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Carl Wilén, Pia Salokoski, Esa Kurkela and Kai Sipilä

Finnish expert report on best available techniques in energy production from solid recovered fuels

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Foreword

The European Council Directive on Integrated Pollution Prevention and Control (IPPC Directive 96/61/EC of September 24, 1996) aims at an integrated approach of pollution prevention and control arising from industrial activities listed in its Annex I. The directive requires that "The Commission shall organize an exchange of information between Member States and the industries on best available techniques, associated monitoring, and developments in them". The results of exchange of information will be published by the Commission as best available techniques reference documents (BREFs) on each industrial activity listed in Annex I. To organize the exchange of information the Commission has set up the so called Seville process in order to produce BREFs in all for 33 industrial activities. One of the BREFs will be the BREF on Waste Treatments (WT) and Waste Incineration (WI).

"Finnish expert report on best available techniques in energy production from solid recovered fuels" gives a comprehensive review over the energy production from solid recovered fuels in Finland. The report is focused on co-firing in combined heat and power production, mainly on fluid-bed combustion and gasification technologies and advanced gas cleaning. This report describes an integrated waste management system, emphasizing a simultaneous and efficient material and energy recovery from waste. The objective of this report has been to produce information to be used in the European Commission work to generate descriptions of best available techniques dealing with utilization of waste as energy.

The report was prepared by Carl Wilén, Pia Salokoski, Esa Kurkela and Kai Sipilä from Technical Research Centre of Finland, VTT. The project has been guided by national technical working groups on waste treatment and waste incineration consisted of experts of industry and authorities. The steering group has provided comments on the draft reports and offered a platform for discussion on the scope, themes and results of the study. We would like to thank the writers and all the other experts for excellent collaboration and support received. Specially we would like to thank Mr. Matti Hiltunen and Mr. Juha Palonen from Foster Wheeler Energy Oy, Mr. Jouni Kinni from Kvaerner Power Oy, Mr. Matti Kivelä and Mr. Hemmo Takala from the Lahti Energia company and Ms. Tarja Rintala and Mr. Pentti Rantala from Tampere Regional Solid Waste Management Ltd for the information received.

In Helsinki on the 25th of February

Seppo Ruonala	Hille Hyytiä
Project manager	BAT-coordinator

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General information

1.1 Introduction

In Finland, the national waste management strategy is presented in the National Waste Action Plan [1] for the year 2005 reflecting the EU Directives, especially the Waste Directive. The key objective is to prevent the generation of municipal solid waste by 2005 at least 15 % of the waste amount predicted and to increase the recovery rate of MSW from present about 40 % to more than 70 % by the year 2005. There are also targets for waste reduction, material recovery rates for some material fractions like packaging wastes, for doubling the landfill tax, and for reduction figures for combustible and organic materials. It has been estimated that significant additional volumes of MSW should be used for energy on top of the highest priority material recycling. About 1 Mt/a of MSW should be used for energy if no new large-scale recycling alternatives can be found. Waste-to-energy technology in Finland is focused on co-firing in combined heat and power production, mainly on fluid-bed combustion and gasification technologies and advanced gas cleaning. The quality of Solid Recovered Fuel (SRF) will be based on good source separation and recovered fuel production technology. Landfill disposal is still the dominating alternative for MSW in Finland. However, material recycling and composting of biowaste are the most rapidly growing alternatives.

Today there is one MSW incineration plant in the city of Turku (50 000 t/a), and about 300 000 t/a of dry solid recovery fuel is co-fired in industrial and municipal boilers. At present some 20 medium and large-scale fluidised bed boilers co-fire SRF for heat and power production [2]. For the new investments, the references are typical mixed-waste incineration plants in Europe, most of them generating only electricity and some units in Scandinavia also district heat. In Finland, most of the solid fuel boilers generate combined heat and power (CHP) for municipalities or industry, and there are more than 150 biomass-fired boilers where also high-grade SRF could be co-fired. The power price in the Scandinavian grid is low, typically 3–4 cent/kWh, and economically condensed-mode separate power production from waste fuels is not attractive. For new CHP or heat generation capacity, most of heat loads in cities have already been built, and it is difficult to sell additional SRF-based energy to the market other than for co-firing in CHP boilers. This issue will be critical for gate-fee estimates besides additional costs due to EU's Waste Incineration Directive for waste-to-energy operators. New technologies and concepts are needed to intensify the material recycling and energy recovery. The European trend of using additional renewable energy including biomass and waste will catalyse this development and business opportunities.

The Finnish waste management and solid recovered fuel production is based on an efficient and extensive source separation practise. A typical distribution of waste fractions in household waste in Finland is presented in Figure 1. Source separation and kerbside collection make it possible to separate about 50 % of the mixed waste for energy use and direct half of the waste stream to material recovery (paper, metals, glass, compost/digestion). Furthermore, a more favourable basis for production of a clean SRF is created by separating impurities at an early stage.

Figure 1. Typical waste fractions in household waste in Finland.

1.2 Waste composition

The waste owner, i.e. the company, the municipality or the person who owns the waste material, is responsible for the waste handling. The municipalities must provide the collection and handling of household waste and the similar commercial waste.

Handling of commercial waste, construction waste and demolition waste and also the industrial waste are the responsibility of the company producing the waste. These companies can co-operate with the municipality, but because of the differences in the quality of the waste originating from households or from industry, different processing options are often relevant for these waste streams.

Municipal Solid Waste (MSW) comprises three main fractions in Finland: household waste, commercial waste from shops, offices and companies, and also process waste from small enterprises because it is collected together with the other MSW fractions. This fraction also contains some construction waste.

Fuel properties of the combustible part of the above mentioned waste fractions are presented in Table 1. The values are long-term mean values based on analyses carried out at VTT Processes. Solid recovered fuels are produced mainly from the dry waste fraction of MSW and from dry commercial waste. Commercial waste contains mainly polyethylene plastics, wood, paper and board.

Table 1. Typical properties of various waste fractions.

		Commercial waste	Construction waste	Household waste
Lower heating value	MJ/kg	16 – 20	14 – 15	13 – 16
as received	MWh/t	4.4 – 5.6	3.8 - 4.2	3.6 - 4.4
Moisture	wt%	10 - 20	15 - 25	25 - 35
Ash	wt%	5 - 7	1 - 5	5 - 10
Sulphur	wt%	<0.1	<0.1	0.1 - 0.2
Chlorine	wt%	< 0.1 - 0.5	<0.1	0.3 - 1.0

The waste coming from shops, supermarkets, department stores, etc., is good raw material for high-grade recovered solid fuels. The composition of waste from industrial companies varies. Companies producing problematic waste streams are, however, fairly few and identifiable, and the problems associated with these wastes controllable. The waste from households is more diverse and concern the whole population. A better fuel can be produced from commercial waste with current technology than from household waste.

1.3 Source separation schemes of household waste

The existing source separation system in Finland is based on source separation of 2–6 fractions in households and commercial waste sources like offices, superstores, etc. Various cities do not always apply the same source separation procedure due to historical or local reasons. Typically paper, biowaste and dry waste are collected in households of the major cities. Kerbside collection of some waste fractions, e.g. paper, cardboard, glass and metals, is combined with household separation. Source separation is the key of good material separation for recovery and for the production of high-quality SRF.

The composition of household waste separated using two 5-bin and a 2-bin separation scheme is presented in Figure 2 [3]. The composition of the dry fraction and energy fraction, which are used as feedstock for solid recovered fuel production, were further analysed by hand-picking. The dry fraction still contains almost 30 % of biowaste and about 15 % of other impurities. The energy waste obtained in one of the 5-bin separation schemes was considerably “cleaner” due to the fact that a separate bin for landfill waste was provided in that particular scheme. Correspondingly, the yield is much lower than in the other schemes.

The results indicate that source separation could still be improved in households. An efficient source separation scheme (e.g. energy waste separation) improves the quality of SRF with regard to combustion properties. The amount of chlorines, alkalies and aluminium can be reduced considerably, Table 2 [3]. Data in Table 2 is compiled from a single measurements study and cannot be considered representative in a broader context.

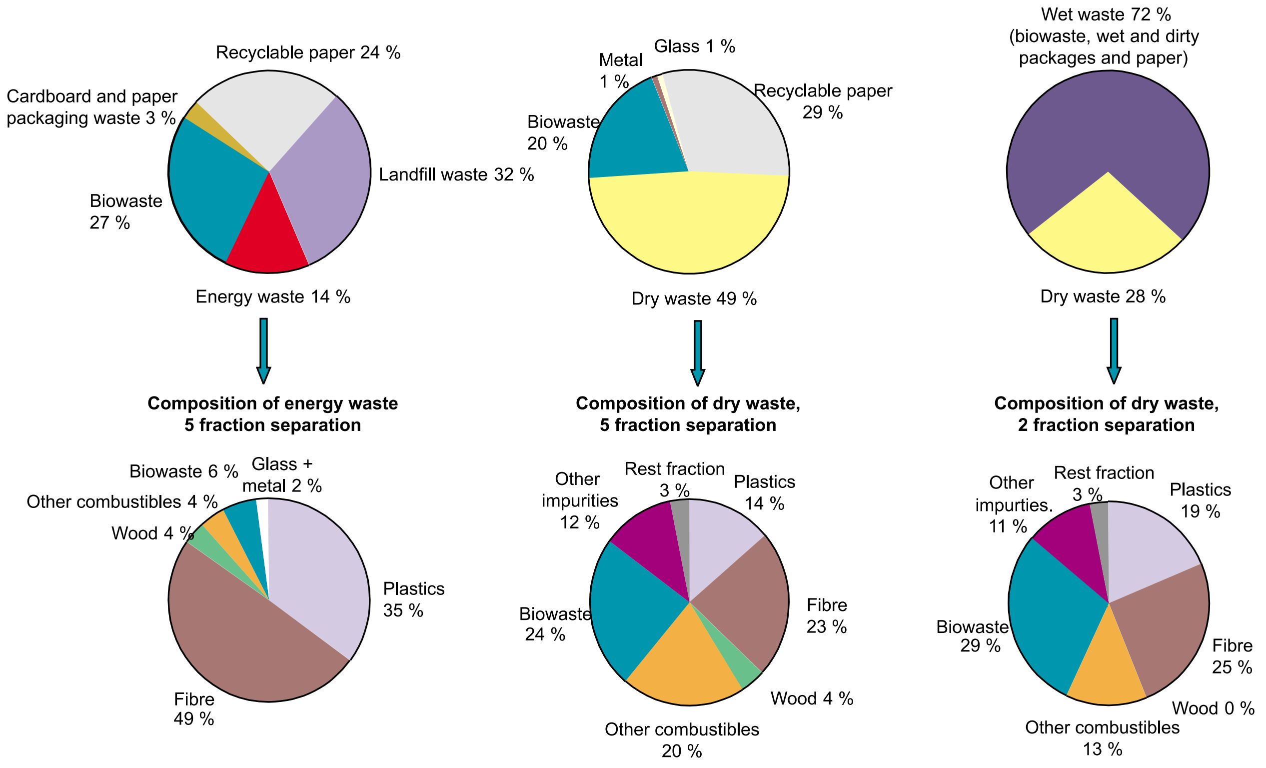

Figure 2. Source separation systems and measured waste fractions [3].

Table 2. Quality of recovered solid fuels produced from energy waste and dry waste.

Element/characteristics	Energy waste (5 fraction sep.)	Dry waste (5 fraction sep.)	Dry waste (2 fraction sep.)
Cl, w-% d.b.	0.34	0.76	0.82
S, w-% d.b.	0.06	0.10	0.08
N, w-% d.b.	0.4	0.5	0.6
K+Na, w-% d.b.	0.17	0.38	0.37
Al, w-% d.b. (metallic)	0.16	0.63	0.87
Hg, w-% d.b.	<0.1	0.6	0.29
Cd, w-%, d.b.	0.33	1.3	0.43
LHV MJ/kg (as received)	19.9	16.7	16.4
Moisture, w-% (as received)	11.8	23.0	24.2
Ash, w-% d.b.	7.3	9.7	9.4

Further improvement of the quality of SRF produced from household waste is required to avoid corrosion and fouling tendency of the heat exchange surfaces in high efficiency CHP boilers. These problems are caused by combination of chlorine, different alkali metals, aluminium, etc. in the SRF.

1.4 Quality assurance manual

A national standard for recovered fuels was issued for the SRF quality control for co-firing in large fluid-bed boilers with peat and wood fuels in 2002. The Quality Assurance Manual for Recovered Fuels [4] was created to stimulate the SRF market. The implementation of this Manual has boosted the use of SRF as a complementary fuel by setting up quality classes and defining analysis procedures and recommendations for recovered fuels. The three quality classes are described in Table 3 below.

Table 3. SRF quality classes according to the Quality Assurance Manual.

Topic	Characteristics	Focus of application	Unit	Reporting precision	Quality class		
					I	II	III
1	Chlorine content for dry matter	1)	% (m/m) 2)	0.01	<0.15	<0.50	<1.50
2	Sulphur content for dry matter	1)	% (m/m) 2)	0.01	<0.20	<0.30	<0.50
3	Nitrogen content for dry matter	1)	% (m/m) 2)	0.01	<1.00	<1.50	<2.50
4	Potassium and sodium 3) content for dry matter	1)	% (m/m) 2)	0.01	<0.20	<0.40	<0.50
5	Aluminium content (metallic) for dry matter	1)	% (m/m) 2)	0.01	4)	5)	6)
6	Mercury content for dry matter	1)	mg/kg	0.1	<0.1	<0.2	<0.5
7	Cadmium content for dry matter	1)	mg/kg	0.1	<1.0	<4.0	<5.0

1) The limit value concerns a fuel amount of £ 1 000 m^3 or a fuel amount produced or delivered during one month, and it shall be verified at least for a respective frequency.

2) % (m/m) denotes the percentage by mass

3) Total content (K+Na) of water-soluble and ion-exchangeable proportion for dry matter.

4) Metallic aluminium is not allowed, but is accepted within the limits of reporting precision

5) Metallic aluminium is removed by source-separation and by the fuel production process

6) Metallic aluminium content is agreed separately

The standard defines the procedures and requirements by which the quality of recovered fuel, produced for the purpose of energy production from source separated waste, can be controlled and reported unambiguously. In addition to defining the quality class of the SRF fuel according to Table 3, other characteristics and limit values (e.g. other fuel operating properties, heavy metals, noxious constituents) of the fuel can be agreed upon in the delivery contract using a normative data sheet included in the standard.

The standard covers the whole chain of supply from the source separation of waste to the delivery of recovered fuel. The standard does not concern untreated wood wastes like bark, sawdust, and forestry residues. There is a proposal under preparation for a CEN standard for solid recovered fuel.

2 Applied processes and techniques

This report reviews the Best Available Techniques (BAT) in Finland used in production of recovered solid fuels from source separated waste streams and the subsequent energy use of these fuels in production of combined heat and power.

2.1 Solid recovered fuel processing

2.1.1 Processing options

The waste owner, i.e. the company, the municipality or the person who owns the waste material, is responsible for the waste handling. The municipalities must provide the collection and handling of household waste and the similar commercial waste.

Handling of commercial waste, construction waste and demolition waste and also the industrial waste are the responsibility of the company producing the waste. These companies can co-operate with the municipality, but because of the differences in the quality of the waste originating from households or from industry, different processing options are often relevant for these waste streams.

The better source separation usually enables the production of better quality SRF. From commercial, industrial, demolition and construction waste it is usually easier to separate the impurities, like aluminium or PVC. This kind of waste can be processed to a SRF I quality class fuel. Also the processing of such waste does not require complex equipment. Crushers, sieves and magnetic separators combined with good source separation may well be enough for achieving good-quality SRF. For household-derived SRF, more advanced SRF plants are needed. The separation of biowaste and miscellaneous fines is essential.

