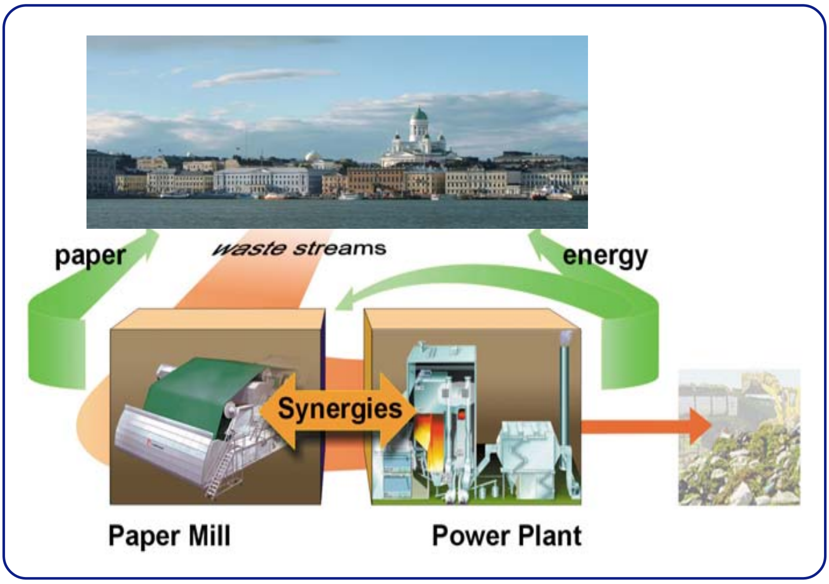
ESPOO 2002

VTT SYMPOSIUM 222



# Power production from waste and biomass IV

## Advanced concepts and technologies

VTT SYMPOSIUM 222

**Keywords:**
bioenergy, municipal solid waste, residues, recovered fuels, combustion, gasification, cogeneration, cofiring, emissions control, recycling

# Power production from waste and biomass IV

## Advanced concepts and technologies

Espoo, Finland, 8–10 April, 2002

Edited by

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Organised by

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Otamedia Oy, Espoo 2002

# Abstract

The seminar on Power Production from Waste and Biomass IV, with emphasis on advanced concepts and technologies, was held on 8–10 April 2002 in Espoo, Finland. The meeting was organised by VTT Processes in co-operation with EC DG TREN, Novem (from the Netherlands), IEA Bioenergy Task 36, Tekes and the Finnish Ministry of Trade and Industry.

Overviews of the European waste policies, waste management and waste-to-energy practices were given. Most of the relevant directives were presented including the directive concerning integrated pollution prevention and control (IPPC). The directive on waste incineration and its practical implications for fluid bed combustion and gasification of solid recovered fuels were discussed actively in the meeting. An overview of traditional massburning of mixed waste was given. The main focus, however, was on advanced process concepts and technologies. For example, in Finland, recovered fuel production and cofiring, based on either direct combustion in fluid bed boilers or pregasification, have been introduced successfully at several power plants. Fuel specifications are controlled by the Finnish recovered fuel standard. In Europe, a project for preparing the future CEN standard was presented and discussed. Experiences and R&D activities in the areas of fluid bed combustion and gasification, including gas cleaning and monitoring practices, were presented.

Modern waste-to-energy concepts will play an important role in advanced waste management business concepts. Future integrated waste recycling and energy production concepts, based on source separation and recovered fuel production, were presented. New R&D results were also presented concerning additional paper and plastic recovery from commercial and industrial waste, typically packaging waste.

National waste management policies and practices in the Netherlands and in Finland were presented based on the bilateral information exchange between Novem of the Netherlands and Tekes of Finland. The proceedings include the presentations given by the key speakers and other invited speakers, as well as papers based on some of the poster presentations.

# Preface

The seminar on Power Production from Waste and Biomass IV, with emphasis on advanced concepts and technologies, was held on 8–10 April 2002 in Espoo, Finland. The previous seminars organised by VTT had been held in December 1992, March 1995 and September 1998 and the proceedings of these seminars have been published in the VTT Symposium series.

The meeting was organised by VTT Processes in co-operation with EC DG TREN, Novem (from the Netherlands), IEA Bioenergy Task 36, Tekes and the Finnish Ministry of Trade and Industry. Results of the Finnish Waste-to-Energy R&D Program were presented. The Program constituted 60 projects with a total budget of 16 million euros. Additional information is available at www.wastetoenergy.vtt.fi. Key results of the Dutch – Finnish information exchange, supported by Novem and Tekes, were presented by Ir. Kees Kwant of Novem.

In Europe, several directives will set targets for future waste policy. The directive on landfilling will reduce significantly the volumes of combustible fractions; several countries have already set a total ban on the landfilling of combustible material. On top of traditional massburning of mixed waste, there is a need for advanced concepts with higher material recovery and higher efficiency in energy production. In the future, instead of mixed municipal solid waste, quality controlled recovered fuels will be produced and used as such or co-fired in existing power plants. The directive on waste incineration will set tight limits on emissions. A significant part of future investments aimed at reducing landfill waste volumes will be allocated to waste-to-energy projects. The directive on electricity production from renewable energy sources will catalyse green power production from the biogenic waste fractions. The target of increasing renewable energy production in Europe from 6 to 12% by 2010 will boost R&D, future investments and business opportunities. Modern waste treatment practices will have an important role to play in meeting the goals of the Kyoto Protocol.

Indicative of the interest in power production from waste and bioenergy was the participation of about 160 specialists from 19 countries. Industrial companies were well represented, indicating the existence of good business opportunities in this field. The next seminar on power production from waste and biomass will be organised in 2005.

Espoo, April 2002

Kai Sipilä

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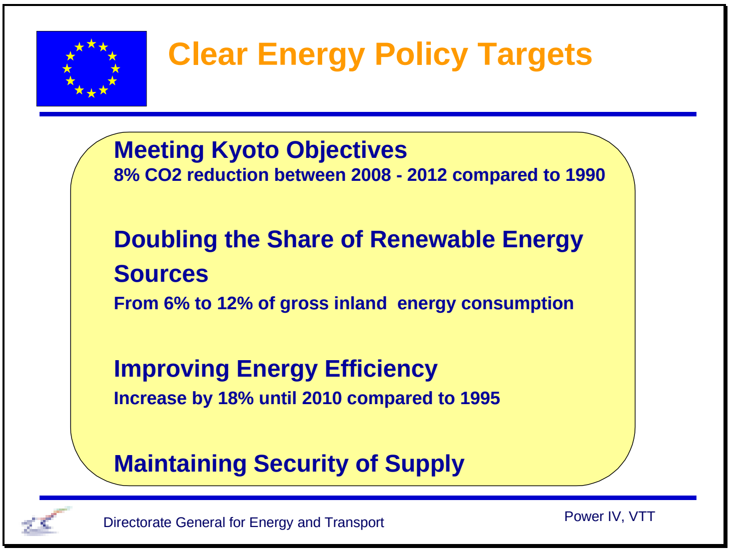
**MSW RECYCLING – WASTE TO ENERGY**

## WASTE TO ENERGY TECHNOLOGIES AND EMISSIONS

**EXTENDED POSTER PRESENTATIONS**

# Overview of EU waste to energy aspects & RES

Kyriakos Maniatis
EC DG TREN



## Clear Energy Policy Targets

**Meeting Kyoto Objectives**
8% CO2 reduction between 2008 - 2012 compared to 1990

**Doubling the Share of Renewable Energy Sources**
From 6% to 12% of gross inland energy consumption

**Improving Energy Efficiency**
Increase by 18% until 2010 compared to 1995

**Maintaining Security of Supply**

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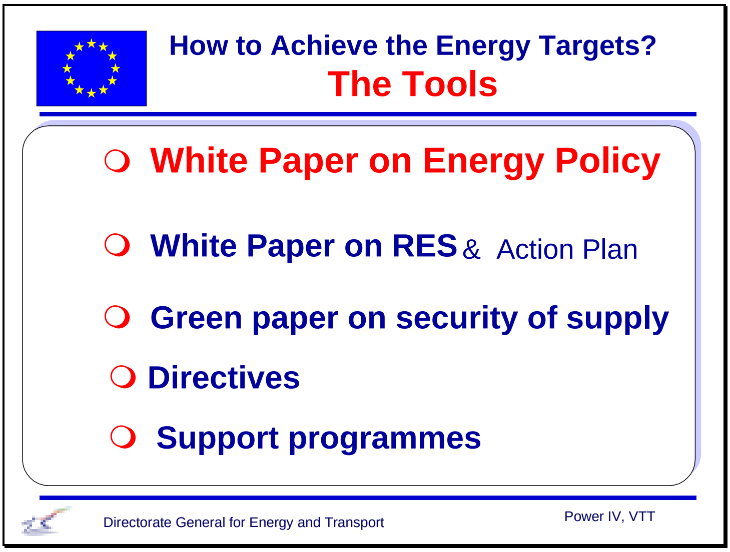

## How to Achieve the Energy Targets?
## The Tools

- White Paper on Energy Policy
- White Paper on RES & Action Plan
- Green paper on security of supply
- Directives
- Support programmes

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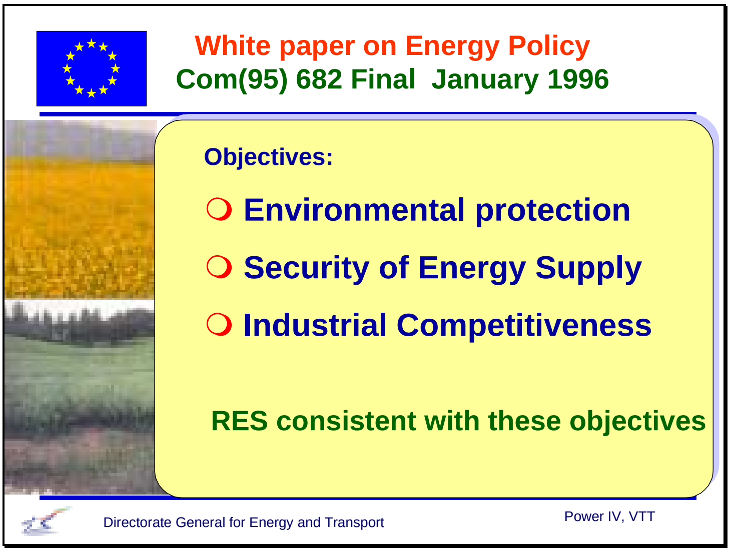

## White paper on Energy Policy
## Com(95) 682 Final  January 1996

**Objectives:**

- ❍ Environmental protection
- ❍ Security of Energy Supply
- ❍ Industrial Competitiveness

**RES consistent with these objectives**

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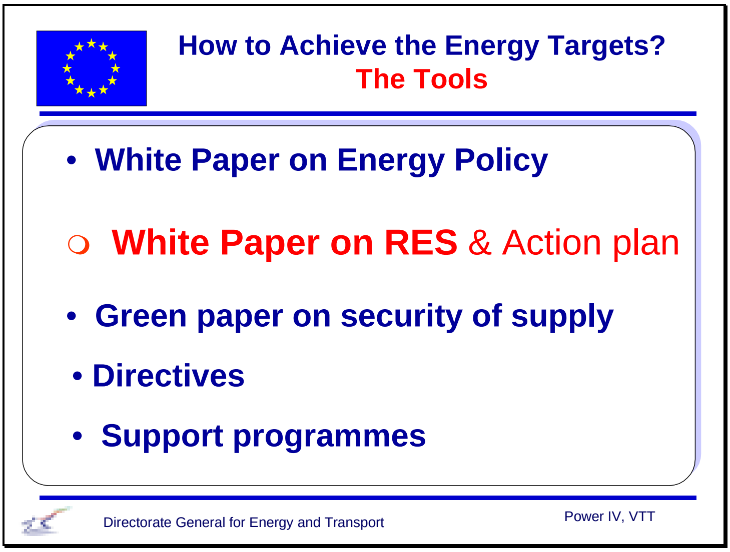

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## White Paper on Renewable Energies
## COM(97)599, 26.11.97

- Sets out Community Strategy and an Action Plan to double the share of Renewable energy from 6 to 12 % in Gross Inland Production by 2010
- Establishes Sub-targets in the various sectors.
- Preserves flexibility in view of Community enlargement.
- Instigates a tri-annual review procedure.

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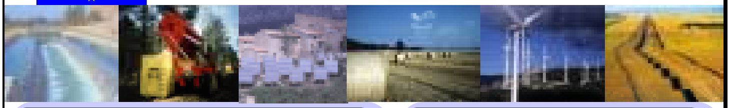
## Action Plan



- ❍ Internal market measures
- ❍ Reinforce Community policies
- ❍ Support measures
- ❍ Campaign for take off
- ❍ Improve co-ordination with Member States

**The Campaign for Take Off (99-03)**

1,000,000 Photovoltaic Systems

10,000 MW for Large Wind Farms

10,000 MWth for Biomass Plants

RES Integration in Communities

5 Million tonnes of Liquid Biofuels

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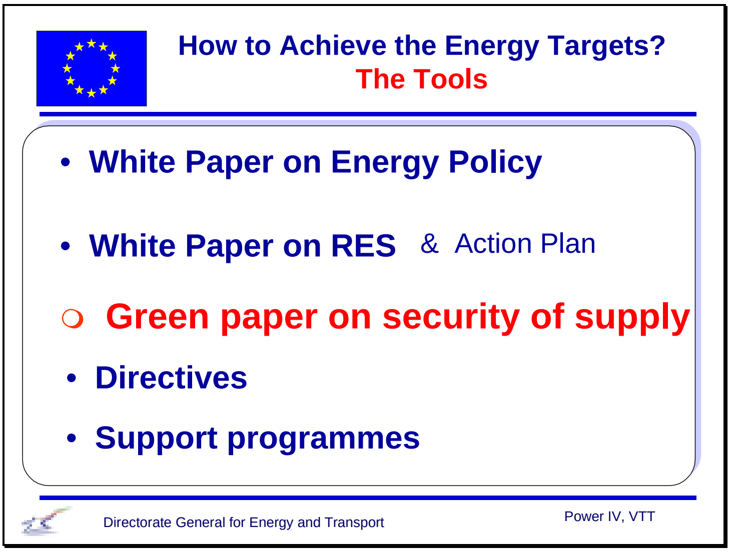

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- **Directives**
- **Support programmes**

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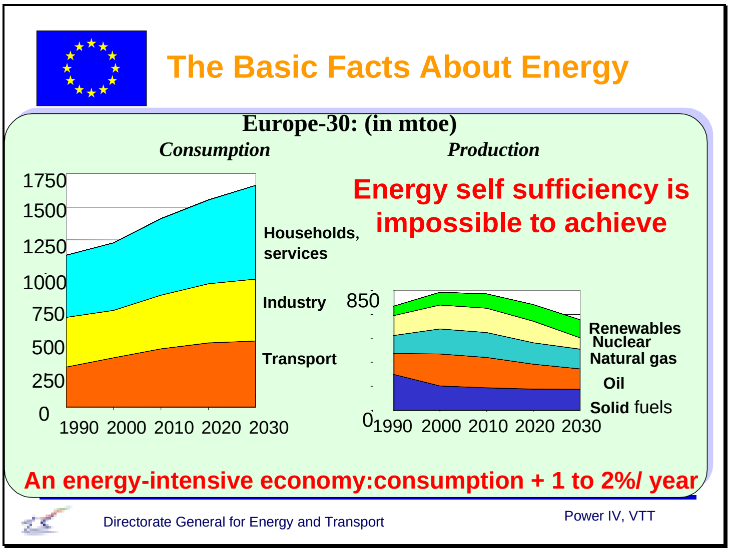

## The Basic Facts About Energy

**Europe-30: (in mtoe)**

*Consumption* *Production*

**Energy self sufficiency is impossible to achieve**

**An energy-intensive economy:consumption + 1 to 2%/ year**

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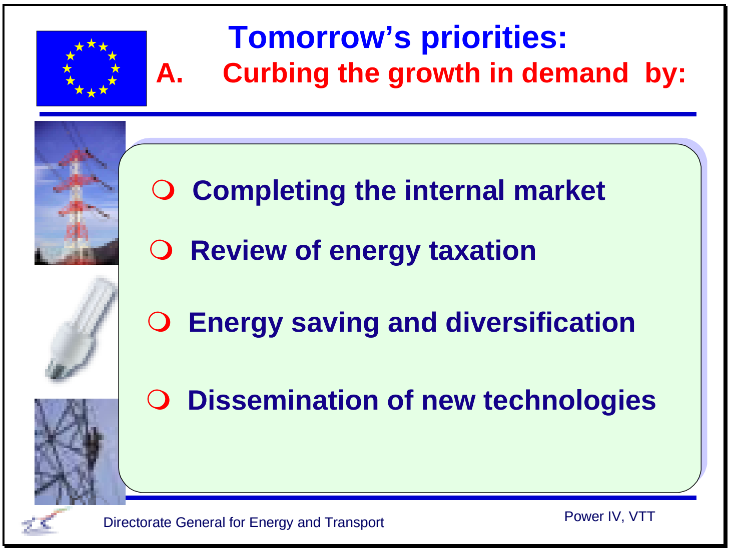

## Tomorrow's priorities:

### A. Curbing the growth in demand by:

- Completing the internal market
- Review of energy taxation
- Energy saving and diversification
- Dissemination of new technologies

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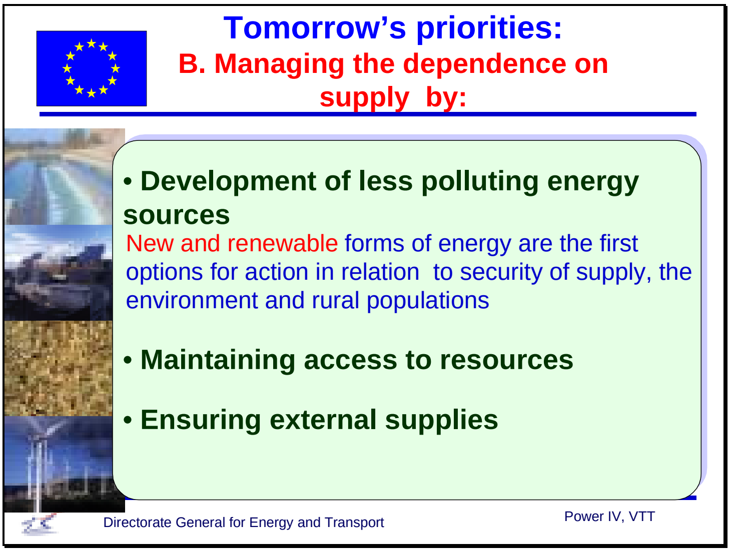

## Tomorrow's priorities:

### B. Managing the dependence on supply by:

- **Development of less polluting energy sources**

  New and renewable forms of energy are the first options for action in relation to security of supply, the environment and rural populations

- **Maintaining access to resources**
- **Ensuring external supplies**

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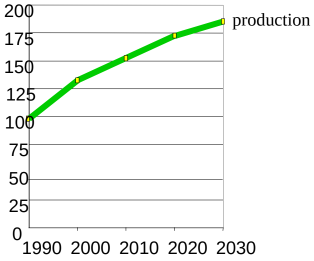
## New and renewable energy sources: a political priority

- Renewables offer a potential to be exploited
- EU target: 12% of total energy consumption in 2010
- They have differing growth prospects
- Their takeoff assumes that financial or tax incentives will be provided

*Europe-30: renewables*
*(reference scenario in mtoe)*



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## How to Achieve the Energy Targets?
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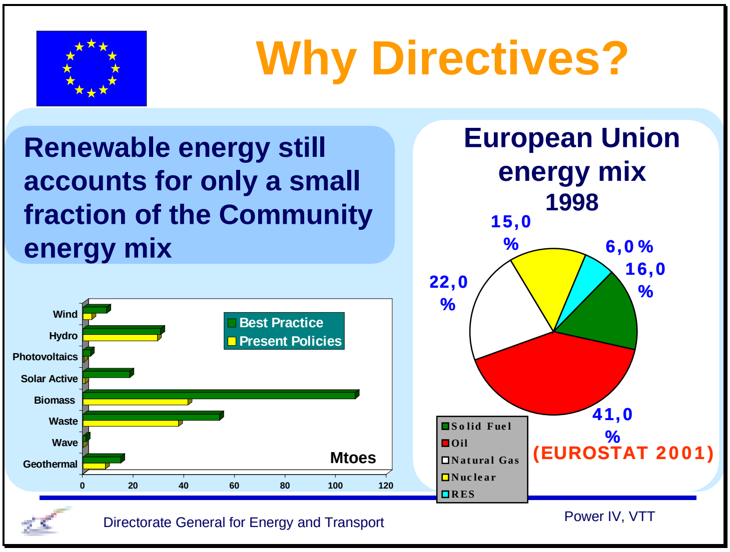
- ❍ **Directives**
- Support programmes



## Why Directives?

**Renewable energy still accounts for only a small fraction of the Community energy mix**

**European Union energy mix 1998**

(EUROSTAT 2001)

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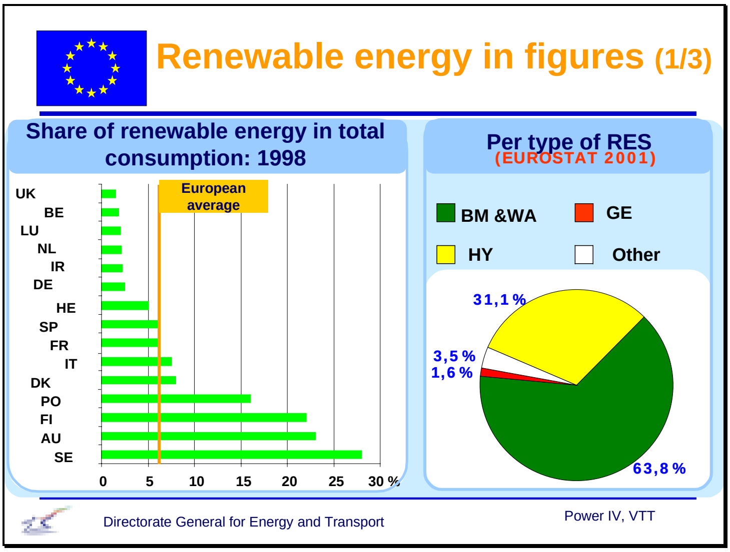

## Renewable energy in figures (1/3)

**Share of renewable energy in total consumption: 1998**

**Per type of RES**

(EUROSTAT 2001)

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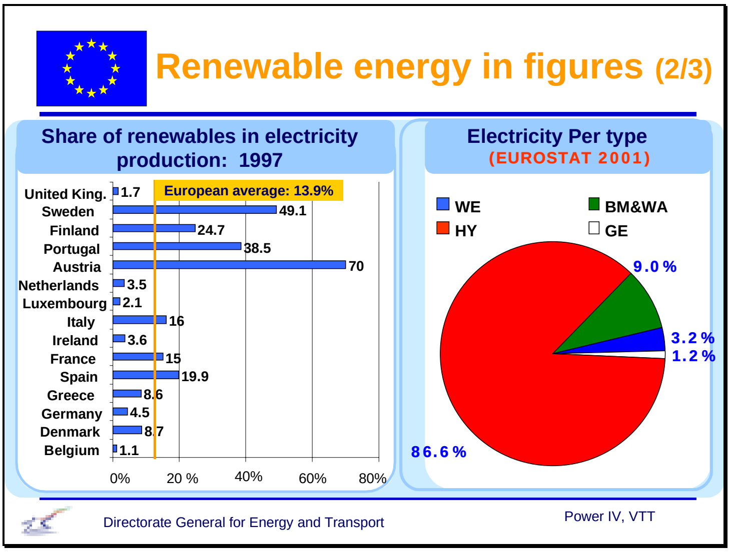

# Renewable energy in figures (2/3)

**Share of renewables in electricity production: 1997**

**Electricity Per type**
(EUROSTAT 2001)

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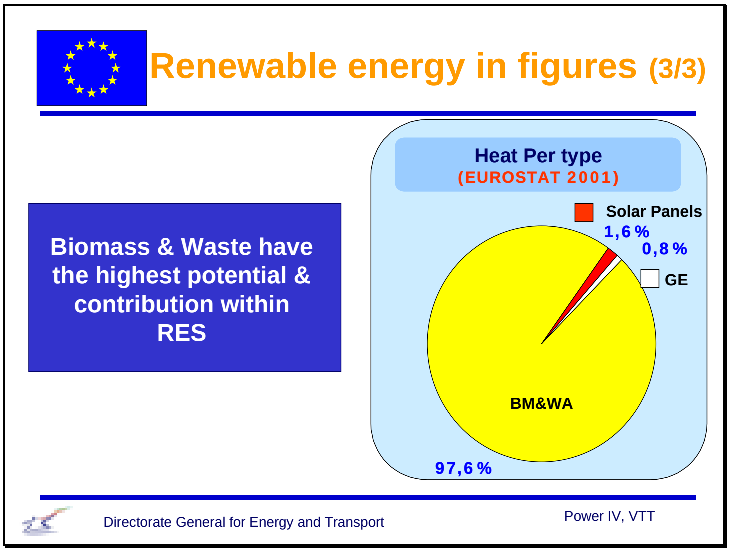

