

# **IEA Bioenergy Task 23**

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## **CO-FIRING OF MSW AND RDF**

VTT ENERGY

Fuels and Combustion, New Energy Technologies

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Jyväskylä 13.12.2000

## **Notice**

This study has been performed for the working group of IEA Bioenergy Task 23: Energy from Thermal Conversion of MSW and RDF, as a part of topic 5, Co-firing of MSW & RDF.

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Execution of the study was limited to public information, material delivered from Foster Wheeler Energia Oy, Ab Ekorosk Oy, Pirkanmaan Jätehuolto Oy, Säkkiväline Ympäristöpalvelut OY (earlier WM Ympäristöpalvelut Oy), Sermet Oy, and those power plants answered to inquiry.

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## **1. Introduction**

The concept of Waste to Energy is strengthening in many countries. Closing of landfill sites, waste taxes and growing landfill gate fees all increase the interest in recycling waste and using it as a source of energy. A condition of using waste for energy is that emissions from the process follow the ever-tightening EU and national norms. Making use of large quantities of waste in energy generation means that energy technology has to be developed for different waste flows and various power station types.

In Finland new energy technology is being developed for growing markets under the Waste to REF & Energy Technology Programme (1998–2001) launched by Tekes (the National Technology Agency). The aims of the programme are to develop methods of recovering energy from different waste components and to develop methods of recycling materials, to develop sorting methods for waste at the point where it is generated, manufacturing methods for recovered fuel, to create a quality classification system for refuse recovered fuel (REF), and to apply new solutions in order to achieve savings of at least FIM 100/tonne in treatment/handling costs, which is equivalent to annual savings of FIM 200-400 million compared with incineration and landfilling.

For some countries where collecting landfill gases is not mandatory such a plant can be a solution to reduce greenhouse gas emissions because landfill emissions are nominally 50 % hydrocarbons with 20 – 30 times the potential of CO<sub>2</sub> for greenhouse warming .

The basic aims of waste management are the same in Finland as in the other EU member states:

- to prevent the generation of waste
- to make use of waste in the form of materials and energy
- to carry out safe final disposal of unusable waste.

The waste, best suited to energy recovery, is industrial and commercial packaging wastes, paper and plastic waste and construction waste, which together correspond to 70-80% of the amount of waste taken to landfill sites. Utilising of waste for energy cuts the methane emissions from landfill sites, making it easier for Finland to achieve its reduction targets in climate agreement.

## **2. Waste segregation systems and / or processing technologies for RDF production**

### ***2.1 Finland***

In Finland the waste management is based on source separation of waste in order to increase the material recycling and to source separate the combustible fraction not

suitable for recycling. This dry, combustible fraction is processed for recovered fuel, which is used in the nearby district heating/power plant for energy recovery.

The most important waste fraction for co-firing is the commercial waste; packaging materials, card board/paper and construction and demolition waste. The energy potential from co-firing of recovered fuel derived from the commercial waste is 80 % and that of municipal waste 20 %. There are many straightforward systems to produce recovered fuel from commercial waste. The system consists of reception, conveyers, metals separation, crushing, conveyer and storage. An example is shown in figure 1.

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A waste processing plant for source separated household waste includes usually secondary crushing, magnetic separation and sometimes also an eddy current for non-metallic material removal. An example of a plant processing household waste and some commercial waste for recovered fuel is shown in figure 2. The waste is supplied to the plant through two main lines and one side line. The first line processes source-separated waste, formed in households, industry, stores and construction. The capacity of the line is 15 t/h. The second line processes source separated combustible waste, which is mostly from commercial, industrial and construction activities. The capacity of the line is 8 t/h. Between the lines there is a hydraulic grab, which can remove objects unsuitable for the process. Waste is crushed in primary crushing to 200 mm pieces. Magnetic metals are removed by a belt magnet. After the metal removal harmful fractions for combustion, such as glass and bio waste, are removed from the product. The construction costs of Ressu waste processing plant were 43.0 million FIM.

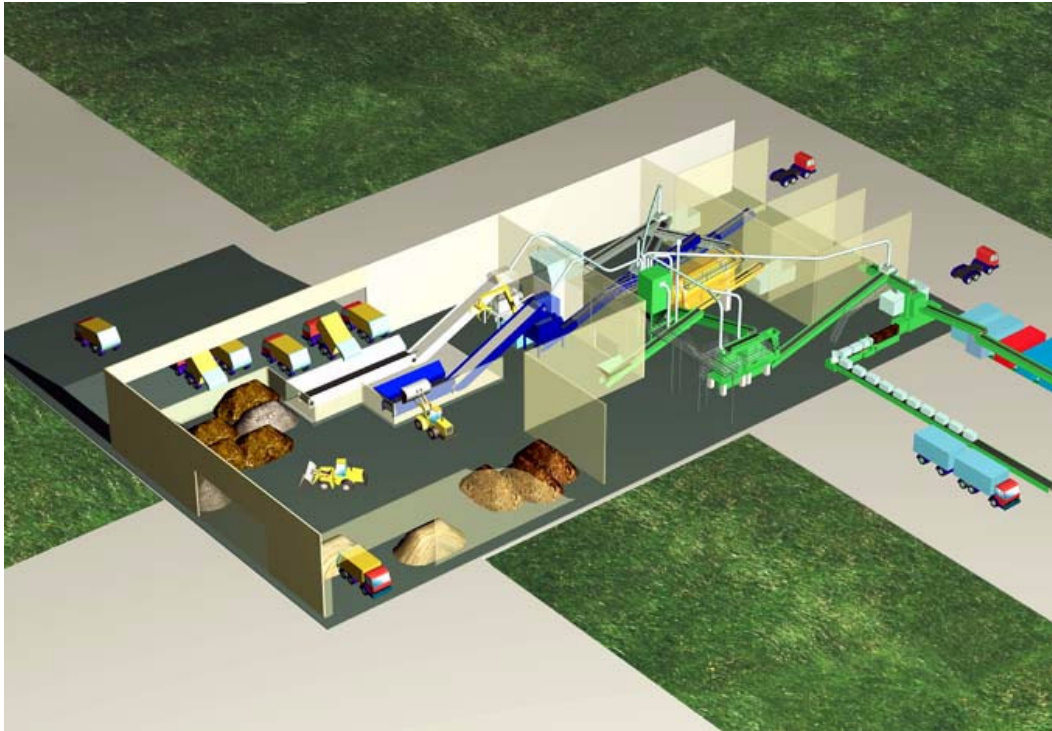
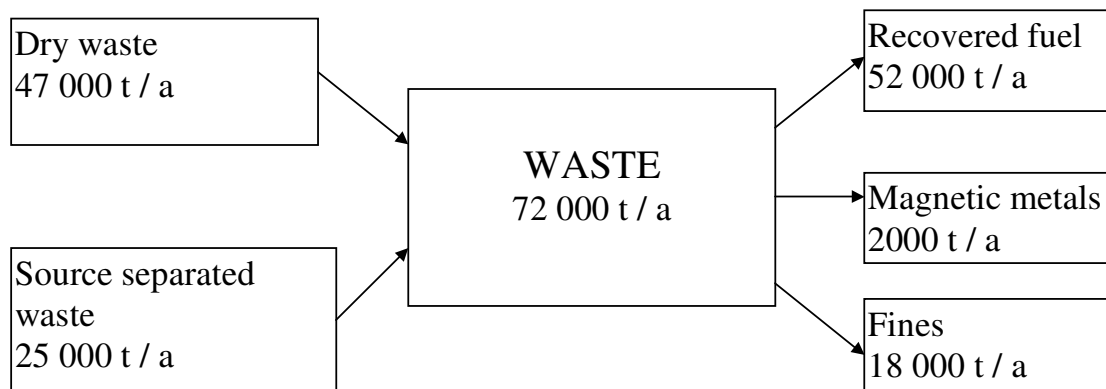


Figure 2. Resso waste processing plant owned by Pirkanmaan Jätehuolto Oy in Tampere.

Resso waste processing plant annually treats 72 000 tonnes of waste, of which the share of dry waste is 47 000 tons and source-separated combustible waste 25 000 tons. The plant produces 52 000 t of recovered fuel per year.



In Western Finland there is an integrated solid waste management system in operation. The system is a combination of biogas generation and a process for deriving fuel pellets from plastic and paper waste. The pellets have high energy density and they can be stored and combusted in a rational manner. The pellets are used as fuel by the wood-

pulp and paper company UPM Kymmene power plant at Pietarsaari. The pellets are mixed with wood-residue fuel and combusted in a bubbling fluidised-bed boiler. The annual capacity will be 30 000 tons pellets and the value of the pellets is 20 MJ/kg. The mass flow lines of the plant are shown in the figure 3. The flow sheet of the process and sources of waste materials are shown in Appendix 1.

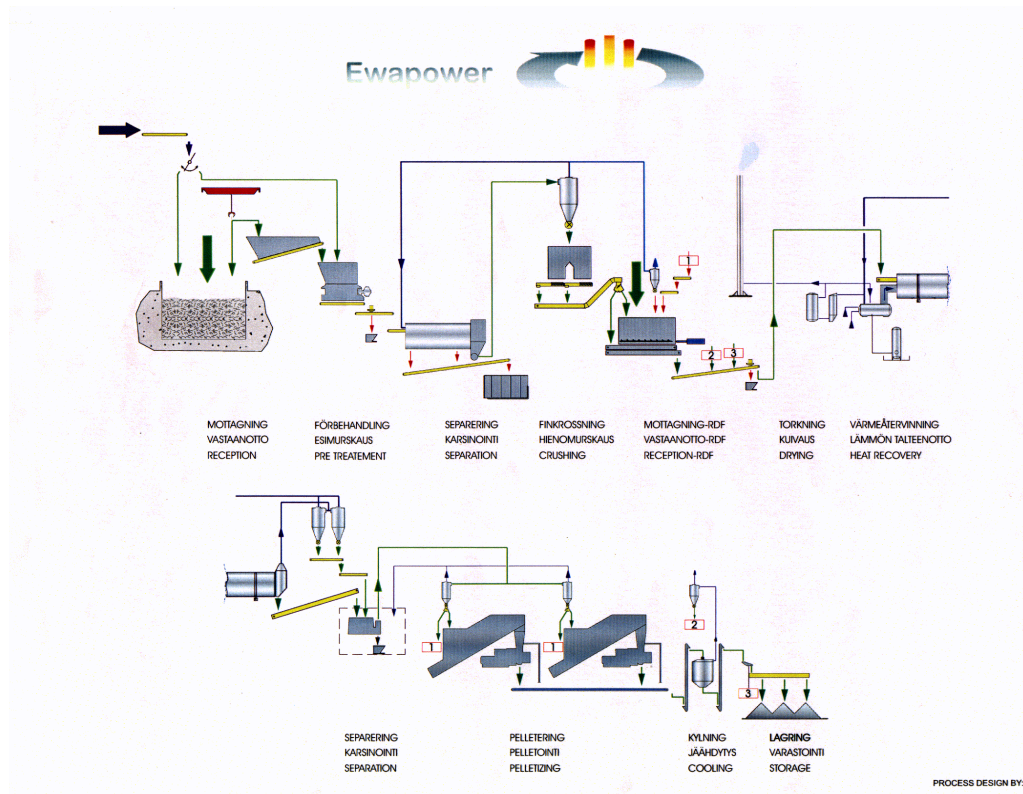


Figure 3. The waste processing plant of Ewapower in Pietarsaari.