A typical Finnish waste management scheme is illustrated in Figure 3. There are about 20 waste recovery/sorting plants in operation in Finland and several smaller crushing plants for combustible industrial and commercial waste material. The SRF production technology is continuously developed to facilitate more efficient material recycling and better fuel quality.

2.1.2 SRF production from household waste

Source separated household waste requires a fairly complicated production plant including operations like crushing, magnetic separators, screening, eddy-current for non-magnetic materials, pneumatic separation and optic sorting. The purpose is to separate the impurities (typically biowaste, glass, metals, aluminium, PVC) as well as possible and to produce good-quality SRF to be used in fluidised bed energy recovery plants. These plants have typically an annual capacity of about 40 000 tonnes. High-quality recovered fuels (SRF I) can also be produced from commercial waste. In this production scheme the sieving of the pre-crushed "energy waste" is usually bypassed because the waste contains little biowaste and

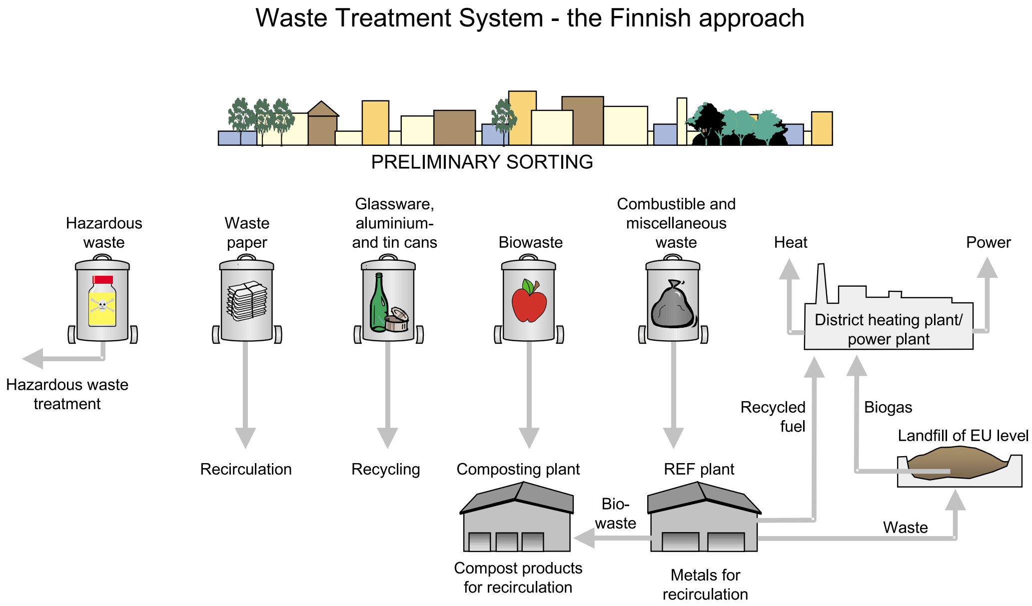

Figure 3. Urban waste management scheme and SRF production.

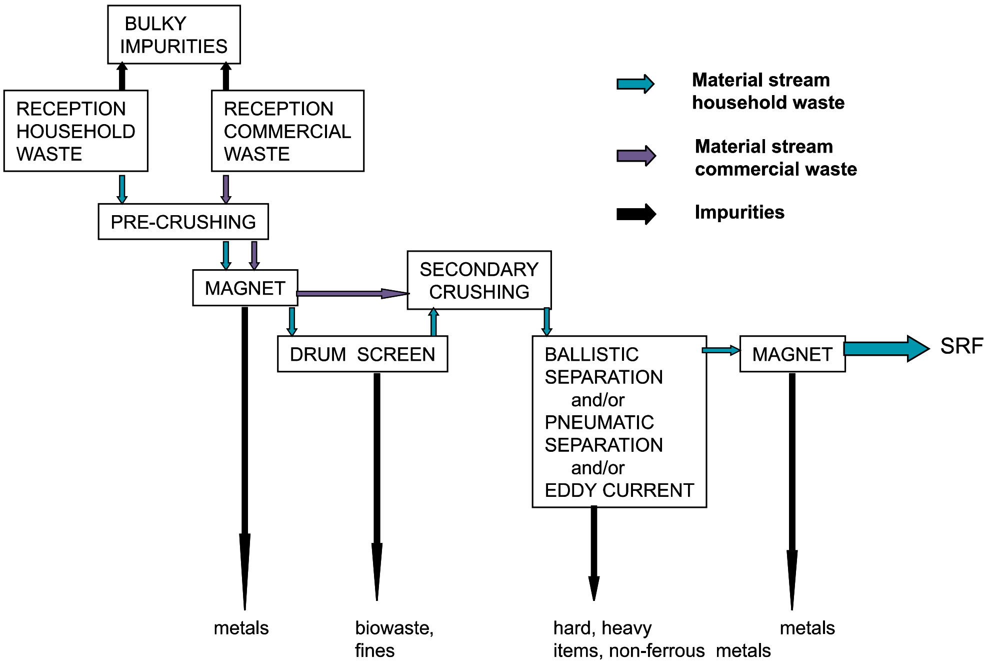

Figure 4. SRF production from household waste and commercial waste.

fine impurities. Figure 4 presents a flow diagram of a typical SRF production plant. Figure 4 presents a flow diagram of a typical SRF production plant.

Pirkanmaan Jätehuolto Oy is owned by 23 municipalities in Tampere area and it is serving some 376 000 inhabitants. At one of its landfill sites the company runs an SRF production plant with a capacity of 30 000 SRF t/a. Both commercial and household waste is accepted. Recovered fuel of quality class SRF II–III is produced from household waste in a production line comprising the following process steps:

- coarse pre-sorting of large impurities on the floor of the receiving hall
- magnets (belt and drum), metal detector (can be used if waste contains much metals)
- primary shredding, below about 150 mm
- magnet, separation of metals
- screening in a sieve drum, separation of biowaste and fines
- ballistic separation of heavy impurities (glass, PVC)
- secondary shredding, below about 50 mm
- magnet separation of metals
- baling and covering of the product (if stored for longer time)

A layout of the Tarastenjärvi plant is presented in Figure 5.

Figure 5. The Tarastenjärvi SRF production plant.

SRF fuel is utilised by several fluidised bed boilers to produce power and district heat. The biowaste is composted of the residue fractions at the site and it is mostly used for covering of the landfill. Metal and glass are recycled.

The material streams and some fuel properties are presented in Table 4 and 5 [5]. The SRF production efficiency of the plant has been between 75 and 81 %.

Table 4. Product and residue streams of the Tarastenjärvi plant.

Year	Waste input, t	SRF output, t	Metals, t	Fines, t	Heavy residues, t	Land fill residue, t
2000	23 809	17 790	772	4 731	163	568
2001	21 721	17 649	738	3 546	94	429
2002	22 676	17 368	792	4 406	104	368

Table 5. Some fuel properties of SRF produced from commercial waste and source separated household waste (dry fraction). Mean values over the period 1998-2003.

	SRF from commercial waste (energy waste)	SRF from household waste (dry waste)
Moisture, w-%	17,0	30,3
Ash, w-% d.b.	9,3	10,3
LHV, MJ/kg d.b.	21,4	21,7
LHV, MJ/kg as recieved	17,2	14,4
Chlorine, w-% d.b.	0,43	0,49
Met. Aluminium, w-% d.b.	0,29	0,41

A similar SRF plant is operated by Loimihämeen Jätehuolto Oy. The fuel from this plant is transported directly to the power plant (66 MWth, BFB) nearby owned by Vapo Oy, Figure 6.

The present operating values of the Loimihämeen Jätehuolto plant are [6]:

- input waste stream 15 000 t/a
- SRF production 8 000–9 000 t/a (mostly paper, cardboard, wood, fibres, plastics)
- biological waste 4 000–5 000 t/a
- metals (Fe, Al) 300–500 t/a
- residues to landfill 800–1 000 t/a.

The plant is operating at short capacity mainly because of a lack of fuel demand. The aim of the company is to increase the production to about 45 000 t/a by the year 2007.

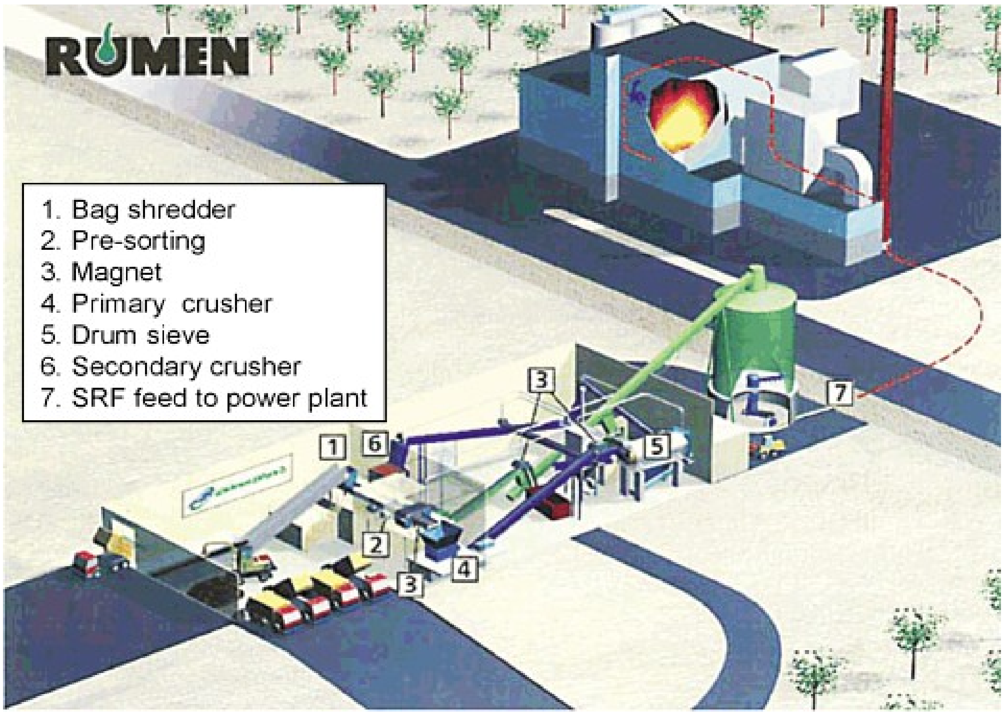

Figure 6. SRF production connected to a power plant.

2.1.3 SRF plants processing commercial waste

Plants processing commercial waste (mainly package waste) are usually technically more simple than SRF plants that process household waste. The quality of the produced SRF is also better; the quality class is SRF I or SRF II. The SRF plants usually include one or two crushers, magnetic separators and possibly an Eddy Current for non-ferrous metals. A typical of 20 000 t/a commercial waste SRF plant is presented in Figure 7. These plants produce very little residues. The metals and non-ferrous metals separated from the waste stream are mainly recycled. The fuel produced has a mean particle size of below 50 mm, has a high energy value, about 16–20 MJ/kg, and a low moisture content of 10–20 %.

Figure 7. Processing of commercial waste: shredder, magnet and Eddy Current.

A new SRF processing plant was taken into operation by Lassila & Tikanoja Oy in 2003 using new crushing technology by BMH-Wood Technology Oy. A single rotor crusher equipped with a interchangeable screen plate reduces the particle size of the commercial waste to below 50–100 mm in one step, depending of the screen size. The design capacity of the crusher is 20 t/h. The process is technically fairly simple, Figure 8. After crushing the metals are removed by magnets and the SRF fluff is eventually baled. A solid recovered fuel of quality class SRF II or better is produced at the plant.

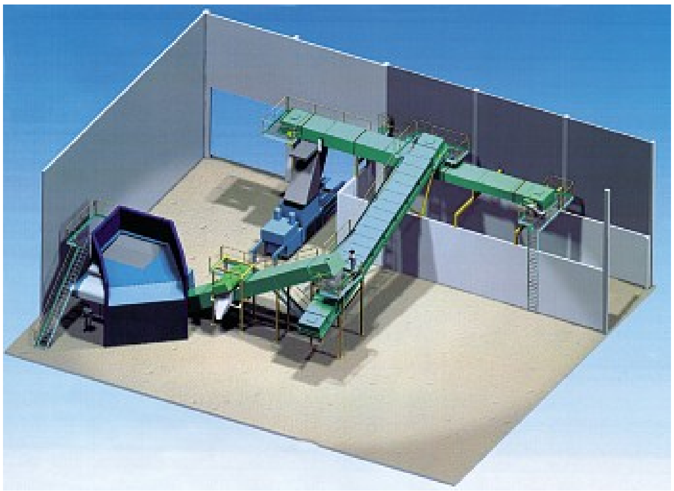

Figure 8. Production of SRF from commercial waste.

2.1.4 SRF plants processing construction and demolition waste

Wood, soil, stones and stone-like waste, metallic waste, and hazardous waste are source separated at the construction site for different places, enforced by the Finnish Act on building and construction waste. Today the amount of wood waste, paper, board and plastics from construction and demolition sites is increasingly used for energy instead of landfilling. These fractions are usually treated at separate SRF plants designed for this kind of waste. A new plant commissioned in 2002 processing construction waste in Helsinki Metropolitan Area (Ekopark Oy) is shown in Figure 9. The plant processes about 35% of the annual 200 000 t construction waste produced in the metropolitan area [7].

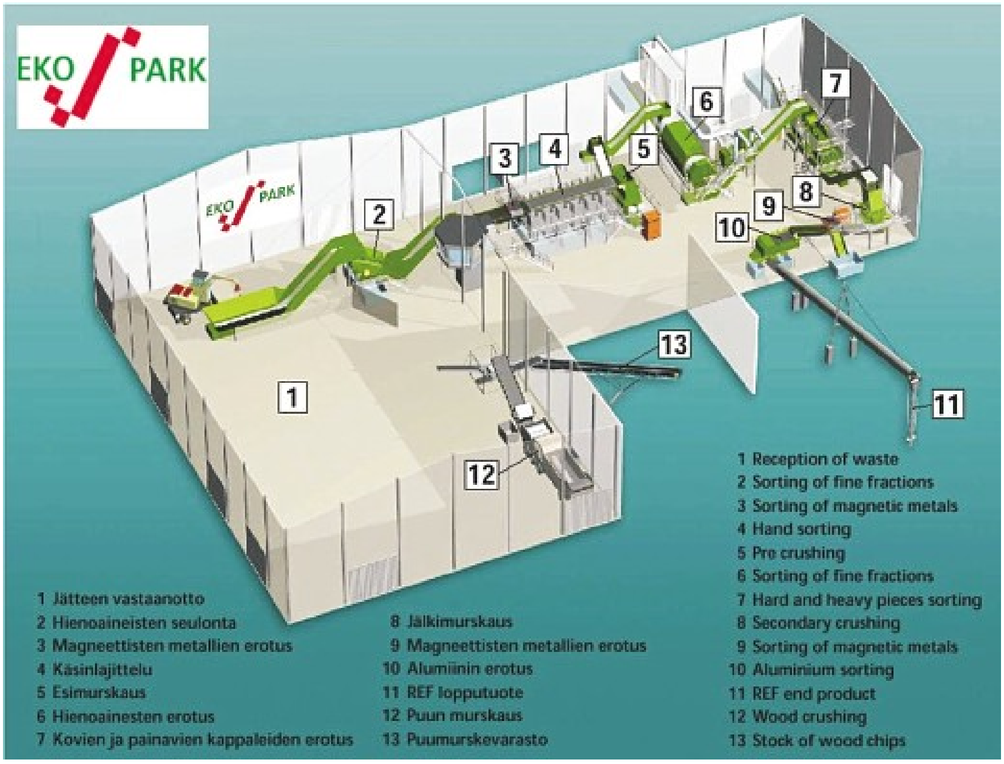

Figure 9. Processing of construction and demolition waste, Rakentajien Ekopark Oy.