# Renewable energy in figures (3/3)

**Biomass & Waste have the highest potential & contribution within RES**

**Heat Per type**
(EUROSTAT 2001)

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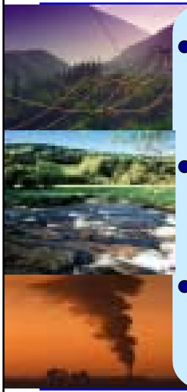
# Directives

•**Directive on the promotion of electricity from renewable energy sources in the internal electricity market**

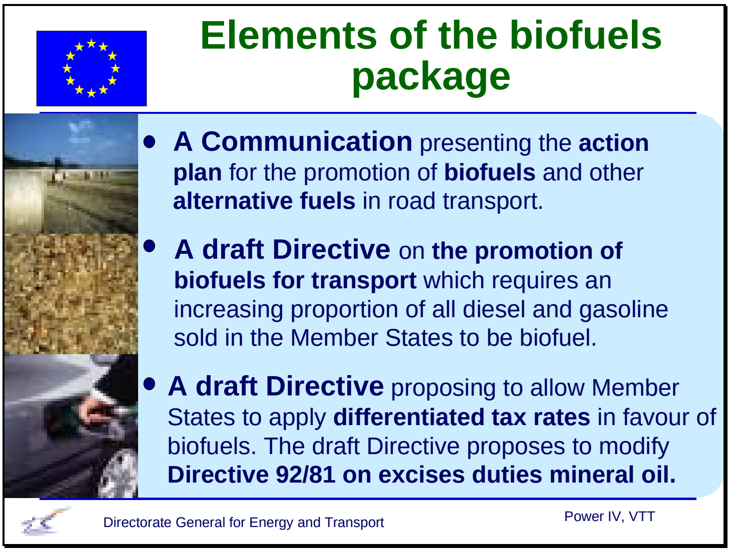
•**Draft Directives on Liquid Biofuels**
**mandate for a minimum use of biofuels and their de-taxation**

•**Draft Directive on Combined Heat and Power**
**Target: doubling the share of CHP from 9% (1994) to 18% (2010) Special provision for renewables.**

# The Targets of the RES-E Directive



- **To establish** a framework to **increase the share of green electricity from 14% to 22%** of gross electricity consumption **by 2010**
- **To help** to **double** the share of renewable energy **from 6% to 12%** of gross energy consumption in Europe **by 2010**
- **To further** compliance with the commitments made by the EU under the 1997 Kyoto Protocol on **reducing greenhouse gas emissions**



## Elements of the biofuels package

- **A Communication** presenting the **action plan** for the promotion of **biofuels** and other **alternative fuels** in road transport.
- **A draft Directive** on **the promotion of biofuels for transport** which requires an increasing proportion of all diesel and gasoline sold in the Member States to be biofuel.
- **A draft Directive** proposing to allow Member States to apply **differentiated tax rates** in favour of biofuels. The draft Directive proposes to modify **Directive 92/81 on excises duties mineral oil.**

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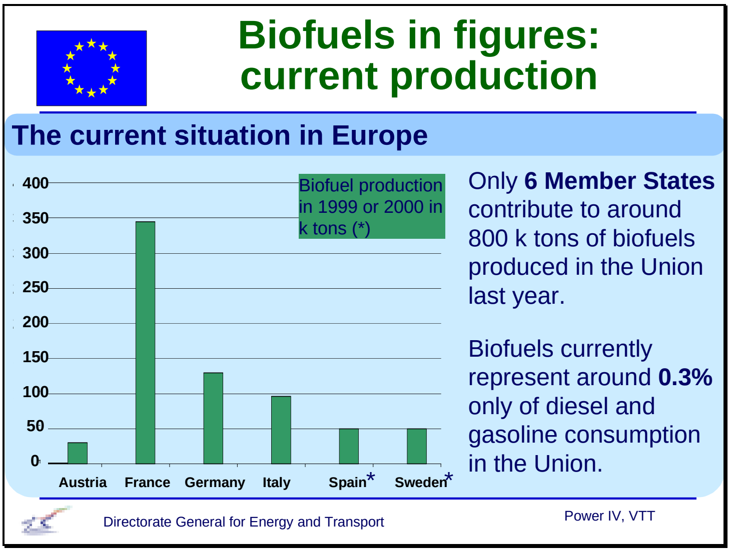

## Biofuels in figures: current production

### The current situation in Europe

Only **6 Member States** contribute to around 800 k tons of biofuels produced in the Union last year.

Biofuels currently represent around **0.3%** only of diesel and gasoline consumption in the Union.

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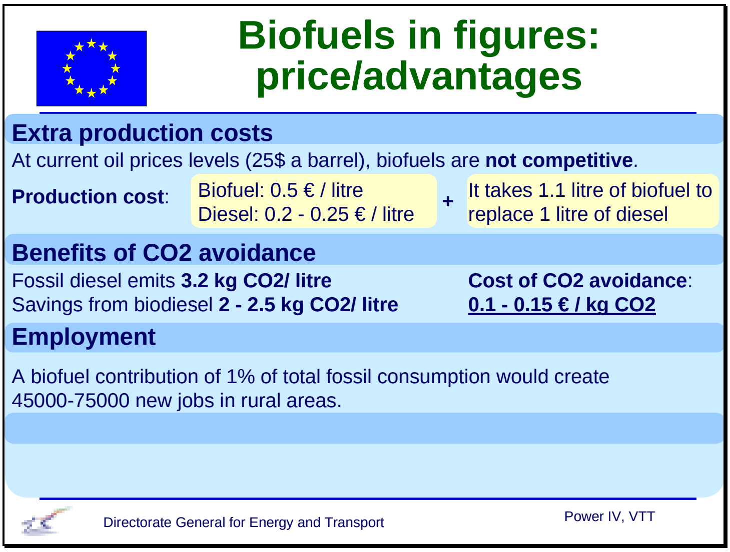


## Biofuels in figures: price/advantages

### Extra production costs

At current oil prices levels (25$ a barrel), biofuels are **not competitive**.

**Production cost**: Biofuel: 0.5 € / litre
Diesel: 0.2 - 0.25 € / litre
+ It takes 1.1 litre of biofuel to replace 1 litre of diesel

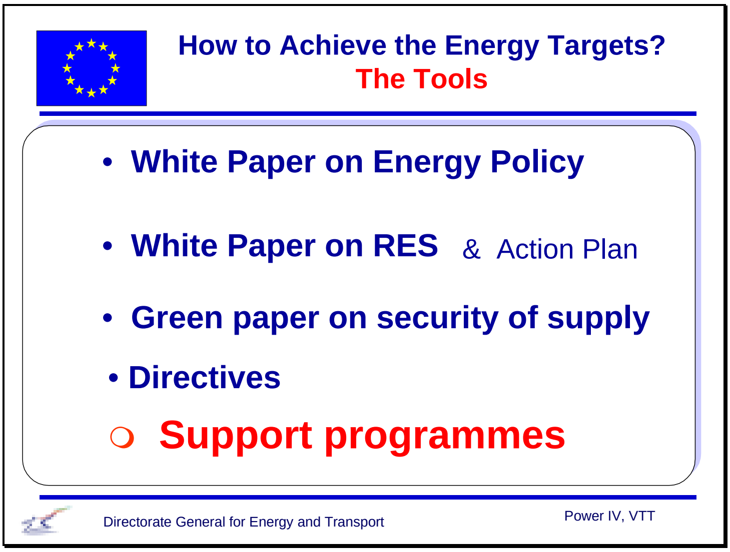
### Benefits of CO2 avoidance

Fossil diesel emits **3.2 kg CO2/ litre**
Savings from biodiesel **2 - 2.5 kg CO2/ litre**

**Cost of CO2 avoidance**:
**0.1 - 0.15 € / kg CO2**

### Employment

A biofuel contribution of 1% of total fossil consumption would create 45000-75000 new jobs in rural areas.



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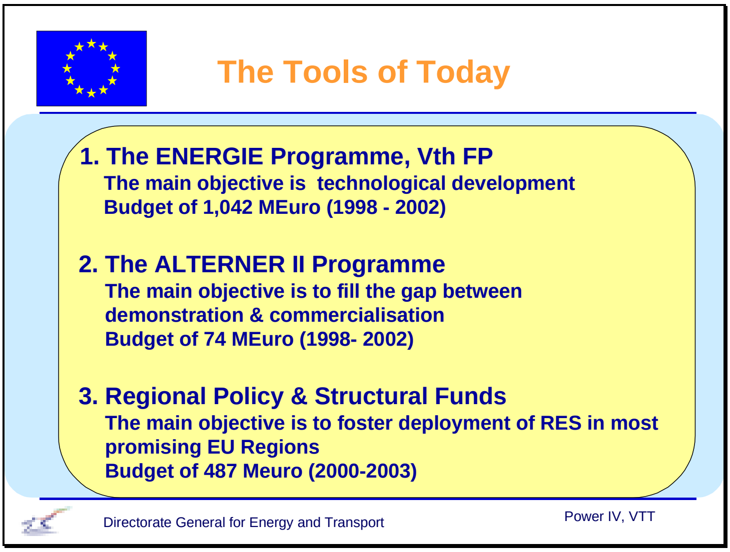

## The Tools of Today

**1. The ENERGIE Programme, Vth FP**
The main objective is technological development
Budget of 1,042 MEuro (1998 - 2002)

**2. The ALTERNER II Programme**
The main objective is to fill the gap between demonstration & commercialisation
Budget of 74 MEuro (1998- 2002)

**3. Regional Policy & Structural Funds**
The main objective is to foster deployment of RES in most promising EU Regions
Budget of 487 Meuro (2000-2003)

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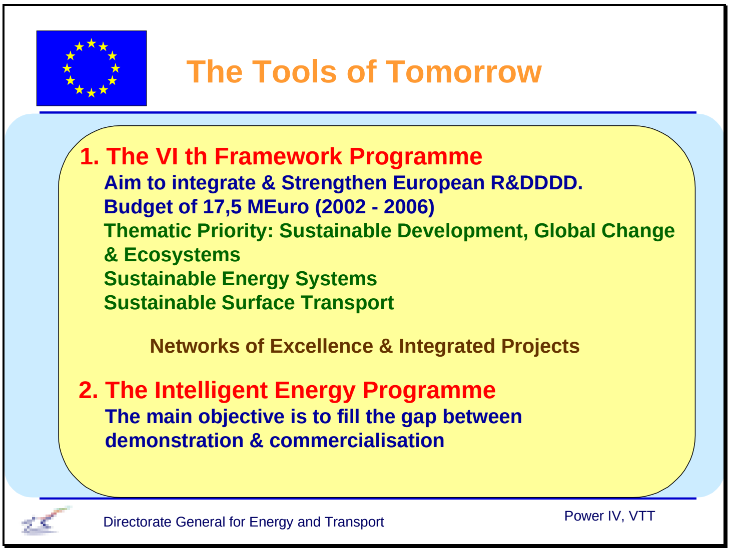

## The Tools of Tomorrow

**1. The VI th Framework Programme**
Aim to integrate & Strengthen European R&DDDD.
Budget of 17,5 MEuro (2002 - 2006)
Thematic Priority: Sustainable Development, Global Change & Ecosystems
Sustainable Energy Systems
Sustainable Surface Transport

Networks of Excellence & Integrated Projects

**2. The Intelligent Energy Programme**
The main objective is to fill the gap between demonstration & commercialisation

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## The RES Directives & EfW

- The Biodegradable fraction of MSW is RES.

- Energy and fuels from waste is thus covered by the Directives.

- One of the main problems is how to determine the biodegradable fraction of waste streams??

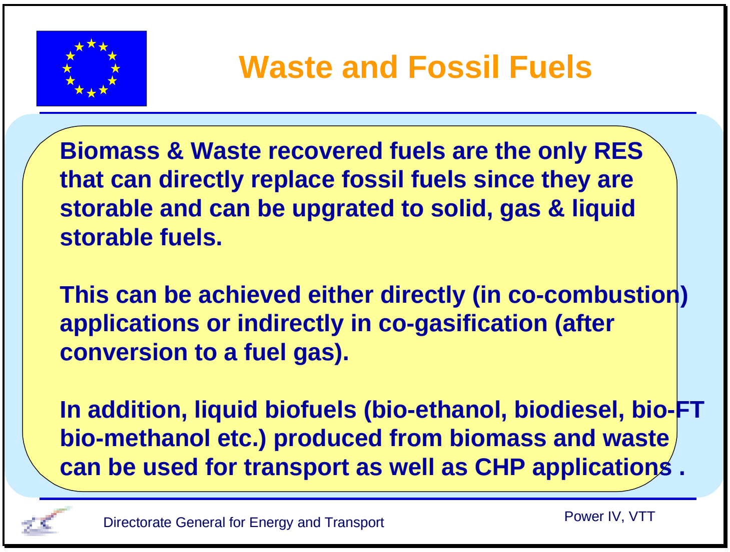
## Wastes and Fuels

### The need for RES fuels markets

If the targets of the Energy Policy are to be met, biofuels & solid recovered fuels markets have to be developed.

For such a market to function properly, confidence between producers and users of fuels must be Established.

This necessitates market tools.

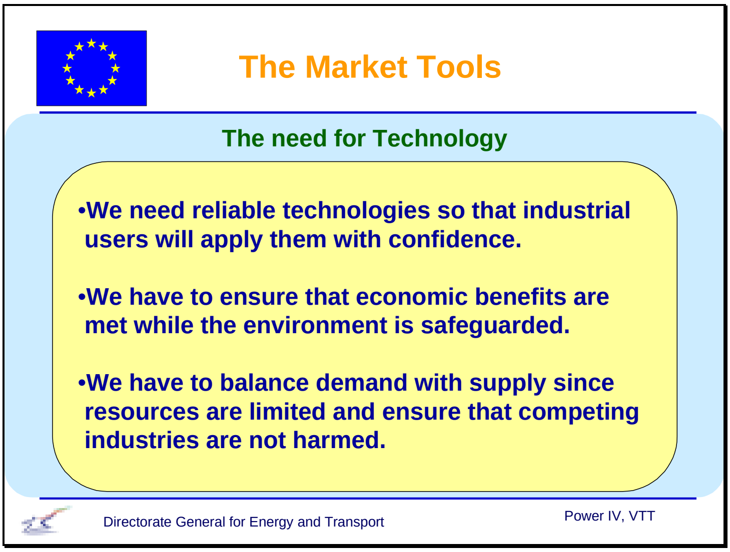


## Waste and Fossil Fuels

Biomass & Waste recovered fuels are the only RES that can directly replace fossil fuels since they are storable and can be upgrated to solid, gas & liquid storable fuels.

This can be achieved either directly (in co-combustion) applications or indirectly in co-gasification (after conversion to a fuel gas).

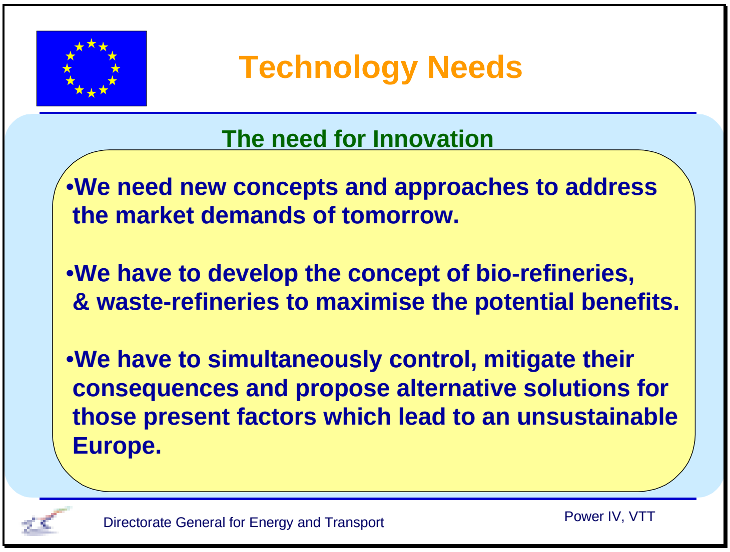
In addition, liquid biofuels (bio-ethanol, biodiesel, bio-FT bio-methanol etc.) produced from biomass and waste can be used for transport as well as CHP applications .



## The Market Tools

### The need for Technology

- We need reliable technologies so that industrial users will apply them with confidence.
- We have to ensure that economic benefits are met while the environment is safeguarded.
- We have to balance demand with supply since resources are limited and ensure that competing industries are not harmed.



## Technology Needs

### The need for Innovation

- We need new concepts and approaches to address the market demands of tomorrow.
- We have to develop the concept of bio-refineries, & waste-refineries to maximise the potential benefits.
- We have to simultaneously control, mitigate their consequences and propose alternative solutions for those present factors which lead to an unsustainable Europe.

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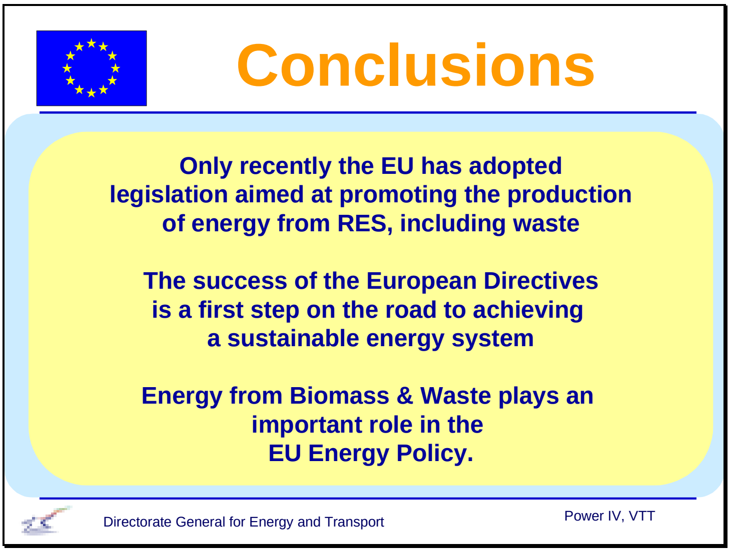

## Conclusions

Only recently the EU has adopted
legislation aimed at promoting the production
of energy from RES, including waste

The success of the European Directives
is a first step on the road to achieving
a sustainable energy system

Energy from Biomass & Waste plays an
important role in the
EU Energy Policy.

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# Waste to energy policy in the Netherlands and financial support for renewable energies

Kees W. Kwant,
Novem B.V.
Utrecht, The Netherlands

## Abstract

To achieve a place for renewables and energy from waste in a *liberalized energy market* the government has to focus on a more demand-driven approach and on a number of specific areas, a more supply-driven policy will be required. The available financial and fiscal instruments, regulations and voluntary agreements provide new opportunities. The Dutch government supports renewables with *fiscal instruments* (green funds, tax credits and an energy tax) since 1996. As a follow-up of the green energy market and the mandated share set by the energy companies, the government introduced in 2001 a system for tradable *green certificates*. On July 1, 2001, the market for green electricity became liberalized and the consumers of green electricity were free to choose their own supplier, and the number of green consumers went up to 700,000 by the end of 2001.

## 1. Policies

Renewable energy policies are driven by the well-recognised need for a sustainable society. Environmental programs and a white paper on energy have been formulated as a consequence of international agreements on climate change.

The Dutch government aims in its White Paper on Energy (1995) at a simultaneous approach of continuous energy savings, efficiency improvement (33% in 2020) and the further development of renewable energy (10% in 2020). This target for renewable energy is almost fivefold of the present 53 PJ to 270 PJ in 2020. From this target 40% (120 PJ) could be realised with energy from waste and biomass.

Following European discussions, bioenergy is since 1999 defined as the energy from the organic content of waste and biomass. Thus the energy from the fossil part of waste (plastics, etc.) no longer contributes to renewable energy.

In the Energy Report from 1999 the government presents the policies in the liberalised market:

1. Consumer-driven approach in the renewable energy market;
2. Voluntary agreements with specific sectors in the market;
3. Greening the fiscal system by increasing the energy tax;
4. Encouraging research and development through specific programs.

These general lines can be made more specific for bioenergy:

1. New technologies with higher efficiencies have to be developed to improve the price performance ratio;
2. Biomass resources have to be available in large quantities at a reasonable price;
3. Public acceptation of bioenergy as a renewable energy source is needed;
4. Administrative bottlenecks (permissions, clear regulations) have to be removed.

# 2. Strategy

Up till now, waste incineration with energy recovery generates the major part of bioenergy (Table 1). The next major market is expected in the area of **co-combustion** of waste and wood in (coal-fired) power stations (2000–2010).

The government is proposing an agreement with the coal sector in the Netherlands to reduce $CO_2$ emissions by 6 Mton. Co-combustion of biomass could be a major contribution (3 Mton) to realise this target. Market penetration of small-scale systems (gasifiers, anaerobic digestion) is foreseen in new, green, $CO_2$ neutral, sustainable dwelling or industrial areas. Gasification technology could play an important role both for cofiring and small-scale systems.

*Table 1. Prognosis of bioenergy potential [PJ].*

| **Technology** | **1995** | **2000** | **2010** | **2020** |
|---|---|---|---|---|
| Waste incineration | 5.6 | 11.6 | 15 | 20 |
| Wood combustion in households and industry | 6.4 | 7.4 | 8 | 8 |
| Co-firing | 0.1 | 1.8 | 39 | 42 |
| Stand-alone combined heat and power | - | 1.5 | 10 | 40 |
| Landfill gas/digestion | 5.0 | 5.5 | 8 | 10 |
| TOTAL BIOENERGY | 17.1 | 27.8 | 80 | 120 |
| Wind, solar and others | 3.9 | 9.2 | 70 | 180 |
| TOTAL RENEWABLES | 21.0 | 37.0 | 150 | 300 |
| **% of total energy** | **0.7** | **1.2** | **5** | **10** |

In an agreement between the Government and the Association of Waste Processors (1999) it has been stipulated that while municipal solid waste contains about 50% organic material (biomass) a 50% repayment on electricity generated by waste incinerators will also take place. An additional law (Environmental Tax Law, art. 36-r) has been put into force to encourage energy generation from waste. The money generated (50 M€) will be channelled into a fund to improve and increase energy generation by 4 PJ before 2003.

## 3. Financial support

The shift to a sustainable and prosperous society can be supported by ecologising (or greening) the fiscal system. In this context, a Regulated Energy Tax was introduced in the Netherlands in 1996. The energy tax encourages energy conservation and the use of renewable energy by making fossil energy much more expensive. The reduction in the energy tax and the zero tariff for ‘green’ electricity, provide a further strong incentive to use renewable energy. Furthermore, the system with specific fiscal instruments focuses on supporting investments.

## 3.1. Support for investments

The following different schemes to improve the profitability of renewable energy options can be seen: *Green Funds, Accelerated Depreciation, Tax Credit.* From these three instruments, Tax Credit is the strongest one. The combination of them equals a subsidy on the investment of 25–35%, depending on the profit and fiscal situation of the company.

Banks offer lease constructions on renewable energy equipment, where these fiscal measures are incorporated, making financing easy and interesting for all parties.

## 3.2. Higher payment for electricity from renewables

Households and small and middle-sized enterprises (SMEs) pay an energy tax on electricity and natural gas. This tax is paid to the utility companies, which in turn pass this on to the taxation authorities (Ministry of Finance). However, utility companies are **exempted from paying tax** on energy generated from renewable insofar this energy is accompanied by a specific ‘green’ contract between the energy company and the consumer. (Environmental Tax Law, art. 36-i, the so-called zero-tariff) This means that this green energy becomes less expensive.

Besides that, producers of renewable energy get an allowance from the energy tax revenues. (art. 36 o). In art. 36-o renewable biomass is described as any organic material, **not** containing plastics or other material originating from fossil resources.

Table 2 presents the increase of the energy tax and allowance to producers over the recent years.

*Table 2. Energy Tax Netherlands on electricity €cts.*

| **Year** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** |
|---|---|---|---|---|---|---|---|
| Energy tax | 1.34 | 1.34 | 1.34 | 2.25 | 3.72 | 5.83 | 6.02 |
| Feed back tax | | | 1.34 | 1.47 | 1.61 | 1.94 | 2.00 |

# 4. Free consumers of green energy

Green electricity is a commercial way of selling renewable energy. Since January 1, 1999, the consumers of green electricity no longer have to pay an energy tax resulting in only 1 cent higher price for electricity from renewables, compared to normal electricity.

The additional sum is used to pay the producers of renewable electricity about 6 cents, and the other 2 cents is used for administration and advertisements. The number of consumers has increased considerably over the recent years (Figure 1).