The specifications of the final recovered fuel (REF) are:

- Moisture content: < 6 %
- Calorific value: 21 MJ/kg dry basis)
- Ash content: 7 - 10 % (dry basis)
- Volatile matter: 80 % (dry basis)
- Sulphur content: 0,13 – 0.2 % (dry basis)
- Chlorine content: 0.4 % (dry basis)
- Potassium content: 1.7 % (dry basis)
- Sodium content: 0.2 % (dry basis)
- Aluminium content: 0.8 % (dry basis)

Lahden Lämpövoima Oy is a Finnish power company producing power and district heat for the City of Lahti. Lahden Lämpövoima Oy operates the Kymijärvi Power Plant located nearby Lahti in Southern Finland. In Kymijärvi plant the gasification of solid bio

fuels and recovered fuels (REF) and co-combustion of the gases is performed in the existing coal-fired boiler. The system to collect combustible, source separated waste started at the end of 1997 in the Lahti area. This waste originates from industry, stores and households.

The recovered fuel is produced at Kymijärvi power plant. Roxon has supplied the waste processing equipment. The processing equipment consist of refuse reception, preliminary crushing (REF 150 m<sup>3</sup>/h), magnetic separation, disc screening, secondary crushing (50 m<sup>3</sup>/h) and mixing. The capacity of the line is 100 t/h. The process flow-lines are shown in appendix 2.

The specifications of the final recovered fuel (REF) are:

Particle size: 90 % < 50 mm

Moisture content: 40 %

Calorific value: 20 MJ/kg dry basis)

Ash content: 5 % (dry basis)

Volatile matter: 80 % (dry basis)

Sulphur content: 0,06 % (dry basis)

Chlorine content: 0.05 % (dry basis)

Potassium content: 0.06 % (dry basis)

Sodium content: 0.02 % (dry basis)

Aluminium content: < 0.30 % (dry basis)

Bulk density: 250 kg/m<sup>3</sup>

The construction costs of processing plant were 11.7 million Euro.

## **2.2 Japan**

Japanese government promotes broadly the treatment of waste for recovery. The policy is to introduce facilities which can treat 100 tons or more waste and operate (incinerate) 24 hours in a day, and to reduce emissions of dioxins. However, the present condition is that enlargement is not promoted. So, municipalities cannot get sufficient volumes of wastes for incineration, and have to operate intermittently.

Municipalities that use RDF production facility have increased. RDF are used at RDF power generation facilities, cement factories etc. There are about 50 RDF production facilities in Japan. Recycle Management of Japan (RMJ) is occupying 20 % share and this is top share in Japan. The following text is based on answers, Hiroshi Sano got from Japan Recycle Management Co., Ltd and the Kawasaki Steel Corporation. Kawasaki Steel Corporation is investing to RMJ.

The location of MSW to RDF plants in Japan is shown in the appendix 3. The processing equipment consist of 1) pre-crushing a) bag tearing device (2 shafts shearing shredder with selective separator), b) first step crusher (2 shafts shearing shredder with selective separator), 2) magnetic separation (magnetic separator), 3) drying (Kiln type



hot air drier with mixer blade), 4) Screening separation (Air classifier), 5) After-crushing (Vertical shear crusher) and 6) pelletizing (Mill type vertical former).

The capacities of MSW to RDF plants are shown in table 1. The process flow is shown in figure 4, energy balance in figure 5 (numerical values in the figure 5 are averages of 11 plants under operation), and material balance is shown in figure 6 (numerical values in the figure 6 are averages of 11 plants under operation).

Table 1. Capacity of MSW to RDF plants.

Number	Plant name	Plant scale (t/d)	Location	Completion date
1	Haibara plant	10	*	Nov. 1990
2	Nogi plant	10	*	Dec. 1992
3	Tonami plant	28	*	Mar. 1995
4	Aichi Plant	22	*	Mar. 1996
5	Itakura plant	20	*	Mar. 1996
6	Kousei plant	16	*	Mar. 1998
7	Tsunoyama plant	6	*	Mar. 1998
8	Kamo plant	30	*	Mar. 1999
9	Shinnanyou plant	48	*	Mar. 1999
10	Okutano plant	6	*	Mar. 1999
11	Miyama plant	20	*	Mar. 1999
12	Shiida plant	25	*	Under construction
13	Tobe plant	23	*	Under construction

\* The left number is corresponding with the number of Appendix 3.

Specifications of the final fuel is:

Particle size:  $\varnothing$  10 – 30 mm, and length 30 – 50 mm

Moisture content: 10 % and less

Higher heating value: 16,7 MJ/kg and over

Ash content: about 10 – 20 %

Volatile content: about 70 %

Sulphur content: about 0,2 – 0,3 %

Chlorine content: about 0,5 – 1,5 %

Potassium content: not determined

Sodium content: not determined

Aluminium content: not determined

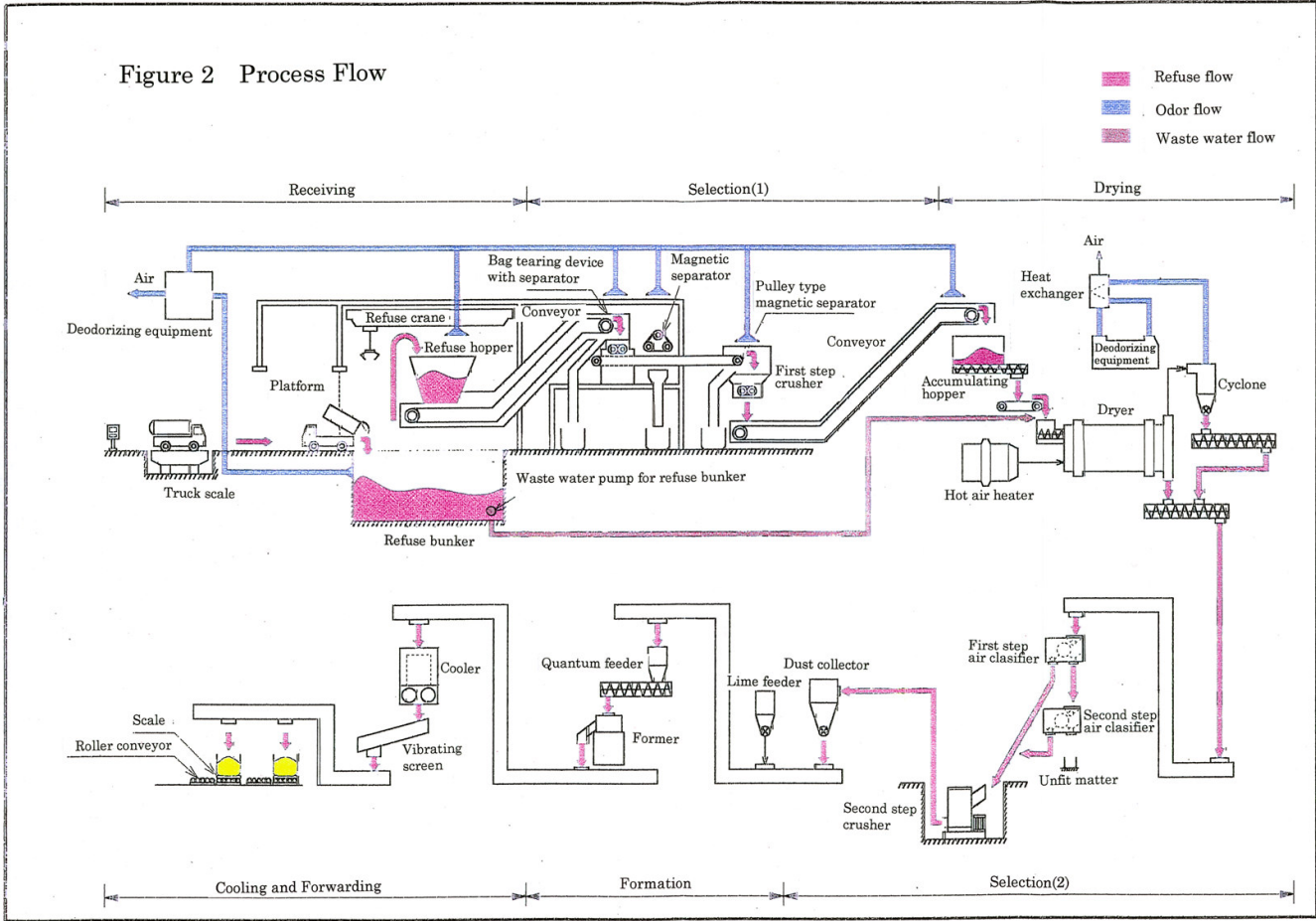
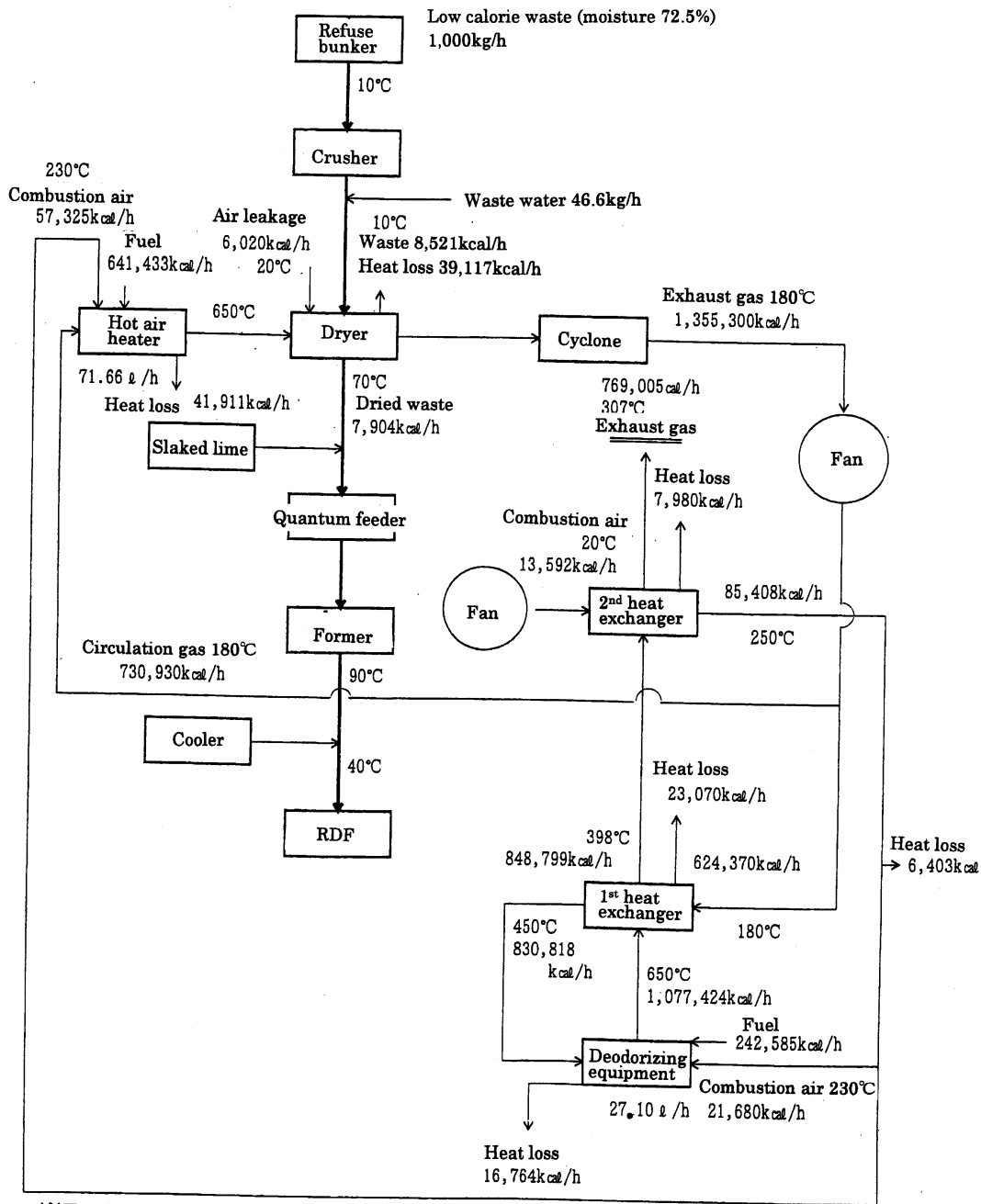