The design capacity of the plant is 50 000 t/a. The products and reject of the plant are roughly

- 40 % of SRF product for energy use
- 20 % of fines and inert rock material
- 7 % of metals for recycling
- 33 % of residues to be landfilled.

The demolition waste plant includes a process step where manual hand-picking is employed to sort out rocks, metals (Cu etc.) and hard plastics (PVC). The hand-picking is carried out before the material is crushed. Excessive fines have, however, been removed by sieving.

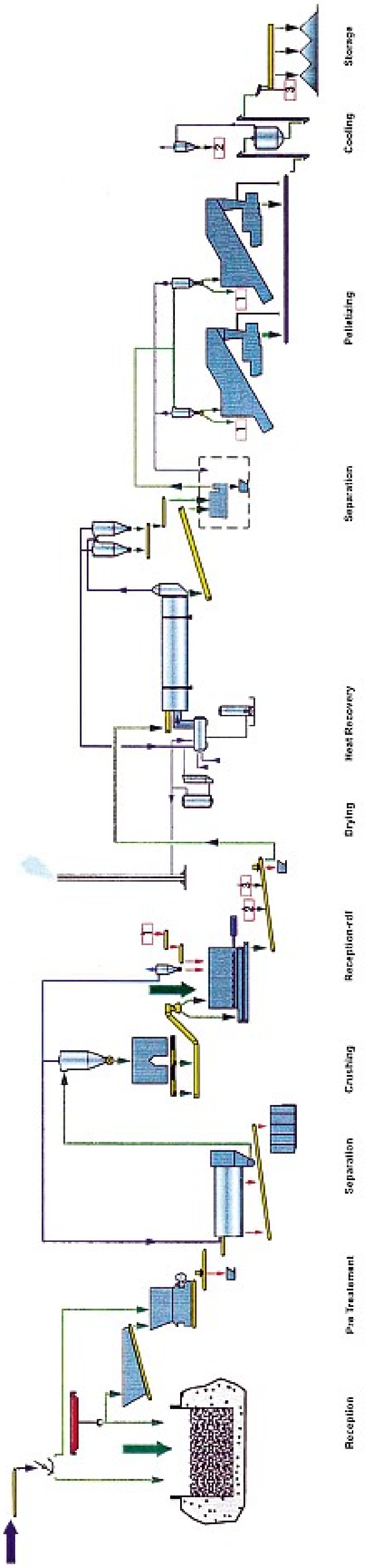

Figure 10. The Ewapower Oy Ab pellet plant.

2.1.5 Pellet production from waste

Ekorosk Oy is covering the Pietarsaari area and the neighbouring municipalities. The waste is source separated to two fractions: so-called wet and dry fraction. The wet fraction includes all the organic material (like biowaste, plants) and the dry fraction all the combustibles (like packages, non-recyclable paper, plastics). The wet and dry fractions are source separated at households to differently coloured bags (black and white, respectively) and all the bags are collected in the same waste bins. The bags are separated by optic sensors, and the wet fraction is taken to the Vaasa biogas plant and the dry one is taken to the Ewapower pelletising plant and then for energy use. Other fractions, like glass, metals and recyclable paper, are collected by kerbside collection. Source separation based on coloured bags and optical sorting is also used in some areas in southern Finland.

The Ewapower pelletising plant includes pre-crushing, magnetic separator, air and drummer sieves, secondary crushing, drying (drum dryer using fuel oil), air separator, pelletiser (three pellet presses, capacity about 5 t/h each), cooling and dust separation. The process is presented in Figure 10. The incoming waste consists of the dry fraction from the source separated household waste (the white bags) and industrial and commercial dry waste from the area.

The pellets have high energy density and they can be stored and combusted in a rational manner. The pellets are used as fuel mixed with wood residue fuel or peat and combusted in a bubbling fluidised bed boiler. The annual capacity is 30 000 t/a of pellets and the heating value of the pellets is 20 MJ/kg. The specifications of the final fuel are presented in Table 6.

Table 6. Properties of pellets produced at Ewapower Oy.

Moisture content	< 6	wt-%
Calorific heating value	21	MJ/kg (dry basis)
Ash content	7–10	wt-% (dry basis)
Volatile matter	80	wt-% (dry basis)
Sulphur content	0.13–0.2	wt-% (dry basis)
Chlorine content	0.4	wt-% (dry basis)
Potassium content	1.7	wt-% (dry basis)
Sodium content	0.2	wt-% (dry basis)
Aluminium content	0.8	wt-% (dry basis)

Pelletising is a rather complicated process and require drying of the material to be pelletised below about 10 % moisture content beside size reduction. Both investment and production costs are considerably higher than for normal SRF production. Due to drying and compacting the energy consumption of the process is rather high. About 15 % of the energy content of the product is consumed in the processing. The product is, however, dry and storable, and has a high energy density.

2.1.6 Industrial production waste

The forest industry and the packaging industry produce some non-recyclable waste fractions like paper, plastics and wood, which are mainly crushed at their own power plants and co-combusted mixed with the main fuels. The amount of this waste fraction varies annually between 50 000 and 100 000 t/a. The quality of such waste is usually good (SRF I) as a result of good source separation.

2.2 Combustion of SRF in fluidised bed boilers

2.2.1 Background

Waste incineration has not been a very attractive alternative in Finland due to mistakes and failures made earlier. Dumping waste into the landfills has also been easy due to space available. However, new EU legislation requires decreasing the amount of waste landfilled. This makes energy use more essential. EU's emission standards, modern combustion technology and flue gas cleaning make waste combustion safe and environmentally acceptable.

2.2.2 Waste-to-energy in Finland – current situation

In Finland there is only one waste incineration plant combusting solely waste. The plant is located in the city of Turku and it produces district heat for the Turku region. The plant was built in the 70's and modernised in 1995. The plant operation is based on grate combustion technology and it is equipped with Alstom's semi dry flue gas scrubber with active carbon injection. The incineration plant does not meet the new EU's emission standards and thus it has to be replaced with a new one. The new plant will most probably be a CHP plant with combined heat and power production.

An increasing amount of waste is burnt in Finland in co-combustion with wood, peat and coal. Co-fired waste, solid recovered fuel, is usually processed source separated household waste or packaging waste from stores and industry. There are about 20 co-firing plants in Finland nowadays. The amount of waste co-fired is usually about 10 % of fuel heating value.

The co-combustion plants have usually good experiences of waste co-firing. For example Fortum Power and Heat Oy's plant in Kauttua has used waste-derived fuels for many years now. Nowadays 50 % of the fuel used is wood waste, 15 % package waste from industry and shops, 5 % paper waste from local package industry, and the rest is peat. Very small amount of coal is burnt to assure steady boiler operation. The boiler in Kauttua is 65 MW_{th} Pyroflow, CFB boiler producing steam with 84 bar and 500 °C. Because of the waste co-firing, some changes have been made to fuel receiving and handling. There is now a separate fuel feeding line for SRF. A new grate type has been chosen as well. The chlorine content of the SRF has been limited to 0.1–0.3 %, and the boiler is used at somewhat lower steam temperature, 485 °C. Aluminium has not caused any problems.

Also Forssa Energy Oy is co-firing waste continuously in its 66 MW_{th} BFB boiler, Figure 11. Main fuels are wood chips, bark, sawdust and peat. The share of SRF is about 3-4 %. SRF is coming directly from the SRF production plant nearby, owned by Loimihämeen Jätehuolto Oy. There have been some corrosion and slagging problems in the boiler, which restricts the amount of SFR used in the boiler. Also aluminium has caused some problems. The grate has been modified to improve the ash removal.

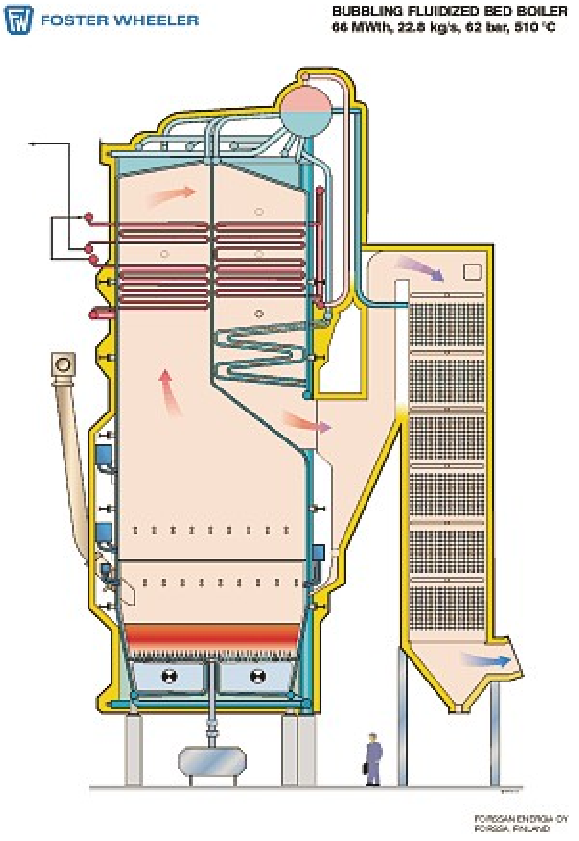

Figure 11. The Forssa co-combustion plant (Foster Wheeler BFB).

EU directive for waste combustion in old combustion plants comes into effect in the beginning of 2006. It is possible that waste co-combustion will end completely or at least drop essentially in consequence of the directive in Finland. Allowable emission limits will tighten and especially NO_x and SO_2-limits are difficult to reach for many boilers without new investments. Nowadays the emission limits are determined by the main fuel and boiler size. The directive includes also obligations concerning measuring, which will raise the expenses of co-combustion. However, co-combustion can continue at some extent if waste handling can be developed. The continuation of co-combustion would also require abatement to the measurement demands.

2.2.3 Fluidised bed combustion

Fluidised bed combustion technology is suitable for co-combustion of different fuels. Intensive combustion behaviour and careful mixing make it possible to burn fuels with a high moisture content. There can be variations in fuel's calorific value without significant changes in combustion temperature level. Both BFB and CFB are suitable for co-combustion of waste fuels. Waste can be fed into the furnace either via a special waste feeding line or in mixture with main fuel. Feeding together with the main fuel enables better mixing but because of the difficulties caused by the waste fuel, separate feeding lines for different fuel species are preferred. When having a problem in waste fuel feeding system, the boiler can be kept in production with separate main fuel feeding line. This also allows for a quick interruption of the waste fuel feeding without interfering with the main fuel supply, for instance in case of temporary exceeding of the emission values.

The harmful substances in waste can set limits for co-combustion. Waste must be well sorted and crushed into specified particle size. Especially chlorine makes co-combustion difficult because it can cause fouling and corrosion together with alkali metals. Aluminium in waste can lead to bed agglomeration and blocking of air injection ports. For these reasons the share of waste fuel is usually kept under 10 % even if the SRF co-fired is of Class I.

The fluidised bed technique has been used for combustion purposes for more than 20 years, and it is now regarded as an efficient and environmentally benign combustion technique for a wide range of fuels, especially heterogeneous fuels. These characteristics make it well suited for waste combustion. In order to find the environmentally best solutions there are ongoing changes in waste handling, which affects the composition of various waste streams as well. There is also a trend towards increased diversification of the waste streams. One reason for this is that several fractions of industrial waste, which were not classified as waste earlier will be such today. Another reason is that some fractions of the source separated waste are unsuitable for material recycling. Sewage sludge is another type of waste that needs new treatment technology since the possibility to utilise it, for instance, as a fertiliser spread in fields is very limited due to its high content of heavy metals and toxic substances. Altogether this makes the fuel flexibility as one of the most important criteria in many waste combustion projects.

In spite of low energy utilisation of waste in Finland, big boiler manufacturers can be found here. The biggest FB boiler manufacturers from Finland are; Kvaerner Power Oy and Foster Wheeler Energia Oy. Kvaerner delivers both BFB and CFB boilers for waste combustion and Foster Wheeler delivers CFBs for waste fuels. Both have an extensive list of references and have a long experience in developing fluidised bed combustion.

Technology

Although fluidised bed technology is well suited for waste combustion, it needs a size reduction process to produce SRF with a particle size below 50–100 mm before the combustion step. If the waste is well sorted and a special energy fraction with low chlorine content is used, the boiler can use higher steam values and have higher efficiency than in mass burning incinerators.

In fluidised bed technology fuel is mixed in a furnace with hot inert bed material. Bed material functions as a thermal flywheel, which ensures rapid ignition and stable temperature profile. Efficient heat and mass transfer allow operation at low temperatures. Combustion temperatures are typically 850–1 000 °C. In this temperature range thermal NO_x is not formed, and the temperature is high enough to enable the use of SNCR in NO_x-reduction. Bed additives can be used to limit the SO_x-content in flue gas.

The above mentioned combustion temperature is high enough to prevent the formation of dioxins (PCDD/F). No recent public information from emission measurements at power plants co-firing SRF is available. Earlier studies [8, 9] at a 65 MW CFB plant equipped with only ESP flue gas cleaning, normally firing a mixture of peat and coal, indicated that an addition of 10–20 % of industrial waste or SRF did not increase the level of dioxins above the normal 0.1 ng I-TEQ/m^3n (toxic equivalents) when using the base fuel mixture. Research [10] conducted in a small 4 MW BFB boiler burning SRF (15–30 %) together with wood chips and peat also showed dioxin concentrations well below the 0.1 ng I-TEQ/m^3n limit of the Waste Incineration Directive.

A number of considerations must be taken into account when handling demanding waste fuels [11,12]. Especially external equipment and boiler design are important factors. In addition to specific fuel handling and flue gas cleaning, there are some main differences in the equipment compared to a plant for biomass combustion, Figure 12. The differences are described in the following.

- The fuel feeding system must be non-compacting in order to get an even feed of the waste fuel.
- The high ash content and coarse ash particles call for a high discharge capacity of bed material to keep a good bed quality and fluidisation. The bed material is transported to an ash classifier, where the fine material is separated and returned to the furnace while the coarse material is rejected.
- The furnace bottom has to be equipped with specially designed directional nozzles to enable fluent ash transportation.
- The boiler height has to be adjusted according to the new regulations regarding the retention time at a temperature above 850 °C. For a large CFB the boiler height determined by the cyclone will fulfil this requirement.
- The boiler has to be equipped with a support burner, which starts automatically if the combustion temperature falls below 850 °C.
- The corrosion and fouling problems can be controlled by controlling the fuel quality and also by using specially designed construction for fluidised bed boilers.