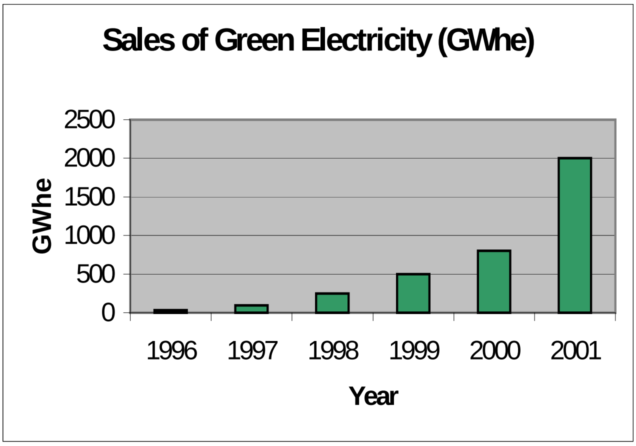

*Figure 1. Sales of green electricity in the Netherlands.*

There is a debate on the green picture of bioenergy. There is even a difference between the utilities. Some consider only biomass from energy crops and thinnings from forestry as green, and others include arboricultural residues and restwood from wood shavings, etc.

The Electricity Act has made a resolution on renewables stating that the Minister has the possibility to declare that a certain percentage of energy should be sold as renewable energy (the mandated share). In the 1999 Energy Report [1] the Minister made a decision, approved by the Parliament, that the Government should not imply an obligation to buy renewable energy. Instead, there will be some obligations focused on the conditions determining the supply of renewable energy.

# 5. Conclusion

In general, it can be concluded that the new markets, either created through the certificates system, the fiscal incentives from the government or the green consumer, show promise to function well in the liberalised energy market. Harmonisation at a European level is required to allow for trading at the European market of renewable energy.

# References

1. Ministry of Economic Affairs, Energy Report 1999, November 1999, http://www.minez.nl/english.

# Overview of Finnish waste to energy R&D programme

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Espoo, Finland

The official waste strategy of Finland is presented in the Waste Action Plan. One of the key targets is to increase the MSW based recovery rate from present 40% to 70% by the year 2005. Waste to energy volumes should be increased up to 1 Mt/a on top the highest priority material recycling. For the combustible fractions, bio waste-based composting, and source separation of paper fractions and plastics are the most important options. 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 will be based on good source separation and recovered fuel production technology. Results of the Finnish Waste to Energy Programme, carried out in 1998–2001, are presented in the paper. In total, 60 projects were carried out with a total budget of € 16 million. Networking of various players in waste management and energy industry, manufacturers, authorities, research organizations and universities was the main benefit on top of numerous reports and products from the projects. Intensive European and international co-operation through Novem in the Netherlands and IEA Bioenergy MSW task has been an important part of the work and implementation of results.

I wish to present my best thanks to all participants in the Waste to Energy Programme for excellent work and co-operation during the National Technology Agency of Finland, Tekes, Technology Programme.

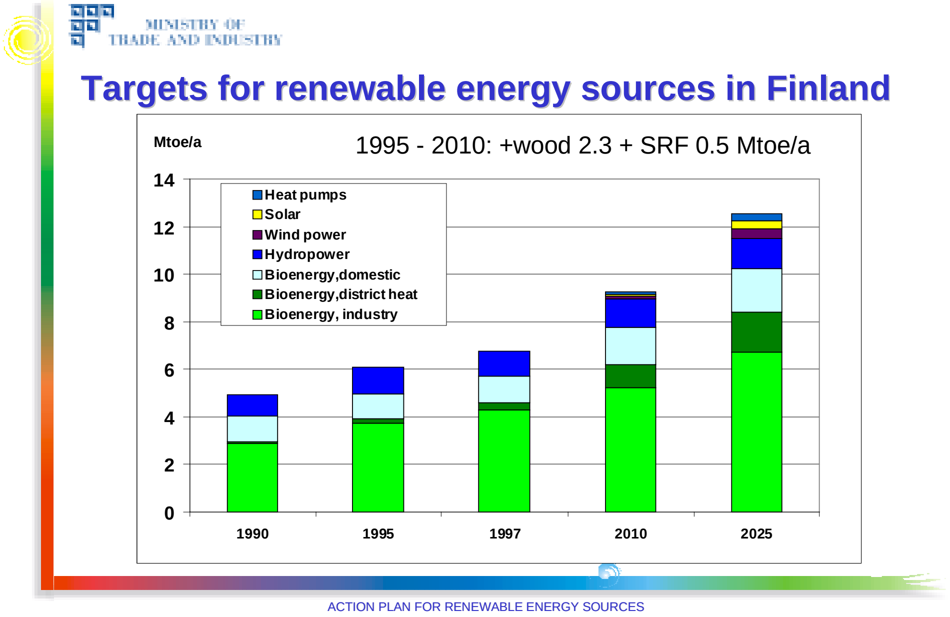
## 1. Introduction

In Finland, the national waste management strategy is presented in the Waste Action Plan for the year 2005 reflecting the EU Directives, especially the

Landfill Directive. The key objective is 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. 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, commercial packaging waste-based solid recovery fuel (SRF) are co-fired in industrial and municipal boilers. 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 2 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 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.

In Finland, the governmental implementation plan for renewable energy will support the use of bioenergy and the biodegradable fraction of MSW for energy applications, the target being to add the use of bioenergy by 50% from the level of 1995 to 2010 (Figure 1).



MINISTRY OF TRADE AND INDUSTRY

Targets for renewable energy sources in Finland

1995 - 2010: +wood 2.3 + SRF 0.5 Mtoe/a

ACTION PLAN FOR RENEWABLE ENERGY SOURCES

*Figure 1. The Finnish action plan for renewable energy.*

## 2. Waste to energy in Finland

The existing system 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. In Finland, one mixed-waste incineration plant has been in operation in the city of Turku, and its gas cleaning train was updated in 1995. Source-separation is the key of good material separation for recovery and for the production of good solid recovered fuel (SRF). SRF is produced especially from dry commercial packaging wastes, which contain mainly polyethylene plastics, wood, paper and board. 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 2000. The national SRF standard and results of various source separation projects are presented in a paper by Juvonen[1]. There are almost ten REF production facilities in operation, producing about 300 000 t/a recovered fuels. They include typically crushers, sieves, magnetic and non-magnetic separators and optionally air sieves. One unit, Ewapower Company in Pietarsaari, produces pellets from RDF. Pellets are conveyed in existing feeding lines and co-fired in existing boilers. The bulk density can be up to 350 kg/m$^3$ compared to fluffy form of RSF, 80–150 kg/m$^3$. In Finland, the residue fractions of paper industry are typically bark, sawdust and biosludges, which are not included in the Waste Incineration Directive. Packaging wastes, when containing some plastics or contaminated material, are of interest when selecting future boilers operated in conformance with the EU Waste Incineration Directive, compared to conventional biomass boilers and relevant gas cleaning procedures.

Figure 2 illustrates the main combustible fractions used for energy applications in Finland.

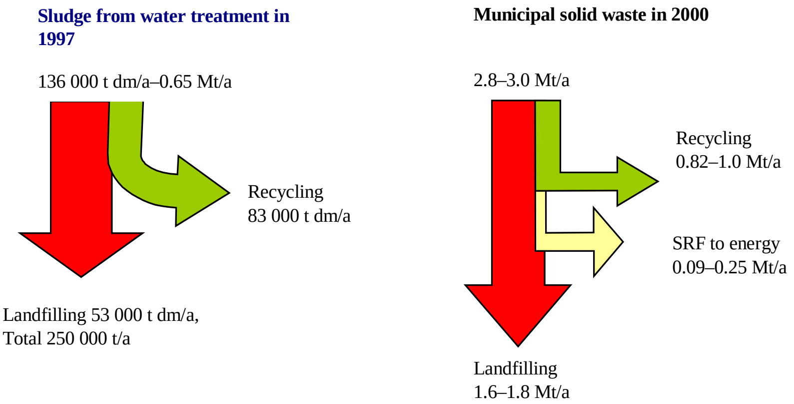


*Figure 2. Main combustible fractions used for energy applications in Finland.*

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[1] Juvonen, J. Source separation tests and SRF quality at various REF-production facilities. Tekes Project Reports 2002.

The key strategy in developing waste to energy applications has been an integrated approach of total MSW recovery instead of mixed waste mass incineration. This principle is indicated in Figure 3, where the key topics are:

- source separation
- production and quality control of solid recovered fuel
- co-firing in existing or new CHP plants
- gasification technologies and advanced gas cleaning
- emission control supported by high quality control of fuel
- integrated material and energy recovery, especially metals, glass and paper.

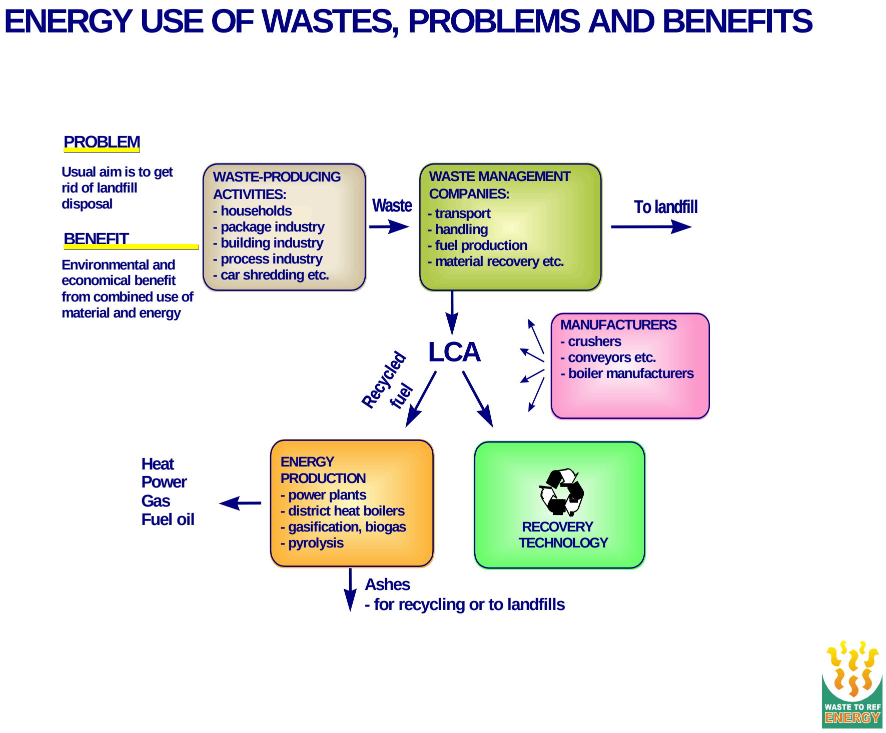
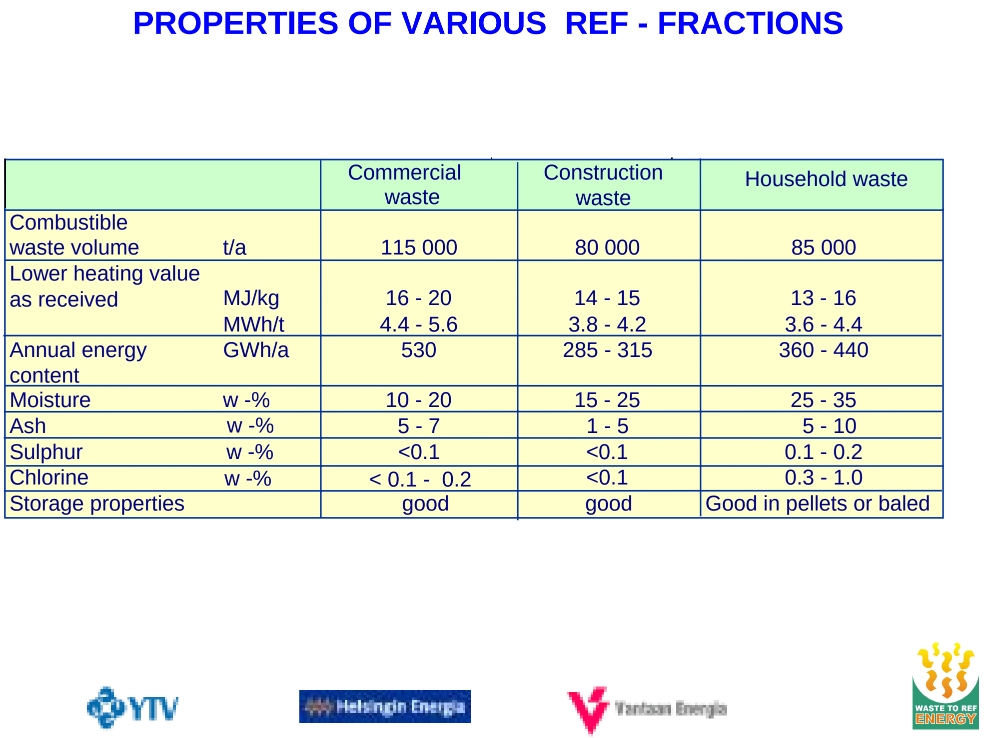


*Figure 3. Waste to energy as an integrated approach for material and energy recovery.*

Helsinki Metropolitan Area published a study in 2000[2], where MSW volumes, properties and end-use applications were identified in order to close the disposal of organic material to landfills. The metropolitan area has a population of one million, generating about 790,000 t/a waste, of which 480,000 t/a is disposed to landfills after the separation of recyclable material. It was estimated that 280,000 t/a of solid recovered fuel can be produced for energy applications, especially for co-firing in three CHP units. The quality of the fuel was analysed, results are shown in Figure 4.



PROPERTIES OF VARIOUS REF - FRACTIONS

| | | Commercial waste | Construction waste | Household waste |
|---|---|---|---|---|
| Combustible waste volume | t/a | 115 000 | 80 000 | 85 000 |
| Lower heating value as received | MJ/kg | 16 - 20 | 14 - 15 | 13 - 16 |
| | MWh/t | 4.4 - 5.6 | 3.8 - 4.2 | 3.6 - 4.4 |
| Annual energy content | GWh/a | 530 | 285 - 315 | 360 - 440 |
| Moisture | w -% | 10 - 20 | 15 - 25 | 25 - 35 |
| Ash | w -% | 5 - 7 | 1 - 5 | 5 - 10 |
| Sulphur | w -% | <0.1 | <0.1 | 0.1 - 0.2 |
| Chlorine | w -% | < 0.1 - 0.2 | <0.1 | 0.3 - 1.0 |
| Storage properties | | good | good | Good in pellets or baled |

*Figure 4. Characteristics of SRF – solid recovered fuel – in Finland, based on source-separation into three waste bins in households[2].*

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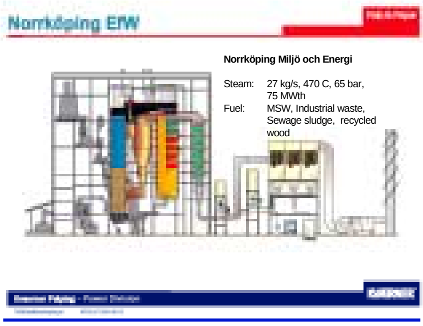
[2] Mäkinen, T., Sipilä, K., Hietanen, L. & Heikkonen, V. Survey of the use of wastes to energy in Helsinki Metropolitan Area. Final report. Helsinki: YTV – Helsinki Metropolitan Area Council, 2000. 69 p. + app. 12 p. (Publication Series of Helsinki Metropolitan Area C: 2000). (In Finnish).

# 3. Key energy technologies – fluid bed combustion and gasification

In Finland, the dominating solid fuel power plant technology is fluid-bed combustion of biomass, peat and coal. In Figure 5, typical examples are shown. Details will be discussed by the coming presentations at this seminar. Examples of the Figure are from Kvaerner Pulping and Foster Wheeler. The key issues include fuel properties, low maintenance cost, high availability and emission control.



Norrköping EfW

Norrköping Miljö och Energi

Steam: 27 kg/s, 470 C, 65 bar, 75 MWth

Fuel: MSW, Industrial waste, Sewage sludge, recycled wood

Fluid Bed Combustion 20 - 300 $MW_f$

- multi fuel BFB and CFB technology
- co-firing biomass and coal, lignite
- high efficiency, low emissions
- proven technology
- typical investment ca. 2-3000 €/kWe

Fluid Bed Gasification 15 - 120 $MW_f$

- multi fuel BFB and CFB technology
- co-firing the clean gas in coal boiler
- high efficiency, low investment
- typical investment ca. 6-800 €/kWe in co-firing large coal/oil/gas power plant

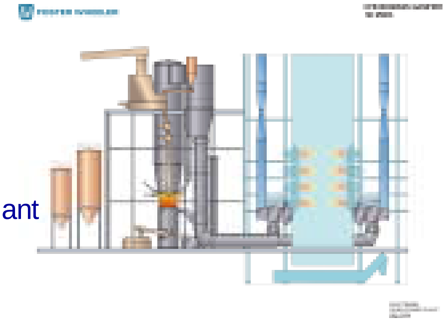


*Figure 5. Fluid bed combustion and gasification for solid recovered fuels.*

Various speakers have discussed fuel properties in their presentations. The key aspects are physical properties reflecting handling and feeding properties. As regards the chemical composition, the most important properties are typically heating value, chlorine, sulphur, aluminium and heavy. In Europe, the CEN standard will harmonize and help the production, trade and equipment for solid recovered fuels.

There are a high number of relevant examples in Europe, in which SRF is successfully fired in fluid-bed boilers. Problematic issues have been, when out of control, e.g., high-temperature corrosion due to high chlorine content, superheater deposits due to metallic aluminium in the fuel. For flue gas cleaning the EU Waste Incineration Directive sets clear and even limits for operators in Europe, for new units in December 2002, and for the existing plants in December 2005. The effect of the directive on fluid-bed boilers and gasifiers was discussed in a separate presentation at the seminar.

A CFB-gasifier has been in operation at Kymijärvi Power Plant in Lahti since 1998. Local SRF and forest and wood residues are co-gasified in an existing coal fired CHP boiler. Coal can be substituted up to 15% of energy by biomass. The gasification concept was the most attractive solution in Lahti to co-fire biomass in the pulverized coal boiler. The gasification plant has operated successfully. The fuel quality is controlled, especially the level of impurities like alkali and heavy metals, aluminium and sulphur. Mr. Kivelä gave a more detailed presentation in this seminar.

Gasification technology has been further developed to hot gas cleaning. By filtering at 350–400ºC temperature, most impurities can be removed and clean gas can be introduced to a coal, oil or natural gas boiler. Especially, heavy metals and chlorine can be removed at a high efficiency, and the SRF-based ash is collected separately from coal ash without interfering the coal ash recycling practices. As an example, a schematic concept of Foster Wheeler for Helsinki applications is shown in Figure 6.

The hot gas cleaning has been an area of intensive R&D at VTT in Finland. In atmospheric CFB/BFB gasification test facilities, several test procedures have been carried out by Kurkela[3] and Nieminen. Some test results are presented in Figure 7. In Varkaus, a 40 MW BFB-gasifier has been installed by Corenso Ltd delivered by Foster Wheeler, for processing PE plastics with metallic aluminium recovery from recycling of liquid cartoon.

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[3] Kurkela, E. REF gasification and gas cleaning. Presentation at the seminar on Power Production on Waste and Biomass IV. Espoo, Finland, 8–10 April 2002.

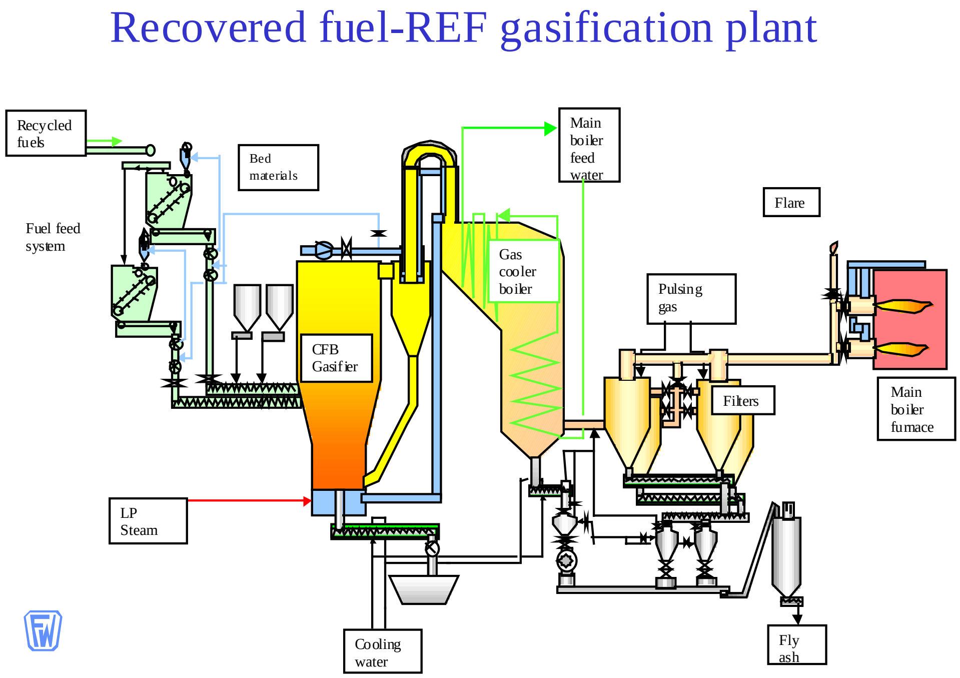

*Figure 6. Recovered fuel gasification and gas cleaning concept by Foster Wheeler.*

A techno-economic assessment was carried out for processing the 280,000 t/a recovered fuel to co-firing in existing CHP power plants in co-operation with local energy companies in the Helsinki Metropolitan Area. A boiler input of 85 MW fuel was chosen the nominal effect representing about 110,000 t/a SRF with 5000 h/a operation time of the CHP plant. Two alternatives (Figure 8) are co-firing in existing coal pulverized fired boilers, either based on co-gasification or coupling a new SRF boiler steam cycle to the existing coal boiler cycle. As an input, the value of the electricity was 23.6 €/MWh (140 FIM/MWhe) and district heat 13.5 €/MWh (80 FIM/MWh heat). In the Figure, estimated gate-fee prices are presented for several alternatives. The gate-fee values were still lower than a typical landfill gate fee, including tax 15.1 €/t, or a mass-burning option with separate power production and no heat benefit.

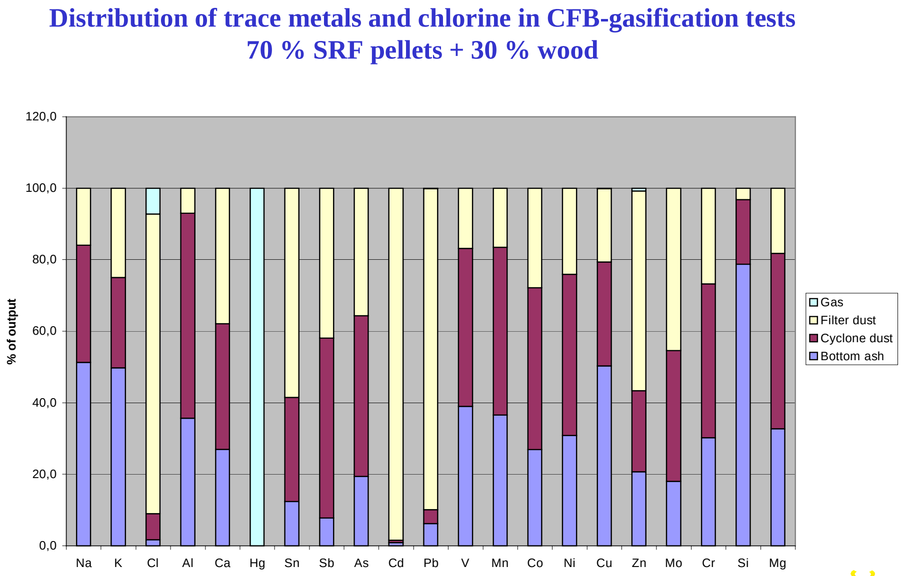

*Figure 7. Gasification and gas filtration tests by Kurkela and Nieminen*[3].

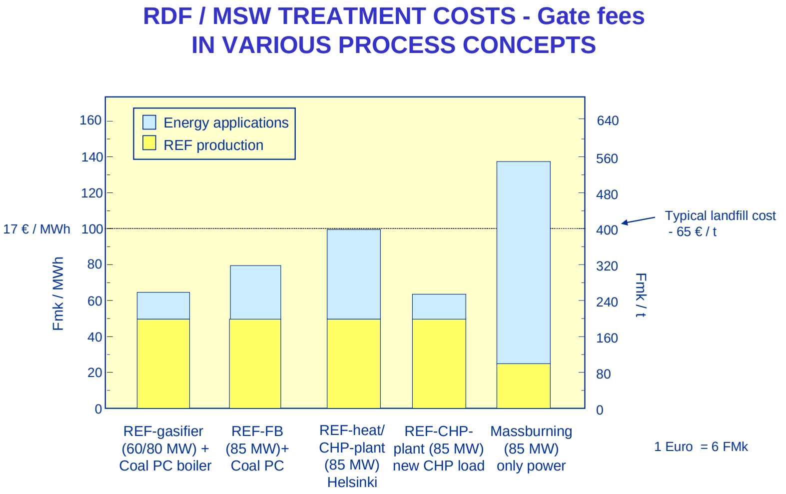

*Figure 8. Gate-fee estimates in various WtE cofiring modes*[2].