Figure 4. The process flow of RDF plant.



※Fuel for hot air heater and deodorizing equipment is kerosene. The hot air heater uses kerosene 71.66l/h, the deodorizing equipment uses kerosene 27.10l/h.

※Waste is warmed by hot air directly in dryer. So, this system needs a cyclone.

Figure 5. Energy balance of RDF plant.

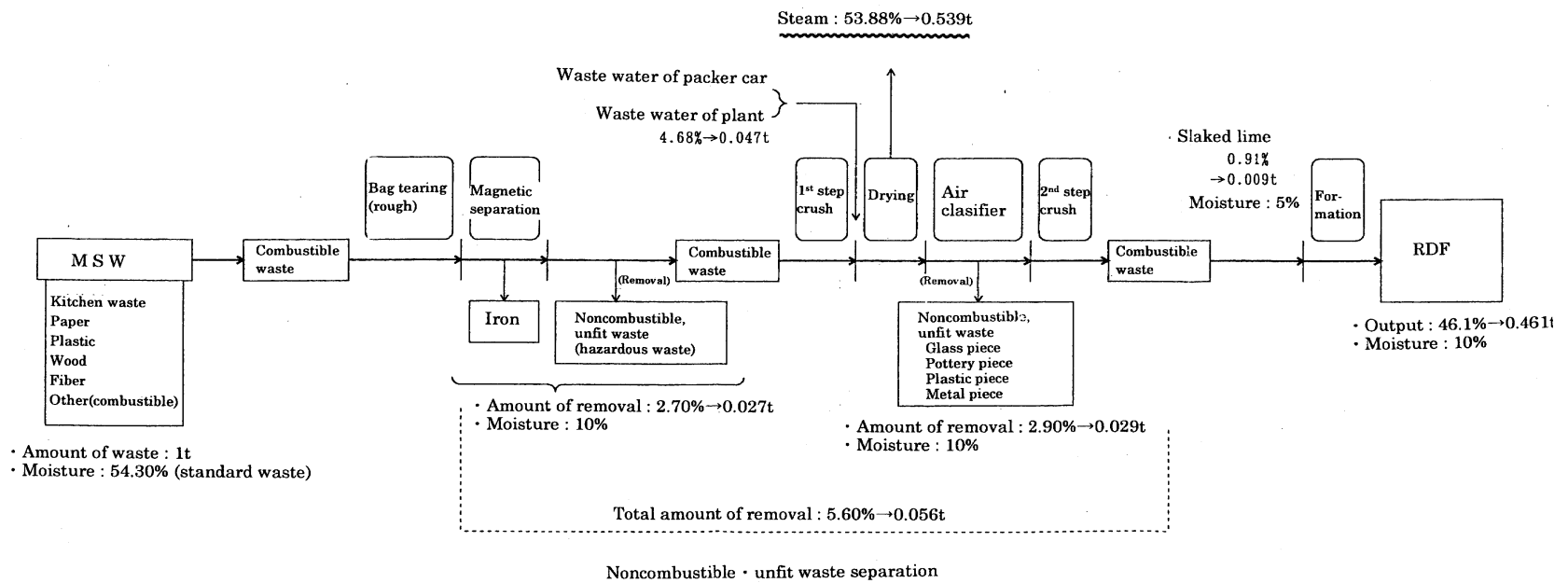


Figure 6. Material balance of RDF plant.



Economic characteristics:

The construction costs of plant is in the case of 7 – 8 h/day operating: 81.82 – 90.91 Euro/waste ton (1 Euro = 110 YEN) and in the case of 16 h/day operating: 54.55 – 63.64 Euro/waste ton. The operating costs are 54.55 – 63.64 Euro/waste ton. The maintenance costs are 36.36 – 45.45 Euro/waste ton. These 10 facilities sell RDF at 9.09 Euro/RDF ton. RDF manufacturer pays the transportation costs of RDF by.

### 3. Technologies for co-firing

#### 3.1 Grate firing

##### 3.1.1 Process technology

Grate combustion has been the most common form of combustion in small scale. However, in smaller-capacity boilers, below 20 MW<sub>th</sub>, and for wet fuels like bark residues in sawmills, grate firing methods offer competitive solutions with minor fuel preliminary treatment investments and low emissions. Improved grate firing makes it possible to combust REF with very moist fuels, such as sawdust. (fig 7). Effective and low emission firing of residues from sawmills and other wood processing plants can be achieved with advanced combustion technology only. Advantage of underfeed rotating grate is simple and reliable operation. Fuels with very high moisture content can also be used. Capacity range is 1 - 8 MW<sub>th</sub>.

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Figure 7. Sermet Biograte compact for combustion of high moisture fuels as bark, sawdust, wood chips, sod peat and co-firing of packaging materials and other recovered fuels. (Sermet Oy, Kiuruvesi Finland)

#### Finnish examples

##### 3.1.1.1 A 4 MW district heating plant

The first district heating plant, which burns recovered fuels as the main fuel, has been commissioned in Finland in September 1998. The fuels used in this 4 MW<sub>th</sub> plant are waste wood, packaging waste, plastic and forest chips. The recovered fuel mixture consists of wood waste (70 %), packaging waste (20 %), plastics (10 %). The heating value of the mixture is 10 – 25 MJ/kg. The moisture content of forest chips is 30 – 55 % and the heating value 6.6 – 11 MJ/kg. The pre-chamber of the boiler combination has been equipped with a mechanical inclined grate, which makes it possible to obtain good combustion results with different fuels. The investment costs are 2.1 million Euro.

A flue gas condensing scrubber is used to reduce particle concentration and acid components like sulphur dioxide and hydrogen chloride in flue gas. The basic idea in flue gas condensation is to get benefit of the higher heating value of a fuel, including

also the condensation of water vapour. Flue gas is cooled by spraying water into the flue gases. Some alkali, e.g. sodium hydroxide is added into the circulating water. The two staged impulse scrubber supplied by Condens Oy is used at the district heating plant. There is a continuous measuring of oxygen and carbon dioxide at the plant. The oxygen content is at least 6 % and the carbon monoxide content less than 250 mg/m<sup>3</sup><sub>n</sub>. The particle concentration is usually less than 80 mg/m<sup>3</sup><sub>n</sub> and the maximum HCl concentration 50 mg/m<sup>3</sup><sub>n</sub>.

### 3.1.1.2 A 13 MW district heating plant

The plant was supplied in 1980. The flue gas cleaner is of cyclone type. The fuel efficiency is 13 MW and the heat efficiency 10 MW. The main fuel is wood (bark, sawdust, shavings) 31000 ton/a. REF is used 330 t/a.

The typical fuel properties are:

	Wood	REF
Moisture content m-%	54	24.2
Heating value as received MJ/kg	7.6	14.5
Ash content, m-%	1.2	7.7
Volatile matter, m-%	76.7	
Sulphur content, m-%	0.03	
Chlorine content, m-%	0.066	0.75
Sodium content, m-%	0.24	
Density kg/m <sup>3</sup>	310	140

### 3.1.1.3 A 12 MW district heating plant

A district heating plant has been supplied in 1983. The flue gas cleaner is a cyclone (since 1983) and a scrubber (since 1990). The fuel efficiency of the plant is 12 MW. The main fuel is wood (6307 tonnes per annum) and peat (674 tonnes per annum). Recovered fuel has been used 187 tonnes per annum.

### 3.1.1.4 A 60 MW municipal district heating plant

H. Mattila & al. have made combustion test in a 60 MW district heating plant at 60 % load. In normal operation coal and bark were used as fuels. The district heating plant consists of a fuel input system, a combustion chamber with chain grate, water cooled tubes as a heat exchange unit, an electrostatic precipitator as a flue gas cleaning system and a chimney stack. Primary fuel and mixed plastics were fed by a screw conveyor. Air was fed into the combustion chamber through the grate as primary air and into the upper combustion zone as secondary air (H. Mattila & al., 1992).