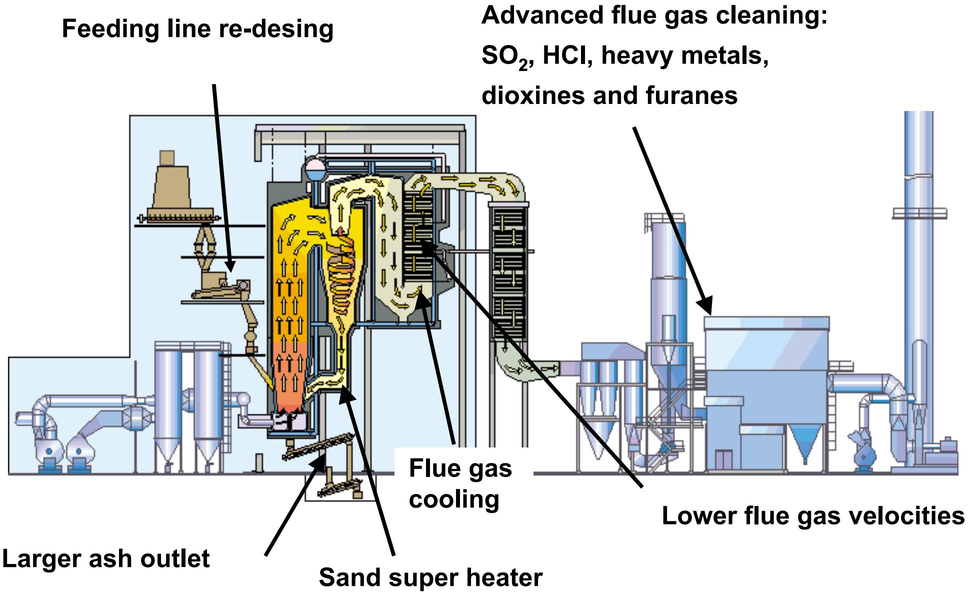

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Figure 12. Power plant modifications for SRF.

Nowadays even sludge can be burnt together with waste, which represents an economical and environmentally sound solution. It has been proven that even 40% of sewage sludge can be co-fired with waste in fluidised bed boiler.

Fluidised bed combustion technology has achieved a predominant share of the market for solid fuel electricity and heat generating plants probably due to its level of fuel flexibility and the unique combustion characteristics. The technology is recognised as the leading method of burning a wide range of solid fuels in an environmentally benign and efficient manner. For combustion of municipal solid waste, fluidised bed combustion can be seen as a leading and well-proven technology in those countries, which lead the world in the field of modern waste handling. A special BFB design by Kvaerner Power is shown in Figure 13.

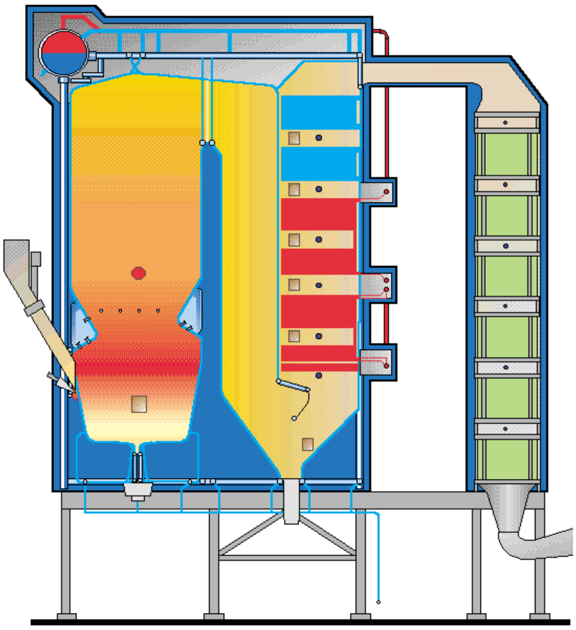

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Figure 13. Schematic BFB design of waste-to-energy plant (Kvaerner Power). Lidköping, Sweden, MSW boiler 22 MWth.

Emissions and flue gas cleaning with fluidised bed combustion

NO_x emissions in fluidised bed boilers are usually low because of the low combustion temperature (850–1 000 °C). Due to the strict emission limits, SNCR (Selective Non-Catalytic NO_x reduction) is used in most cases. Normally ammonia or urea is injected into the boiler at a certain temperature area to reduce the NO_x emissions. Catalytic NO_x reduction (SCR) is not normally needed.

For SO_2 and HCl removal, Alstom's NID process (dry fluegas desulphurisation system) is the most popular flue gas cleaning method used in FBC of waste. NID (Novel Integrated Desulphurisation) consists of a mixer, a reactor and a bag filter.

Lime is mixed with water and introduced into the mixer alone with fly ash from the boiler and more water. The moistened particles are then injected into hot flue gas in the reactor, in which activated carbon can be added if necessary. An even distribution of particles in the flue gas flow ensures an efficient adsorption in the reactor. The flue gas then passes through the bag filter where the particles are removed.

The lime additive binds chlorine and sulphur, while the activated carbon is used for separation of dioxins and some heavy metals. Some of the fly ash is deposited in a silo, but most of it is re-circulated through the mixer and the reactor to give the additives enough time to react. NID is capable of achieving over 90 % SO_2 removal, irrespective of sulphur content in the fuel. With NID alone, the required emission limits can be achieved but sometimes the flue gas cleaning system includes also a wet scrubber for the reduction of Hg and other trace elements, as shown in Figure 14.

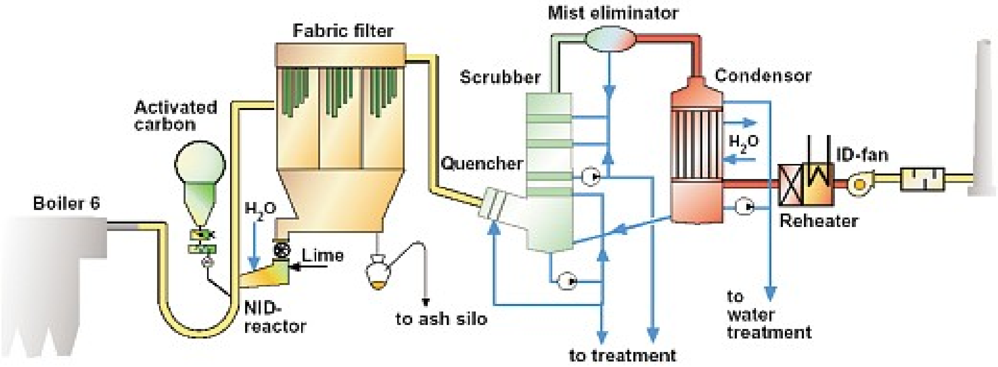

Figure 14. Flue gas cleaning at Högdalen waste-to-energy plant.

Heavy metal emissions in sorted waste combustion are lower than in mass burning facilities because of the lower heavy metal content in waste. Most of the heavy metals are in fly ash and if in a leachable form the dumping of fly ash must take place at a qualified landfill or the ash has to be pre-treated in order to reduce the leaching.

Formation of dioxins and furans is low in fluidised bed combustion because of good combustion stability and uniform temperature. Fouling can be limited with design and construction and by controlling fuel quality.

Particle emissions can be controlled with an effective bag house or a combination including electrostatic precipitator and a bag house depending on the desulphurisation system used.

2.2.4 Boiler manufacturing in Finland

Finland is a leading country in fluidised bed boiler production as mentioned earlier. There are two big boiler manufacturers (Kvaerner and Foster Wheeler) that have built about 50% of fluidised bed boilers in the world. They have many references in co-combustion and mono-combustion of waste fuel. Some of the achievements are described in the following.

Foster Wheeler built the first waste combusting unit with high heating value in Europe. The unit started operation in Högdalen, near Stockholm in 1999. The unit generates district heat for the Stockholm community and electricity for the local net. The base of the fuel is sorted industrial waste [13].

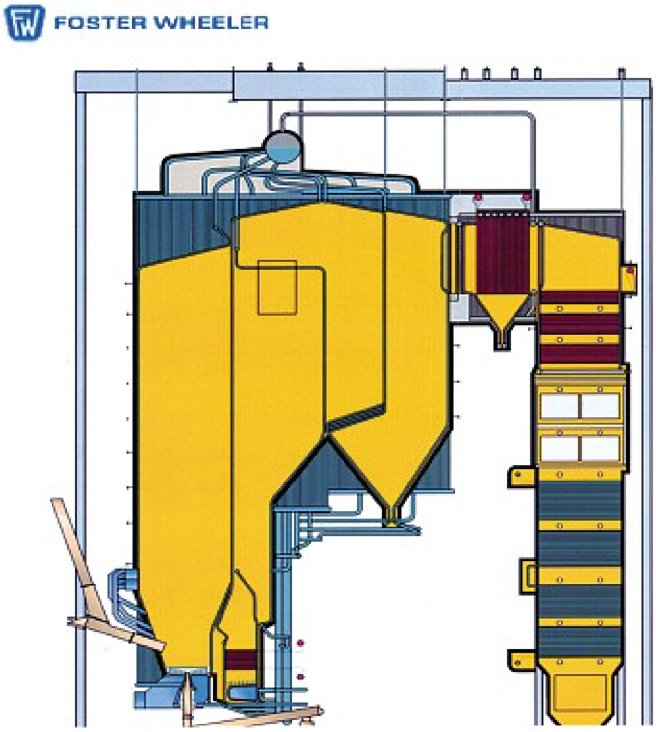

Figure 15. The Högdalen CFB boiler is designed especially for the combustion of recovered fuels. It has a rated thermal effect of 92 MWth [13].

The boiler in Högdalen is the first modern Foster Wheeler CFB, which was especially designed to minimise the risk of fouling and superheater corrosion in the convection section. The boiler utilises the compact CFB design with rectangular solids separators, together with two INTREX^{TM} superheaters and a cooling channel for the flue gas. With this design, the risk of superheater corrosion in the combustion of fuels containing high amounts of chlorine, sulphur and alkali metals has been minimised.

The SRF is produced from industrial waste. Household wastes are not combusted in the Högdalen boiler. To achieve optimal fuel quality, some pretreatment is carried out. The fuel is provided by several different SRF plants in Stockholm area, containing mainly paper, wood and plastics.

The boiler is equipped with Alstom's NID flue gas cleaning system and a wet scrubber. NO_x emissions are handled with SNCR system, where ammonia water solution is injected into the boiler to reduce NO_x emissions. The CO emissions have been very low, which indicates complete combustion.

The other Foster Wheeler's modern waste-to-energy plant, Lomellina, is situated in Parona, Italy. The plant is designed to recover material and energy from MSW. About 60 % of the MSW can be converted into RDF. The process also separates reusable aluminium, ferrous materials, glass and compost from the waste [13].

The fuel fed into the CFB boiler is burnt at a temperature between 850 and 900 °C. The flue gas and the entrained solids exit the furnace through the cyclone, where coarse solids are separated from the gas stream, which exits the top of the cyclone. The cyclone separates the entrained solids including unburnt carbon from the flue gas, and returns them to the furnace, providing an excellent carbon burnout.

The flue gas cleaning system of the Lomellina plant consists of a conditioning tower to control moisture and temperature levels, a flue gas dry scrubber with injection of lime and active carbon, and a fabric-filter baghouse. Due to the quality of the combustion process, there is no need for a $DeNO_x$ system.

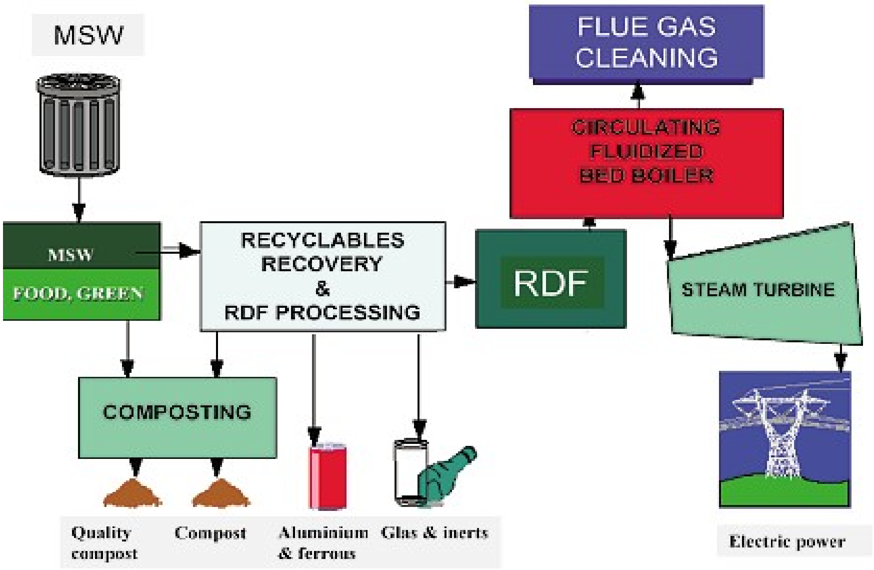

Figure 16. Flow diagram of the Lomellina waste-to-energy plant [13].

Untreated fly ash is classified as a hazardous substance, and it is treated in a cold process to meet the requirements of non-hazardous landfill. Fly ash is mixed with cement and water, and then poured into 1 m^3 bags. The bags are temporarily stored until the concrete solidification is complete.

Table 7. Permitted emissions at the Lomellina WTE plant [13].

Substance	Permitted daily average	Permitted hourly average
Dust, mg/Nm^3	10	30
SO_2, mg/Nm^3	100	200
NO_x, mg/Nm^3	200	400
HCl, mg/Nm^3	20	40
CO, mg/Nm^3	50	100
HF, mg/Nm^3	1	4
VOC, mg/Nm^3	10	20
Sb+As+Pb+Cr+Co+Cu+Mn +Ni+V+Sn, mg/Nm^3	0.5	
Cd+Tl, mg/Nm^3	0.05	
Hg, mg/Nm^3	0.05	
Aromatic hydrocarbons, mg/Nm^3	0.01	
Dioxins and furans, ng/Nm^3	0.1	

Kvaerner's modern waste-to-energy plant, SOGAMA, is located near the town of Cerceda in Galicia, northwest of Spain. The plant is designed to process approximately 650 000 tonnes of MSW annually to 400 000 tonnes of SRF to be used for combustion and generation of electricity. The combustion technology used is the Kvaerner CFB boiler system. The main purpose of the SOGAMA plant is to recover useful materials, generate electricity from SRF and to reduce the waste to be landfilled [14].

The SOGAMA boilers were fired on SRF for the first time in December 2000. The plant performance during the first few moths was poor, mainly due to problems with the fuel preparation plant. By the end of February 2002, the boilers had been in operation on SRF approx. 6 800 hours and the operation confirmed the good combustion characteristics typical for CFB, resulting in good burnout and emissions performance within the fuel span.

Kvaerner's latest waste-to-energy plant in Norrköping, Sweden, started operation in 2003, Figure 17. The plant is 75 MWth CFB boiler equipped with Alstom's NID flue gas cleaning system. For the NO_x reduction there is an SNCR system with ammonia-injection. The fuel mix comprises a number of different waste fractions, such as assorted municipal solid waste, industrial waste, sewage sludge, rubber chips, and demolition wood waste. The boiler is similar to those two in SOGAMA [14].

Table 8 shows the emissions during the performance test. As a comparison, the guaranteed emissions for both SOGAMA and Norrköping are added, as well as the emission limits in the new EC directive for waste combustion. It is evident that the emissions are well below all these limits. Also, the requirement of a two-second gas residence time above 850 °C after the last air injection and with the O_2 concentration, over 6 % (dry gas) was confirmed by means of in-situ measurements over the furnace cross-section on two elevations.