# 4. Greenhouse emissions and waste management policies

Key aspects for the green house gas emissions (GHG) are landfill gas emissions, as methane is a stronger GHG gas component compared to carbon dioxide. When using MSW in energy production, the biodegradable part of MSW can be calculated as a GHG-neutral fuel like biomass. In Finland, the waste management strategies will play a significant role in the national Kyoto policy, especially when most of methane is still today emitted from present landfill sites. For the Helsinki Metropolitan Area, a study was carried out, in which the significant effect of the selected waste to energy concept is indicated (Figure 9).

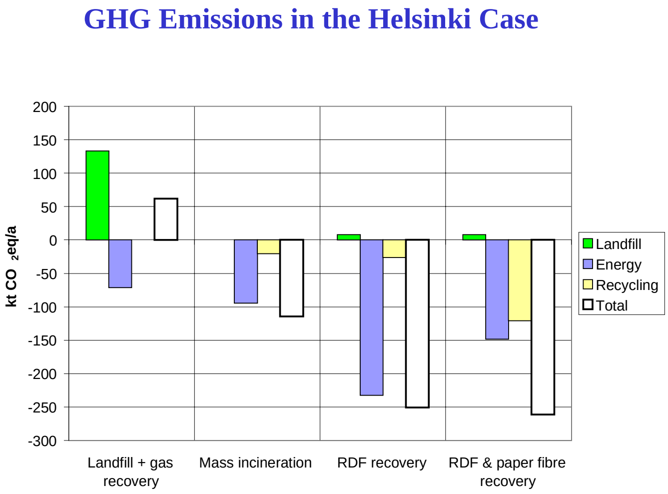

*Figure 9. Greenhouse gas emissions in different waste management options.*

In the first column a good landfill-disposal practice is presented, in column two, a good mass incineration energy practice with separate power generation at 22% net efficiency. The third column is a SRF co-gasification mode, where coal is replaced at a high efficiency of 85–90%. Most metals and glass from the REF plant are recycled.

Results are reported by Tuhkanen et al.[4].The fourth column is based on a new Urban Mill concept by Ristola[5], where additional fibre could be recovered from the solid recovered fuel stream before energy applications. The concept is based on water pulping, shown in Figure 10.

**Urban Mill**
**Novel Concept for Waste-to-Energy**
**and Recycled Paper Making**

**Principle - new solutions**

Urban Mill introduces recycled fiber based papermaking in combination with waste-to-energy. Designed for the urban context, Urban Mill utilizes the city waste streams as raw material for the paper mill and as fuel for an advanced waste-to-energy power plant.

**Material Recovery with Economy !**

**Europe 65 Mt/a**

*Figure 10. An integrated concept for additional paper recovery from MSW, Ristola*[5].

# 5. Tekes Waste to Energy Technology Programme 1998–2001

In 1998, the programme was described as follows: “The aim of the Waste to Energy Programme is to study and develop enterprise- and customer-specific

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[4] Tuhkanen, S., Pipatti, R., Sipilä, K. & Mäkinen, T. The effect of new solid waste treatment systems of greenhouse gas emissions. Fifth International Conference on Greenhouse Gas Control Technologies (GHGT-5). Cairns, Australia, 13–16 August 2000, 2000.

[5] Ristola, P. New approach to recycling and waste-to-energy in paper production, Urban Mill. Presentation at the seminar on Power Production from Waste and Biomass IV. Espoo, Finland, 8–10 April 2002.

alternatives for the energy use of different waste fractions and for material recovery with special emphasis on system study. The work will be market-oriented and focused on problems related to the energy use of wastes in enterprises. In addition, special know-how will be developed for converting wastes to fuels, and for overall waste conversion technologies. Single waste treatment techniques will not be developed generically without a clear connection with users or investment plans."

The programme will also concentrate on the characterisation and quality classification of RDF and recovered fuels in order to develop recovered fuels to real market fuels. Environmental issues related to the quality and use of waste fuels will also be studied.

The focus of the programme is on energy technology, but the whole chain must be known and all parties should operate towards the common target. The research field is not energy-specific, but with regard to overall economy, the energy use is one of the most profitable ways to utilise large waste masses in addition to material recovery. The integration of energy business to waste business enables feasible and profitable business activities and results in significant savings in waste management compared to those of landfill disposal or mass combustion.

The aim of the programme is to create a network of enterprises participating in the development of the concept for recycled fuels, including product manufacturers (producing waste from products or packages), waste producers, waste service enterprises, waste converting enterprises, material recovery enterprises, users of recovered fuels, equipment manufacturers, and researchers and authorities. This will secure the application of research results to practice and the information exchange between parties, in which problems were identified in an earlier study concerning wastes.

The programme aims at savings of about € 17/t, in waste handling costs through new systems covering the whole chain of waste management, compared to landfill disposal or mass combustion. On an annual level, this would involve savings of € 70–100 million in Finland. Reduction in greenhouse gases would be equivalent to about 2 million t/a $CO_2$ when landfill disposal is replaced by energy use."

In total 59 projects, 30 by universities and research organizations and 29 industrial projects, have been performed under the programme. The total budget has been 4.6 M€ for the research projects and 10.3 M€ for industrial projects, in total 16.1 M€ during 1998–2001. The funding from Tekes has been 2.8 M€ and 4.4 M€, in total 7.5 M€, covering 48% of the cost. Rest of the funding was obtained from industries, authorities, research organisations and universities. Additional information is available at www.wastetoenergy.vtt.fi.

Dr. Helena Manninen acted as the contact person of Tekes. Dr. Kari Mutka of Vapo Biotech Ltd. represented the industry as the chairman of the Executive Committee. Prof. Kai Sipilä of VTT Processes co-ordinated the programme.

# 6. Conclusions

In Finland, the Governmental Waste Action Plan will increase the MSW recovery from present 40% to 70% by the year 2005. EU Landfill Directive is the key driver in Finland as well as in other parts of Europe. It is estimated that by 2020 about 100 Mt/a of combustible material should be used for energy applications instead of disposing to landfills, if no new and low-price recycling alternatives are available. In Finland, the present consumption of solid recovered fuels, mainly in co-firing in multifuel fluid-bed boilers, amounts to about 300, 000 t/a. In 2005, the new EU Waste Incineration Directive will stop some SRF co-combustion due to additional cost of gas cleaning. About 20 new or updated waste to energy plants are needed in 2005 in order to reach 1 million t/a SRF volume and 70% MSW recovery rate. The main energy market is in co-firing for combined heat and power production. SRF will be produced on good source separation and fuel production practices. This is the key factor in persuading the utilities and boiler manufacturers to invest on new technologies and investments. Fluid-bed combustion and gasification with advanced gas cleaning will have the highest priorities. Integrated concepts with additional material recovery and reject fuel utilisation on energy markets will often give the highest profit to future investments. Liquid fuels for boilers, diesel power plants and transport will be a future trend in Europe besides electricity generation. The RES-E directive and the proposal of liquid fuels for transport are boosting this development.

The Finnish Waste to Energy R&D Programme has been successful. In 1998–2001 close to 60 projects were carried out, their total budget being € 16 million. The strongest benefit has been networking of various parties in the national field of waste management, authorities, industry, energy companies, research organisations and universities. European, especially Dutch co-operation through Novem, and international co-operation within IEA Bioenergy Agreement have played an even more important role in networking large groups of specialists and companies.

The new European 6. Framework Programme will open new instruments for European forums. In Finland, Tekes and various R&D organisations, universities and industries are looking actively for new instruments, like “centres of excellence” and “integrated projects” for improving the results and implementation of bioenergy and waste related research, development and dissemination activities.

# Activities of the European IPPC Bureau with particular reference to the waste incineration and combustion sectors

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## Abstract

The activities of the IPPC Bureau are discussed, with particular reference to industrial sectors, where waste is incinerated in both the dedicated incineration sector and other industries. An introduction is given to the IPPC Directive (96/61/EC), meaning and derivation of BAT, and the role Technical Working Groups (TWG) in the production of BAT Reference documents (BREF). The content and purpose of BREFs is also explained. Some specific comment is made regarding the work of the EIPPCB in respect of wastes, and on the relationship between the Waste Incineration Directive and the IPPC Directive.

## 1. The IPPC Directive

The Directive 96/61/EC concerning integrated pollution prevention and control (IPPC) requires Member States to introduce a system of operating permits for certain categories of industrial activities. The core activities covered by IPPC are given in Annex 1 to the Directive. They include waste incineration (and some other waste treatments), large combustion plants, most installations for the manufacture of chemicals; production of iron, steel and non-ferrous metals, treatment of textile; intensive rearing of poultry and pigs and the processing of animal and vegetable raw materials into food products. The Directive must be transposed into national legislation and Member States are free to apply their national IPPC legislation to a wider scope of installations than the minimum required in the Directive.

The Directive requires Member States to introduce this permit system no later than October 1999 for new and substantially changed installations and no later than 8 years later by October 2007 for all existing installations. The permit shall cover core Annex 1 activities and other directly associated activities on the site in order to consider all the important activities in an integrated way. The permit shall include conditions and emission limit values based on “best available techniques” (BAT) but taking into account local considerations such as the technical characteristics of the installation and any special needs of the local environment.

## 2. Best Available Techniques (BAT)

Article 2(11) of the Directive defines BAT.

- “best available techniques” shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole;
- “techniques” shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- “available” techniques shall mean those developed on a scale, which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
- “best” shall mean most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, in determining the best available techniques, special consideration should be given to the items listed in **Annex IV** of the Directive. Here are listed a number of considerations to be taken into account generally or in specific cases when determining “best available techniques”. This should include consideration of the likely costs and benefits of a measure and the principles of precaution and prevention:

1. the use of low-waste technology
2. the use of less hazardous substances
3. furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate
4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale
5. technological advances and changes in scientific knowledge and understanding
6. the nature, effects and volume of the emissions concerned
7. the commissioning dates for new or existing installations
8. the length of time needed to introduce the best available technique
9. the consumption and nature of raw materials (including water) used in the process and their energy efficiency
10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it
11. the need to prevent accidents and to minimise the consequences for the environment; and
12. the information published by the Commission pursuant to Article 16 (2) or by international organisations.

Note that the Directive requires a balanced decision on what constitutes BAT and that decision must take into account costs to the operator and advantages to the environment of implementing an emission reduction measure. Also note that the principle of precaution and pollution prevention is fundamental under IPPC in the way techniques includes more than just the technology involved and the emphasis placed on waste minimisation at source.

Items 4 and 5 in Annex IV demonstrate the dynamic nature of BAT, and items 6, 7 and 8 are installation specific which means that the decision on what constitutes BAT for an individual installation can only be made at the local level and that decision remains the responsibility of the competent permitting authority.

In the Directive, Article 16(2) provides that there shall be an information exchange between Member States and the industries concerned on “best available techniques” associated monitoring and developments in them and then item 12 of Annex IV then refers to reference documents being prepared under that information exchange, which is the work of the European IPPC Bureau in the IPTS Sevilla, Spain.

## 3. BAT reference documents (BREFs)

As mentioned above, Article 16(2) of the Directive states: The Commission shall organise an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring, and developments in them. Every three years the Commission shall publish the results of the exchanges of information. Also note Article 18(1) which states: Acting on a proposal from the Commission, the Council will set emission limit values, … for which the need for Community action has been identified, …

It is important to recognise that Article 16 refers to BAT and not to emission limit values and Article 18 does not refer to BAT but does refer to first identifying a need for Community Emission Limit Values which may *inter alia* be identified through the reporting of limit values set by competent authorities in permits.

For the European Commission, DG Environment have the oversight of IPPC implementation within their portfolio and in response to the obligation on the Commission under Article 16(2) have put into effect a 3 tier structure to carry out the information exchange. First was established the Information Exchange Forum (IEF), a group chaired by DG Environment with participants from Member States, some non-Member States and future Member States who are obliged to implement the Directive, Industry represented through UNICE and non-Governmental environmental groups represented through the European Environment Bureau. The IEF meet about twice a year and form a steering group for the whole information exchange exercise.

It was decided to carry out the detailed technical work with Technical Working Groups (TWGs), each dedicated to a specific work area, either addressing a vertical industry sector such as pulp and paper manufacture or a horizontal subject across IPPC industries such as monitoring or cooling systems. The European IPPC Bureau was established in late 1996 to work with these TWGs to collect relevant information and to draft reference documents reflecting the views of the TWG. The acronym of **B**AT **REF**erence (BREF) document came into use when referring to these documents.

A general outline for reference documents is developed at the IEF. For vertical industry sector BREFs some general information about the industry sector is followed by technical descriptions of the applied processes and techniques in the sector. Describing what is involved in carrying out the industrial activity, what process steps are involved so that a permitting authority considering an application for a permit might begin to appreciate the operations within the installation. Then a collection of data on current emission and consumption levels across the sector, a non-judgemental but comprehensive snapshot in time of environmental performance at the time of writing. So far this information should represent more factual information reported as background information to the subsequent chapters, which focus more on the future under IPPC.

Next comes the heart of the BREF. A catalogue of environmental techniques, in the sense of the IPPC Directive, to consider in the determination of BAT. Here is a selection of techniques, considered by the TWG to be those worth of detailed examination to assist in the decisions that have to be made within the BREF in a general sense and subsequently in determining BAT in specific cases. A standard framework to present these techniques has evolved with the writing of the first few BREF documents. Each technique is briefly described and then (as objectively as possible) the related environmental advantages, cross media and cost implications are presented together with information as to what may have driven the development and implementation of the technique, an idea of how widely it has been applied and where with references to pertinent literature. Without objective data, the expert views of the TWG are sought to complete this section.

Importantly for each technique the applicability is considered in terms of whether it is equally applicable to all installations in a sector, whether it is appropriate for new installations or there are some limiting factors as to where the technique could be applied. In this way information is presented to stimulate both the operator and the permit writer in considering what options exist at any installation. It also provides the basis for the next section on what constitutes BAT in a general sense for the sector.

Bearing in mind what has been said above, a BREF outline cannot propose emission limit values nor can it state categorically what BAT is for every installation. The determination of appropriate BAT-based permit conditions remains a decision to be made by the permitting authority. A BREF does however, present techniques that are considered to be appropriate to the sector as a whole arising from the procedure adopted in the work and reflected in the BREF as a whole:

- identification of the key environmental issues for the sector;
- examination of the techniques most relevant to address those key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and world-wide;
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques;
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(11) and Annex IV of the Directive.

Recognising the expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG), emission or consumption levels "associated with best available techniques" are to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The remaining outline of a BREF includes some information on any emerging techniques identified in the work, some recommendations for future work and a summary of the document. The document includes also a standard preface describing the structure of the document, the legislative context, the way in which the document was generated (e.g. how information was collected and assessed) and how it can be used.

From the above it is clear that there is a huge need for information to complete a BREF and the TWG is the principal source of such information. An expert within the EIPPCB is dedicated to each TWG and works with the group to collect and validate information then compile it into a draft document, which is circulated to the TWG for comments, additional information and is subsequently redrafted. The TWG meets in plenary usually only twice over a period of about two years with most of the work carried out between plenary meetings on an individual or sub-group basis. The bureau expert plays an important role in validation of information and drawing the TWG towards consensus.

Whilst a consensus view on all points within a BREF is highly desirable, it is often not achievable due to differing opinions on the cost benefit balance stemming from different importance given to certain pollutants. Many participants fear that emission levels in a BREF and associated with the use of BAT will become *de facto* emission limit values. This is an issue that will only be resolved at the time of permitting although if a permitting authority takes a strong environmental stance and sets demanding challenges for industry to meet. This follows the stated aim of Article 1 of the IPPC Directive “to achieve a high level of protection of the environment”.

## 4. Implications of the BREF documents

Clearly the unknown factor is how the series of reference documents will be used in practice under IPPC and even outside the scope of the Directive. The documents represent a wealth of information intended to guide the IPPC permit writers and industrial operators alike in pursuance of improved yet sustainable environmental performance. The emission levels associated with BAT in a BREF are not suggested emission limit values but are intended as a reference point against which to judge current performance levels, applications for permits and the eventual permits themselves. For some operators this will mean embarking upon significant expenditure to achieve better standards but for others it simply means continuing to act responsibly towards the environment as they perform their activities.

For equipment manufacturers and suppliers, and for the general public the series of BREFs represents both a snapshot of the current situation and a forward view of what might be expected as IPPC is implemented. Even for those outside the scope of the IPPC Directive or the transposing national legislation the BREFs can help to inform those who wish to become better informed on environmental issues.

IPPC is all about balancing environmental issues and considering the operation of potentially polluting industrial activities in an holistic manner considering all options to improve environmental performance. Many of the more innovative solutions to better environmental performance are integrated technical solutions with cost and process advantages to the operator. Waste minimisation and energy efficiency are good for both the operator and the environment.

# 5. Current BAT / BREF work in the waste and combustion sectors

In some cases the differences between the industrial sectors described by the Directive are very clear and there can be little debate concerning the scope of the BREF. In other cases the situation is less clear and decisions need to made concerning the inclusion of certain activities within one BREF rather than another.

In particular, it is recognised that because potential and actual wastes arise and are dealt with by a variety of industries, both within production processes, on the site of production and at off site installations, the decisions regarding which BREF should deal with which aspect requires thought.

Guidance on how to divide the work has been provided to the EIPPCB by the Information Exchange Forum (IEF). In the case of the burning of waste this dealt in particular with the division of the work between the incineration BREF and the cement & lime and large combustion plant BREFs.

With the above in mind the division of the BAT work relevant to the waste and combustion sectors as follows:

| BREF | SCOPE | STATUS |
|---|---|---|
| Waste incineration | Dedicated waste incineration, waste pyrolysis & gasification<br>Dedicated RDF burning plants | Kick off meeting held Dec 2001 |
| Large combustion plant | Combustion of primary fuels (includes bio-mass fuels)<br>Combustion of wastes and waste derived fuels with primary fuels at LCP | Draft issued<br>Under development |
| Cement & lime | Cement and lime production processes<br>Combustion of wastes and waste derived fuels with primary fuels in C&L industry | Completed |
| Waste treatments | Waste treatments – including the preparation of fuels from wastes | Kick off meeting held Jan 2001 |

## 6. Relationship between the Waste Incineration (2000/76/EC) and IPPC (EC/96/61) Directives

The most recent European legislation concerning incineration is the Waste Incineration Directive (WID) (2000/76/EC).

It is important to note that recital 13 of WID states:

*(13) Compliance with the emission limit values laid down by this Directive should be regarded as a necessary but not sufficient condition for compliance with the requirements of Directive 96/61/EC. Such compliance may involve more stringent emissions limit values for the pollutants envisaged by this Directive, emission limit values for other substances and other media, and other appropriate conditions.*

Achieving WID standards **does not** therefore automatically mean that the requirements to use the Best Available Techniques (under IPPC) have been fulfilled. The WID **does** however lay down the **minimum performance standards** for certain incinerators (exclusions are listed in Article 2.2 of WID) and will apply to new incinerators from December 2002 and to existing incinerators from December 2005.

Of interest will be that the formal record of the TWG kick-off meeting for the Waste Incineration BAT work includes the following statements:

- *It is reported that a significant number of waste incineration plants within Europe already operate at emission levels that are routinely below the ELVs in the WID.*

AND…

- *In adopting the integrated (IPPC) approach to considering the environmental performance of an installation or technique it would be incorrect to automatically assume that a technique that reduces emissions to one environmental media is automatically BAT. Determining BAT must also involve consideration of the impacts on other environmental media, energy and materials consumption, costs and reliability.*

As the work of the waste incineration TWG progresses the actual performance levels associated with the use of BAT will become clearer and enable comparisons with those minimum standards required by the WID.

## References

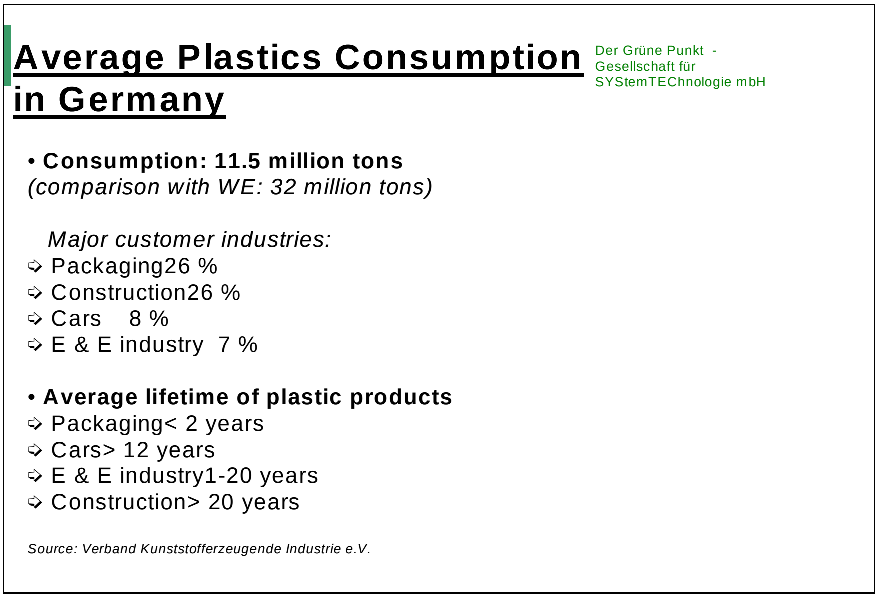
1. The IPPC Directive (96/61/EC) http://eippcb.jrc.es/pages/FAbout.htm.
2. The Waste Incineration Directive (2000/76/EC) http://europa.eu.int/eur-lex/en/lif/dat/2000/en_300L0076.html.
3. Waste Incineration (WI) FINAL Record of Kick-Off Meeting - Technical Working Group (SEVILLA 3-5 DECEMBER 2001) - visit EIPPCB website to download visit report by clicking MR on the waste incineration table entry http://eippcb.jrc.es/pages/FActivities.htm.
4. The BREF Outline and Guide – *visit EIPPC web site and click the link to the BREF Outline and Guide at* http://eippcb.jrc.es/pages/FAbout.htm.

# Resource management by the Green Dot in Germany

Dr. Gerhard Fahrbach,
Gesellschaft für SYStemTEChnologie GmbH
Germany

The recycling of materials and products will continue to become more important in the 21st century.

Packaging recycling is only the beginning and the need to recycle many of our products and materials will soon follow. Higher recycling quotas for plastics throughout the entire European Union, for instance, will increase the conservation of crude oil.



**Average Plastics Consumption in Germany**

Der Grüne Punkt - Gesellschaft für SYStemTEChnologie mbH

- **Consumption: 11.5 million tons**
*(comparison with WE: 32 million tons)*

*Major customer industries:*
➪ Packaging26 %
➪ Construction26 %
➪ Cars 8 %
➪ E & E industry 7 %

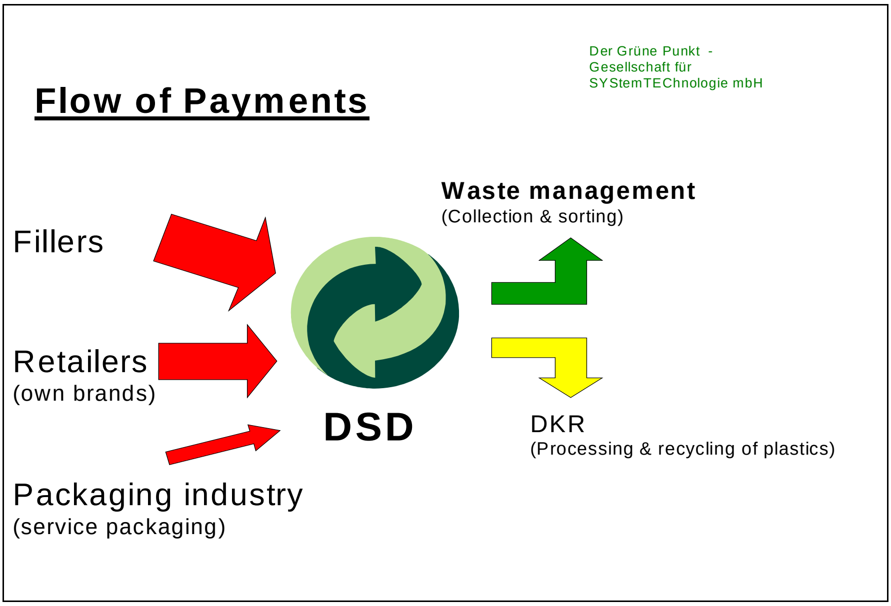
- **Average lifetime of plastic products**

➪ Packaging< 2 years
➪ Cars> 12 years
➪ E & E industry1-20 years
➪ Construction> 20 years

*Source: Verband Kunststofferzeugende Industrie e.V.*

Taking plastic packaging as an example, I would like to share with you our experiences in Germany with taking the first step towards a closed-loop economy. Because of the outstanding performance – excellent barrier and mechanical properties combined with extremely low weight – plastics play a major role in packaging. But they require immediate action of recycling because the life cycle of packaging is a maximum of 2 years, meaning that the used plastic packaging piles up immensely.

With the Packaging Ordinance in June 1991, German industry was required to take back used sales packaging for recycling. Industry and trade established a privately organized system, Duales System Deutschland AG (DSD), to solve the problem of waste recycling. Under the control of the state, DSD is a non-profit company, which operates all over Germany and organizes the collection, sorting and recycling of used sales packaging. This is carried out in densely populated cities, as well as, in rural areas.

