stages of forwarding, road haulage and chipping.

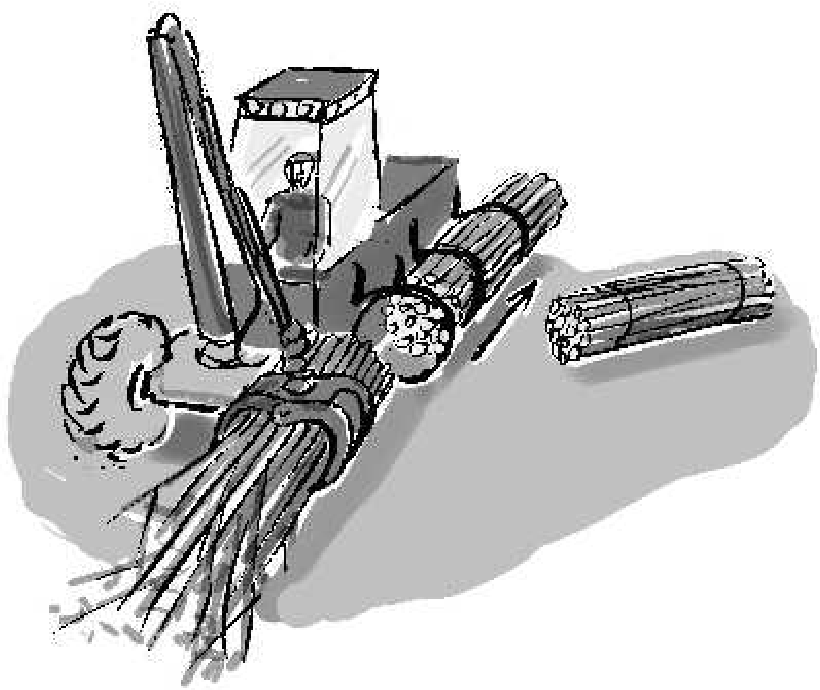

Figure 7. Baling of thin stems could both simplify handling and reduce costs.

3. New regulation

New recommendations from the forestry Board regulates the handling of logging residue in order to guarantee the long term nutrient balance in soil. To keep the nutrient balance there are two ways;

- Either a majority of needles should be left spread over the area or,
- Ash recycling should take place.

These new regulations together with the deposite tax on 250 SEK/tonne has led to increased interest to find ways of efficient ash recycling and also an interest of how to solve the problem to leave a majority of the needles left on the clearcut.

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Nordic Treasure Hunt
Extracting Energy from Forest Residues

Abstract

The programme of the international wood energy workshop, entitled “Nordic Treasure Hunt: Extracting Energy from Forest Residues”, organised on 30^{th} August, 2000 in Finland, consisted of six papers from Finland and five papers from leading experts from Sweden and Denmark. Some papers reported on recent research findings and progress, and some reviewed the past development and present status of large-scale production and use of forest chips.

This seminar was focused on forest residues and its uses in the context of Nordic experiences and technologies. Competitiveness and costs as well as environmentally sound forestry are the key issues. The seminar was organised in collaboration with the Finnish Wood Energy Technology Programme and the OPET Finland.

In connection with the international programme, an annual seminar was held on August 29, 2000 at the conference centre in Jyväskylä, Finland.

Keywords

biomass, biofuels, wood fuels, forest residues, renewable energy sources, forest chips, combustion, properties, quality, emissions

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