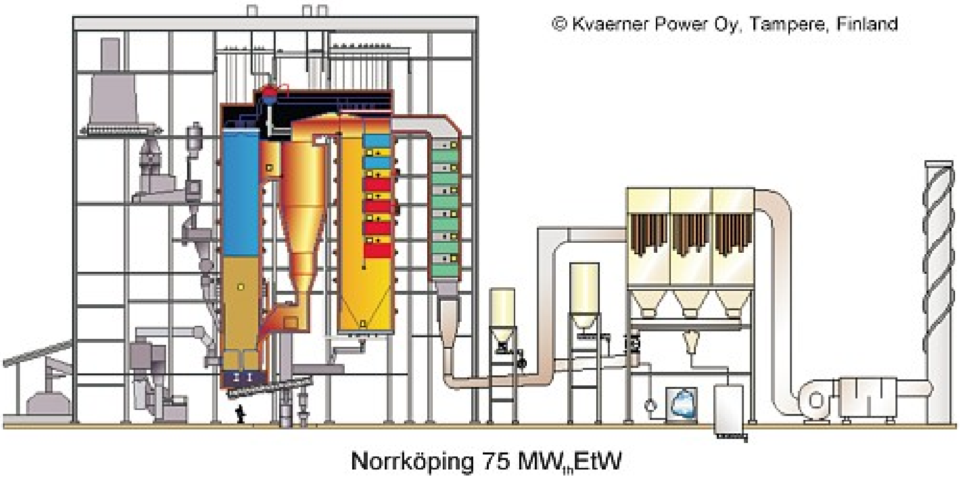

Figure 17. Side view of the Norrköping CFB boiler.

Table 8. Gaseous emissions. Reference conditions: 273 K, 101,325 kPa and 11 % O_2 vol. dry gas [14].

Compound	Unit	Directive 2000/76/EC	Guarantee SOGAMA	Perf. test SOGAMA	Guarantee Norrköping
Particulates	mg/Nm^3	10	10	2	*1)
Org. comp. as TOC	mg/Nm^3	10	10	<1	10
CO	mg/Nm^3	50	50	10	50
NO_x	mg/Nm^3	200	300	180	120-150 *2)
HCl	mg/Nm^3	10	10	<1	*1)
HF	mg/Nm^3	1	1	<0.3	*1)
SO_2	mg/Nm^3	50	50	<1	*1)
As+Co+Ni+Pb+Cr +Sn+Cu+Mn+V+Sb	mg/Nm^3	0.5	0.5	0.35	*1)
Cd+Tl	mg/Nm^3	0.05	0.05	<0.02	*1)
Hg	mg/Nm^3	0.05	0.05	<0.002	*1)
Dioxin	ngTEQ/Nm^3	0.1	0.1	0.002	*1)
NH_3	mg/Nm^3				10
N_2O	mg/Nm^3				40

*1) Not within Kvaerner*s delivery

*2) Differs over the load range. With SNCR

2.3 SRF gasification for co-combustion in pulverised coal boilers

This part presents a summary on the operation and environmental experiences obtained at the Kymijärvi Power plant in Lahti Finland [15]. In addition, the gasification-based co-combustion technology is generally described including the emerging gas cleaning technology. The paper is based on information supplied by Foster Wheeler Energia Oy and by Lahti Energia Oy. In addition, the new gas cleaning data of the Technical Research Centre of Finland (VTT) is presented.

2.3.1 Introduction

Almost all large (>200 MWe) coal-fired power plants are based on pulverised combustion. These boilers dominate in most European countries. During the last two decades many of the large PC-boiler plants have been equipped with efficient environmental control equipment. In addition to electric precipitators, different types of desulphurisation processes are widely utilised. The NO_x-emissions in old plants are often minimised by low-NO_x burners, while catalytic DeNO_x-technology is utilised in new power plants. The emission limits set by the European LCP-directive to the old power plants can be reached without desulphurisation and DeNO_x plants by using clean low-sulphur coal and low-NO_x burners. The Kymijärvi power plant at Lahti, Finland, described in this report represents this type of old pulverised coal-fired steam boiler utilising coal, which has low sulphur and chlorine contents. In this type of a boiler, the use of gasification gas produced from biomass and waste-derived fuels makes it possible to lower the sulphur and CO_2 emissions compared to 100 % coal-firing.

Presently the international targets for reducing the CO_2 emissions are governing the energy policies in most European countries. The renewable energy sources play a key role in the European CO_2 reduction targets. Biomass and biodegradable part of household and industrial wastes are the main feedstocks, the share of which can be considerably increased already at short and medium term. Biofuels, as well as waste-derived fuels, are local feedstocks. The energy density of these fuels is small and therefore, transporting from long distances is not an attractive solution in economical sense. This is the main reason why biofuel-based power plants are typically quite small compared to the coal-fired power plants. The specific investment and operation costs for small stand-alone biomass power plants are always much higher than in large coal or natural gas fired power plants. In addition, the power production efficiency is typically lower in small plants.

Thus, the replacement of coal in existing large pulverised coal-fired boilers is a cost-effective technology, which can significantly lower the CO_2 emissions of power production in many countries already at short term. In Europe, it is typical that about 30–100 MW of biofuels and suitable waste-derived materials is available within 50 km from a given power plant, a sufficient amount to gasify and utilise in medium or large size coal-fired boilers. Thus, a power plant concept consisting of a gasifier connected to a large conventional boiler with a high efficiency steam cycle offers an attractive and efficient way to use local biomass and waste sources in energy production.

The fluidised bed gasification technologies originally developed in 1980's for woody biofuels can be utilised with a wide range of waste-derived fuels. However, source-separation and/or effective pre-treatment of the waste material are required in this technology. The Finnish solution has been the production of Solid Recovered Fuel (SRF), which fulfils quality requirements defined in a fuel standard [16]. The SRF production is based on source-separation at homes, offices and industries followed by crushing, sieving and separation of different impurities at local or regional SRF production plants. The resulting SRF-material is in many respects similar to biofuel and it contains typically ca. 70 wt-% of biodegradable materials (e.g. paper and wood). This feedstock can be utilised together with locally available biomass residues in fluidised bed gasifiers connected to PC-boilers.

2.3.2 Gasification process alternatives

The leading gasification technology applied in co-fining applications is the Circulating Fluidised Bed (CFB) gasifier. Finnish compay Foster Wheeler Energia Oy is the leading technology supplier at present. The first CFB gasifier of Foster Wheeler has since 1983 replaced 35 MW fuel oil in a limekiln at Wisaforest Oy, Pietarsaari, Finland. Since then similar gasification plants having the same basic technology have been installed at two pulp mills in Sweden and one mill in Portugal. These gasifiers produce limekiln fuel from bark and waste wood and they also utilise part of the generated gas in drying plants [17, 18]. At Lahti, this technology is applied to SRF and mixtures of SRF and biomass fuels. CFB gasifiers have also been developed in Europe by other companies: Lurgi GmbH (Germany), Termiska Processer Ab (Sweden) and Austrian Energy/Babcock Borsig (Austria). So far, Foster Wheeler's technology has been commercially and technically the most successful and all constructed plants have been in successful commercial operation for several years. Presently, Foster Wheeler is constructing a Lahti-type gasifier plant to a coal-fired boiler in Ruien, Belgium.

Atmospheric-pressure bubbling fluidised-bed gasification (BFB) technology has also been developed in recent years in Finland. The BFB technology seems to be economically more suitable to medium-size applications (15–40 MW) while the CFB technology is most economic on larger scale (40–100 MW). The first commercial application of the atmospheric pressure BFB gasification in Finland was realised in Varkaus, central Finland, by Corenso United Ltd. This gasifier supplied by Foster Wheeler utilises plastics and aluminium containing reject material coming from the recycling process for used liquid cartons. In this process, the aluminium is removed from the gas as utilised for recovered aluminium production, while the product gas produced from the plastic material is combusted in a steam boiler. The 40 MW_{th} gasifier has been taken into operation in 2001. Since then it has been in commercial operation with high availability.

BFB gasification technology has also been developed for MSW-derived SRF by Powest Oy (a subsidiary of Pohjolan Voima Oy) and Foster Wheeler Energia Oy. The gasification and gas cleaning process has been tested at a 1 MW pilot plant located at the Technical Research Centre of Finland (VTT). So far ca. 500 hours of pilot testing has been carried out and simultaneously the first industrial demonstration plant is being designed.

Development of fluidised-bed gasification and gas cleaning technology for waste derived fuels has also been conducted by Powest Oy (a subsidiary of Pohjolan Voima Oy) and Vapo Oy with VTT Processes acting as technology partner. Extensive testing has been carried out at the VTT 1 MW pilot plant in Otaniemi, Espoo. The first commercial gasification venture of the companies is planned to be realised in connection to the Martinlaakso power plant, owned by Vantaan Energia Oy. A 80 MW gasification plant for solid recovered fuels is designed to replace about 30 % (energy content) of the current coal consumption. Foster Wheeler delivers the gasification plant for Powest´s and Vapo´s gasification projects.

2.3.3 Gas cleaning options

Figure 18 illustrates the different gasification and gas cleaning options. With woody biofuels and clean waste-derived fuels the simplest connection without gas cleaning is sufficient as will be described later on in this report for the Lahti gasifier. In this case the efficient gas combustion below the coal flames together with the flue gas cleaning equipment will guarantee excellent environmental performance. This technology has reached fully commercial state.

The second process alternative is based on dry gas cleaning prior to the boiler. This alternative makes it possible to utilise high-alkali biofuels (such as straw) as well as SRF with higher chlorine and heavy metal contents. This technology is ready for large-scale demonstration, but has not yet reached commercially proven status. The developed method is based on gas filtration at 200–450 °C temperature in a bag filter unit. With SRF fuels and other fuels containing a lot of plastic material, the filtration temperature has to be higher than 350 °C in order to avoid tar condensation problems. Ceramic filter bags are used. Calciumhydroxide or other alkali sorbents are injected into the gas before the filter unit, if necessary, to improve chlorine capture. However, the inherent fuel alkali metals and the calcium-based bed materials also react efficiently with HCl during gas cooling and especially in the filter cake. All heavy metals except mercury are also almost completely (> 99 %) removed from the gas during filtration.

The efficiency of the gas cleaning process has been demonstrated at the pilot plants of VTT (both CFB and BFB gasification plants) using different types of SRF and biomass fuels. Foster Wheeler has also operated similar-type of gas cleaning process at their 3 MW CFB gasification pilot plant. Presently Foster Wheeler is constructing a slip stream gas cleaning train to be connected to the Lahti gasifier. Long-term tests are required to demonstrate the durability of the filter media as well as to test the developed operation methods in a real plant site.

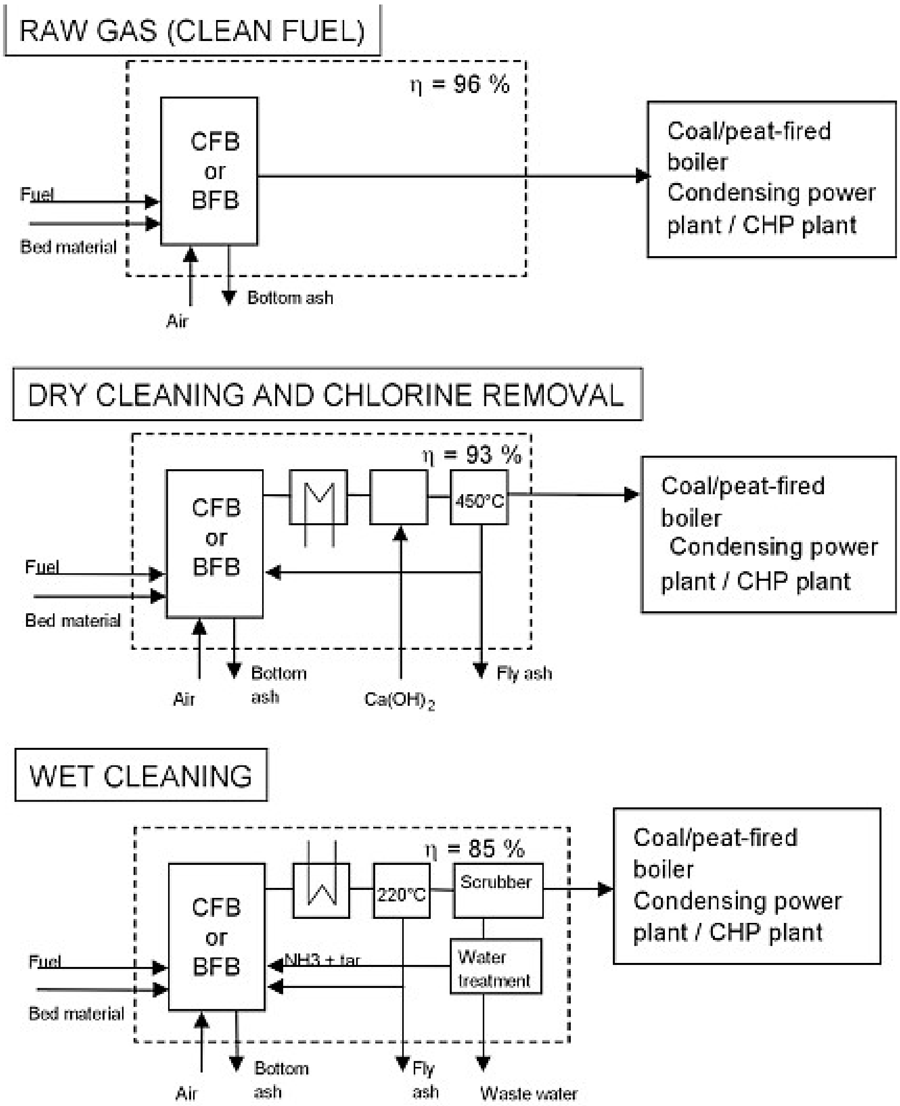

Figure 18. Different principle connections of the gasifier to the coal-fired boiler.

The third alternative including wet gas cleaning is a method, which can produce a very clean gas, but investment costs are roughly 50 % higher than in two previous cases. In addition, the wastewater treatment may be difficult to design in an environmentally fully acceptable manner.

2.4 Kymijärvi power station in Lahti

2.4.1 Power plant description

The Kymijärvi power plant was started in 1976. Originally, the plant was heavy-oil-fired but in 1982 it was modified for coal firing. The boiler is a Benson-type once-through boiler. The steam data is 125 kg/s 540 °C/170 bar/540 °C/40 bar and the plant produces electric power and district heat to the Lahti city. The maximum power capacity is 167 MWe and the maximum district heat production is 240 MW. The annual operating time of the boiler is about 7 000 h/a. In the summer, when the heat demand is low, the boiler is shut down. In the spring and autumn, the boiler is operating in low capacity, with natural gas as the main fuel. In 1986, the plant was furnished with a gas turbine connected to the heat exchanger preheating the boiler feed water. The maximum electrical output of the gas turbine is 49 MWe, when the outside temperature is -25 °C.

The boiler uses 1 850 GWh/a (270 000 ton/a) of coal and about 100 GWh/a of natural gas. The boiler is not equipped with a sulphur removal system. However, the coal utilised contains only 0.3 to 0.4 per cent sulphur. The burners are provided with flue gas circulation and staged combustion to reduce NO_x emissions.

The biomass/SRF gasifier was connected to the boiler at the end of 1997. The arrangement is illustrated in Figure 19.

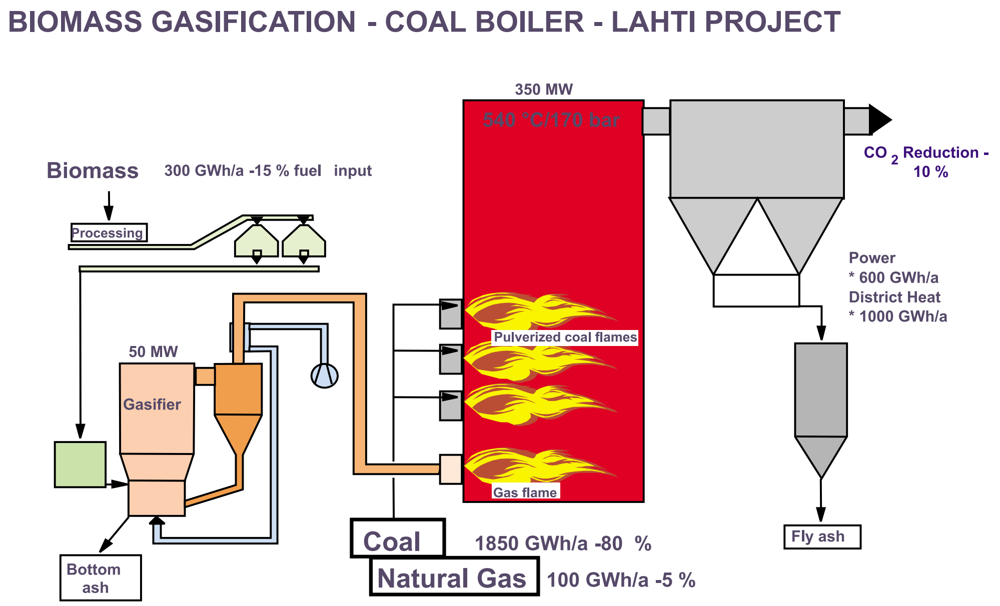

Figure 19. Flow sheet of the Lahden Lämpövoima Oy gasifier.