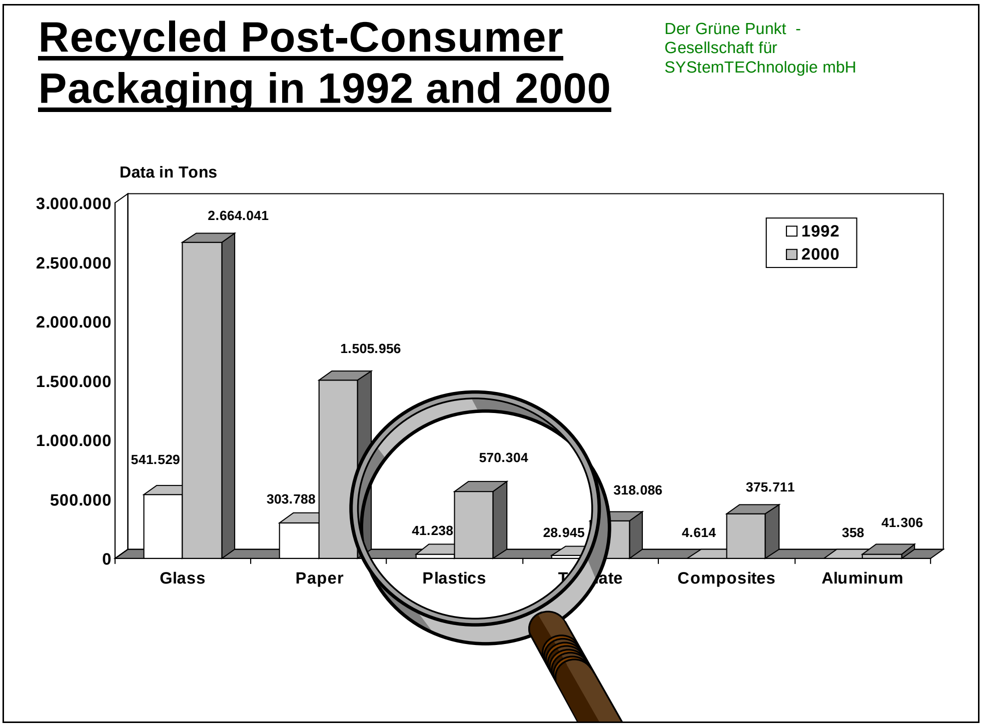


The system is financed by granting licenses to the producer and fillers for use of the Green Dot on their packaging. A viable financing model – the Green Dot – provides industry an incentive to develop and produce recycling-friendly packaging, to reduce the use of packaging and packaging materials and hence, the corresponding ecological costs. The industry, of course, may incorporate recycling costs into the product price if competitive pressure allows it.

Today, the Green Dot can look back on more than a decade of recycling. Since it started operation ten years ago, the Dual System has been able to process more than 36 million tons of packaging waste for recycling. This volume would fill a freight train with a length in excess of 67,500 kilometers and it would stretch more than one and a half times around the world.

Most important, the success of the Dual System depends largely on the consumers' cooperation. And this consumer will only participate if he or she sees the benefits of separating used packaging from the rest of the household waste. This pre-sorting at the consumer level has been a substantial contribution to the system's success. By the way, we are not the modern hangman. We are a non-profit organization.

Over 2.6 million tons of glass, 1.5 million tons of paper and 0.6 million tons of plastics were recycled from post consumer packaging in 2000 within the "Green Dot" system.


**Recycled Post-Consumer Packaging in 1992 and 2000**

Der Grüne Punkt - Gesellschaft für SYStemTEChnologie mbH

The history of the “Green Dot” system has shown a growing level of recycling volume. Taking plastics as one example, the recycling rate rose from 40 000 tons in 1992 to 570,000 tons in 2000.

The consumer accepts the Dual System. Nine out of ten German citizens separate their waste. According to a study in 1999, 65 percent of the people questioned feel that the Green Dot has proved itself.

Duales System Deutschland AG has the objective to lead in organizing a progressive resources management strategy in ecological and economic terms. This new orientation of the company was first articulated by the Green Dot at the "Resources Summit" in Berlin, a conference in held during May 2000 and focused on the future of the closed-cycle economy. One of the primary objectives of the new orientation has been to upgrade the annual mass flow verification, which documents and balances the quantity of packaging waste collected and recycled each year. To this end, the Dual System has developed a new instrument – the **resources balance**.

The resources balance clearly illustrates how packaging recycling can help to conserve natural resources. The eco-efficiency, with which packaging marked with the Green Dot is recycled, is made completely transparent in this way.

In the plastic sector, the Dual System is promoting process and product innovations in order to lower costs while improving ecological standards.

By efficiently combining automatic sorting and the processing of material streams into marketable products, the Dual System´s future aim is 100-percent recycling of all waste – not only packaging, but also sorting residue and production waste.

To this end, the logistical system of the Dual System is to be applied to other materials, such as waste electrical and electronic equipment. This will give consumers a greater chance to save resources on a day-to-day basis – without cutting down on anything they need while sustaining their quality of life.

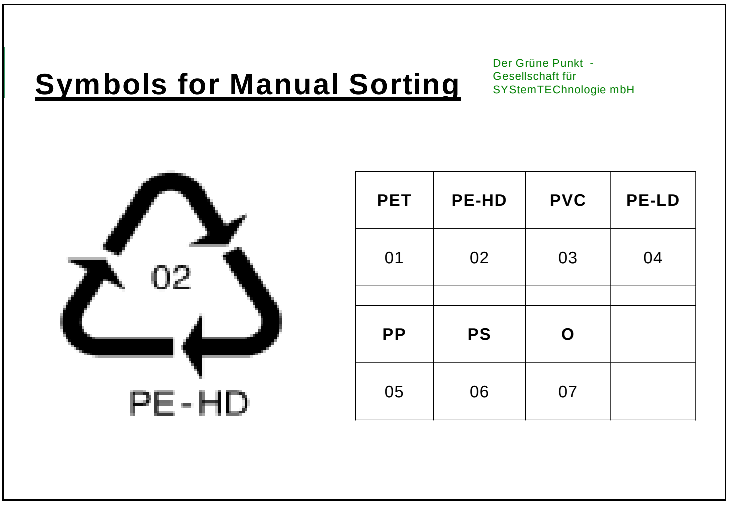
In Germany, we do not want to reduce the quality of life and we do not want to sacrifice our standard of living. We should be aware of limited resources, use where necessary, reduce where possible and do recycling where it makes sense.

The Dual System does not intend to restrict its work as a resources manager to Germany alone. The know-how and experience that have been accumulated in one decade of successful waste management are also being made available internationally. Today, the Green Dot is the most widely used trademark in the world.

The "Green Dot" license fee is still a burden on both industry and consumer. This burden can only be reduced by improving recycling technologies and/or by developing new ones. The Dual System is investing in ultramodern, fully automatic sorting and processing techniques in the sorting and processing of packaging waste while simultaneously guaranteeing a high quality output.

Founded in 1997, Der Grüne Punkt – Gesellschaft für SYStemTEChnologie GmbH (SYSTEC), a subsidiary of the Dual System, is engaged in the promotion of efficient sorting, processing and recycling techniques as well as the international marketing of recycling know-how and technologies. The ongoing development of technical know-how includes, for instance, the improvement of sorting and processing techniques and the optimization of diverse processes for the spectroscopic sorting of plastics and other sales packaging. Actually we operate about 300 sorting stations. Through automation we want to reduce to approx. 100 stations nationwide.

As mentioned before, one of SYSTEC's major goals is to market these technologies and knowhow internationally. To meet this goal, it looks for arrangements with international partners. SYSTEC has come to be known as a reliable partner for custom-tailored consulting and engineering services in numerous countries. With representative offices like in the United States, China and Japan, SYSTEC is able to provide reliable full service close the customers.



## Symbols for Manual Sorting

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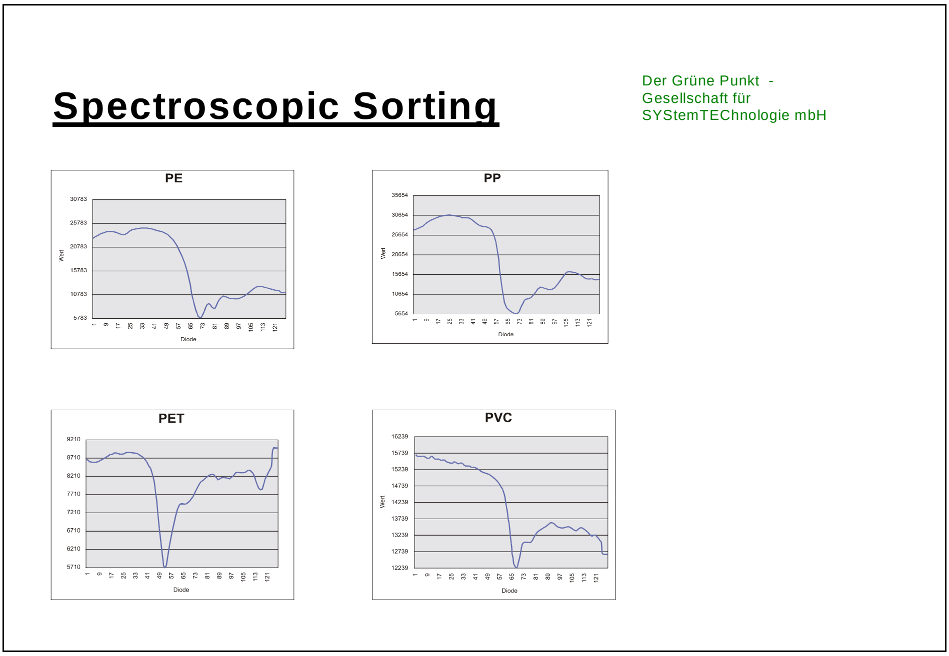
| PET | PE-HD | PVC | PE-LD |
|---|---|---|---|
| 01 | 02 | 03 | 04 |
| | | | |
| **PP** | **PS** | **O** | |
| 05 | 06 | 07 | |

The economically efficient sorting and recycling of plastics packaging is one of the most ambitious tasks the Dual System has to fulfill jointly with its contract partners. Manual sorting according to symbols printed on the packaging material is not efficient enough. Because of the variety of plastics, it is essential to separate them into homogeneous fractions each fraction offering other characteristics for numerous recycling processes. High-quality secondary raw materials can only be produced from homogeneously separated materials – especially in the plastics sector.

This is made possible by spectroscopic sorting of the different polymers. The key characteristics of spectroscopic sorting are optimum coordination of techniques for identifying materials with the near-infrared technology (NIR) and localization of packaging on the conveyor belt with cameras. NIR analyses the polymeric composition out of which the packaging is made. Special lamps illuminate and scan the objects on the conveyor belt. A camera, connected to the software, analyses the colour of the objects and compares it to the spectrum determined for separation. If both spectra correspond, pneumatic valves blow out the object.



## Spectroscopic Sorting

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The processing alternatives we represent are chemical, feedstock and mechanical recycling. SYSTEC – this technology branch of the Green Dot – besides sorting also plays a key role in developing and optimizing the dry processing of recycled plastics. Technically speaking, the processing of mixed plastics is a sequence of separating and shredding steps. Various units (above-belt magnets, eddy current separators, etc.) remove impurities from pre-shredded flakes. Subsequently the plastics are compressed into compact, transportable agglomerate with the aid of frictional heat. All agglomeration processes take place below the melting point of the plastic.

Of course, we need workhorses to get rid of 600,000 tons per year. Half of it we do with chemical and feedstock recycling.

SYSTEC technology is at the very center of agglomerate production of more than 300,000 tons per year. During feedstock recycling, agglomerate is converted into chemical raw materials for subsequent material use. This helps to conserve primary resources. The recovery of synthetic gas from mixed plastics for the production of methanol is only one example of chemical recycling processes. Every year, over 130,000 tons of mixed plastics are processed by the chemical industry to recover their primary chemical elements.

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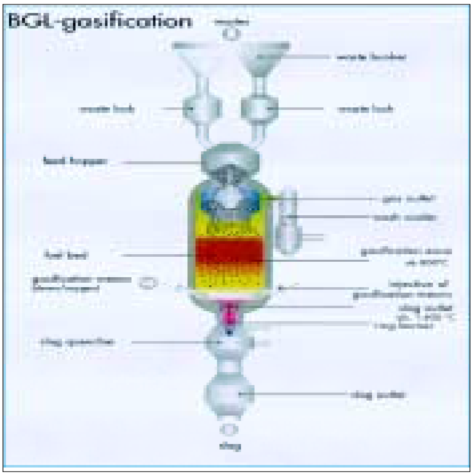
## Chemical Recycling - Gasifier



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## Feedstock Recycling - Blast Furnace

As seen, feedstock recycling is carried out not only in the chemical industry in refineries, but also in blast furnaces of the steel industry.

Over 180,000 tons of mixed plastics are annually consumed in the blast furnace process in Germany. Cumulatively, over 600,000 tons of plastic waste has been processed since 1994 as seen in the diagram, where the amounts injected into two blast furnaces are shown.

For the pyrolysis processes, plastic waste is either converted into synthetic gas or refinery products. So-called syngas is a source for C1 chemistry.

In the pyrolysis process, developed by BASF and marketed by SYSTEC all over the world, organic materials are decomposed by heat under an inert atmosphere. This naphtha-type product can be converted into olefins in a steam-cracker. The olefins are used as basic precursors or monomers for the production of plastics. A pilot plant with a capacity of 15,000 tons per year has been successfully operated for several months now.

PET has entered this field only recently but in rapidly increasing amounts. Thus, the sorting criteria “bottle” is not suitable anymore to create a sorting fraction mainly consisting of HDPE. Because of that problem, DSD agreed with its contracting partners, the sorting stations, that PET-bottles will be sorted in a different homogeneous fraction than bottles made out of polyolefines. Recycled PET packaging has considerable value. Therefore, new recycling techniques in addition to existing processes for fiber and fleece new production methods are urgently needed. In cooperation with Hamburg University, SYSTEC is developing a chemical decomposition process that uses the PET fraction chemically and tolerates colors, dirt, incorrect sorting and varying composition without producing the unwanted inorganic salt. Also the bottle-to-bottle technologies have advanced from the research to the production level.

The other half – 300,000 tons – we do recycle mechanically. The plastics are separated increasingly by automation, thoroughly washed and granulated for use in the production of plastic articles. Using several NIR-units for sorting plastics, PE, PP, PS and PET can be separated into different fractions. Thus, a considerably higher share of homogeneous plastics fractions is produced in an economical way for high-quality mechanical recycling compared to manual sorting of bottles and cups. These are only a few examples that demonstrate the varied use of recycled plastics. Huge fields coming up are drainage systems and plastic pallets substituting wooden pallets.

## Examples for mechanical recycling

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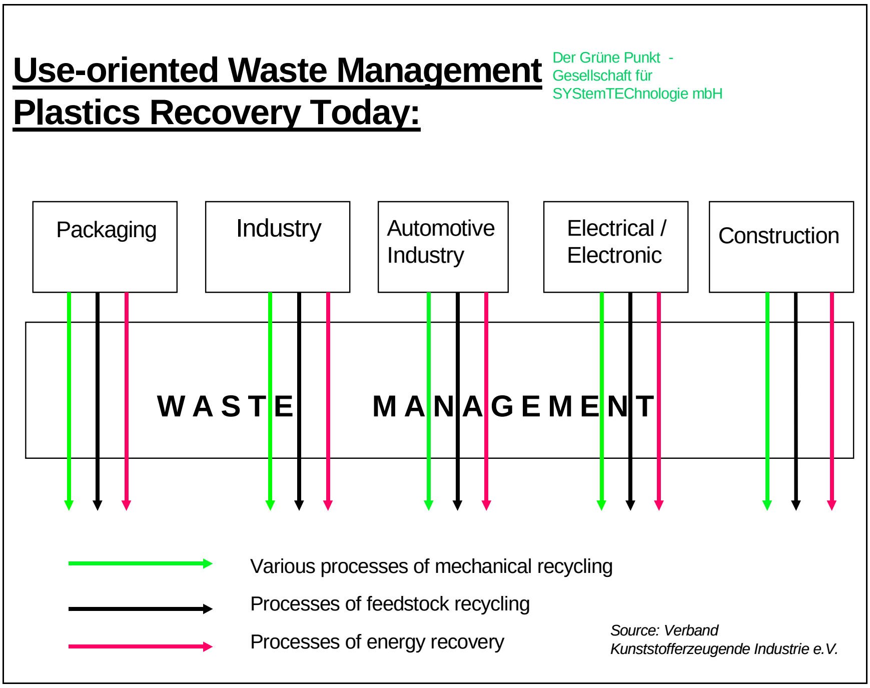

## Use-oriented Waste Management Plastics Recovery Today:

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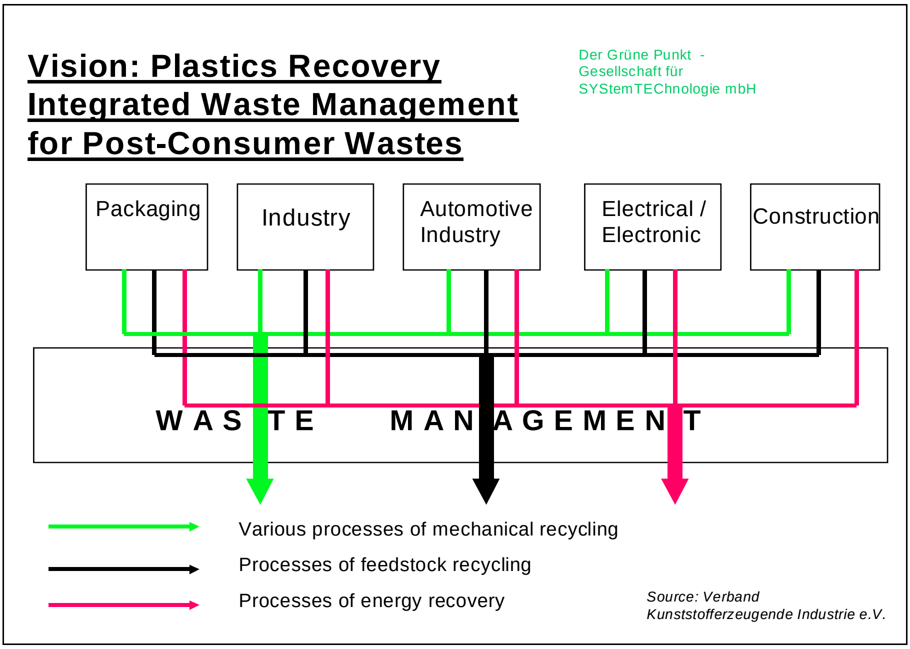
→ Various processes of mechanical recycling

→ Processes of feedstock recycling

→ Processes of energy recovery

*Source: Verband Kunststofferzeugende Industrie e.V.*

Actually, all sectors are still following individual recycling and recovery routes. But all industrial sectors involve plastics that are recyclable with identical equipment and know how. Polypropylene does not care whether it was a car bumper or a yogurt cup.



**Vision: Plastics Recovery Integrated Waste Management for Post-Consumer Wastes**

Der Grüne Punkt - Gesellschaft für SYStemTEChnologie mbH

*Source: Verband Kunststofferzeugende Industrie e.V.*

The integrated approach in my opinion is absolutely necessary to reduce recycling costs. Not only in plastics manufacturing, but also in its recycling, economy of scale is extraordinarily important.

Recycling plays a central role because it conserves resources and necessitates the consistent use of efficient techniques and creativity for the benefit of economy and ecology for mankind and nature.

# MSW management policy and practices in Helsinki region

Jukka Paavilainen
YTV Waste Management Department
Helsinki, Finland

## 1. Introduction

Helsinki Metropolitan Area Council (YTV) is a statutory, co-operative organisation operating in the municipalities of Helsinki, Espoo, Vantaa and Kauniainen. YTV works on waste management, public transport and land use co-operation, and monitors the air quality in the metropolitan area.

The YTV Waste Management Department plans and develops waste management, and co-ordinates waste transports; it handles waste and composts biowaste, collects in some extent reusable waste, and manages hazardous waste; YTV also gives advice on waste management in the metropolitan area.

The metropolitan area population is approximately 960,000 on an area of approximately 740 km$^2$. The area is about 95% urban and is made up of 75% high-rise apartment blocks. Approximately 450,000 households are covered. The average population density is 1,260 people per km$^2$, though the density is much higher in the urban centre.

The metropolitan area produces about 1.1 million tons of waste every year. Close to 600,000 tons of the total amount of waste is taken to the YTV waste-handling centre in Espoo. The only landfill site in the metropolitan area is also located at the same site and it and receives about 400,000 tons of municipal waste. Some 55% of all the waste produced in the metropolitan area is recycled or reused.

The operational strategy of YTV Waste Management has been divided into three substrategies:

1. the waste minimisation strategy, which aims at reducing the amount of waste generated and increasing recycling through source separation of waste;
2. the strategy for safe and customer-oriented waste management services; and
3. the strategy for treatment and final disposal of waste.

## 2. Waste avoidance and reuse

YTV has prepared this year the Helsinki area waste prevention strategy. According to the strategy and previous measures the main tools for waste prevention are information and training for various target groups, e.g. schools, institutions, companies.

As an example, YTV has created a continually updateable, customer-oriented waste benchmarking system to be viewed on the web pages of YTV. In these pages the joined companies can compare their proportional waste production with the other firms of same type. The benchmarking system also gives good hints to minimise the waste production. To promote the use of the system, YTV selects the winner of the annual title of "The Natural Resources Saver" from among the organisations, which have participated in the benchmarking system. The title is in good use in the winning companies PR and advertising work.

Reuse opportunities are offered by the Recycling Centre Ltd., which is partly owned by YTV. The Recycling Centre Ltd operates three sites in the metropolitan area. The Recycling Centres run flea markets, repair shops for old goods and goods exchange services, and provide environmental information and training services.

## 3. Waste collection and transport

YTV arranges waste (refuse and biowaste) transport for most households: 80% of the general population are YTV's clients. The rest, i.e. the dwelling houses in the city centre of Helsinki, make their own waste collection arrangements. Also industrial and commercial property owners are responsible for collection and transport of their waste.

The "YTV areas" are divided into 60 sub areas called squares, and YTV prepares waste transport plans for each and then the plans are sent out for bidding. Generally, waste is collected and transported by waste collection vehicles equipped with compaction machinery. Over 80% of household waste is collected in 600–660 litres waste bins.

Waste transport is based on competitive bidding among private companies. A winning company gets a fixed price contract for five years period. The system has cut the collection costs. Simultaneously the quality and environmental impacts of the waste transports have improved due to the challenging demands set forth in the contracts.

# 4. Biowaste

Separate collection of biowaste was started in 1993 and is covering the whole area. The collection takes place weekly. All compostable food and garden wastes are collected.

Larger blocks over nine flats/block, which are covering about 75% of the population and larger producers (cafeterias or restaurants with over 50 kg of biowaste per week) have to join the separate collection of biowaste. Small apartment blocks (less than 10 apartments) and one-family houses do not participate in biowaste collection but YTV promotes home composting by leasing good-quality composters. A wide variety of information material for home composting is also available in YTV’s waste advising department.

In 2001, 34 000 tonnes of biowaste was collected. This material was delivered to the Ämmässuo biowaste composting plant.

# 5. Recyclables

The Metropolitan area waste management regulations require separate collection of paper from premises comprising more than four dwellings and also of cardboard and office paper from major producers. Premises subject to separate collection have paper and cardboard collection bins in their refuse areas.

For small apartment block areas, there are approx. 400 area collection points for paper. Paperinkeräys Oy (waste paper receiving company jointly owned by Finnish paper companies) carries the producer’s responsibility in collection of the waste paper. The recycling rate of paper is now over 80% in YTV area.

For the packaging recyclables as glass, metals, cardboard and collection bins in the metropolitan area are mainly situated near the larger shopping centres. The system is now converting to producer’s responsibility principle.

# 6. Hazardous waste

YTV is responsible for the hazardous waste management of households in its operating area. Also most of small and medium-sized enterprises use YTV’s hazardous waste services. A major processor of hazardous waste in Finland is Ekokem Oy, which operates in Riihimaki.

Hazardous household waste is collected in various ways, such as:

- At permanent hazardous waste collection points. There are over 100 points comprehensively covering the metropolitan region;
- In spring and autumn hazardous waste collection vehicles pick-up material from 400 locations in the metropolitan region;
- At many of the glass collection points in the area there are also collection bins for small used batteries.

# 7. Landfilling of residual waste

The Ämmässuo landfill is the largest in Finland. The total area is 150 hectares and the heaping area currently in use covers 50 hectares. In 2001, 362,000 tons of residual household waste was deposited in Ämmässuo landfill. The currently used area is expected to be sufficient for landfilling to the year 2006.

Waste deliveries to Ämmässuo are fully controlled. All waste loads are weighed and the amounts and type of materials are registered on computer. Waste tipping on the area is monitored by YTV's load inspectors, who check the grades of refuse coming into the landfill. After tipping, the waste is crushed and compressed with landfill compactors and covered daily with a layer of sand.