Emissions caused by four different kinds of fuel mixtures of coal, bark, non-chlorinated and chlorinated waste plastic material were compared. The response of additives in plastics, especially copper, to formation of PCDDs and PCDFs as a catalyst was clear. However, the total PCDD and PCDF emissions as Nordic toxic equivalents (TEQs) from co-combustion of mixed plastics related to municipal solid waste was only 38.4 pg/m<sup>3</sup><sub>n</sub>. This value was clearly below the proposed EC standard 0.1 ng TEQ/m<sup>3</sup><sub>n</sub>. Emissions from combustion of coal and bark were 16.4. pg TEQ/Nm<sup>3</sup> which increased to 23.2 pg TEQ/m<sup>3</sup><sub>n</sub> with co-combustion 4.1 % (w/w) of non-chlorinated plastics in fuel mixture (H. Mattila & al., 1992).

### **3.2 Bubbling fluidised bed**

#### **3.2.1 Process technology**

Fluidised-bed technology has been commercially proven in its superiority in efficient, economic and environmentally sound combustion of a large variety of fuels. During the last twenty years the development of fluidised bed combustion (FBC) technology has made it possible to significantly increase the utilisation of various solid bio mass and wastes in power and heat generation. The pulp and paper industry served as a pioneer because of the adequate bio mass and waste fuel supply and energy demand on site. Fluidised bed combustion has mainly been used in new plants and many pulverised or grate-fired boilers have been converted to fluidised bed boilers.

Finnish boiler suppliers have been among the leading companies in the world in development of fluidised bed combustion technologies since the end of the 1960s. In a bubbling fluidised bed (BFB) boiler the fluidising air is blown at a lower velocity and the bed particles behave like a boiling fluid but stay in the bed. An example of a bubbling fluidised bed boiler burning wood chips, wood residues and RF is shown in figure 9.

#### **Finnish examples**

##### **3.2.1.1 The bubbling fluidised boiler in Forssa**

Forssan Energia Oy owns a 66 MWth BFB power plant, commissioned in October 1996. The bubbling fluidised boiler burns forest chips, bark, saw dust and recovered fuels. The cross-section of the boiler is shown in figure 8.



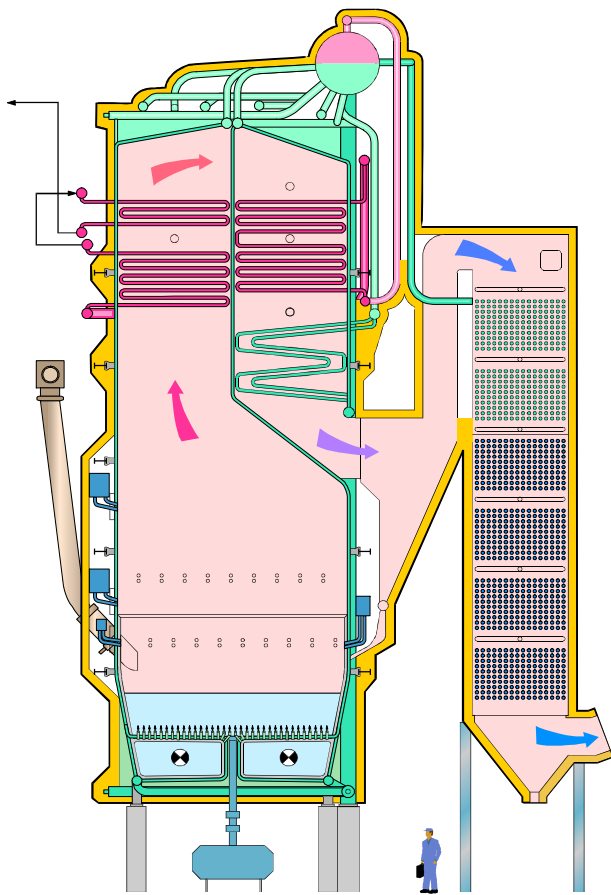


Figure 8. Bubbling fluidised bed boiler in Forssa Finland burning wood residues and recovered fuel (Foster Wheeler Energia Oy).

### 3.2.1.2 A bubbling fluidised bed boiler

The fuel power of boiler is 110 MW, the thermal output 96 MW and electricity output 25 MW. Flue gas cleaners are a cyclone and an electrostatic precipitator. The main fuel of the power plant is milled peat (136 700 t/a). 24 000 t/a wood has also been used. REF used at power plant is paper refuse (1900 t/a) and sewage sludge (29 600 t/a).

Nitrogen oxides emissions are 40 mg/MJ (licence condition 150 mg/MJ) and particulate 15 mg/MJ (licence condition 50 mg/m<sup>3</sup><sub>n</sub>). Ash production builds up 6 900 t/a. 6800 t/a are landfilled. 100 t/a are used for practical application.

### 3.2.1.3 A 25 MW bubbling fluidised bed boiler

The bubbling fluidised bed boiler has been commissioned in 1993. The flue gas cleaner is an electrostatic precipitator. The fuel power of the plant is 25 MW, the thermal output is 17 MW and the electrical output is 6.2 MW. Main fuels are peat (31378 tonnes per annum) and wood (4787 tonnes per annum), also 181 tonnes of recovered fuel (RF) has been used per annum. The moisture content of RF is 10 – 25 %. The effective heating value is 19 – 35 MJ/kg.

### 3.2.1.4 A 15 MW bubbling fluidised bed boiler

The plant has been commissioned in 1983. The main fuels are sawdust (11 859 tonnes per annum) and peat (28 879 tonnes per annum). 548 tonnes of RF has been used per annum. The typical fuel properties are shown below:

	Milled peat	Recovered fuel
Moisture content, m-%	48.6	6.9
Gross calorific value on a dry basis, MJ/kg	22.99	22.03
Lower calorific value on a dry basis, MJ/kg	21.77	20.96
Ash content, m-%	6.0	5.2
Sulphur content, m-%	0.2	
Chlorine content, m-%		0.17
Aluminium content, m-%		0.30
Bulk density, kg/m <sup>3</sup>	320	240

The annual ash volume is 2000 m<sup>3</sup>.

### 3.2.1.5 A 155 MW bubbling fluidised bed boiler

The earlier combustion technology of the plant was grate firing, but it was changed to bubbling fluidised bed in 1996. The flue gas cleaner is an electrostatic precipitator. The fuel power of the plant is 155 MW and the thermal output 140 MW. The main fuel is bark (376 860 m<sup>3</sup>/a). The recovered fuel is used as pellets (11242 tonnes/a). Waste paper and plastic refuse have also been combusted (26605 m<sup>3</sup>/a). The particle content of flue gases is 32 – 42 mg/m<sup>3</sup>n (6 % oxygen content). The amount of ashes formed 5551 tonnes/a. Ashes are landfilled. Costs of combustion residue disposal are 8 700 Euro. The construction costs of plant are 25 228 000 Euro. Costs of main fuel are 3 850 000 Euro and the costs of REF pellets are 530 500 Euro. 1 Euro = 5.94573 FIM.

Typical fuel properties are shown below:

	Bark (conifer 60 % and birch 40 %)	REF-pellets
Moisture content, m-%	57	2.3 – 6.3
Carbon content on a dry basis, m-%	55.3	48.7 – 50.3
Hydrogen content on a dry basis, m-%	6.3	6.69 – 7.0
Sulphur content on a dry basis, m-%	0	0.08 – 0.41
Nitrogen content on a dry basis, m-%	0.5	0.45 – 0.75
Ash content on a dry basis, m-%	1.6	6.4 – 14.4
Effective heating value on a dry basis,	21.08	20.9

MJ/kg		
Effective heating value as received, MJ/kg	7.67	17.4 – 20.0
Aluminium on a dry basis, g/kg	0.16 – 2.5	3.7 – 17.8
Cadmium on a dry basis, mg/kg	0.25 – 0.37	< 1 – 5.3
Copper on a dry basis, mg/kg	2.7 – 3.8	33 – 430
Lead on a dry basis, mg/kg	0.8 – 1.3	34 - 1120

### 3.2.1.6 Tests in a 4 MW bubbling fluidised bed boiler

Co-combustion trials were made in a 4 MW bubbling fluidised bed boiler in Saarijärvi town in Central Finland in autumn 1992. The plant has been planned to combust peat and wood chips. Main fuel is milled peat. Flue gas cleaner is an electrostatic precipitator (ESP). During the combustion tests several combustion parameters and the properties of the fuel, the flue gas and the fly ash were measured and analysed.

Refuse derived fuel (RDF) has been burned with wood chips and milled peat in a 4 MW bubbling fluidised bed boiler. Emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F) in flue gases expressed as TCDD -equivalents were significantly below the emission limit 0.1 ng/m<sup>3</sup><sub>n</sub> I-TEQ (11 % O<sub>2</sub>). Also PCDD/F -concentrations of fly ashes separated by an electrostatic precipitator are significantly below the 1 ng/g I-TEQ limit for agricultural soil in Germany. Disturbances in the fuel feed made the combustion of mixtures more difficult as was evident in the carbon monoxide content of flue gases. The carbon monoxide content was rather high, but typical for many small district heating plants. The concentrations of other chlorinated aromatic compounds were also low, in some tests below a detection limit. The concentrations of polyaromatic hydrocarbons (PAH) were rather high. The leachable metal content of the fly ash generated were analysed using U.S. EPA TCLP test (Toxicity Characteristic Leaching Procedure). All concentrations fell below boundary levels (Vesterinen, R. & Flyktman, M., 1996).

### 3.2.1.7 A 7 MW<sub>th</sub> bubbling fluidised bed boiler

As part of her doctoral thesis Helena Manninen has made co-combustion tests in a 7 MW<sub>th</sub> bubbling fluidised bed boiler built by Outokumpu EcoEnergy. The boiler is designed and used for combustion of coal and watery sludge. The boiler produced process steam (2.5 kg/s, 18 bar, 239 °C). The flue gas was processed with an electrostatic precipitator (ESP). Coal, sand and limestone were fed above the bed and milled plastics waste was pneumatically fed into the fluidised bed. The tests were carried out at a 3 MW thermal load and using a bed temperature of 850 °C. The oxygen content of the flue gas was maintained at approx. 10 % (Frankenhaeuser, M, et. al, Chemosphere 27(1-3), 309 – 316).

The tests showed that mixed plastics (4 % Cl) can be burned with coal at levels up to 70 % of the thermal feed. As plastics do not contain sulphur or nitrogen, emissions using a co-fuel feed of this type are lower than using a pure coal (0.5 % S) feed. The flue gas emissions of PCDD/PCDF were below 0.1 ng/m<sup>3</sup><sub>n</sub> (TE-Nordic) during all tests. No clear

correlation to increased mixed plastics feed could be seen. Tetra- and penta chlorinated dibenzofurans were the dominating congeners in flue gas but in fly ash the dominating groups were penta, hexa and hepta chlorinated dibenzodioxins (Frankenhaeuser, M, et. al, Chemosphere 27(1-3), 309 – 316).