2.4.2 Gasifier fuels and fuel handling equipment

Approximately 300 GWh/a of different types of biofuels and SRF fuels are available in the Lahti area. On an annual basis this amount is enough to substitute about 15 % of the fuels burned in the main boiler. Table 9 presents a summary of the available biofuels in the Lahti area. Table 10 shows analysis data for the gasifier fuels and coal used in 2001.

The solid recovered fuel, SRF, is produced from the in origin classified refuses, which derive from households, offices, shops and construction sites. The processing of SRF was started by the municipally owned waste management company (Päijät-Hämeen Jätehuolto Oy) in 1997. The SRF consists of 5–15 wt-% plastics, 20–40 wt-% paper, 10–30 wt-% cardboard and 30–60 wt-% wood. In addition to these fuels listed, demolition wood waste, and shredded tires have also been used as fuels in the gasification plant.

Table 9. The available local fuels on annual basis in the Lahti area (total 300 GWh/a) [17-19].

Fuel	Amount %-weight of total	Moisture %-weight
Saw dust	10	45 – 55
Wood residues (bark, wood chips, wet and fresh wood residues, etc.)	30	45 – 55
Dry wood residues from the wood working industry (plywood, particle board, cuttings, etc.)	30	10 – 20
Solid Recovered Fuel (SRF)	30	10 – 30

Table 10. Analysis data for the fuels used in 2001 [20].

		Wood	Glue wood	Municipal sludge	SRF	Wood+glue wood + SRF	Coal
LHV, w.b.	MJ/kg	7.61	15.84	7.12	16.04	11.48	25.14
Sulphur, d.b	wt-%	0.03	0.01	0.93	0.08	0.05	0.36
Ash, d.b	wt-%	3.77	1.19	46.92	6.3	3.79	14.66
Trace components	d.b						
Cl	ppm-m	87	115	178	2580	1700	93
Na	ppm-m	146	1830	1570	1190	725	1 700
K	ppm-m	1710	720	1820	670	910	3 110
Br	ppm-m	< 3	< 3	< 3	< 3	< 3	< 3
F	ppm-m	3	< 3	39	43	12	25
As	ppm-m	0.3	0.3	3.2	1.4	0.6	5.5
Cd	ppm-m	0.4	0.1	0.8	0.1	0.2	< 0.02
Cr	ppm-m	15	10	45	21	26	23
Cu	ppm-m	5.2	3.5	160	20	29	7.1
Ni	ppm-m	3.4	2.2	26	8.5	8.2	6.1
Hg	ppm-m	< 0.2	< 0.2	0.6	0.3	0.2	0.2
Tl	ppm-m	0.1	0.1	0.1	< 0.05	0.1	< 0.05
Zn	ppm-m	110	19	390	74	120	15
Pb	ppm-m	1.3	0.9	14	4.3	7.5	3.6

Fuels are transported to the power plant in trucks. There is one receiving hall for SRF and one receiving station for incoming biofuels. The SRF hall is equipped with a receiving pit having a lamella feeder, which controls the fuel flow into a crusher. Coarse biofuel, which originates mainly from the wood working industry, is also fed through the SRF system. The trucks tip SRF and coarse biofuels on the floor of the hall or directly into the pit, after which they are crushed in a slowly rotating crusher. The underground conveyor from the first receiving bunker transports SRF and biofuels from the crusher. The other receiving station is used for the finer biofuel and peat. This biofuel is transported to the site in special trucks. The transport platforms of the trucks are furnished with conveyors. These conveyors discharge biofuel and peat from the trucks and the fuel falls through a screen down onto a chain conveyor at the bottom of the bunker. The coarser particles separated by the screen will be moved to the SRF hall for crushing. The underground conveyor lifts the fuels to the belt conveyor, which has a magnetic separator above it. The belt conveyor transports the fuels onto the disk screen. The coarse fuel fractions from the disk screen fall into the final crusher, while the fine fractions from the screen and the crushed biofuel will be transported by a chain conveyor to the fuel storage silo.

The gasification plant is furnished with one storage silo for fuels. Besides serving as a storage silo, this silo is used for homogenisation of the fuel mixture before it is transported into the gasification building. The discharge of the silo has variable speed controls.

2.4.3 Atmospheric pressure CFB gasification process of Foster Wheeler

The gasifier at Kymijärvi power station is a CFB gasifier (Fig. 20) supplied by Foster Wheeler. The atmospheric CFB gasifier is very simple. The system consists of a refractory-lined reactor where the gasification takes place, a uniflow cyclone to separate the circulating material from the gas and a return leg for returning the circulating material to the bottom part of the gasifier. The operating temperature

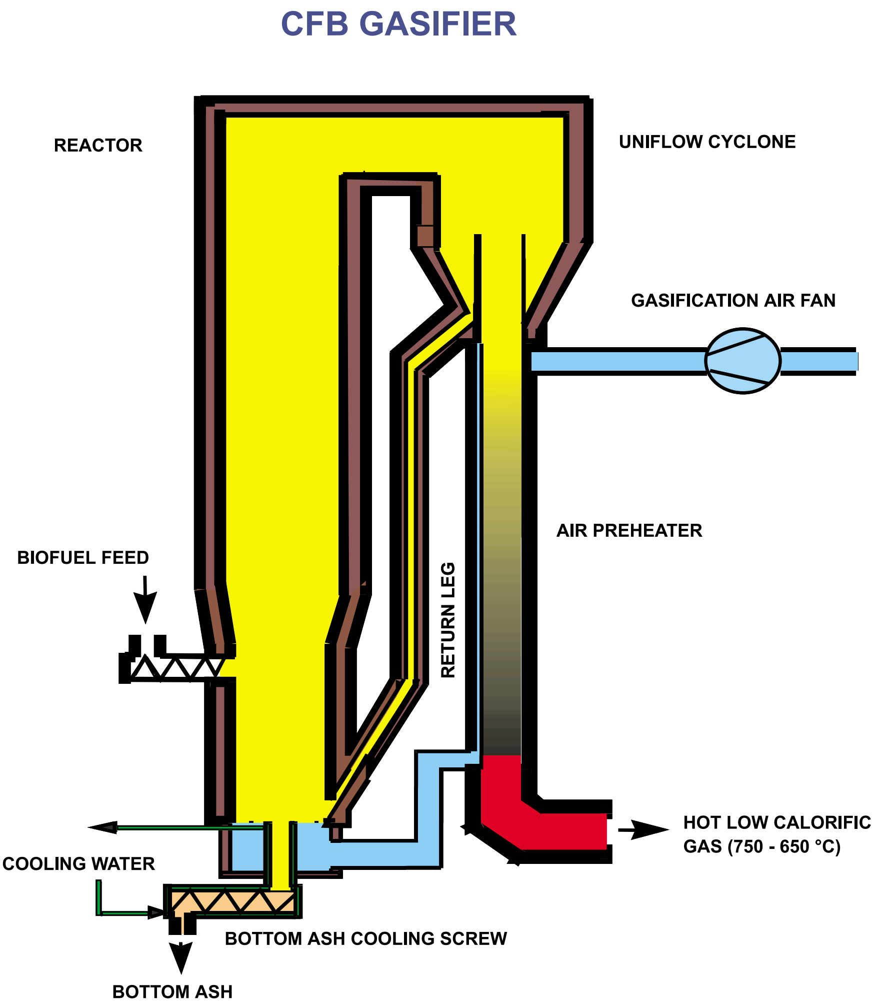

Figure 20. Foster Wheeler CFB gasifier [17].

in the reactor is typically from 800 to 1 000 °C, depending on the fuel and the application. The fuel is fed into the lower part of the gasifier above a certain distance from the air distribution grid. When entering the reactor, the biofuel particles start to dry rapidly and the pyrolysis also occurs. The gaseous products of drying and pyrolysis flow upwards in the reactor.

Part of the charcoal flows down to the more dense part of the fluidised bed while part of the char coal flows up together with the circulating media into the uniflow cyclone. Most of the solids are separated from the gas in the cyclone and returned to the bottom of the bed, where the char coal is combusted with the air that is introduced through the grid nozzles to fluidise the bed.

From the process point of view, the major difference compared to the biomass gasifiers constructed in the mid-80's is that fuel will not be dried in this application although the moisture content of fuel can be up to 60 %. Some mechanical changes have been made to accommodate the special nature of the fuel components to be used in the gasifier. For fuels like SRF, some wood wastes and shredded tires, which may contain different types of solid impurities (nails, screws, metal wires, concrete), the air distribution grid and the bottom ash extraction system have been specially designed. The fuel feeding was also designed in a different way to achieve stable feeding with an inhomogeneous and low-bulk-density fuel.

The product gas for combustion is led directly from the gasifier through the air preheater to two burners, which are located below the coal burners in the boiler. The gas is burned in the main boiler and it replaces part of the coal. When the fuel is wet, the heating value of the gas is very low. Typically, when the fuel moisture is about 50 % the heat value of the gas is only about 2.2 MJ/m^{3}n. The design of the product gas burners is rather special and is based on pilot-scale combustion tests and computational fluid dynamics (CFD) modelling work.

2.4.4 Operation experiences

The gasifier was connected to the main boiler on December 7, 1997. The very first gasification tests were carried out on January 14, 1998 and the unit has been in continuous operation since Week 4, 1998. The gasifier was shut down for the summer maintenance on June 2 and because of the extremely low electricity price in Finland in summer-autumn 1998, the main boiler was put in operation in the beginning of September and the gasification plant two weeks later, i.e. September 21, 1998. Already during the first operating year approximately 4 730 hours of operation in the gasification mode was achieved and the availability of the gasification plant (including fuel reception and handling) was 81.8% (highest monthly availability up to 93 %). The 1999 operational year was even better, the plant operating in the gasification mode for approximately 54 60 hours with an average availability of 87.6 % (highest monthly availability was 95.3 %).

The operating experience of the gasifier has been excellent during the years 1998-2002. On the annual basis, the gasifier availability has been between 96.1–99.3 %. Most of the problems, especially in the beginning, were related to the fuel processing plant. Lack of fuel and operational problems at the fuel processing plant decreased the availability of the whole plant during the first half of 1998. With regard to the gasification plant itself, the problems were related mostly to the use of shredded tires as a fuel in the gasifier. On several occasions the wire content of tires (there is no additional separation of metal wires with magnet after shredding) was so high that accumulated wires blocked the ash extraction system and the gasifier had to be shut down. Otherwise, with all other fuel fractions, the operation of the gasification process was good.

The annual operation hours and the availability figures are given in Table 11 and the annual statistics for the gasified fuels in Figure 21. The availabilities shown in Table 11 are calculated without taking into account the SRF and biofuel handling section of the plant.

Concerning the gasification process itself, the results have met the expectations. The operating conditions as regards temperatures, pressures and flow rates have been as designed and the process measurements as regards the product gas, bottom ash and fly ash composition have been very close to the calculated values. Due to the high moisture content (up to 58 %) of the gasifier fuels, the heating value of the product gas has been low, typically only 1.6–3.2 MJ/m^{3}n.

The stability of the main boiler steam cycle has been excellent. The large openings that were made for the low Btu gas burners have not caused any disturbances into the water/steam circulation. Furthermore, as regards the operation of the product gas burners, the product gas combustion has been stable even though the moisture content of the solid fuel has been mostly high and the heating value of the gas very low. The stability of the main boiler coal burners has been normal despite of the fact that the product gas burners were integrated very close to the lowest level coal burners.

Table 11. Operation figures of the Lahti gasifier plant in 1998–2001 (design values: operation time 6 500 hour/a and energy production 300 GWh/a) [19].

	1998	1999	2000	2001
Operation hours, h	4 730	5 460	4 727	7 089
Gasifier availability, %	99.3	98.9	97.1	96.1
Energy produced, GWh	223	343	295	449

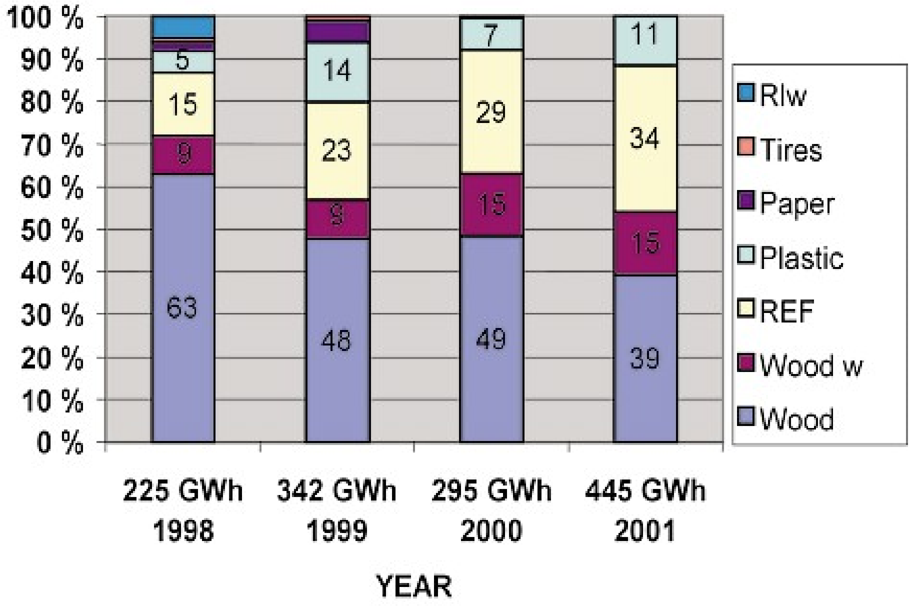

Figure 21. Gasifier fuel distribution and annual consumption in 1998–2001 [21] (Rlw. = railway sleepers, Wood w. = wood waste).

2.4.5 Plant monitoring and environmental effects

A thorough one-year monitoring program was started simultaneously with the start-up and the commissioning phase of the gasification plant. During this one-year long period the operation of the fuel preparation plant, the gasification plant and the main boiler have been monitored and reported. The monitoring included a) corrosion/deposit formation monitoring in the main boiler with probe testing, b) determination of the gasifier fuel gas composition, c) boiler flue gas emissions, and d) characterisation of the gasifier bottom ash and boiler fly ash. In 1997, a reference test run was carried out, during which the main boiler was fired with 100 % coal. The monitoring results are summarised in the following. More detailed information is given in reference 17.

Product gas composition

During the monitoring campaigns of 1998, the operating temperature of the gasifier was typically 830–860 °C and the gasifier effect varied between 35 MW and 55 MW depending on the gasifier fuel moisture content and on the required gasifier load. During the whole year 1998 the moisture content in the fuel mixture was rather high varying typically between 45 to 58 per cent. Due to that the product gas heating value has been relatively low, typically only 1.6–2.4 MJ/m^{3}n. Table 12 summarises typical measured values of the product gas main components. Typical range for the concentration of different trace components are given in Table 13. The fuel mix used is the one described in Figure 21 for 1998.