The landfill is built partly on solid rock and partly on 2 mm thick plastic membrane, which protects the groundwater. All leachate waters in the landfill area are channelled through drains to their own balancing basin, where they are pumped over 6 kilometres to Suomenoja sewage works in Espoo for treatment. The landfill is also equipped with landfill gas collection and recovery system.

# 8. YTV's waste treatment strategy

YTV has planned a waste treatment strategy, which shall be implemented in the end of year 2005. The targets of the strategy arise from expected changes in waste legislation and from tendency towards to ecologically sound waste treatment. In the first phase, YTV has prepared a report of the measures how to reach the above-mentioned targets. The strategy focuses on the residual waste and it's not contradictory or replacing any existing source separation based recycling activities or waste prevention measures.

The technology to be implemented according to the strategy is mechanical-biological process. With a combination of crushing-, separation- and sieving unit-operations the easily biodegradable fraction is diverted and led to biological treatment. The biological treatment can be either composting or digestion with subsequent composting phase. The main idea of biological treatment is to produce possibly inert and homogenous reject fraction to the final disposal. This reject shall be deposited to the extension area adjacent to the present landfill.

Due to the thoroughgoing biological treatment the new deposition area creates only little landfill gas. Thus the greenhouse effects of landfill are minimised. Odour-, bird- and leachate problems can also be avoided simultaneously.

## 8.1. Energy recovery

The treatment plant produces as by-product separated metals for recycling and refuse derived fuel (or recovered fuel, REF), which can be used in energy production substituting fossil fuels. In the strategy it’s estimated, that maximum 200,000 tpa REF could be produced of the dimensioned incoming 430,000 tpa residual waste. In spite of the fact that YTV is not going to invest on the waste-to-energy plants, YTV has co-operated in various projects to promote the creation of REF using capacity in the metropolitan area.

According to the studies, the only realistic alternative to use recovered fuels in the existing power plants within the metropolitan area is their co-combustion either through gasification or in a separate RDF boiler. As it would be technically difficult to use gasifier product gas in existing gas turbine power plants, a decision was made to study the alternative of using this product gas as a fuel in an existing pulverised-coal boiler. In addition, the use of a separate REF boiler in connection with an existing coal-fired power plant by connecting the steam circuits of the REF boiler and the ‘main’ boiler is being surveyed. The fuel output of the REF plants examined ranges 60–80 MW, which means that the volume of recovered fuels required ranges 70,000 and 100,000 tons per year.

The first REF gasifying project in the capital area has finished the environmental impact assessment (EIA) procedure. The plant is planned to be built in connection to the Vantaa Energy's Martinlaakso pulverised-coal power plant. The receiving capacity of the gasifier is planned to be 80 000 tpa REF.

## 8.2 Economical impacts of waste treatment strategy

The planned waste treatment plant and new landfilling area will increase remarkably waste treatment costs. According to the report, the investment costs on waste handling (plant and the new landfill area) will be 100–160 M € by the year 2020. The investment to the plant is estimated to be over half of this sum.

Big investments and respectively high running costs will also increase the waste handling fees. The waste treatment fee is estimated to climb from today's 50 €/t to approximately 150 €/t.

YTV has started the EIA procedure of waste treatment plant in the year 2001. According to present schedule the plant shall be operating in the end of the year 2005. Possible appeals against the permit procedures may postpone this schedule, in worst case, by years.

# Waste separation and energy recovery – energetic and environmental assessment of the complete chain

## Recent developments in the Netherlands

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*KEMA is an independent organization providing services in the field of electrical energy, environment and quality on a professional basis. Its core activities are: research and development, consultancy, testing and inspection as well as product/system certification.*

*KEMA Power Generation & Sustainable:*

- *develops*
- *provides engineering and consultancy services*
- *and optimises*

*effective and reliable solutions for fossil fuelled power plants as well as biomass/waste to energy systems, regarding fuel treatment, plant efficiency, handling and disposal systems and effluent reduction and control systems, with an emphasis on prevention and recycling.*

# List of abbreviations

| | |
|---|---|
| AOO | Dutch Waste Management Council |
| CFB | Circulating Fluidised Bed |
| CSW | Cleaning service waste |
| DW | Demolition waste |
| EPM | Energy performance measure |
| GHHW | Course household waste |
| HHW | Household waste |
| HW | Hazardous waste |
| IW | Industrial Waste |
| NWMP | National Waste Management Plan |
| OR&SW | Office retail and service waste |
| OWF | Organic waste fraction |
| PPF | Paper and plastic fraction |
| RDF | Refuse derived fuel |
| SW | Shredder waste |
| Direct co-firing | Direct mixing of coal with a secondary fuel upstream the hammer mills or by separate grinding and transportation to separate burners in the same coal fired boiler. |
| Indirect co-firing | Separate combustion or gasification upstream the coal fired boiler. Flue gases (from the combustor) or fuel gases (from the gasifier) can be processed at the coal or gas fired power station. |

# 1. Waste incinerator 2005: energetic and economic performance

In the Netherlands, people are presently debating, whether additional domestic waste incineration capacity should be created in the near future, following a period of some years, in which capacity has not been increased. One of the questions being addressed in this context is, whether any new thermal processing capacity should be based on grate furnace technology or one of the new alternative technologies. In order to provide a common basis for the comparison of grate furnace technology with these alternative technologies, a study was made of recent developments in grate furnace technology and their implications for any grate furnace-based domestic waste incineration plants that might be built in the near future. Other new ideas presently being explored, such as fermentation, direct co-firing, etc, were deliberately excluded from the study.

Following identification of the most recently developed grate furnace designs, the technologies in question were studied to assess their potential for use in a waste incineration plant to be commissioned in around 2005. The implications of each of the most promising technologies for the energetic and economic efficiency of the hypothetical plant were determined in relation to three scenarios. Using the calculated data, three models were developed for the 2005 waste incinerator:

- model 1: emphasis on minimising processing costs and maximising reliability;
- model 2: emphasis on maximising electrical efficiency and minimising atmospheric and soil pollution;
- model 3: emphasis on continuity with existing plants, subject to certain improvements in terms of electrical efficiency and bottom ash quality.

In view of the increasing competitive pressure (which will in the future come from sources both inside and outside the Netherlands) to control processing costs, model 1 is considered preferable. With this model, it was calculated that the cost of processing would be EUR 65 per ton, assuming a net electrical efficiency of 24 percent and a private generator tariff of EUR 0.041 per kWh (including 50 per cent regulatory energy tax).

It was calculated that model 2 would have a net electrical efficiency of 29.7 per cent. However, given the private generator tariff referred to above, the cost of processing would be EUR 81 per ton, because the capital cost of this model would be considerably higher. This model, combined with clean residues, constitutes the “government variant”. The third model, which is most similar to existing incinerators, falls between the other two both in terms of net efficiency (26.2 per cent) and in terms of economic efficiency (EUR 75 per ton). Under the present circumstances, model 3 is probably the most practicable model. In other words, the existing incinerators are already very similar to the best option for 2005.

The margin of error in the processing cost calculations is estimated at 15 per cent in absolute terms and about 5 per cent in relative terms (i.e. in terms of the comparability of the figure for one model with the figure for another). However, the cost of processing at a particular plant could differ significantly from the calculated figure because of local factors.

In many cases, there is little motivation to modify existing waste incineration plants to make use of newly developed technologies, largely because the economic value of the existing equipment has yet to depreciate sufficiently for replacement to make financial sense. However, there are three waste incineration plants in the Netherlands whose boilers are nearing the end of their service life. When the time comes for refurbishment of the thermal equipment at these plants, it may be possible to make use of (some) of the new technologies now available.

It does not appear that there is yet any serious alternative to grate furnace combustion in the context of mixed domestic waste incineration. Fluidised bed combustion may in time, however, prove a realistic option for the incineration of certain domestic waste components or other homogeneous forms of waste.

# 2. EPM benchmarking of NWMP scenarios

## 2.1 Introduction

In ten years' time, the AOO anticipates that national production of non-reusable combustible waste will be about eleven million tons a year. This includes a total of about 8.5 million tons of domestic waste (DW), coarse domestic waste (CDW), office, retail and service waste (OR&SW), industrial waste (IW) and construction and demolition waste (C&DW) (Figure 1a). In addition, by the middle of 2012, we will be producing 2.5 million tons a year of "other" waste: sludge, cleaning service waste (CSW), shredder waste (SW) and hazardous waste (HW) (Figure 1b).

Despite measures to prevent waste production and to promote the reuse of products and materials, much of this waste will be suitable for energy recovery and final processing.

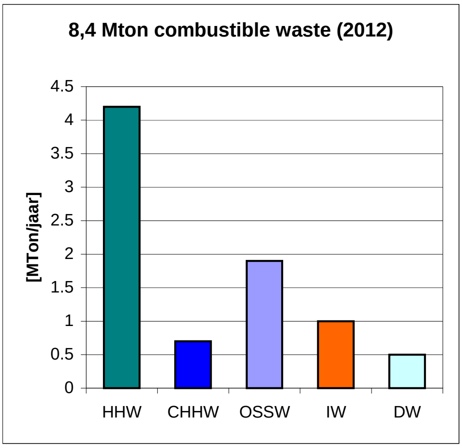

*Figure 1a.*

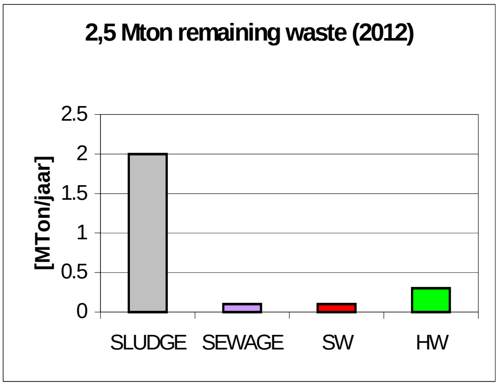

*Figure 1b.*

At present, roughly five million tons of waste is incinerated at the Netherlands' eleven waste incineration plants. Most of the rest of the waste produced – about three million tons a year – is tipped, with the remainder being exported. The tipping of combustible waste is undesirable. The government has recently introduced and increased a levy on the tipping of waste to discourage the practice.

The alternatives to tipping are as follows:

- The separation of various types of waste to produce refuse derived fuel (RDF) and possibly a paper/plastic fraction (PPF), both of which can be used as secondary fuel in high-efficiency plants such as power stations and cement furnaces, with the remaining waste – the organic wet fraction (OWF) – going to waste incineration plants since tipping is undesirable.
- Mixed waste incineration in new high-efficiency waste incineration plants, with reuse of the residues.

On behalf of the AOO, CE has carried out an investigation [CE, 2001] to identify the most appropriate alternative (waste separation or mixed waste incineration) for the National Waste Management Plan (NWMP). For each of the defined scenarios, the amount of energy recoverable from combustible waste has been calculated and the environmental implications of such waste recovery determined. KEMA was asked to benchmark the scenarios using the Energetic Performance Measure (EPM) for a workshop entitled “Utilising the energetic potential in our waste” held on 16 January 2002.

## 2.2 Energetic efficiency of NWMP scenarios for waste incineration

KEMA performed an EPM benchmarking exercise for four scenarios, using 2012 as the reference year and the quantities of waste forecast by the AOO. The benchmarking took account only of plants that generate electricity under optimal conditions, without residual heat utilisation.

### A Status quo (two million tons a year tipped)

The first scenario assumes that the waste processing industry and incineration arrangements remain as they are today. Domestic waste (four million tons a year) and industrial waste (about 1 million tons a year) would go to the existing incineration plants. The OWF from the Wijster plant and ARN would be tipped. About 400,000 tons of PPF a year from industrial waste separation plants would be sent for use at power plants. Unseparated industrial waste (at least two million tons a year) would be tipped.

### B Mixed waste incineration (no tipping)

The second scenario assumes that low calorific-value waste (domestic waste and other comparable forms of waste) would be incinerated at existing waste incineration plants. High calorific-value industrial waste would be burned without separation at new incineration plants with water-cooled grate furnaces or would first be processed and then incinerated in fluidised-bed furnaces.

## C Maximum RDF production (0–0.5 million tons a year tipped)

This scenario is based on all waste flows (domestic waste, coarse domestic waste and industrial waste) being separated into distinct categories, as is presently done at the Wijster plant and the ARN. One alternative technology is the *Herhof Trockenstabilat Verfahren*. Under this scenario, 1.5 million tons of OWF a year, mainly of domestic origin, would be fermented (VAGRON concept). The energy yield of fermentation has been determined in the context of the EPM calculations. Roughly 0.5 million tons of inert separation residue a year would be reused or tipped. The RDF (three million tons a year) would go to new high-efficiency waste incineration plants (CFBs). Nearly 0.8 million tons of PPF a year would be disposed of in the power stations. The low calorific-value residual fraction (2.1 million tons a year) from industry would go to waste incineration plants. Roughly 0.5 million tons a year (metals and such like) would be recovered.

## D Maximum PPF production (0–0.5 million tons a year tipped)

This scenario is based upon waste separation using the VAGRON concept:

- Separation and fermentation of the OWF (at least 33 per cent from household sources and 5 per cent from industrial sources: 1.5 million tons a year), with the biogas being used to power gas engines and the digestate (0.5 million tons a year) going to existing waste incineration plants.
- Separation of PPF and waste wood (2.3 million tons a year) by wind sifting from the RDF production (3.4 million tons a year), with the PPF going to power stations and the RDF to existing waste incineration plants.
- Reuse of metals and inert materials (0.7 million tons a year) and possibly a limited amount of tipping (0.5 million tons a year).

Like the RDF scenario, the PPF scenario would require sufficient processing capacity to handle a total of 8.9 million tons of waste a year, i.e., 0.5 million tons a year more than the primary waste production, since the digestate produced would have to be disposed of at waste incineration plants. The PPF scenario is the most far-reaching of the four, and would result in 7.7 million tons of sorted waste a year being made available for energy recovery.

The EPM benchmarking was carried out on the basis of the assumptions set out in the appendix. The results of EPM benchmarking of the four NWMP scenarios are summarised in Table 1.

*Table 1. Results of EPM benchmarking of NWMP scenarios.*

| **Scenario** | EPM<br>% | **Generated electric power MWe** | **Fossil fuel use avoided[1)] PJ/year** | **Increase relative to status quo %** |
|---|---|---|---|---|
| Status quo | 15.3 | 500 | 31 [2)] | – |
| Mixed waste incineration | 24.8 | 810 | 50 | + 62 |
| Maximum RDF production | 27.4[3)] | 880 | 55 | + 79 |
| Maximum PPF production | 27.9 | 918 | 57 | + 82 |

1) Based on the electrical efficiency of Dutch power stations, assuming a fuel mix of 45 per cent coal and 55 per cent gas and an average electrical efficiency of 43.5 per cent.

2) Not corrected for emissions to the atmosphere from tips.

3) If OWF is tipped, the EPM of the RDF scenario works out at 27.0 per cent.

## 2.3 Realism of NWMP scenarios

The realism of the various the NWMP scenarios is considered below.

### A Status quo

The tipping of combustible waste represents a missed opportunity, since such waste could be used for the production of electricity. If sufficient waste incineration capacity were created in the Netherlands to make the tipping of combustible waste unnecessary, it would be possible to produce roughly 720 MWe, rather than 500 MWe, given an average EPM of 22 per cent. This would mean using 14 PJ less fossil fuel-derived energy a year, or a 44 per cent increase in energy conservation through the use of waste. The status quo scenario is therefore undesirable, partly because of the space needed for tipping.

### B Mixed waste incineration

The existing waste incineration capacity (5 million tons a year) would be devoted entirely to the processing of domestic and coarse domestic waste and the low calorific-value residual fraction of industrial waste. Some 2.5 million tons of industrial waste a year would go to newly created high-efficiency waste incinerators. It is estimated that the calorific value of such waste would be 13.7 MJ/kg. This scenario has advantages and disadvantages: the existing waste incineration capacity would still be utilised, so there would be no premature write-off of assets due to redundancy.

The construction of high-efficiency waste incineration plants is more capital-intensive than the creation of less electrically efficient plants. Furthermore, high-efficiency plants are more complex, which can adversely affect reliability. These disadvantages could be offset by:

- increasing plant scale by 30 per cent
- substantially increasing private generator tariffs for electricity (or regulatory energy tax rebates)
- combining heat and power generation to achieve an EPM of 30 percent

These measures do not appear realistic without additional government support.

### C RDF production

Under this scenario, existing waste incineration capacity would be largely closed down; plant sufficient to process a maximum of two million tons a year would remain in use. New high-efficiency CFB capacity would have to be created for at least three million tons of RDF a year, with a calorific value of up to 17 MJ/kg. Fermentation capacity for 1.5 million tons of OWF a year would also need to be created.

The RDF scenario is not realistic in the short term. It has two serious drawbacks:

- The redundancy of waste incineration plants with a total capacity of three million tons a year would involve the premature write-off of assets;
- At 6.5 MJ/kg, the calorific value of the residual waste sent to the existing waste incineration plants would be too low for normal operations. Technical modifications to allow such waste to be processed are not feasible.

Furthermore, it would be necessary to cover the additional capital cost of high-efficiency CFBs, while ensuring that the international competitiveness of Dutch waste processors was not compromised.

### D PPF production

3.9 million tons of low calorific-value waste a year (8.8 MJ/kg) would be processed at existing waste incineration plants. Some 2.3 million tons of PPF a year would go to power stations and 1.5 million tons of OWF a year would be fermented. Various criticisms of the PPF scenario have been voiced within the waste processing and energy generating industries. These include the following:

- 2.3 million tons of PPF production a year would only be viable if there was a guaranteed market (coal-fired power stations and cement furnaces); investors are unlikely to put up the necessary capital on the basis of the free-market demand alone. Government intervention would therefore be required.
- Because the balance between fuel types is critical, the theoretical limit on the amount of PPF that can be used for direct co-firing in coal-fired power stations in the Netherlands is one million tons a year. However, the practical limit is lower. This means that at least 1.3 million tons a year must be exported. If by mid-2005 neighbouring countries were to have introduced tipping bans on combustible waste, it might be difficult to find export markets for PPF. The possibility of a fall in the market value of FFP cannot be excluded, which would lead to heightened risks for environmental companies.

- It is not desirable to make waste incineration plant with a capacity of one million tons a year redundant in the short term. Furthermore, this scenario would lead to a fall in the calorific value of waste processed by 1 MJ/kg.
- Fermentation of OWF is not necessarily the most appropriate method of processing.

An indicative technical and economical assessment of the NWMP scenarios is presented in Table 2.

*Table 2. Indication of technical and economical advantages and disadvantages of the four scenarios.*

| Scenario | EPM % | Technical simplicity | Economic efficiency2) |
|---|---|---|---|
| Status-quo / Reference | 15.3 | | |
| Mixed waste incineration | 24.8 | ± / – 1) | – 3) |
| Maximum RDF production | 27.4 | - | – |
| Maximum PPF production | 27.9 | - | Uncertain |

1) The technical simplicity is negatively influenced by the introduction of new high-efficiency waste incineration plants.

2) The influence of the tipping tax is not included in the estimation of economic performance.

3) The construction of high-efficiency waste incineration plants (electrical efficiency: 30 per cent) for the incineration of 3 Mtons a year would involve greater investment than the construction of lower-efficiency plants.

## 2.4 Recommendations regarding the recovery of more energy from waste

The recovery of more energy from waste requires substantial investment:

- investment in thermal processing capacity if the emphasis is on mixed waste incineration
- investment in separation plants and in the structure for marketing separation products to power stations, cement plants, etc.

Furthermore, it is important that operational continuity is secured for the depreciation period of the assets.

In the next ten years, considerable benefits can be secured by incinerating mixed waste, which would otherwise have been tipped (scenario B), in plants whose electrical efficiency is moderate (known as commercial waste processing plants; see also Waste Incineration Plant 2005 report). There are two reasons for this:

1 Such a policy would improve energy utilisation levels by 44 per cent compared with the present situation (average EPM of 22 per cent instead of 15.3 per cent);
2 The existing plants are more economical than high-efficiency waste incineration plants.

Waste processing should be organised on an environmentally responsible basis (primary objective). Improved energy utilisation can contribute in this context (secondary objective).

## 2.5 More energy recovery from waste?

It is possible to recover more energy from waste, but the associated investment uncertainties and risks increase as this policy is pursued further:

- High-efficiency waste incineration plants would need to be based on technology that was as reliable as that used in existing plants. However, no suitable designs are presently available;
- It would be necessary to compensate for the competitive disadvantages of high-efficiency waste incineration plants by attaching a higher financial value to the electricity and heat produced at such plants;
- The importance of guaranteed markets for RDF and PPF separation products in the power generation industry would become more important if production were increased. Without guarantees, there would be a danger of demand collapsing, making it necessary to tip separation products, which would obviously be more expensive than tipping non-separated waste, and would undermine support for the separation of waste;

- The scope for direct and indirect co-firing of waste in coal-fired power stations depends on the quality and controllability of separation products. Unless uncertainties in this area can be removed, indirect co-firing in ‘upstream’ installations would be the safest approach, but this has the disadvantage of also being the most capital-intensive approach.

The following recommendations are made regarding the short term:

- The existing waste incineration capacity should continue to be fully utilised. Waste separation should be used only in the processing of industrial waste that contains little or no OWF and can readily be divided into high calorific value RDF/PPF and low calorific value fractions;
- The sale of PPF to coal-fired power stations should be subject to critical assessment. Indirect co-firing in ‘upstream’ combustion or gasification installations would appear to be preferable to introducing the PPF via the coal pulverisers or separate burners in the coal boiler;
- Direct co-firing along with the coal is generally an option only with relatively clean fuels (wood and primary energy carriers), since with other forms of waste the risk of boiler corrosion is too great and the quality of the fly ash cannot be easily guaranteed.

The EPM for this scenario, which is a sort of middle way between scenarios B and D, without OWF production from domestic waste, works out at 25.6 per cent. The features of this scenario are:

- 1.3 million tons of PPF a year (rather than 2.3 million tons) would be indirectly co-fired in upstream installations; of this, 0.5 million tons a year would be exported and 0.8 million tons used in the Netherlands. Alternatively, indirect co-firing by means of gasification should be considered, since this would be preferable – from the point of view of integration – to upstream firing in an installation connected to the steam circuit.
- The remaining industrial waste would go to waste incineration plants, requiring the creation of additional (high-efficiency) capacity capable of processing 1.5 million tons of waste a year.

Further energetic optimisation would be possible, but in the context of a long-term scenario.

A slightly higher EPM of 26.6 per cent could be achieved if 1.3 million tons of PPF a year were directly co-fired in coal boilers. However, it is possible that this could adversely affect the life expectancy of the boilers and the saleability of the fly ash.

In view of the additional costs and operational risks involved, it is questionable whether energetic optimisation along these lines is viable in an increasingly pan-European waste market.

## 2.6 Conclusions of the benchmarking exercise

Separation and refinement into RDF/PPF is only appropriate for industrial waste.

1. PPF production and direct co-firing is energetically attractive even though PPF pre-processing would bring the EPM down by about 5 per cent.
2. The scope for direct co-firing at coal-fired power stations in the Netherlands is limited because of the critical co-firing limits and competition from biomass.
3. NWMP scenario A (status quo) has an EPM of 15.3 per cent. The EPM for scenario B (mixed waste incineration) is 24.8 per cent. NWMP scenarios C and D produce higher EPMs (27 to 28 per cent) but would involve the redundancy of existing waste processing plants.
4. An alternative scenario, involving the construction of new (high-efficiency) waste incineration plants to add to the existing capacity and moderate levels of PPF production from industrial waste, has an EPM of 25.6 per cent. This scenario could be realised in the short term. Furthermore, an EPM of up to about 27 per cent could be achieved, making this scenario energetically comparable to AOO scenarios C and D.

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# Appendix 1. Assumptions for EPM Benchmarking of NWMP scenarios

### Assumptions for EPM benchmarking

| Processing option | Type of waste | Net electrical efficiency |
|---|---|---|
| Existing incineration plants | Heterogeneous waste <11.5 MJ/kg<br>Domestic waste or comparable waste<br>Residual waste separation fractions<br>Digestate | 22 per cent[1)] |
| High-efficiency waste incineration plants | High calorific-value industrial waste > 11.5 MJ/kg<br>RDF | Maximum: 30 per cent[2)] |
| Separation and fermentation (VAGRON) | Domestic waste or comparable waste<br>OWF fermentation; biogas => gas engine | 13 per cent electricity from ONF[3)] |
| Co-firing in coal-fired power stations | PPF/waste wood | 35 per cent[4)] |

1) Source: VVAV

2) TNO/KEMA, 2001. AVI-2005: Evaluatie van huidige en toekomstige technologische ontwikkelingen voor de roosteroven voor het verbranden van huishoudelijk afval [Waste incineration plant 2005: Evaluation of present and anticipated technological developments in the use of grate furnaces for the incineration of domestic waste]. For Novem/VVAV

3) EMW/KEMA, 2001. MER-Systeemkeuze ONF-verwerking [EIS system selection OWF processing]. For Essent Milieu, Wijster. Separation fractions different from OWF: see efficiency figures for existing incinerators, high-efficiency incinerators and coal-fired power stations

4) VGB, 2000. Biomasse: Vergasungs- und Mitverbrennungsprojekte in den Niederlanden [Biomass: Gasification and co-firing projects in the Netherlands]. Contributions by N.V. EPZ and EPON.