### **3.3 Circulating fluidised bed**

#### **3.3.1 Process technology**

In a circulating fluidised bed (CFB) combustion the fluidizing air velocity is higher in a fluidised bed combustion and a large proportion of bed material leaves the bed and is collected by cyclone separators for re-circulation to the bed. Such a conversion can be implemented by retrofitting the boiler with a fixed-bed gasifier or with a special burner. Both technologies are commercial. An example of the circulating fluidised bed boiler is shown in figure 9.

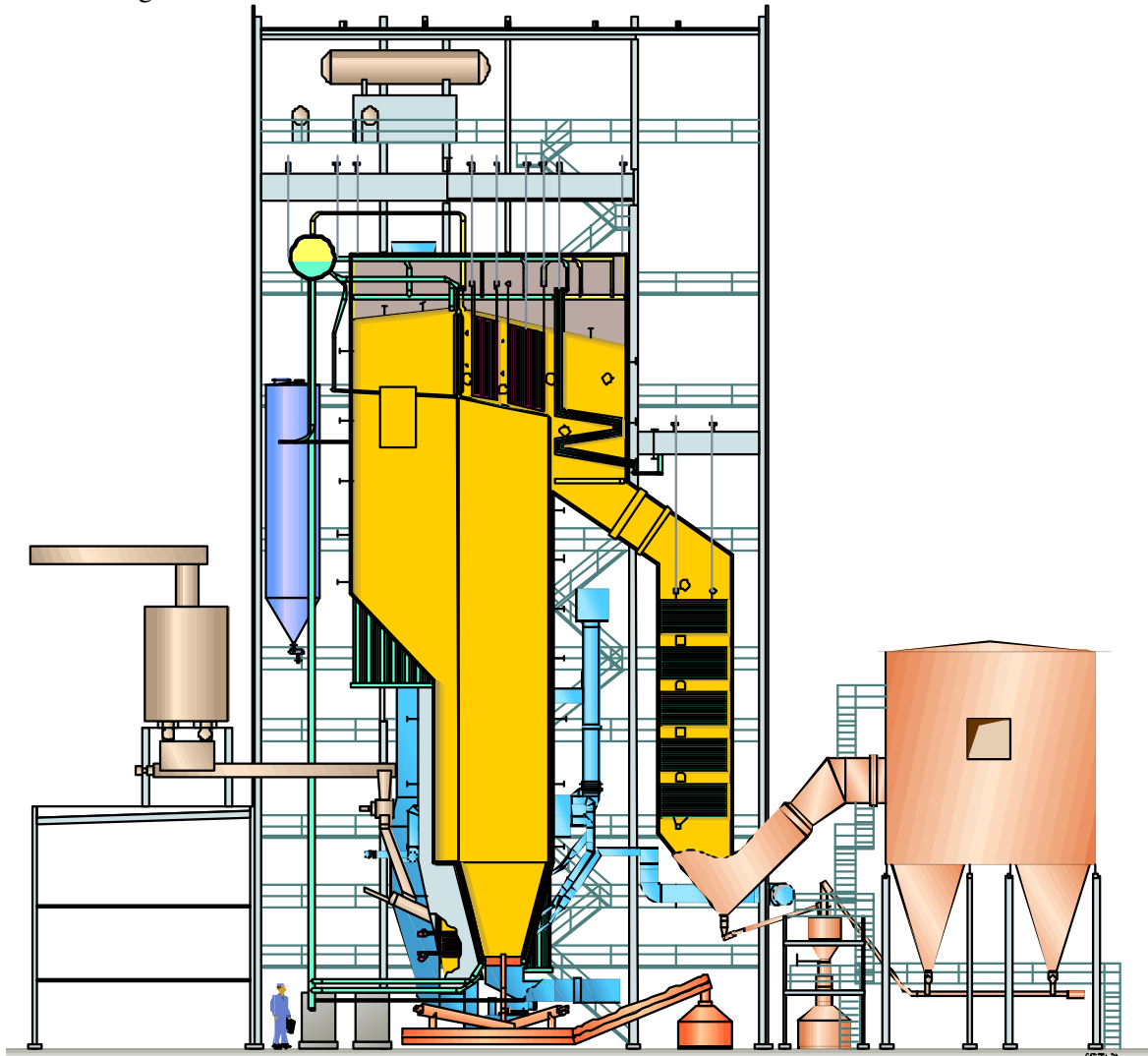


Figure 9. Foster Wheeler CFB in Hornitex burning old structural timber in Germany (Foster Wheeler Energia Oy).

### 3.3.1.1 A pyroflow circulating fluidised bed boiler

The peat-fired power plant was commissioned in 1990. The combustion technique is circulating fluidised bed. The flue gas cleaner is an electrostatic precipitator. The thermal output is 300 MW and the electrical output is 125 MW, the fuel power is 325 MW. Small trials have been made with recovered fuels at power plant. The typical fuel analysis of peat and recovered fuel is shown in table 2.

Peat is main fuel at the power plant. Only short co-firing trials have been made using recovered fuels with peat. The mixing ratio between REF and peat should be less than 5 %.

The ash volume is 20 000 ton/a or 80 000 m<sup>3</sup>/a. The costs of ash disposal are some 83 000 Euro per annum. The bottom ash and fly ash are used for construction of runways.

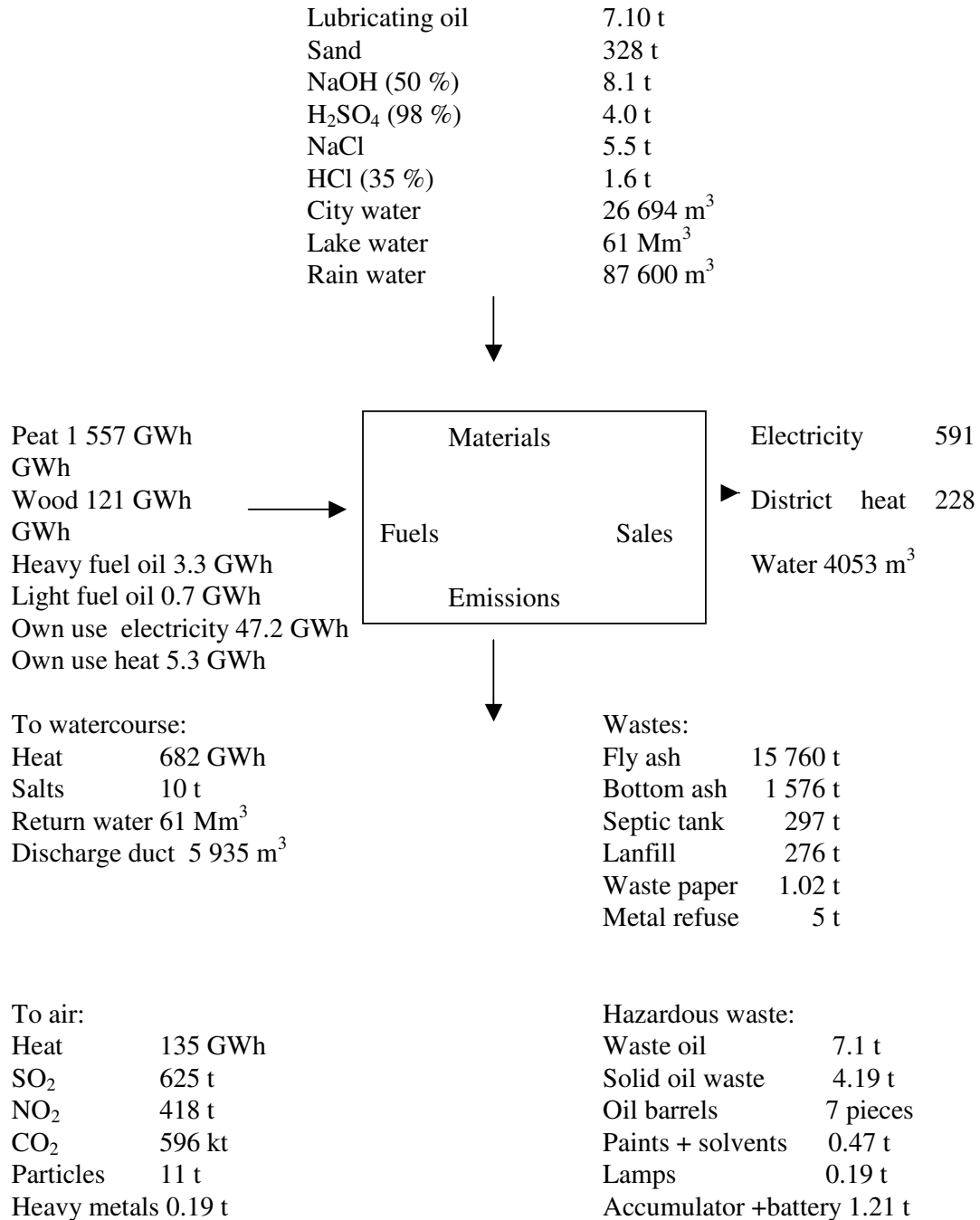
Emissions from peat combustion are sulphur dioxide, 103 mg/MJ (annual mean), nitrogen oxides 150 mg/MJ and particles 50 mg/m<sup>3</sup><sub>n</sub>.

Table 2. The typical fuel characteristics of peat and recovered fuel used at the power plant.

Fuel property	Peat	Recovered fuel
Moisture content, m-%	45	24
Heating value as received, MJ/kg	10.1	20
Ash content, m-%	4.24	12
Sulphur content, m-%	0.15	0.16
Chlorine content, m-%		0.3
Particle size, mm	< 50	< 50
Density, kg/m <sup>3</sup>	305	
Potassium content, m-%		0.054
Sodium content, m-%		0.12
Aluminium content, m-%		0.22

The annual operating costs are 5 million Euro and fuel costs are some 12 million Euro. Construction costs of plant are 100 million Euro.

Energy balances, fuels and residues in 1998 are shown below.



### 3.3.1.2 A circulating fluidised bed boiler

The boiler was commissioned in 1989. The steam output is 60 kg/s and temperature 535 °C. The thermal output is 150 MW and electrical output 34 MW. The main fuel is wood (bark and saw dust) 477 548 t/a and peat 32 131 t/a. Sewage sludge from a biological refinery mill is used 21 360 m<sup>3</sup>/a and reject (plastic) of liquid packing board 3717 t/a.