Table 12. Average values of the product gas main components.

Gas component	Unit	Average
CO_2	%-vol (wet)	12.9
CO	%-vol (wet)	4.6
H_2	%-vol (wet)	5.9
C_xH_y	%-vol (wet)	3.4
N_2	%-vol (wet)	40.2
H_2O	%-vol (wet)	33.0

Table 13.Typical values of the product gas special measurements.

Gas component	Unit	Range
NH_3	mg/m^{3}n (dry)	800 – 1 000
HCN	mg/m^{3}n (dry)	25 – 45
HCl	ppmv (dry)	30 – 90
H_2S	ppmv (dry)	50 – 80
Benzene	g/m^{3}n (dry)	7 – 12
Tars	g/m^{3}n (dry)	7 – 12
Alkalis	ppmw (dry)	< 0.1
Particulates	g/m^{3}n (wet)	6 – 10

Gasifier bottom ash

The main components of the gasifier bottom ash were bed materials, i.e. sand and limestone. Furthermore, small amounts of solid impurities, such as metal pieces, pieces of concrete, glass, etc., were found in bottom ash. Typically, the carbon content in gasifier bottom ash was less than 0.5 per cent. No signs of chlorine were seen in the analyses.

With regard to the trace metals, the following elements were analysed: As, Cd, Cr, Cu, Ni, Pb, Zn and Hg. Elements like chromium (Cr), copper (Cu) and zinc (Zn) were found in the range of hundreds of ppms. When shredded tires were used as a fuel in gasifier, the zinc content in gasifier bottom ash increased to the level of 3 000 ppm. All other analysed elements were in the range of a few ppms or tens of ppms. The major part of the elements escaped the gasifier in the gaseous phase or in the fine fly ash particles.

Besides the standard analyses, leachability tests were also made for the bottom ash. According to the tests, the trace metal leachabilities were low. As a result of low trace metal contents and low trace metal leachabilities, the gasifier bottom ash is disposed today as planned at the beginning of the project.

Main boiler flue gas

The main boiler emissions were perhaps under the greatest interest as regards the measurement program of the monitoring phase. As a summary, it can be stated that the changes in the emissions were very small. As indicated earlier, the main boiler is not equipped with DeNO$_x$ or DeSO$_x$ plants and the emission limit values for the emissions were as follows: NO$_x$ 240 mg/MJ (as NO$_2$) and SO$_x$ 240 mg/MJ. Table 14 summarises the effect of the co-combustion of the gasifier product gas on the main boiler emissions.

Table 14. The effect of gasifier to the main boiler emissions.

Emission	Change caused by gasifier
NO$_x$	Decrease by 10 mg/MJ (= 5 to 10 %)
SO$_x$	Decrease by 20 - 25 mg/MJ
HCl	Increase by 5 mg/MJ *
CO	No change
Particulates	Decrease by 15 mg/m^{3}n
Heavy metals	Slight increase in some elements, base level low
Dioxins	No change
Furans	
PAH	
Benzenes	
Phenols	

The dust content in the flue gas after the ESP decreased approximately 10–20 mg/m3n. The most probable reason to this has been the increase of the flue gas moisture content, which has enhanced the operation of the ESP. Perhaps the most positive phenomenon has been the decrease in the NO$_x$ emission. According to the measurements the NO$_x$ content of the main boiler decreased typically approximately 10 mg/MJ, equalling the decrease of 5 to 10 % from the base level. This was evidently due to the cooling effect of the low Btu, high moisture product gas in the bottom part of the boiler. Obviously, due to the cooling effect, the forming of thermal NO_x was lower in the coal burners located at the lower part of the boiler. Furthermore, because of the extremely low sulphur content of biofuels, the main boiler SO_x emission decreased approximately 20–25 mg/MJ. In contrast, because of the very low chlorine content (0.01 %) of the main boiler coal, the HCl content of flue gas increased approximately by 5 mg/MJ when the gasifier was in operation. The reason for this was the use of SRF fuel and shredded tires in the gasifier. Both of these fuels are known to contain chlorine. As regards the CO emission of the main boiler, no changes could be seen.

With regard to the heavy metal stack emissions, increases in some elements could be seen, but because of the very low base levels in coal combustion, the changes that were measured were in practice very small.

As regards dioxins, furans, polyaromated hydrocarbons, chlorinated phenols and chlorinated benzenes, no changes could be seen compared to the results from 100 % coal combustion.

Main boiler filter ash

The share of the gasifier fly ash of the main boiler total filter ash is small, only 3 to 5 per cent. Thus, it is obvious that the changes in the main boiler filter ash quality are very small in practice. With regard to the amount of unburnt carbon and alkalis, no change could be seen compared to the 100 % coal combustion.

Concerning the heavy metals, the changes in the main boiler filter ash quality were small. Increase in some elements could be seen, but because of the small share of gasifier fly ash, it is obvious that the gasifier fly ash effect on the main boiler filter ash quality is small.

As regards the measured content of organic compounds (dioxins, etc.), no changes could be seen when comparing the results to the data of the reference tests.

The leachability tests were made also for the main boiler filter ash. According to the tests, the trace metal leachabilities were low. Because of the small changes in the ash quality and because of the low leachabilities of trace metals, the authorities have given permission to use the main boiler filter ash today as it has been used earlier on construction works (roads, etc.). However, it is noted that permission from the authorities has to be applied separately for each new application.

Deposit formation monitoring

As regards the results of the corrosion probe monitoring tests no indication of abnormal deposit formation/fouling or corrosion could be seen in the test coupons. Furthermore, in the inspection of the boiler heat transfer surfaces (furnace walls, superheater section, economiser and air pre-heater) during the summer maintenance, no signs of abnormal deposit formation or high temperature corrosion could be found.

2.4.6 Environmental figures in 2001

Annual emission figures reported from the power plant to the environmental authorities in 2001 are summarised in Table 15, results for boiler flue gas emission measurements in Table 16 and data for the ash streams in Table 17. Reference data for 1997 measurements with coal alone are also presented [20].

Table 15. Annual emission report of the Kymijärvi power station to the authorities [20].

Annual emissions		1997	2001
Fuel consumption in total	TJ	6 788	9 079
coal	TJ (%)	465 (70.2)	6 770 (74.6)
natural gas	TJ (%)	223 (29.8)	693 (7.6)
gasifier, total	TJ (%)	0 / (0)	116 (17.8)
- wood	TJ	0	637
- glue wood	TJ	0	241
- SRF	TJ	0	554
- plastics	TJ	0	184
Flue gas emissions			
SO_2	mg/MJ	167	212
NO_x	mg/MJ	218	222
Total dust	mg/MJ	12	5.4
Hg	mg/MJ	0.005	0.0004
Cr	mg/MJ	0.006	0.0049
Ni	mg/MJ	0.009	0.0053
Cd	mg/MJ	0.00002	0.0005
As	mg/MJ	0.002	0.0038
Cu	mg/MJ	-	0.0061
Zn	mg/MJ	-	0.0203
Pb	mg/MJ	0.007	0.0042
HCl/Cl+	mg/MJ	-	5.46
HF/F+	mg/MJ	-	1.07
V	mg/MJ	-	0.0064

Table 16. Special environmental analyses for the gasifier bottom ash and for the two boiler ash streams. Samples represent the 2001 operation period described in Table 15 [20].

	Unit	Boiler fly ash 1997 (only coal)	Boiler fly ash 2001	Boiler bottom ash 2001	Gasifier bottom ash 2001
Chlorophenols	ng/g	nd	< 5	< 5	< 5
PAH compounds	ng/g	nd	16	20	10
Polychlorinated biphenyls and benzenes	ng/g	nd	< 0.5	< 0,5	< 0.5
Dioxins	pg/g	nd	< 0.5	< 0.5	< 0.5
Furanes	pg/g	nd	< 5	< 5	< 5
Cl	mg/kg	200	< 3	< 3	451
F	mg/kg	n.d	160	< 3	90.7
As	mg/kg	20	1.7	0.9	3.6
Cd	mg/kg	0.4	0.8	0.1	0.1
Cr	mg/kg	119	44	38	86
Cu	mg/kg	50	30	60	640
Ni	mg/kg	56	19	20	35
Hg	mg/kg	n.d	0.7	< 0.2	< 0.2
Zn	mg/kg	150	84	190	1 200
Pb	mg/kg	34	10	11	23

Table 17. Comparison of the boiler flue gas emission measurement results from 100 % coal firing (1997) and from co-firing af gasifier gas and coal (2001) [20].

		1997	2001
Fuel consumption	MW	350	349
Coal	MW	350	293
Natural gas	MW	0	0
Gasifier, total	MW	-	56
• wood	MW	-	29
• glue lam wood	MW	-	8
• SRF	MW	-	16
• sewage sludge	MW	-	3
Flue gas emissions			
Flue gas flow rate (wet gas)	m^{3}n/s		118
O$_2$ - content (dry gas)	%	6	6.8
SO$_2$, emission mg/MJ	237	208	
SO$_2$ concentration (dry gas)	mg/m^{3}n	638	636
NO$_x$, emission mg/MJ		264	187
NO$_x$ concentration. (dry gas)	mg/m^{3}n	710	572
Dust emission mg/MJ		11	7
Dust concentration (wet gas)	mg/m^{3}n	29	19
N$_2$O concentration (dry gas)	mg/m^{3}n	nd	< 4
CO emission mg/MJ		11	10
CO concentration (dry gas)	mg/m^{3}n	30	30
CO$_2$ concentration (dry gas)	%	13.3	12.5
TOC emission mg/MJ	nd	< 1	
TOC concentration (dry gas)	mgC/m^{3}n	nd	< 2
HCl concentration (dry gas)	mg/m^{3}n	0,4	34
HF concentration (dry gas)	mg/m^{3}n	2,4	7
PAH-compounds total (dry gas)	mg/m^{3}n	0.03	1
Polychlorinated benzenes (dry gas)	ng/m^{3}n	4	15
Polychlorinated biphenyls (dry gas)	ng/m^{3}n	2	16
Chlorophenols (dry gas)	ng/m^{3}n	50	20
PCDD total conncentration (dry gas)	ng/m^{3}n	0.14	0.01
PCDF total concentration (dry gas)	ng/m^{3}n	0.19	0.001
PCDD/PCDF, I-TEQ (dry gas)	ng/m^{3}n	0.005	0.001
Total heavy metal concentrations in dry flue gas			
Cr	mg/m^{3}n	< 9	4
Ni	mg/m^{3}n	< 9	3
Cd	mg/m^{3}n	< 2	0.2
As	mg/m^{3}n	< 4	2
Cu	mg/m^{3}n	< 9	4
Zn	mg/m^{3}n	< 35	16
Pb	mg/m^{3}n	< 9	< 11
Hg	mg/m^{3}n	< 0,6	1
Sb	mg/m^{3}n	nd	0.4
Co	mg/m^{3}n	nd	0.9
Mn	mg/m^{3}n	nd	22
Tl	mg/m^{3}n	nd	< 8
Sn	mg/m^{3}n	nd	0.8
V	mg/m^{3}n	nd	5
Sum of heavy metals	mg/m^{3}n	-	59

nd = not determined

Based on the environmental measuring data, the following main conclusions can be drawn considering the total environmental effects of the replacement of coal by biomass/SRF-derived product gas at Lahti:

- The emission of CO_2, SO_2, dust and NO_x are lowered due to the use of gasification gas when compared to coal-alone combustion.
- The effect of the gasifier gas on the heavy metal emissions into the boiler flue gas is negligible compared to the effects caused by changes in coal quality. The total emissions are very low when compared e.g. to the limits set by the Waste Incineration directive:
  - Hg emission = 0.001 mg/m³n, WID limit 0.05 mg/m³n (1:50)
  - Cd+Tl emission = 0.0002 mg/m³n, WID limit 0.05 mg/m³n (1:250)
  - other heavy metals emission = 0.06 mg/m³n, WID limit 0.5 mg/m³n (1:8)
- The concentration of dioxins was only 0.001 ng/m³n, while the WID emission limit is 100-times higher (0.1 ng/m³n).
- The emission of HCl is somewhat increased due to the fact that the chlorine content of the used coal is very low. The total HCl concentration in the flue gas of 34 mg/m³n is, however, still rather low.
- The effect of the gasifier gas co-combustion on the ash composition of the main boiler ash is also very small and cannot be clearly detected below the scatter caused by differences in coal quality.

2.4.7 Plant economy

Total costs of the gasification plant at the Kymijärvi power plant were about 12 million euros. This included fuel preparation plant, civil works, instrumentation and control as well as the electrification. The project received 3 million euros support from the THERMIE Program of the European Commission. The estimated payback time of the investment was 5–7 years.

2.4.8 The efficiency of the gas cleaning technology

The very good environmental performance of the Lahti-type of plant can even be improved by installing the dry gas cleaning system described in Chapter 2.3.2. The use of gas cleaning before leading the gas into the boiler will also make it possible to utilise SRF fuels, which have higher chlorine and heavy metal contents than the feedstock mixture used at the Lahti gasifier. Table 18 summarises the measured efficiency of the dry gas cleaning methods developed by VTT for chlorine and heavy metals [22]. All heavy metals except mercury are removed almost completely from the gas. The residual HCl content of < 50 ppmv would also result in the Lahti plant to the final flue gas HCl emission of less than 10 ppmv (WID limit for HCl emissions of waste incinerators) when low-chlorine coal is used as the main fuel and the share of gasifier gas is 15–20 %. Presently, VTT is also studying the mercury removal by different sorbents as a further improvment of the developed dry gas cleaning method.

Table 18. The efficiency of the gasifier gas cleaning for chlorine and heavy metal capture [22].

	Removal efficiency %	Final concentration in clean gas
HCl (ppm-v)	> 90	< 30-50
Heavy metals (ppm-m)		
V	> 99 %	< 0.01
Cr	> 99 %	< 0.01
Mn	> 99 %	< 0.01
Co	> 99 %	< 0.01
Ni	> 99 %	< 0.01
Cu	> 99 %	< 0.02
Zn	> 99 %	< 0.20
As	> 99 %	< 0.005
Cd	> 99 %	< 0.001
Sn	> 99 %	< 0.01
Sb	> 99%	< 0.01
Pb	> 99 %	< 0.03

The effects of the co-combustion of cleaned product gas on the emissions of the main boiler have also been estimated by VTT. In these calculations, the effects of coal quality and the use of desulphurisation technology have also been studied. The results are reported in reference [23]. The calculation clearly showed that only the emissions of mercury have been looked carefully case by case as mercury is not captured by the present gasifier gas cleaning process. However, with most SRF and biomass materials the mercury content is low and similar-type of results can be expected as have been measured at the Lahti gasifier plant, where the mercury emissions have been very low. According to VTT's estimation, the mercury emissions are below the WID limit even if the mercury content of the gasifier fuel is 0.75 ppm and up to 30 % of coal is replaced by the gasifier gas. However, this also depends on the mercury emissions of coal combustion and the removal efficiency achieved in flue gas cleaning process.

2.4.9 Conclusions

The following conclusions can be drawn on the experiences obtained at Lahti and in the further development work on the gas cleaning:

- The gasification-based co-firing method is a cost-effective and environmentally attractive way of utilising locally available biomass residues and good-quality solid recovered fuels.
- The first commercial plant located at Lahti Finland has demonstrated that the technology is technically proven and is able to reduce the emission of CO_2, SO_2, dust and NO_x compared to coal-alone combustion.
- The emissions measurements clearly show the benefits of this type of waste utilisation technology with respect to dioxin emissions. The reducing gas atmosphere of the gasifier together with the very efficient and high-temperature combustion of the product gas according to the measurements fully eliminate the formation of dioxins. The development of gas cleaning, where over 90 % of chlorine and over 99 % of metals are removed from the gas will even further guarantee the elimination of dioxins without producing problematic dioxin containing solid wastes as in ordinary incinerators.