In the context of EPM benchmarking, the following assumptions were made regarding energy consumption in connection with the separation, pre-processing and transportation of waste:

- 30 kWh required to separate one ton of waste into OWF and RDF.
- 210 kWh [CE, 2001] required to bring one ton of PPF up to co-firing quality by pelletisation and micronisation.
- 1.4 MJ required for each ton-kilometre of transportation. Transportation energy was taken into account only in connection with the export of PPF over an average distance (separation plant to co-firing plant) of at least 500 kilometres.

# Environmental evaluation (BPEO)

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## 1. Introduction

Decision-making on policy and in some cases implementation of infrastructure for municipal solid waste (MSW) management has been informed by the use of life-cycle based analysis. In recent years much effort has been directed toward developing the analytical tools and models to undertake such analysis most notably in the USA and the UK by their respective environmental agencies. In the latter case a working model has been released for use by municipalities in the UK and there is an implied requirement, under guidance given in the National Strategy for MSW, for its use in justifying the implementation of infrastructure for MSW management.

This paper presents the results of analysis using such LCA tools in developing regional and local strategies for MSW management and comments on advantages and limitations of this type of modelling approach.

The paper describes the approach that one regional waste management authority (Authority X) has taken in deciding on a waste management infrastructure for the future. Like many authorities in the UK Authority X currently relies on landfill disposal. However, the need to respond to EU and National legislative pressures to recycle and divert waste from landfill is forcing waste management authorities to develop the systems for the future. To inform their decision-making these authorities are applying the Best Practicable Environmental Option (BPEO) method.

# 2. The BPEO

The UK Royal Commission on Environmental Pollution defines the Best Practicable Environmental Option as

*“a BPEO is the outcome of a systematic procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes for a given set of principles, the option that provides the benefits of least damage to the environment as a whole at an acceptable cost, in the long as well as the short term.”*

Thus, following the evaluation of a number of options, the BPEO can be identified as that option which

- has the least environmental emissions
- has the lowest, or acceptable, cost
- meets legislative requirements e.g. recycling and diversion targets.

It is unlikely that one option will come out as best against all criteria – so invariably a matrix approach needs to be developed to identify the BPEO.

# 3. Waste management options

Authority X manages about 550,000 tonnes of MSW of which 9% is recycled and the rest consigned to landfill. Table 1 lists the options (including the existing system which acts as the base case) considered for the future – these include source segregated (3 and 2 container system) recycling as well as residue treatment by energy from waste (EfW) incineration. Thus the infrastructure requirements would include materials recovery facilities (MRF), composting facilities, EfW facilities and refuse transfer facilities (RTS) as well as landfill for residual wastes.

*Table 1. Waste management options for Authority X.*

| | | **Mode of waste collection** | **Mode of waste treatment/ disposal** |
|---|---|---|---|
| 1 | Base case | Kerbside collection of dry recyclables. Household waste reception centre collection of green waste | MRF, composting & landfill |
| 2i | Intensive HH and HWRC recycling with landfill | 3 stream alternate weekly household collection (dry, organics and residual). Household waste reception centre collection green waste & dry recyclables. | Composting of green waste & organics, new MRF and centralised aggregates processing, bulking transfer stations and residues to landfill |
| 2ii | Intensive HH and HWRC recycling with EfW and landfill | 3 stream alternate weekly household collection (dry, organics and residual). Household waste reception centre collection green waste & dry recyclables. | Composting of green waste & organics, new MRF and centralised aggregates processing, bulking transfer stations, EfW incineration and residues to landfill |
| 3i | HWRC recycling with EfW and landfill | Single bin mixed waste household collection. Household waste reception centre collection green waste & dry recyclables. | Composting of green waste, centralised aggregates processing, refuse transfer stations, EfW incineration and residues to landfill |
| 3ii | HWRC recycling with dirty MRF/FBC and landfill | Single bin mixed waste household collection. Household waste reception centre collection green waste & dry recyclables. | Composting of green waste, centralised aggregates processing, dirty MRFs with FBC incineration, and residues to landfill |
| 4i | Intermediate HH and HWRC recycling, with EfW and landfill | 2 bin alternate weekly household collection (dry recyclables and residual). Household waste reception centre collection of green waste & dry recyclables. | Composting of green waste, new MRF and centralised aggregates processing, refuse transfer stations, EfW incineration and residues to landfill |
| 4ii | Intermediate HH and HWRC recycling, with landfill | 2 bin alternate weekly household collection (dry recyclables and residual). Household waste reception centre collection of green waste & dry recyclables. | Composting of green waste, new MRF, centralised aggregates processing, and residues to landfill |

| | |
|---|---|
| HH | Household |
| HWRC | Household waste reception centre |
| MRF | Materials reclamation facility |
| EfW | Energy from waste incineration |
| FBC | Fluidised bed incineration with energy recovery |

The assessment of the various options was made in 3 parts:

1. *Performance against targets*

A mass flow analysis determines the tonnages of waste recycled and diverted for landfill. Various targets are set for waste management in the UK (summarised in Table 2) and the performance of each option against these targets is determined.

*Table 2. MSW management targets.*

| **Target** | **2003** | **2005** | **2010** | **2013** | **2015** | **2020** |
|---|---|---|---|---|---|---|
| Best value | 12% | 18% | | | | |
| Recycling | | 25% | 30% | | 33% | |
| Recovery | | 40% | 45% | | 67% | |

2. *Costs*

An economic assessment is undertaken to determine the annual costs of waste management by the chosen options as well as a lifetime (20 year) cost for the system.

3. *Environmental Assessment*

A life cycle assessment tool (the UK's WISARD Model) is applied to determine the inventory of emissions of the various options. These emissions are grouped into impact assessment categories to allow comparisons to be made. The five impact assessments chose for consideration were:

- climate change
- air acidification
- ground level ozone formation
- eutrophication of water
- depletion of non-renewable resources.

Figures 1, 2 and 3 present illustrative examples of the type of (graphical) output that is provided by the assessment of performance cost and environmental impacts – in the latter case the transport kilometres/y incurred in moving waste around.

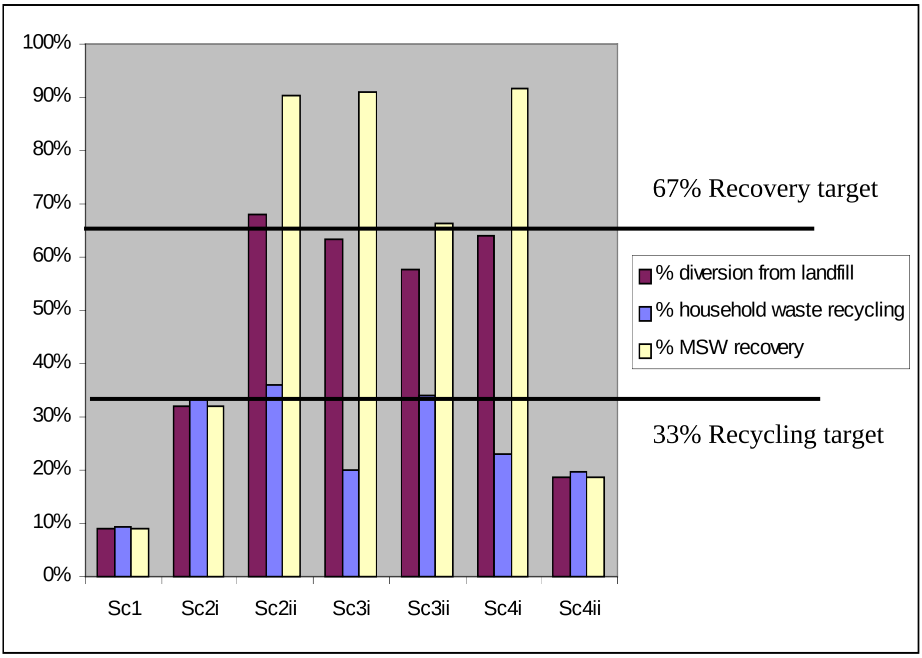

*Figure 1. Recycling, recovery and diversion rates, and comparison with targets.*

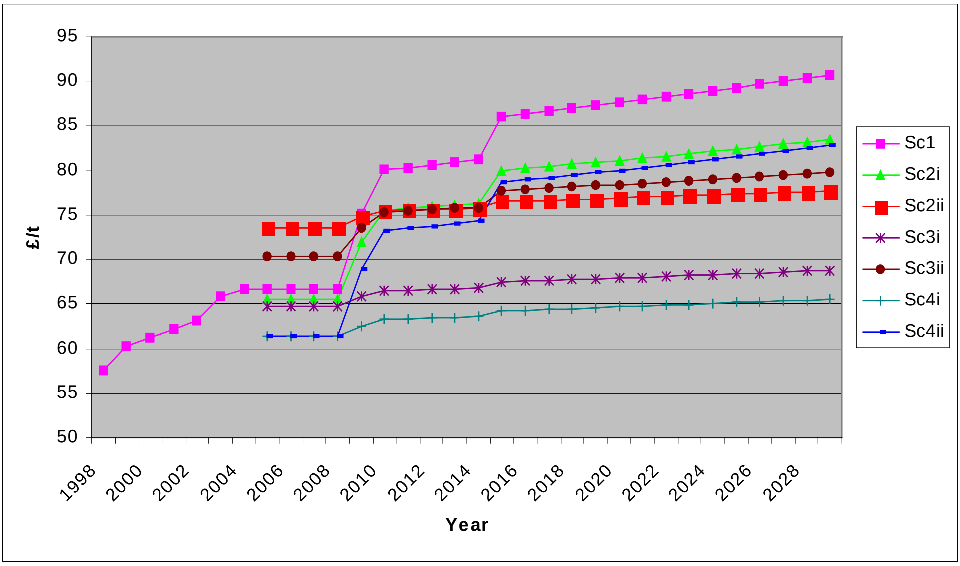

*Figure 2. Total cost (collection, treatment + disposal) with time.*

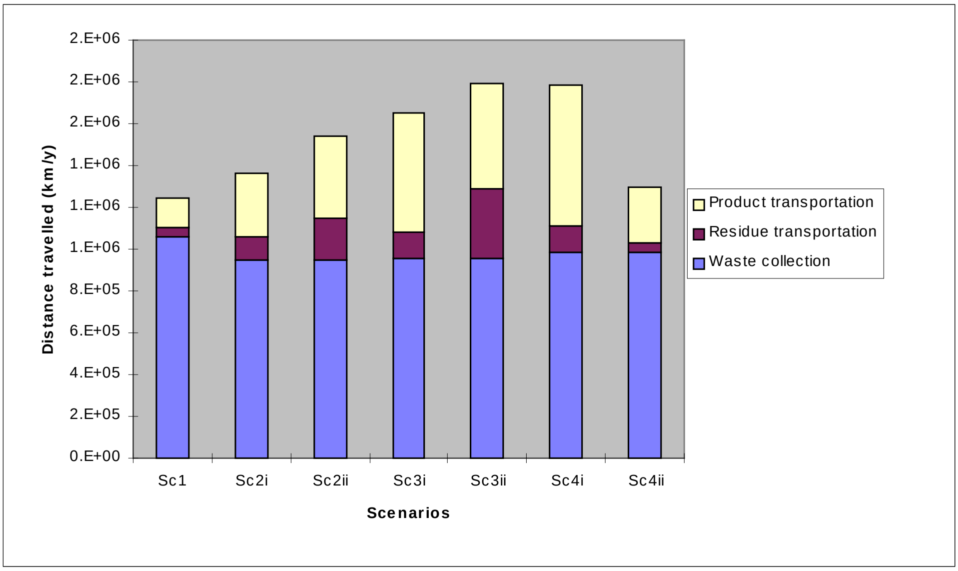

*Figure 3. Transport kilometres/y.*

# 4. Results

The (numerical) outcome of the assessment of performance against targets, costs and environmental impacts is displayed in Table 3.

The analysis presents a complex picture; as no single scenario is best against all criteria, deciding on the most appropriate option is not simple. It is difficult to compare cost and environmental criteria and making such comparisons requires agreement not only of the criteria themselves, but also of their relative importance (i.e. their relative weighting or ranking).

Formal techniques for ranking impacts have been developed. The technique used here is based on utility theory, in which each impact is scored against some criteria. For example global warming potential could be given a 0 score for maintaining current emission levels, a score of +1 for achieving a 25 per cent reduction and a score of –1 for a 25 per cent increase. This analysis is presented in Table 3, which is based on the scoring weightings given in Table 4. Highlighted entries indicate a score of 3 or 4.

*Table 3. BPEO assessment matrix.*

| | 1 | 2i | 2ii | 3i | 3ii | 4i | 4ii |
|---|---|---|---|---|---|---|---|
| | Base case | Intensive HH and HWRC recycling with landfill | Intensive HH and HWRC recycling with EfW | HWRC recycling with EfW | HWRC recycling with dirty MRF/FBC and landfill | Inter-mediate HH and HWRC recycling with EfW | Inter-mediate HH and HWRC recycling with landfill |
| Climate change | 0 | 4 | 4 | 4 | 4 | 4 | 1 |
| Air acidification | 0 | 2 | 4 | 4 | 4 | 4 | 4 |
| Ground level ozone | 0 | 3 | 4 | 4 | 4 | 4 | 4 |
| Water eutrophication | 0 | 1 | 4 | 4 | 4 | 4 | 1 |
| Depletion of resources | 0 | –3 | 4 | 4 | 4 | 4 | 4 |
| Total contract value cost | 0 | 2 | 2 | 3 | 2 | 4 | 2 |
| Achieves 33% recycling rate | –3 | 0 | 0 | –2 | 0 | –2 | –2 |
| Achieves 67% recovery rate | –4 | –3 | 2 | 2 | 0 | 2 | –3 |
| Achieves 2020 target Landfill Directive | –3 | –3 | 2 | 4 | –2 | 4 | –3 |

*Table 4. BPEO assessment scoring.*

| Score | Measure (compared to base case or target) |
|---|---|
| –1 | 0 to 25% worse (or under target) |
| –2 | 26% to 50% worse |
| –3 | 51% to 75% worse |
| –4 | more than 75% worse |
| 0 | equivalent to base case or target |
| 1 | 0 to 25% improvement (or exceedence of target) |
| 2 | 26% to 50% improvement |
| 3 | 51% to 75% improvement |
| 4 | more than 75% improvement |

The results indicate that no one scenario performs best against all criteria, so that there is no one scenario that can be considered the best practicable environmental option in terms of the criteria considered. However, some general trends are discernible.

Only those scenarios involving an element of EfW meet the landfill Directive requirements for the diversion of biodegradable waste (Scenarios 2ii, 3i and 4i). Of these, only Scenario 2ii meets both this and the recycling and recovery targets, largely as a result of the intensive recovery of household organics through the three-bin collection system. However, this system places the largest demands both on householders and the collection authorities and therefore may be less favoured in practice.

Scenarios 3i and 4i both achieve a higher score than Scenario 2ii in terms of total contract cost and diversion of biodegradable waste from landfill, with Scenario 4i offering the cheaper overall service. The latter represents a highly integrated scheme, with a mixture of household and HWRC recycling, relatively low demands on the householder and collection authorities through alternate weekly waste household collection of dry recyclables and residual waste, and energy recovery through incineration.

# 5. Next steps

The results of the BPEO assessment are being used by Authority X a part of a wider consultation with stakeholders on the future waste management system. The consultation itself may lead to different weighting being given to certain criteria and hence may impact on the BPEO.

In the past the decision on waste management has relied on only on cost – the lowest cost system, landfill in the case of the UK, has therefore dominated. Performance e.g. recycling and diversion from landfill is now only being considered due to legislative (or political) pressures. Finally the availability of lca tools such as WISARD means that an environmental element is now also becoming an integrated part of the decision making process. Whilst there is a greater degree of certainty in costs, because of the tendering regime that is undertaken, the degree of uncertainty in the environmental assessment is greater – both the quality of data and the methodology of LCA are open to question. However, take together i.e. performance, cost and environmental impact, a consideration of the criteria as set out in this paper does at least allow for an informed dialogue with stakeholders of the relative merits of various systems and this may make the delivery easier.

# New approach to recycling and waste-to-energy in paper production, Urban Mill

Petri Ristola
Metso Corporation
Finland

## 1. Bringing papermaking back to the city

Greenfield paper mills are commonly perceived as massive investments with a high level of associated impact on the local environment. Parallel to this, increasingly strict targets are being set by modern legislation for reducing waste disposal at landfills. One long-term solution to this dilemma lies in extended materials recycling, combined with effective utilisation of waste as energy. Metso Paper's Urban Mill is a unique pilot concept that promises to become an important part of such a solution.

The novelty of Metso Paper's new eco-efficient Urban Mill concept lies in its combination of a small paper mill with using solid waste to generate energy.

The roots of the concept go back to the early 1990s, when several mini-mills were built to produce raw materials for corrugated containers in North America. The competitiveness of mini-mills like this is based on several benefits: low-cost, high-quality waste paper raw material, utilisation of adjacent facilities for utilities, and modern machines with lean manning and low inbound and outbound logistics costs.

## 2. Extending the concept

Metso Paper's Urban Mill extends the mini-mill concept by integrating mill operations with advanced, local waste-to-energy operations based on technologies such as fluidised bed combustion and gasification.

This type of integration offers a number of tangible benefits by eliminating costly rejects and generating inexpensive energy from waste. It also opens up the possibility of cooperation between paper and waste management companies in the form of long-term outsourcing and sharing the heavy initial capital expenditure associated with building a new paper mill.

A dedicated waste-to-energy facility can be a significant energy producer, but its feasibility depends on the gate fees associated with the incoming waste. As a result, close daily cooperation with an industrial customer is an attractive means of improving the economical and environmental performance of solid waste management.

## 3. Using solid waste as a dual source

The Urban Mill concept is covered by a number of patents pending around the world. One of the concept's most significant features is its solution for recovering paper fibre from solid waste.

The manual and automatic sorting methods used to date offer poor yield and low quality at high cost. The novel idea in the Urban Mill 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.

New de-trashing and cleaning technology produces recycled fibre of a comparable quality to any separately collected waste paper stream. More significantly, it also produces a high-quality fuel for advanced waste-to-energy operations based on fluidised bed or gasification technology.

# 4. A promising solution

Demand for recycled fibre as a raw material for paper products is on the increase. As a result, it will be crucial for industry to secure optimal usage of recycled fibre by taking advantage of high-quality fractions in recycled papermaking and using the remainder for energy.

In normal waste paper processing, the high price of both waste paper and related reject disposal has resulted in producers rejecting a very low percentage of recycled fibre. This easily causes quality problems in the end product, as well as runnability problems in the production process. Chemicals are being used in increasing quantities to solve these problems. In the future, the Urban Mill could be a better solution.

The Urban Mill makes recycled fibre-based papermaking self-sufficient in terms of energy, and comparable to chemical pulping, in which approximately 50% of wood matter is utilised as fibre and the rest as energy.

In the Urban Mill model, the poorest-quality fibre fraction, combined with other associated combustible wastes, is used in papermaking to provide all the energy needed. Under most national legislation, this energy has the benefit of being classified as $CO_2$-free, like biomass.

From the holistic viewpoint, therefore, the Urban Mill concept can be seen as having a very positive effect on the total material balance. At the same time, it offers paper producers an excellent opportunity for enhancing their image, away from that of a smokestack industry to that of a good corporate citizen in an increasingly urban society.

## Introduction

”Bringing papermaking back to the city”

- Greenfield vs mini-mills
  - Recycled raw material (OCC and mixed waste paper) => low variable costs
  - Purchased energy (and water treatment) => competitive investment cost
  - Modern machines with lean manning => competitive fixed cost
- Urban Mill with waste-to-energy
  - Extended materials recycling
  - Effective utilisation of waste as energy
  - Pilot concept

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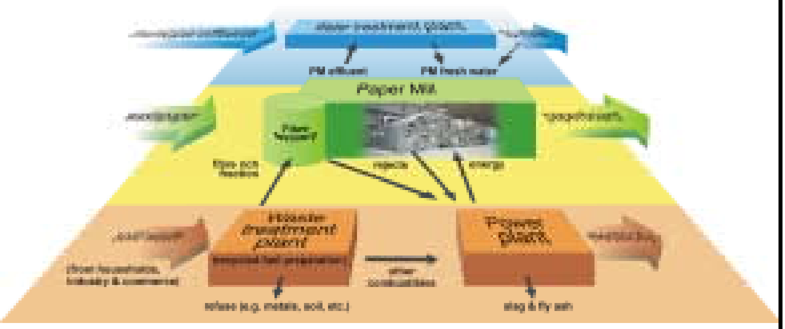
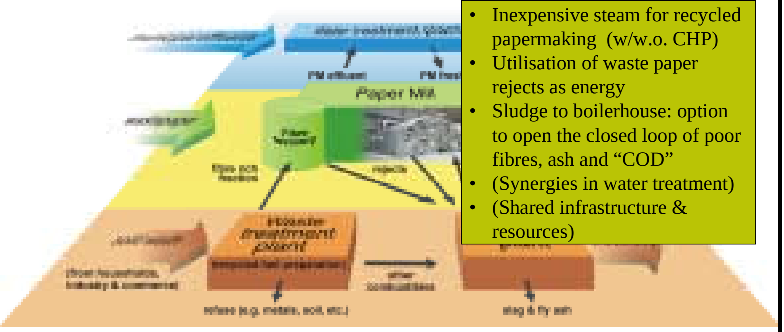
## Waste as dual source

System overview



## Waste as dual source
### Benefits of waste-to-energy



- Inexpensive steam for recycled papermaking (w/w.o. CHP)
- Utilisation of waste paper rejects as energy
- Sludge to boilerhouse: option to open the closed loop of poor fibres, ash and “COD”
- (Synergies in water treatment)
- (Shared infrastructure & resources)

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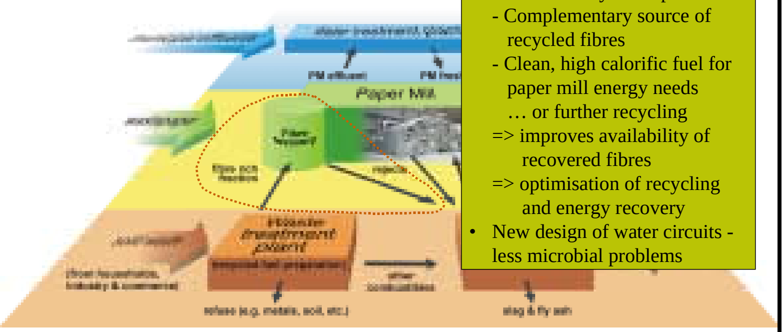
## Waste as dual source
### Fibre Recovery Concept



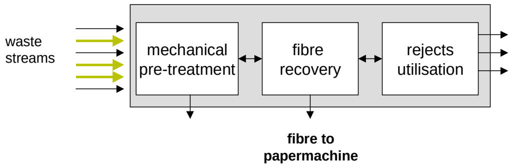
- Fibre recovery concept:
  - Complementary source of recycled fibres
  - Clean, high calorific fuel for paper mill energy needs … or further recycling
  - => improves availability of recovered fibres
  - => optimisation of recycling and energy recovery
- New design of water circuits - less microbial problems

patents pending

## Waste as a dual source

### System components

- Heart of the system is a pulping process (wet) that includes a number of proprietary features to Metso
- Mechanical pre-treatment includes e.g. size reduction, metals removal and fines removal
- Fibre recovery yields fibre, but also several fractions of non-fibrous material which must be treated (minimum dewatered) for further utilisation
- Further upgrading of the fibres yields low calorific sludge that must be utilised as well



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## Research evidence

- Fuel properties
- Paper technical properties
- Harmful compounds

### Paper technical properties

•Tests run at pilot paper machine to verify paper technical potential (~ 5 tons of stock)

•Fibres obtained are technically suitable for

-manufacture of corrugated containers

-manufacture of special grades, e.g. core board, gypsum board, etc.

-manufacture of cartonboard

-manufacture of printing papers?

-manufacture of low-grade tissue papers?

metso

## Pulping of FRF for board machine trials

- Continuous LC pulping
- Fine screening
- 3-stage LC cleaning
- Thickening
- Hot dispersion

- Total amount of stock:
  **10 tons FRF / 5 tons pulp**

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metso

## Research evidence

### Harmful compounds

- Heavy metals
- Organic compounds (PCB, dioxins)
- Microbes

## Microbiological problems in paper industry

- Microorganisms spoiling of raw materials, e.g. breaking down cellulose, starch, casein, rosin etc.
- Microorganisms causing problems in the process, e.g. producers of slime and deposits
- Microorganisms threatening process safety, e.g. harmful to human health in the process environment
- Microorganisms reducing the quality of the end products, e.g. harmful to human healts / hygiene of the end product
- Microorganisms that can cause smell or taste defects, e.g. in the course of metabolism

## Summary

- From technical / system perspective there is a win-win opportunity for recycling and advanced waste-to-energy
- Market test of the concept remains a challenge
- Piloting / demonstrating the concept in industrial scale will take place step-by-step
- System solution with wide implications - discussion with stakeholders important in parallel to technical development

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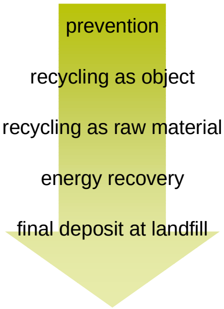
## Waste hierarchy



prevention

recycling as object

recycling as raw material

energy recovery

final deposit at landfill

# Dutch national waste management plan, considerations, instruments and goals

Herman Huisman
AOO: LAP
The Netherlands

King Midas, I refer to a Greek myth, was granted a favour by Bacchus. Midas asked him that everything he touched would turn into gold. We have a similar ability. Everything we touch, turns into waste.