The typical fuel properties are:

	Wood	Reject (plastic of liquid packaging board)
Heating value in dry basis MJ/kg	10.0 – 3.8 (6.5)	30
Ash content, m-%	3	3.6
Volatile matter, m-%	76	> 84
Sulphur, m-%	0.06	0.03
Chlorine, mg/kg		Max. 0,15
Na + K mg/kg		200
Density, kg/m <sup>3</sup>	300 - 450	> 50

Emissions are:

Sulphur dioxide	82 t/a
Nitrogen oxides	372 t/a
Particles	18,7 t/a

Ash volume is 8509 t/a in dry basis. 7664 t are landfilled. The landfill fee is 27 FIM/ton and the transport fee 29 FIM/ton.

### 3.3.1.3 A 180 MW circulating fluidised bed boiler

The CFB was commissioned in 1996. The flue gases have been cleaned by an electrostatic precipitator and wet scrubber. The fuel power of the plant is 180 MW, the thermal output 160 MW and the electrical output 33 MW. The main fuel is bark (310 000 tonnes per annum). REF has been used 207 500 tonnes (including fines and bio sludge) per annum. REF consists of rejected paper (10000 tonnes per annum), flour and bio sludge (in total 180 000 tonnes per annum). In addition to source separated waste wood has been used 3500 tonnes per annum and sleepers 14 000 tonnes per annum.

Typical bark characteristics are; moisture content 59 %, effective heating value as received 6.7 M/kg and ash content 2.0 %. Typical flour and bio sludge characteristics are; moisture content 60 %, effective heating value as received 2.5 MJ/kg, ash content 45 % and sulphur content 0.8 %.

The licence conditions are following: sulphur dioxides 140 mg/MJ, nitrogen oxides 150 mg/MJ and particles 50 mg/m<sup>3</sup><sub>n</sub>. The annual ash volume is 33 000 m<sup>3</sup>/a or 20 000 tonnes/a. The moisture content of ash is 20 % and bulk density 600 kg/m<sup>3</sup>.

#### 3.3.1.4 A 94 MW circulating fluidised bed boiler

The boiler was commissioned in 1990. The flue gas cleaner is an electrostatic precipitator. The fuel power is 94 MW, the thermal output is 60 MW and the electrical output 30 MW. There are also a grate boiler and a bubbling fluidised bed boiler in the plant. The main fuel is wood (157 800 tonnes/a) and peat (118 000 tonnes/a). REF consists of commercial and industrial packing material (660 tonnes/a) and construction waste as chips (1 180 tonnes/a). The chlorine content of REF is 0.07 m-%.

The licence conditions are following: sulphur dioxides 230 mg/MJ, nitrogen oxides 150 mg/MJ and particles 25mg/MJ. The annual ash volume is 6180 m<sup>3</sup> or 3120 tonnes. 2320 tonnes will be transported to landfill and 800 tonnes are utilised.

The construction costs of the plant are 183 million FIM. The annual fuel costs are 17 million FIM.

#### 3.3.1.5 Tests in a 65 MW<sub>th</sub> circulating fluidised-bed boiler

Dr. Helena Manninen has made for her doctoral dissertation co-firing or co-combustion tests in a 65 MW<sub>th</sub> circulating fluidised-bed boiler. The refuse derived (RDF) and packaging derived fuels (PDF) have been combusted with coal and peat. The fraction of PDF and RDF varied, but all heating values were higher than the heating value of peat. The fraction of PDF and RDF varied between 8 % and 26 % of the thermal input of the fuel mixture in different circulating fluidised bed tests. All tested PDF and RDF were found to be suitable for co-combustion. However, proper particle size for PDF/RDF was important for stable fuel feeding and efficient combustion. Due to the lower sulphur content of the PCF and RDF in comparison to coal, SO<sub>2</sub> emissions decreased in co-combustion compared to the reference peat/coal combustion. Hydrochloric acid emissions increased in co-combustion due to the higher chlorine content of PDF and RDF compared to peat and coal. PDF and RDF had no effect on total particulate emissions or operation of the electrostatic precipitator. Heavy metal emissions did not correlate with the fraction of the PDF or RDF. Most of the metals concentrated into the fly ash. Polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran (PCDD/PCDF) emissions expressed as toxic equivalents did not increase significantly in co-combustion compared to the reference peat/coal combustion (Manninen, H., 1996).

### **3.4 Gasification**

#### 3.4.1 Process technology

Circulating fluidised bed (CFB) gasification technology has been developed in Finland for various bio mass since the 1970's. In gasification air and steam are used to gasify the



fuel. The product gas is burned in a boiler equipped with a gas burner. Steam can be used to control the consistency of the ash. The moisture content of the fuel may be up to 50 %. Commercial applications ranging from 15 to 35 MW<sub>th</sub> were delivered before the mid-1980's and applied in sulphate pulp mills for firing low-grade product gas

The promising new alternative is co-firing, in which bio mass (sawdust, wood residues) and recycled fuel (REF) gasification is integrated to a pulverised coal-fired boiler. The composition of REF is following: plastics 5 - 15 %-weight, paper 20 - 40 %-weight, cardboard 10 - 30 %-weight and wood [dry wood residues from the wood working industry (plywood, particle board, cuttings, etc)] 30 - 60 %-weight. Gasification of bio mass and REF and co-firing of the product gas in existing coal-fired boilers offers a number of environmental advantages: recycling of CO<sub>2</sub>, reduction of dust, SO<sub>2</sub> and NO<sub>x</sub> emissions, and efficient utilisation of bio mass and recovered fuels. Investment and operation costs are low and existing power plant capacity can be utilised. Only minor modifications are required in the boiler. Lahden Lämpövoima Oy, a power company owned by the city of Lahti, has built a 40 - 50 MW<sub>th</sub> gasification plant connected to a 350 MW<sub>th</sub> steam boiler flexibly fired with coal, natural gas and oil (fig. 10).

The main fuel is coal (200 000 tonnes/a). REF consists of commercial and industrial packing material, source separated household dry household waste, construction wood, plastic and waste paper (35 000 tonnes/a).

**CO-UTILISATION OF GASIFIED BIOMASS AND SOURCE  
SEPARATED REFUSE AND COAL IN CHP PLANT**  
**Lahden Lämpövoima Oy & Foster Wheeler Energia Oy, Finland**

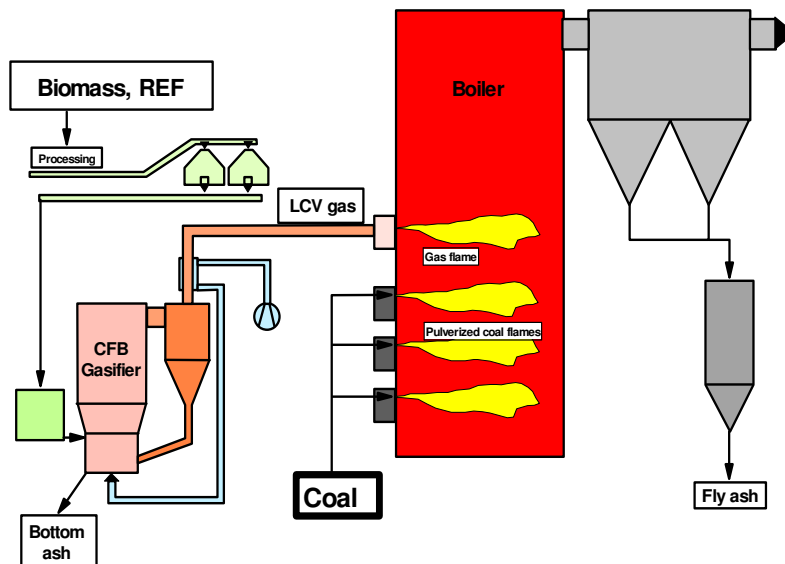


Figure 10. A 40 - 50 MW<sub>th</sub> CFB gasification plant connected to a 350 MW<sub>th</sub> pulverised coal-fired steam boiler in Lahti. Source: VTT Energy.

The total investment costs of the gasification plant in Lahden Lämpövoima Oy including fuel preparation, civil works, process instrumentation and control as well as the electrification are about 11 million Euro.

## **4. Energy from co-firing of coal and waste-derived fuel**

### ***4.1 Slough Trading Estate Power Plant in UK***

Slough Heat & Power Ltd Has updated the Slough Trading Estate power plant, fired on coal, oil and gas to reduce operating costs and increase efficiency. The modernisation involved the construction of two advanced multi solids fluidised bed combustion systems to generate 35 MW at 11 kV of electricity plus steam from coal. The boilers installed were designed to handle a mixture of fuels and are now used to co-fire coal with densified refuse-derived fuel (dRDF), and “fibre fuel” which is formed from commercial waste. The fuel mix is a constant 40/60 (waste/coal) by heat input. The two identical boilers together are used to produce 180 tph of steam at a pressure of 87 bar and a temperature of 509 °C. The overall efficiency of the unit is 86 % (Gross CV basis) (Dr A R Ellis, The case study of Thermie project “ European Co-combustion of Coal, Biomass and Wastes”).

The dRDF is delivered in pellet form and the fibre fuel, which is mostly waste paper and cardboard, is delivered as 25 – 50 mm cubes. The ash is taken off site in tankers as a dry powder to be used as an alkali to neutralise waste acid by-products in another process.

The fuel is fed into two identical multi solids fluidised bed boilers which were originally based on the Batelle Institute Design. These are circulation fluidised beds where combustion takes place in three zones, each with a different cross sectional area. The coal being used during the project has an energy value of around 27 GJ/t, and the RDF around 18 GJ/t. The fluid beds operate at around 850 °C. Approximately 250 kg of bed material is replaced daily with sand. The total air flow-rate in the beds is 33.71 kg s<sup>-1</sup> at full load giving a superficial fluidising velocity in the lower part of the bed of 7 – 9 m s<sup>-1</sup>; primary air is around 40 % of the total

The annual input of main fuels is 60 000 tonnes for coal and 40 000 tonnes for natural gas. The annual input of waste fuel is 18 000 tonnes for RDF and 40 000 tonnes for fibre fuel (REF). The sulphur content of the waste derived fuels is relatively low. In the dRDF, it is around 0.6 w-% and in the coal around 0.8 w-%. The sulphur oxides level is

controlled by adding limestone to the bed at a rate of up to 1 t/ day. The typical fuel analyses of coal and dRDF are given below.

Fuel property	Coal	DRDF
Moisture content, w-%	10	10
Higher heating value, MJ/kg	28	20
Ash content, w-%	10	10
Volatile content, w-%	40	70
Sulphur content, w-%	0.8	0.15
Chlorine content, w-%	0.1	0.15
Potassium content in ash, w-%	0.5	0.5
Sodium content in ash, w-%	1.5	0.5
Aluminium content, w-%	Not analysed	Not analysed

SO<sub>x</sub>, NO<sub>x</sub>, CO, HCl and particulates are continuously monitored. The pollution control devices are a bag house filter and limestone injection.