- The heavy metal emission in Lahti is very low when compared to the emission limits by WID. The performance will be further improved by using gas cleaning before the boiler.
- The most simple gasification concept realised without gas cleaning is suitable to clean biofuels and clean waste-derived fuels, which do not contain high amounts of chlorine or heavy metals. Product gas cleaning makes it possible to utilise also fuel with higher chlorine and metal contents. However, the gas cleaning still has to be demonstrated before it can be considered as fully proven technology.

3

Best Available Technique

This report describes an integrated waste management system, emphasizing a simultaneous and efficient material and energy recovery from waste. Source separation and material recycling has long traditions in Finland. Fluidised bed combustion is extensively used in combined heat and power production from various biofuels and fossil fuels. Gasification of biomass and waste-derived fuels and co-combustion of the fuel gas has been convincingly demonstrated in the Lahti project, first of its kind in Europe. Production of solid recovered fuels has been developed and utilised in Finland to meet the fuel specifications for the fluidised bed combustion and gasification energy recovery processes.

The described system differs in many aspects from the conventional MSW incineration in large grate-fired mass burn facilities commonly used in Europe. The environmental performance of both systems is, however, regulated by the Waste Incineration Directive, which sets uniform emission limits to both systems.

The best available technique in energy production from solid recovered fuels consists of optimised unit processes; production and energy use. These processes must be designed in such a way that they fit together. The system can then be considered best available technique in integrated waste management, offering a number of environmental, economic and technical benefits:

- Source separation of household waste makes collection of clean waste fractions, like paper, cardboard, glass, metals etc., possible for extensive material recovery.
- Processing industrial and commercial waste and the energy fraction of household waste to SRF produces a fairly clean fuel fraction. Several of the reject streams of the process, i.e. metals and non-ferrous metals, can be recovered. Biological residues and fines are used for composting. The process can be optimised for material recovery and for removing harmful components, like chlorine and aluminium, with regard to efficient FB combustion.
- Fluidised bed combustion is very fuel-flexible and particularly well suited for co-combustion of waste-derived fuels. High steam values and consequently high power production efficiency can be obtained when the share of SRF is kept on a level of 10-20 %.
- The Lahti concept has shown that gasification-based co-firing of SRF in PC-boilers is cost-effective and environmentally attractive. Emissions of CO_2, SO_2, dust and NO_x are reduced compared to coal-alone combustion. Product gas cleaning (to be demonstrated) makes it possible to utilise also low quality waste fuels with higher content of chlorine and heavy metals.

4

Emerging techniques

4.1 Recycling of liquid packaging

Corenso United Ltd produce core board using recycled fibre from liquid packaging as a raw material, Figure 22. The plant enables the complete exploitation of used packages containing wood fibre, plastic, and aluminium. It will be the first plant in the world that is able to recycle the aluminium in used liquid packaging to create a raw material for foil for its original purpose, while simultaneously exploiting the plastic contained in the packages to produce energy.

Liquid packaging comprises about one-third of plastic and aluminium, which results in a huge landfill load. The fibre material in multi-layer packages can be recycled in core board, and, instead of being dumped as landfill, the aluminium and plastic remaining from the packaging is gasified in Corenso's new gasification plant. The aluminium being recycled as raw material for foil and the plastic fraction

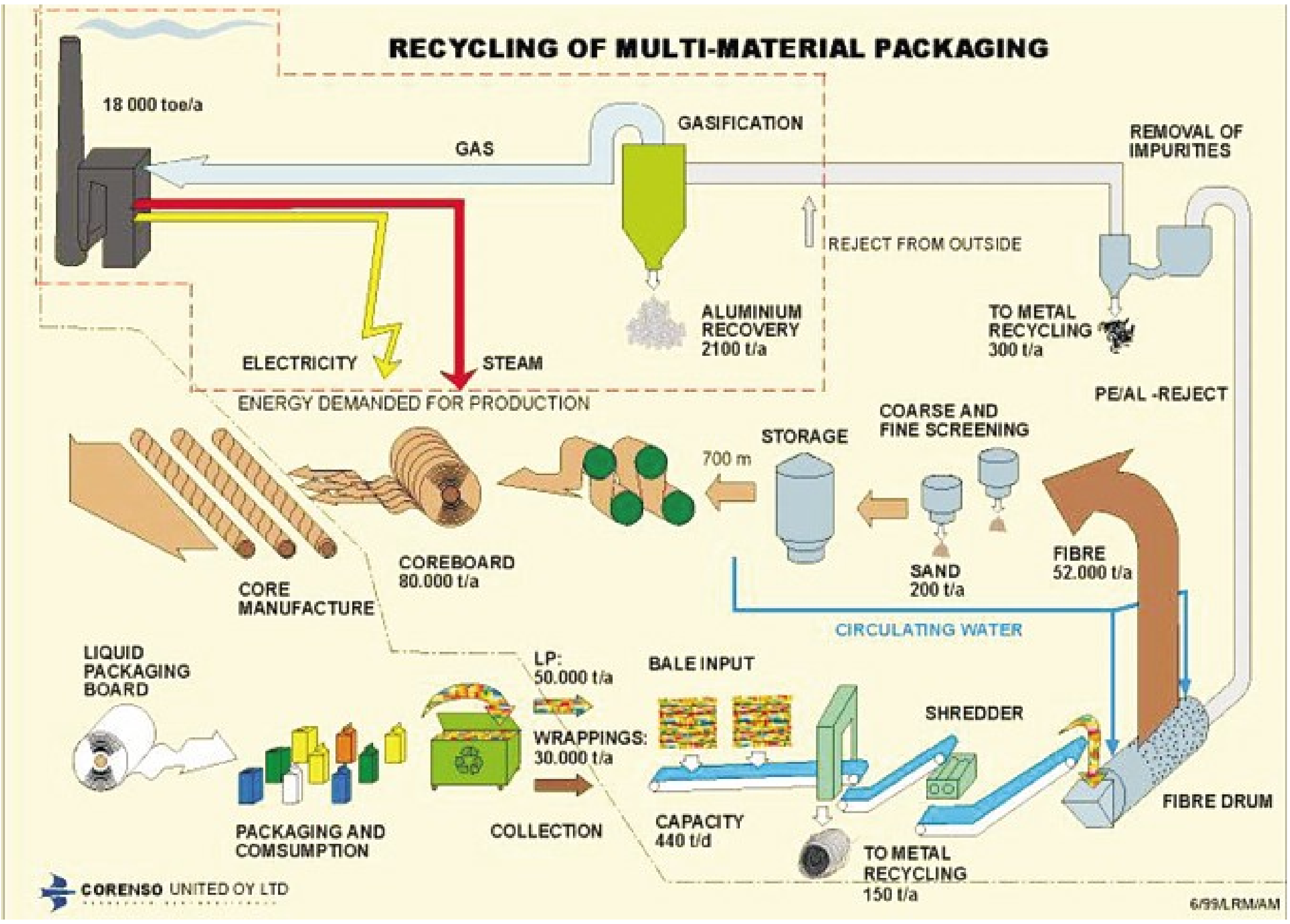

Figure 22. Recycling of liquid packaging, Corenso United Ltd.

is used as energy. The new gasification plant helps to fully recycle packaging containing aluminium foil. The method can also be applied to other waste and industrial by-products containing aluminium or other fusible metals.

The new gasification process was developed in cooperation with VTT Processes and supplied by Foster Wheeler Energia Oy. It was commissioned in 2001 and about 40 MW of heat is generated, with an annual total energy production in the region of 165 GWh.

4.2 Fibre recovery

Paper recycling rates have been increasing in Europe during the 1980's and 1990's. However, still some paper/fibre is landfilled, mostly packaging waste or paper, which is not separately collected, but remains in the MSW. Metso Corporation has developed an integrated material and energy recovery concept for waste. The idea is to exploit the raw material potential in various paper-containing waste streams by utilising recycled fibre for paper and board production and the rest mainly as fuel in energy production.

Metso has been developing a concept, Figure 23, in which source-separated 'dry fraction' of waste is processed in an advanced SRF plant, where additional material is recovered (metals, glass, aluminium, paper fibre). The recovered fibre will be used in a paper or board production and SRF will be used in a shared waste-to-energy plant. This type of integration offers a number of tangible benefits by eliminating costly rejects and generating inexpensive energy from waste.

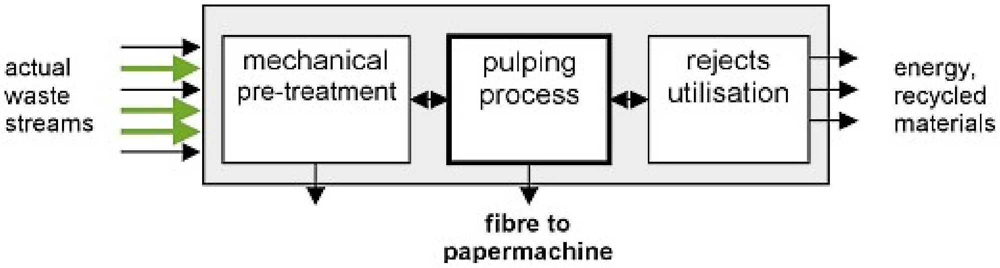

Figure 23. The fibre recovery concept of Metso Corporation.

Metso has been carrying out research and pilot plant testing on subject considering the commercial and technical status of the concept [24, 25]. Approx. 80 per cent of the paper and board contained in dry waste material can be recovered and reused for core board manufacturing. It has been possible to demonstrate the main idea of the method, i.e. fiber recovering from dry waste, in the pilot unit which was started up at Ahlstrom's Core Board Mill in Karhula, Finland, in June 2003. The feeding capacity of the mobile unit, 4 tons of presorted dry waste per hour, is significant. In continuous operation it would correspond to the dry waste amount produced by a 100 000 person community. In addition, fiber recovery also enables further processing of the plastics contained in the waste for material recycling.

The novel idea in the fibre recovery process is to selectively use solid waste with a low initial content of food waste. This type of waste can be obtained from most industrial and commercial waste producers and from households where a system of selective biowaste collection is in place. Simple pre-treatment, including size reduction and gravimetric separation, is applied to the waste, and the resulting fibre-rich fraction can be fed directly for pulping.

4.3 MBT-process

Vapo Oy Biotech has developed a mechanical-biological (MBT) treatment plant for refining recovered fuels. The technology is based on the tunnel composting system developed and marketed by the company for bio-waste treatment. Biothermal drying is used in the process to dry mechanically de-watered municipal and industrial sludge to a solid fuel with a moisture content of 40-50 %. The produced fuel can be utilised for energy production in co-combustion the same way as SRF.

Nomenclature

BAT	best available techniques
BFB	bubbling fluidised bed
CFB	circulating fluidised bed
CFD	computational fluid dynamics
CHP	combined heat and power
ESP	electrostatic precipitator
FB	fluidised bed
FBC	fluidised bed combustion
I-TEQ	international toxicity equivalents
LHV	lower heating value
MBT	mechanical-biological treatment
MSW	municipal solid waste
NID	novel integrated desulphurisation
PAH	polycyclic aromatic hydrocarbons
PC boiler	powdered coal boiler
PCDD	polychlorinated dibenzo-p-dioxin
PCDD/F	polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofuran
PCDF	polychlorinated dibenzofuran
SNCR	selective catalytic nitrogen reduction
SRF	solid recovered fuel
TOC	total organic carbon
WID	waste incineration directive
VOC	volatile organic compound
WTE	waste to energy

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Documentation page

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Title of publication	Finnish expert report on Best Available Techniques in energy production from solid recovered fuels		
Parts of publication/ other project publications	The Publication is available on the Internet: http://www.environment.fi/publications		
Abstract	This BAT report describes an integrated waste management system, emphasizing a simultaneous and efficient material and energy recovery from waste. Waste to energy technology in Finland is focused on co-firing in combined heat and power production, mainly on fluidised-bed combustion and gasification technologies. The Finnish waste management and solid recovered fuel (SRF) production is based on an efficient and extensive source separation practise. Processing industrial and commercial waste and the energy fraction of household waste to SRF produces a fairly clean fuel fraction. Fluidised bed combustion is very fuel-flexible and particularly well suited for co-combustion of waste derived fuels. High steam values and consequently high power production efficiency can be obtained when the share of SRF is kept on a level of 10-20 %. Gasification of SRF and co-firing the product gas in pulverised coal boiler is a cost-effective and environmentally attractive way of utilising locally available waste derived fuels.		
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Tiivistelmä	Tässä BAT raportissa kuvataan integroitua jätehuoltojärjestelmää, jossa painotetaan samanaikaista tehokasta materiaali- ja energiahyödyntämistä. Suomessa jätteiden energiahyödyntäminen kohdistuu rinnakkaispolttoon yhdistetyssä sähkön ja lämmön tuotannossa käyttäen leijukerros- ja kaasutustekniikkaa. Suomen jätehuolto ja kierrätyspolttoaineiden (SRF) valmistus perustuu tehokkaaseen ja laajaan jätteiden syntypistelijitteluun. Kaupan ja teollisuuden jätteestä sekä kotitalousjätteen energiafraktiosta valmistetaan kierrätyspolttoaineen valmistusprosessissa polttoainetta energiakäyttöön. Leijukerrostekniikka on joustava polttoaineen laadun suhteen ja soveltuu siten erityisen hyvin jäteperäisten polttoaineiden rinnakkaispolttoon. Kierrätyspolttoaineiden osuuden ollessa 10-20% saavutetaan tehokkaalla poltolla korkea sähkön hyötysuhde. Kierrätyspolttoaineiden kaasutuksella ja kaasun oheispoltolla hiilipölykattilassa voidaan paikallisia jäteperäisiä polttoaineita hyödyntää taloudellisesti ja ympäristöystävällisesti energiantuotannossa.	
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Sammandrag	Denna BAT rapport beskriver ett integrerat avfallshanteringssystem som betonar såväl materialåtervinning som energiutnyttjande. I Finland har avfallbaserad energiutnyttjande fokuserats på kombinerad värme- och elproduktion, främst via fluidiserad bädd förbrännings- och förgasningsteknik. Det finska avfallhanteringssystemet och produktionen av återvinningsbränslen (SRF) baserar sig på effektiv och omfattande källsortering. Framställning av SRF ur industriavfall, kommersiellt avfall och energifraktionen av hushållsavfall skapar ett rätt rent bränsle. Förbränning i fluidiserad bädd är mycket bränsleflexibelt och tekniken lämpar sig väl för parallellförbränning av avfallsbaserade bränslen. Parallellförbränning av 10-20 % återvinningsbränlen möjliggör effektiv förbränning och högt elutbyte. Förgasning av SRF och parallellförbränning av produktgasen i kolpulvereldad panna är ett ekonomiskt och miljövänligt sätt att utnyttja lokala avfallsbaserade bränslen.		
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Finnish expert report on best available techniques in energy production from solid recovered fuels

"Finnish expert report on best available techniques in energy production from solid recovered fuels" gives a comprehensive review over the energy production from solid recovered fuels in Finland. This report describes an integrated waste management system, emphasizing a simultaneous and efficient material and energy recovery from waste. The report is focused on co-firing in combined heat and power production, mainly on fluid-bed combustion and gasification technologies. The objective of this report has been to produce information to be used in the European Commission work to generate descriptions of best available techniques dealing with utilization of waste as energy.

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