Dr A R Ellis has listed the following benefits of co-combustion:

- Waste-derived fuel has proved to be a low-cost fuel and the electricity generated from it attracts a premium price.
- Burning waste-derived fuel avoids the cost and environmental problems associated with disposing of the combustible fraction of waste to landfill.
- Waste-derived fuel is a renewable energy source, which is being used to substitute directly for coal, resulting in lower net CO<sub>2</sub> emissions.

#### **4.2 Slag forming 7 MW cyclone combustor test facility**

L. Bonfani, et. al. have made co-firing tests of pulverised coal and RDF (refuse derived fuel) in a slag forming combustor. The tests were performed in a 7 MW plant combustor. The plant consisted of an air cooled, slag forming cyclone combustor test facility attached to a package boiler. The RDF was obtained from Italian municipal solid waste via mechanical processing. The coal was an U.S.A bituminous coal. A small ratio of natural gas was also used during all tests (Bonfanti, L., et.al, 1994).

The nominal RDF/pulverised coal mass flow ratios of 10 %, 20 % and 40 % were used. One test was made using only coal as a blank condition. The characteristics of the fuel in dry basis are shown below.

Parameter	Coal	RDF
Moisture, w-%	1.7	3.0
Volatile matter, w-%	32.5	74.8
Ash, w-%	54.7	15.6
Carbon, w-%	75.4	50.2
Hydrogen, w-%	4.8	7.6
Sulphur, w-%	1.8	0.3

Nitrogen, w-%	1.3	1.0
Chlorine, w-%	0.1	0.5
Gross calorific value, kJ/kg	29807	20805
Net calorific value, kJ/kg	28706	19105

The PCDD/PCDF concentrations in a stack were 1495.2 ng/Nm<sup>3</sup> in co-firing test of coal and RDF (60:40) and 29.5 2 ng/Nm<sup>3</sup> in only coal test (Bonfanti, L., et.al, 1994).

## 5. Co-firing of lime enhanced refuse-derived fuel (RDF) or recovered fuel (REF) pellets

Oscar O. Ohlsson and Philip Sheperd have made co-firing tests in a 440 MW<sub>e</sub> cyclone fired combustor. The steam generator was a Babcock & Wilcox, lignite-fired cyclone furnace, with a radiant reheat boiler, having a maximum continuous rating of 3,250,000 lb/h steam at 2620 psig and 1005 °F at the super heater outlet. Twelve water cooled cyclone furnaces are located on the front and back sides of the boiler at two elevations, six cyclone furnaces at each elevation. The coal use is approximately 365 tons per hour having a heating value of 6255 BTU/lb. They have prepared cylindrical pellets by combining source separated refuse with a calcium hydroxide binding additive. These pellets are dense and odourless, can be stored for extended periods of time without biological or chemical degradation (Oscar O. Olsson & Philip Sheperd, 1993).

The combustion tests consisted of two different operating conditions conducted over a two day period. The sampling test period of ten hours in which a blend of twelve (12) percent b-dRDF (binder enhanced dRDF) pellets and eighty eight (88) percent coal was fired. The b-dRDF pellets contain 4 percent (by weight) lime binder additive. No PCDD/PCDF emissions were detected during the coal only test runs. The PCDD/PCDF emissions during the blended b-dRDF tests were very low, well below federal or state regulated levels, at 0.246 ng/Nm<sup>3</sup>. Emissions of SO<sub>2</sub>, NO<sub>x</sub> and CO were reduced by co-firing d-dRDF and coal. CO<sub>2</sub>, HF and HBr emission levels were unchanged compared to coal only firing tests. Ash residues from d-bRDF/coal blends successfully passed the TCLP tests (Oscar O. Olsson & Philip Sheperd, 1993).

Oscar O. Ohlsson co-fires d-RDF/coal at ANL in a spreader-stoker fired boiler with state-of-the-art pollution control equipment, including a spray dryer absorber and a fabric filter baghouse. The pellet/coal blend ratios were 0, 10, 20, 30 and 50 percent, based on BTU content. The binder contents were 0, 4 and 8 percent, by weight. The feedstock fuel analysis (percent by weight, as received) is shown below (Oscar O. Ohlsson, 1994).

Parameter	Coal	Pellets
Moisture	10.68	6.54
Ash	8.12	13.09
Carbon	65.01	32.73
Hydrogen	4.72	4.98
Nitrogen	1.42	0.12
Chlorine	0.06	0.31
Sulphur	2.97	0.12

Oxygen	7.02	42.11
Volatiles	36.08	68.30
Higher heating value (kJ/kg)	27 570	18 463
Bulk density (kg/m <sup>3</sup> )	672.13	439.87

The reduction in SO<sub>2</sub> emissions for the blend of 12 % by weight of pellets to coal was 16.9 % in ANL tests. NO<sub>x</sub> emissions were 267 ppm. The reduction was 1.5 %. No dioxins or furans were found at detection levels that ranged from 1 to 5 nanograms per cubic meter during the ANL tests. Emissions of HCl increased over coal only tests, but were within acceptable levels (Oscar O. Ohlsson, 1994).

Gerald W. Culkin and Joseph M. Marchello co-fired RDF/coal blends in full-scale, commercial-sized, coal-fired boiler. The tests were performed at Eastern State Hospital. The unit employed for RDF/coal test burns was the boiler, rated at 20 000 lb-steam/h. The unit was an E. Keeler Co. Type “CP” water tube boiler, installed in 1947. A 200 lb capacity coal scale, fed by auger, automatically dumps fuel to a hopper that feed two spreader stoker arms. Fuel was spread onto a hydraulic dumping-type grate. The grate received both underline air as well as several opposed, over-fire steam-air jets (Culkin, G.W & Marchello, J. M., 1992).

The RDF pellets used were amended with a 4 % lime binder (weight CaO/weight RDF) during their production. The SO<sub>2</sub> emissions from RDF co-firing were approximately 5 % to 45 % less than coal-firing alone. For sake of larger chlorine content of the RDF (0.13 %) relative to coal (0.03 %), HCl emissions from RDF co-firing increased with a larger RDF mass ratio. The combined PCDD/PCDF mass emission rates and exhaust concentrations from worst case RDF combustion (60 % RDF at 80 % load) were approximately 60 % and 50 % less than those from coal-firing alone at 80 % load. The average emissions of PCDD/PCDF from 25 % RDF case were greater than the 0 % RDF and 60 % RDF conditions (Culkin, G.W & Marchello, J. M., 1992).

At VTT Energy in Jyvaskyla Finland have been made co-firing tests in a 15 kW laboratory scale bubbling fluidised bed reactor. The fuel pellets are prepared combining RDF with wood chips or peat. The limestone in mole ratio 3 (Ca/(S + Cl) has been enhanced during preparing pellets. Three types of limestone have been used in pellets. The concentrations of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) in I-TEQ ng/m<sup>3</sup><sub>n</sub>, 11 % O<sub>2</sub> were 38 - 63 % less with the addition of limestone than without limestone, when the main fuel was wood from co-firing of recovered fuels and wood in a 15 kW bubbling fluidised bed reactor. When the peat was as main fuel the concentrations of PCDD/PCDF were 7 - 54 % less with the limestone addition than without limestone. The reduction of PCDD/PCDF concentration (I-TEQ ng/g) in fly ash separated by a cyclone was 34 - 80 %, when wood was as main fuel and 86,8 - 96,6 %, when peat was as main fuel (Vesterinen, R., 1999).

VTT Energy has an ongoing project “Effect of limestone addition on chlorinated emissions from combustion of recovered fuels in grate and fluidised bed boilers”. The project belongs to the national technology programme “Waste to REF & Energy 1998 – 2001” launched by Tekes. The trials have been performed in two boilers. The first was a

3 MW district heating grate-fired boiler. Ab Ewapower Oy has processed pellets from source separated waste. The limestone has been enhanced during pellet process to recovered fuel. The limestone ratio [Ca/(S + Cl)] was 0, 3 and 8. The ratio 3 was not enough for decreasing emissions of chlorinated compounds. The recovered fuel was used with wood fuel 20 % or 40 % as energy. The concentration of PCDD/PCDF was 30 % less when using limestone than without limestone addition (Vesterinen, R., et al., 2000a).

The second plant was 155 MW fluidised bed power plant. The flue gas cleaner was an electrostatic precipitator. The limestone mole ratio [Ca/(S + Cl)] in pellet was 0, 3 and 6. The limestone ratio 3 was enough for decreasing the concentration of chlorinated benzenes in flue gas. The limestone mole ratio 3 was not enough for decreasing the concentration of chlorophenols or PCDD/PCDF in flue gas. The mole ratio 6 [Ca/(S + Cl)] in pellet decreased the concentration of chlorophenols 22 % , chlorinated benzenes 46 % and PCDD/PCDF compounds 25 – 40 %. The concentration of chlorinated phenols in fly ash separated by the electrostatic precipitator decreased 74 %. Correspondingly the concentrations of chlorinated benzenes and PCDD/PCDF decreased 54 % and 61 %. Fuel properties in dry basis of the pellets used in the tests are shown below (Vesterinen, R., et.al., 2000b).

Parameter	Pellet, no limestone	Pellet, mole ratio 3 limestone*	Pellet, mole ratio 6 limestone*
Moisture, w-%	3.86	6.32	4.17
Ash content, w-%	11.7	12.9	13.4
Volatiles, w-%	75.6	75.8	75.5
Calorific value, kJ/kg	22407	22130	21489
Heating value as received, kJ/kg	19981	19171	19091
Carbon content, w-%	50.3	49.7	48.7
Hydrogen content, w-%	7.00	6.89	6.69
Nitrogen content, w-%	0.75	0.53	0.45
Sulphur content, w-%	0.20	0.18	0.15
Fluorine content mg/kg	77.9	161	37.2
Chlorine content, w-%	0.71	0.71	0.51
Cadmium, mg/kg	2.15	4.66	0.56
Copper, mg/kg	773	317	262
Lead, mg/kg	154	132	68.7
Potassium, w-%	0.26	0.18	0.19
Nickel, mg/kg	13.6	15.5	7.88
Sodium, W-%	0.38	0.29	0.26

\*The limestone mole ratio [Ca/(S + Cl)] in pellet

## **6. Future potentials of waste processing and / or RDF technologies**

The EU Directive on landfills<sup>1</sup> states that all the waste going to the landfill must be treated before landfilling. In Finland this must be done by the year 2005. treatment includes source separation. The Directive on landfills set also limits for the biodegradable waste going to the landfills. The amount of biodegradable waste must be under 70 % (from the amount in statistics year 1995) by the year 2005, under 50 % by the year 2009 and under 35 % by the year 2014. All this is going to influence the amount of waste going to be processed for fuel and for energy and material recovery.

Today, most of the processed waste is commercial or demolition waste. It is processed in units from 1000 to 70 000 tons/a. Household waste is processed in 5 bigger units (20 000- 40 000 tons/a) and well source separated waste in small 1000 –5000 tons/a units.

The waste must be processed, in order to minimise the impurities in the fuel, and to be able to material recycle as much as possible

## **7. Future potentials of co-firing technologies**

The amount of municipal waste is over 2 million t/a in Finland. Landfilling has been the predominant waste management system. About 400 000 t/a waste (about 200 000 tons of MSW and 200 000 tons of commercial/demolition waste) was co-combusted or co-gasified year 1999, but due to the legislation and also recycling etc., this number is going to increase in the future. The requirement of 1 million ton increase by the year 2005 in waste to energy is announced by the Ministry of Environment.

In Finland, the waste management system is very different from other European countries. In Finland there is only one mixed waste incineration plant in Turku which treats about 50 000 t/a MSW. Even in Turku waste incineration plant the waste coming to the plant is mostly to be source separated but not processed before.

Most of the waste is source separated at its origin and the recyclable material will be recycled. Most of the households source separate glass, metal, paper and cardboard and also bio waste (organic fraction). The rest dry, combustible fraction then goes to the waste processing plant. There waste is processed with crushers, magnetic separators, eddy current, screening, etc. to a recovered fuel which then can be used in district heating/CHP-plants or co-fired in gasification plant (Lahti).

The future EU Directive on waste incineration will set high standards for the incineration and co-incineration plants. The emission limit values for the old plants co-combusting/co-incinerating for example 1-30 % of REF must meet the same standards

as new plants, and the limits for co-incineration/co-combustion are nearly the same as for waste incineration plants.

At least using REF/RDF in small district heating plants 0-30 %, will not be economically feasible.

Using source separated office/industrial waste, which does not include much impurities, will probably continue in some BFB/CFB-boilers (10-500 MW) largely used in Finland. Using REF originated from household waste will probably not be an option for these plants, due to the problems of alkali and chlorine corrosion etc. For this kind of wastes different options will be considered, like gasification (+gas cleaning) and co-firing of fuel gas, small incineration plants (Energos), BFB/CFB-boilers for REF, etc.

## 8. Conclusions

There are about 50 RDF production facilities in Japan. The processing equipment consist of 1) pre-crushing a) bag tearing device (2 shafts shearing shredder with selective separator), b) first step crusher (2 shafts shearing shredder with selective separator), 2) magnetic separation (magnetic separator), 3) drying (Kiln type hot air drier with mixer blade), 4) Screening separation (Air classifier), 5) After-crushing (Vertical shear crusher) and 6) pelletizing (Mill type vertical former).

There are RDF processing facilities in Finland. One of these facilities produces RDF as pellet form. There are about 30 – 40 power or district heating plants in Finland, which co-fire REF with wood, peat or coal. Several co-firing tests have been performed in Finland and also in other countries. Some co-firing tests have been published in scientific magazines and conference proceedings.

The results have proved that the commercial and industrial packaging materials and source separated, combustible fraction of MSW, mainly consisting of used packing, in levels up to 25 % of thermal feed with wood, peat and coal, may safely used as a co-fuel in heat and power plants. PCDD/PCDF-emissions in flue gas are at the normal power plant level of 0.01 I-TEQ ng/m<sup>3</sup><sub>n</sub>. ). Also PCDD/F -concentrations of fly ashes separated by an electrostatic precipitator are significantly below the 1 ng/g I-TEQ limit for agricultural soil in Germany.

In Finland, the waste management system is very different from other European countries. In Finland there is only one mixed waste incineration plant in Turku which treats about 50 000 t/a MSW. Even in Turku waste incineration plant the waste coming to the plant is mostly to be source separated but not processed before.



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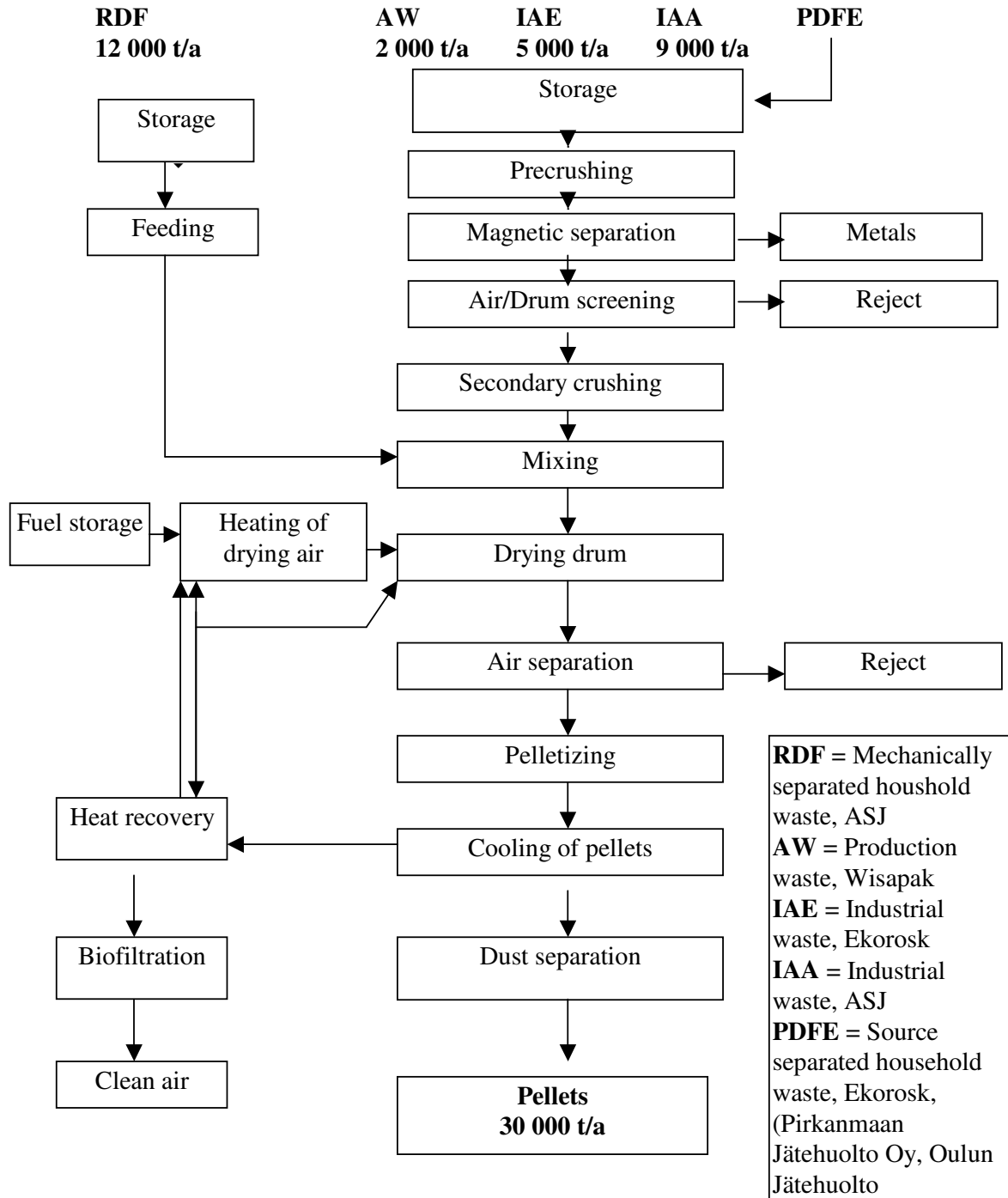
Answers to the questionnaire on “the processing technologies and/or systems”.

Answers to the questionnaire on “the co-firing of municipal solid waste (MSW), refuse-derived fuel (RDF) or recovered fuel (REF)”.

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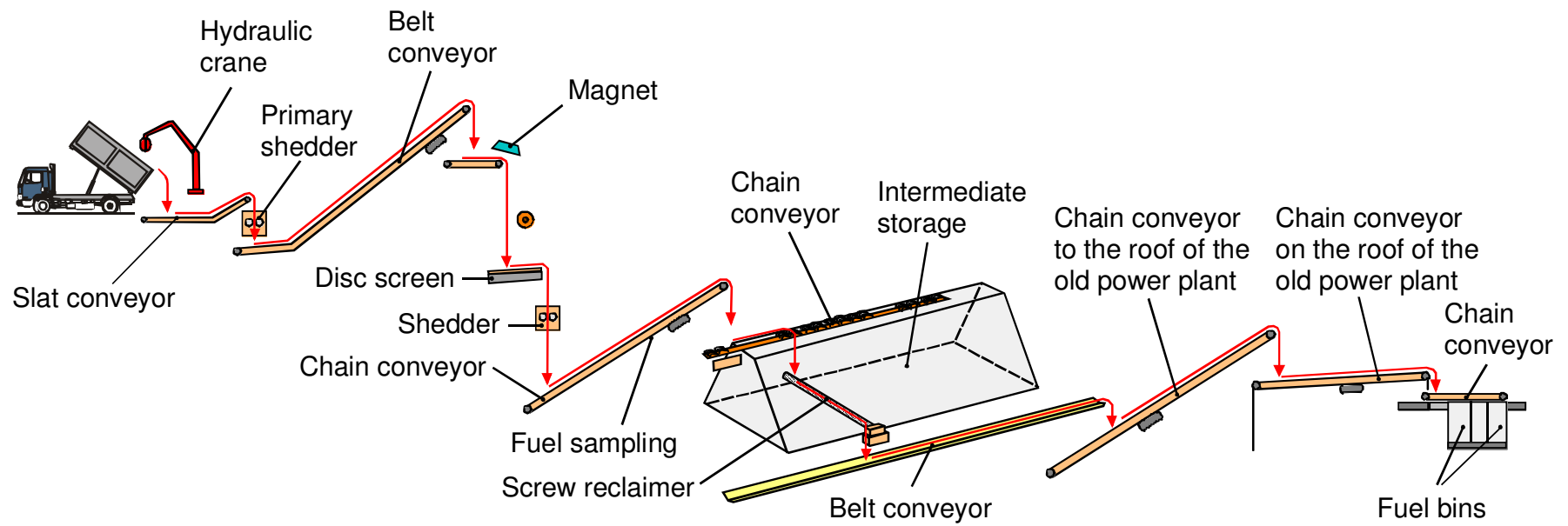
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**THE FLOW SHEET OF THE PROCESS AT EWAPOWER**





The process flow-lines at Lahden Lämpövoima Oy.



The location of MSW to RDF plants in Japan

Figure 1 MSW to RDF Plant Location