I would like to introduce the Dutch Waste Management Plan (DWMP), more specific, the waste to energy policy in the plan.

The Dutch Waste Management Plan consists of several documents:

The policy framework, in which the overall policy is described in 22 chapters on, e.g., the international framework, the waste hierarchy, definitions, disposal and waste to energy.

- In 34 sector plans the specific policy for 98 waste streams are laid down, both for hazardous and non-hazardous waste streams. The sector plans are the basis for licensing facilities for the processing of the waste.

- In 2 capacity plans, the policy regarding disposal is described: both landfilling and incineration.

- An Environmental Impact Assessment has been carried out for the plan. For 25 waste streams, different processing techniques are examined with the LCA (life cycle analysis) technique.

All the documents are available on our web site: www.aoo.nl.

I would also like to refer to the English summary of the Dutch Waste Management Plan. The waste management plan was discussed in the Dutch Council of Ministers, on 12 April 2002 and sent to the Parliament. The draft plan had been sent to the EU, Brussels, at the end of January 2002 for notification. The plan will be enacted in May 2002 if the council of ministers, the parliament and the EU agree.

This new law recentralizes waste management in the Netherlands at the national level, and with this new law, the Netherlands is prepared for a EU-scale in waste management. At the national level the Ministry of environment is responsible for adopting the national waste management plan, licensing disposal facilities, and proposing environmental regulations (Decree on air emissions waste incineration, Decrees on landfill management and bans). At provincial level, the 12 provinces are responsible for the siting of waste facilities (spatial planning), for licensing and, enforcement. And finally, at the municipal level, 500 municipalities are responsible for the (separate) collection of household waste and for licensing of small-scale business, and building permits.

The Dutch Waste Management Council has the following tasks:

- monitoring and evaluation progress in waste management
- advising government on deviation from the plan
- supporting provincial and national government in licensing
- drawing up sector and capacity plans and EIS
- the Waste Management Council has a scientific bureau, which serves as a data bank on waste.

In the following, some phases of the plan are recited:

- In 1998, the National Environmental Plan (NMP)3 was issued. In this plan the Waste-to-energy policy was introduced as a part of a plan for increasing the share of renewable energy in energy production in the Netherlands.

- In 1999–2002, a Convention on Renewable Energy from MSWI was agreed upon and signed between the Dutch Cabinet and the organization of Dutch municipal solid waste incineration plants. In this convention, the MSWI are entitled to 1 € per kWh producers fee.

- In 1999, a Revision of the Waste Management Plan was finalized, in which a moratorium for expanding MSWI was issued in order to promote new techniques with a higher energy yield than the existing MSWI.

- In January 2002, the Draft National Waste Management Plan was published.

- In February 2002, a public consultation and review of the EIS took place, and in May 2002, the National Waste Management Plan will hopefully be enacted.

*Focus on incineration*

- The plan provides, in a continuation of the moratorium on expanding disposal capacity, with exemption for MSWIs with a high energy performance (>30%).

- Stimulation of secondary fuel production and framework for stimulating market for "waste to energy". When established: lift of moratorium for expanding disposal capacity.

- Temporary objections to shipments of low-calorific combustible waste for disposal (D10). Only in border regions, exemptions will be granted as long as it concerns transboundary cooperation between neighbouring regions.

- In 2006, opening borders for incineration (D10) with neighbouring countries.

- High tax on landfilling combustible waste (€ 79).

- Tax benefits for generating renewable energy (36o, r, u) will be replaced by a new framework, and tax benefits to stimulate the <u>demand</u> for renewable energy (36i) remain.

- Coal convention: an agreement between Dutch government and the electricity production sector provides in a reduction of 3 Mt $CO_2$ discharge per year on the electricity sector; by replacing coal by biomass and waste. The coal convention was signed at the end of April.

*European influence*

As we all know, the European Union has a strong influence on national waste policies. First of all, most of the definitions concerning waste, recovery, disposal, etc., are derived from the Framework Directive: Waste is any substance or object, which the holder discards or intends or is required to discard. The definition of disposal: any operation in Annex II A Framework Directive 91/156. Further on: the definition of Recovery: any operation in Annex II B of the Framework Directive. Waste hierarchy is also described: prevention – recovery – disposal. Recently, the definition "renewable" is agreed upon in the (2001/ RES Directive).

Ordinance 259/93 sets rules for transboundary waste transport. The Framework Directive also provides an obligation to draw up waste management plans and to deploy a licensing framework

The IPPC Directive affects the permission process for certain waste treatment operations.

The Directive on Waste Incineration (2000/76/EG) harmonizes the standards for emissions to the air of waste incineration processes

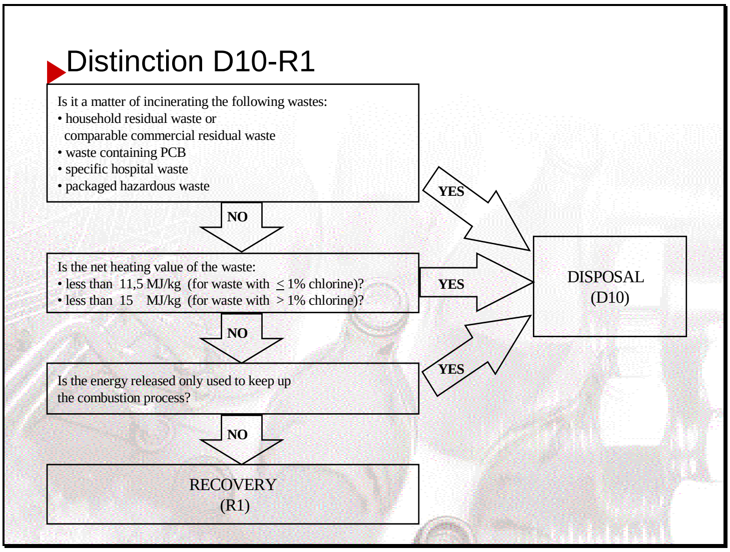
Finally, there are targets for landfilling in the Landfill Directive, for the share of renewables in energy production and for recycling packaging waste.

*Essential elements*

The following facts are essential elements in waste: For recovery operations there is a liberated EU-market: free trade, no planning, no borders. For disposal operations, each country may close its borders and aim at self-sufficiency and planning.

However, a clear distinction between recovery and disposal is lacking. Any attempt to make such a distinction will be artificial: not scientific but political. Much of waste exports results from differences in taxes, standards, prices. Waste will always follow the road of the cheapest price. E.g., the Netherlands exports recovered fuel to Sweden and imports wood for incineration, only because of artificial prices, which are a result of differences in taxes and subventions.

Not all EU member states comply with all the directives, but what’s even more important: Enforcement of proper handling of waste in compliance with the EU Directives is poor.



Distinction D10-R1

Is it a matter of incinerating the following wastes:
- household residual waste or comparable commercial residual waste
- waste containing PCB
- specific hospital waste
- packaged hazardous waste

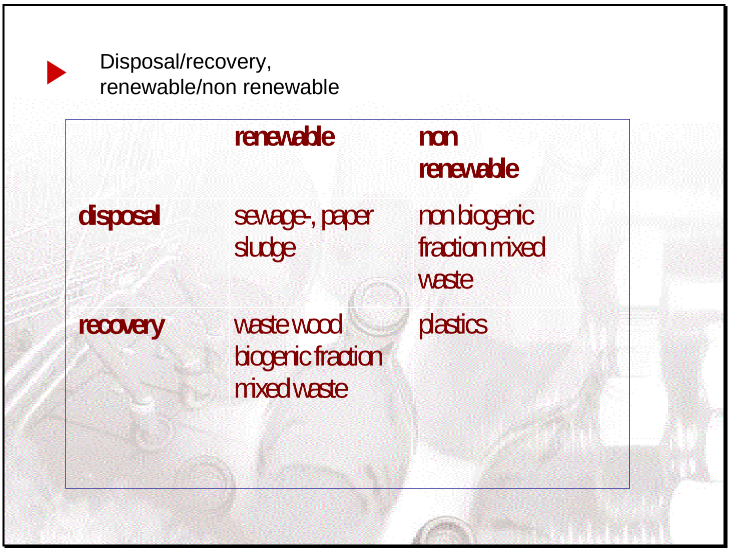
Is the net heating value of the waste:
- less than 11,5 MJ/kg (for waste with ≤ 1% chlorine)?
- less than 15 MJ/kg (for waste with > 1% chlorine)?

Is the energy released only used to keep up the combustion process?

RECOVERY
(R1)

DISPOSAL
(D10)

Because any clear distinction was made neither in the ordinance nor in the Framework Directive between incineration on land (D10) and R1 the use of waste as a source of energy, we were forced to do so in our National Waste Management Plan (see above flow scheme).

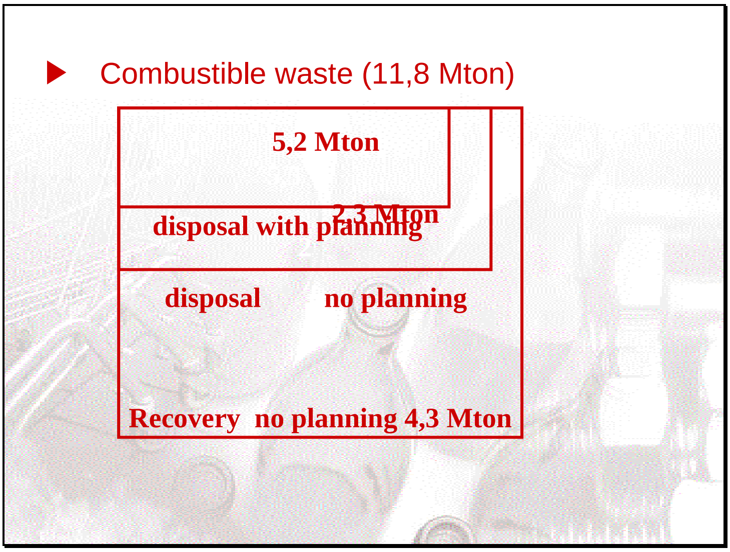


- Disposal/recovery, renewable/non renewable

| | renewable | non renewable |
|---|---|---|
| **disposal** | sewage-, paper sludge | non biogenic fraction mixed waste |
| **recovery** | waste wood<br>biogenic fraction mixed waste | plastics |

Together with the definition of renewables, which was settled recently in the RES Directive, combustible waste can be divided into four categories, each with different policies, regulations and tax-benefits. E.g., sewage sludges are sources of renewable energy, but the incineration of sludges is a disposal activity because of the low calorific value. Plastics, on the other hand, are a source of non-renewable energy, but the incineration is regarded as a recovery activity.

In our plan, we decided to continue the planning of waste incineration (D10), until next year, July 2003. At that time, a new tax for $CO_2$ reduction will be enacted, which will stimulate the expansion of capacity with a high energy-yield.



Combustible waste (11,8 Mton)

5,2 Mton

disposal with planning

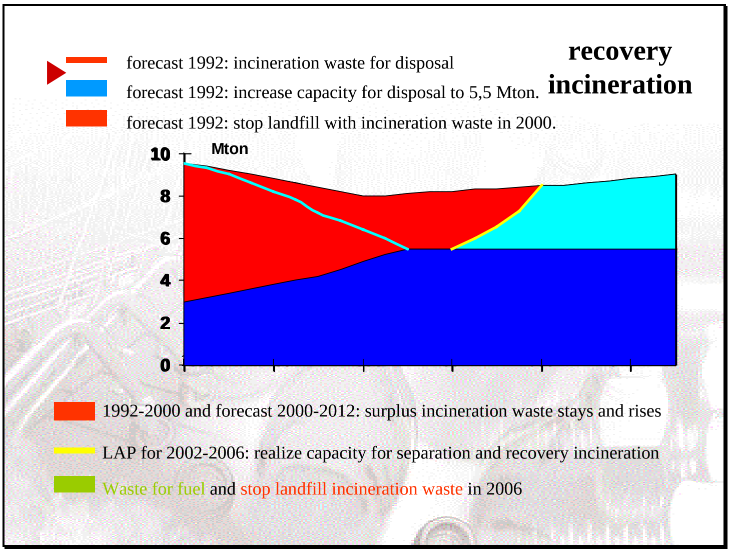
2,3 Mton

disposal no planning

Recovery no planning 4,3 Mton

Combustible waste can be divided into three categories:

- D10 waste :incineration as a disposal activity, with planning, closed borders, etc.
- D10 waste, mostly sludges, without planning
- R1 waste, incineration for recovery” market driven.



**recovery incineration**

🟥 forecast 1992: incineration waste for disposal

🟦 forecast 1992: increase capacity for disposal to 5,5 Mton.

🟥 forecast 1992: stop landfill with incineration waste in 2000.

🟥 1992-2000 and forecast 2000-2012: surplus incineration waste stays and rises

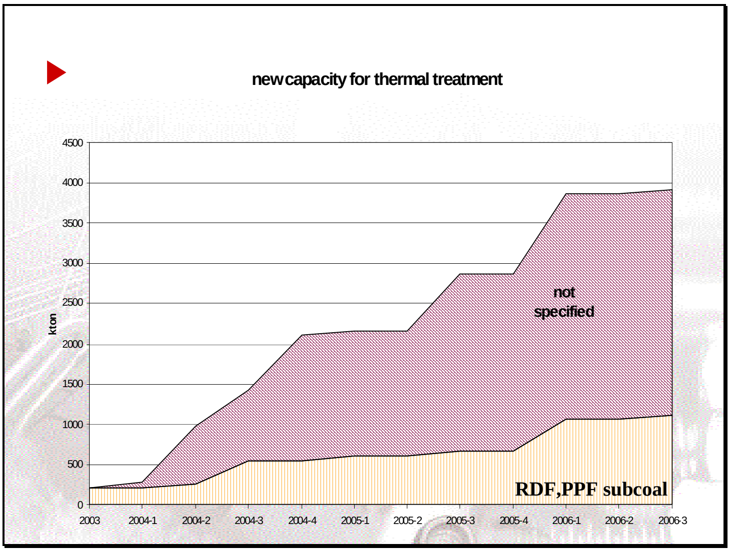
🟨 LAP for 2002-2006: realize capacity for separation and recovery incineration

🟩 Waste for fuel and stop landfill incineration waste in 2006

In 1992, the first Ten-year Waste Programme (AOO 1992) was issued, in which it was specified, which processing capacity (incineration, landfilling and composting) should be provided and which additional measures were needed to guarantee suitable waste disposal. 1995 marked the appearance of the second Ten-year Waste Programme (AOO 1995), which, besides the planning of processing capacity, also expressly focused on the question of how waste streams could be assigned to the desired form of processing.

A weakness in current waste management is that there is still an insufficient grasp of the quantity of waste produced. Particularly in the case of consumer waste and, to a lesser extent, of trade, services and government waste, growth still exists. This is all the more conclusive as these are also the waste streams, for which the level of recovery lags the targets. A great deal of combustible and recoverable waste is still consequently landfilled as a smaller waste supply and a higher degree of separate collection have been assumed in the planning of incineration capacity.

Making landfilling more expensive than the desired alternatives (subsequent separation, composting/fermentation, etc.) means that the desired shift from disposal to recovery can largely be brought about in a manner consistent with the market. In the case of a high landfilling rate, the landfilling of combustible waste is financially clearly less attractive than burning waste in waste incineration plants or treating waste in separating facilities and other facilities for thermal processing.

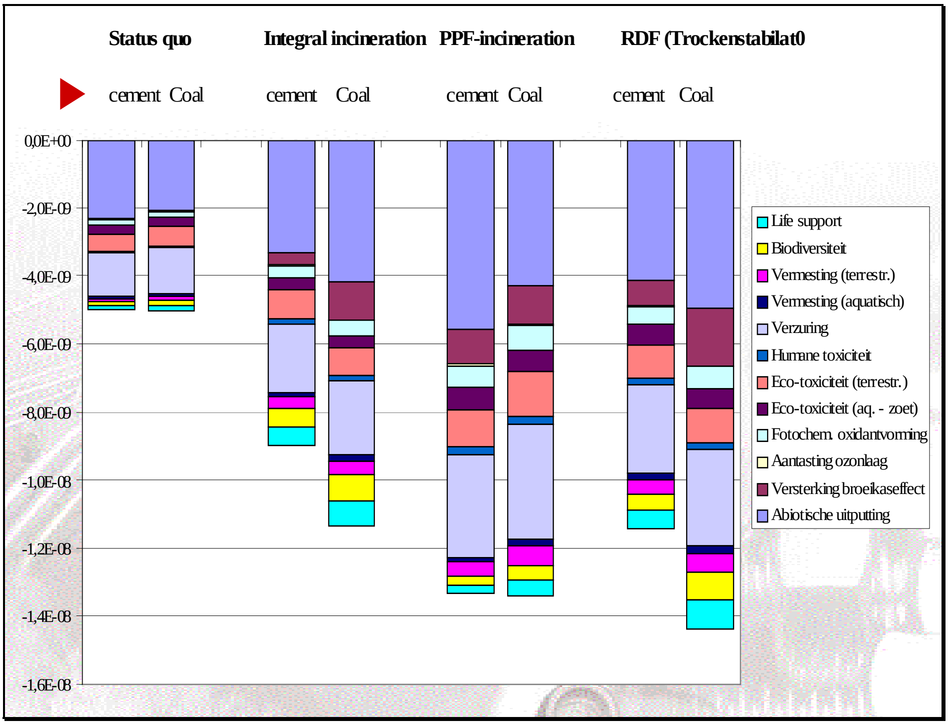


A list of initiatives for expanding thermal processing capacity has been drawn up and presented for checking purposes to the parties on the Secondary Fuels Platform. The list also indicates, which waste substances or secondary fuels are processed in the plants. It is assumed that these will be the waste substances that are currently given an exemption to the dumping ban and are dumped in landfill. The list does not state the capacities for waste wood and sludge. The completion of the capacity for thermal processing of waste substances according to this list is shown in the figure. The initiatives in the figure are intended for domestic residual waste, combustible industrial residual waste and various fuels produced from waste substances such as RDF, Subcoal and Recovered Fuel.

The scenarios are:

1. Status quo. No expansion of present processing capacity and all of excess combustible waste is dumped in landfills. This scenario is the reference scenario.
2. Incinerate all of this waste in waste incineration plants. To do this, the existing D10 capacity would have to be expanded until incineration capacity matches total waste supply.
3. PPF (paper/plastic fraction) scenario. This scenario uses simple techniques to separate the paper/plastic fraction from the combustible residual waste.

4. Maximum PPF scenario. This separates the domestic residual waste after collection and processes it in a digester plant (VAGRON concept), to produce refuse-derived fuels (RDF) that are burned in specific high-calorie incinerators.
5. Maximum refuse derived fuels (RDF) scenario. This scenario provides for a combination of composting and separation after collection (Herhoff plants) to produce RDF that is burned in specific high-calorie incinerators.



The scenarios involving separation after collection (scenarios 3, 4 and 5) emerge from the environmental impact assessment as being the best on all environmental measures.

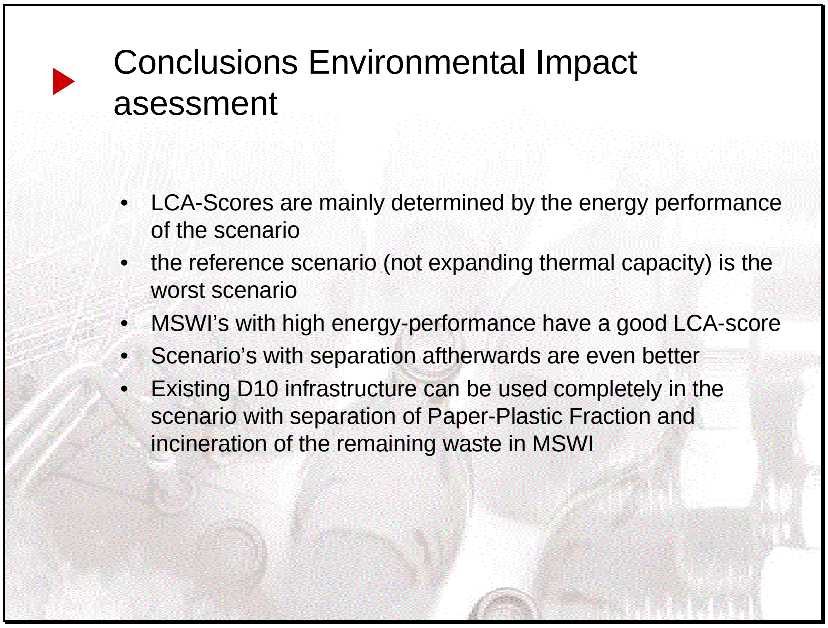
In the PPF scenario the present D10 capacity is sufficient (about 5.4 Mton with a net heat value of 9.2 MJ/kg in 2012). An expansion in the capacity for separating domestic residual waste would be required. The paper/plastic fraction would be burned in coal-fired power stations or cement kilns.

In the maximum PPF scenario, 3.6 Mton capacity for separation after collection and digestion would be realised (VAGRON concept), and by 2012 about 4 Mton RDF would be produced with a net heat value of 13 MJ/kg. This net heat value is too high for the current waste incineration plants (see Figure CTP.3) and new high-calorie incineration plants would have to be built.

The maximum RDF scenario results in separation and processing of all the residual waste after collection, to produce 4.3 Mton 'Trockenstabilat'. This has to be burned in new high-calorie incineration plants that would have to be built. The last two scenarios require a major expansion of both the capacity to separate waste after collection and the incineration capacity for RDF. A large proportion of current D10 capacity would no longer be used by 2012. Even though the amount of combustible waste to be disposed of is less in scenarios 4 and 5 than in the other scenarios, the damage to the environment is about the same as with the PPF scenario.

The scenario of expanding the total incineration capacity scores noticeably worse in the environmental impact assessment than the scenarios involving separation. This difference is reduced, however, at a high-performance waste incineration plant.

The reference scenario (no expansion of thermal processing capacity and continued dumping of 3.2 Mton combustible waste) scores the worst of all.



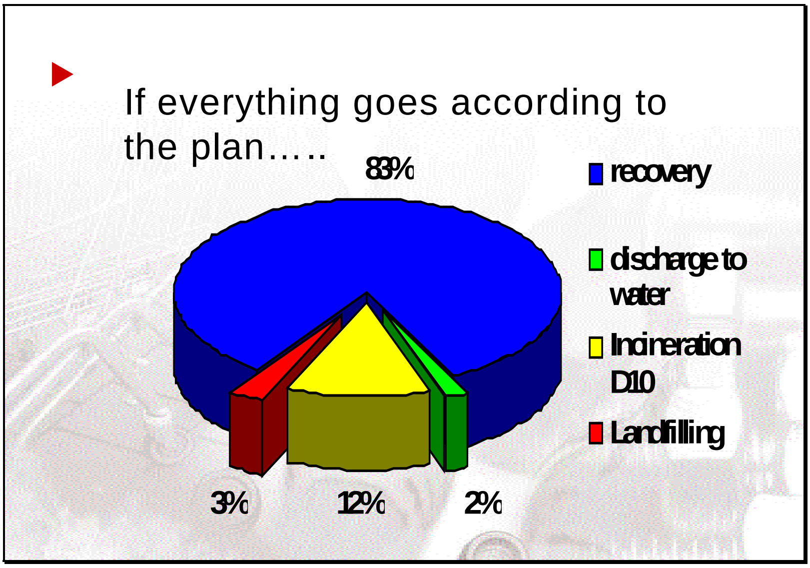
Conclusions Environmental Impact assessment

- LCA-Scores are mainly determined by the energy performance of the scenario
- the reference scenario (not expanding thermal capacity) is the worst scenario
- MSWI’s with high energy-performance have a good LCA-score
- Scenario’s with separation aftherwards are even better
- Existing D10 infrastructure can be used completely in the scenario with separation of Paper-Plastic Fraction and incineration of the remaining waste in MSWI

The environmental impact assessment showed that the PPF scenario has a good environmental score. It also means that the existing waste incineration plants would be sufficient and replacement of the expensive D10 capacity would not be necessary. Expansion of capacity for separating waste after collection and integrated composting or digestion would be necessary. The cost of this is far lower, however, than the cost of expanding D10 capacity.

Based on the results of the environmental impact assessment and in consultation with the waste processing industry, the policy framework has opted for separation, composting/digestion followed by (high-calorie) thermal processing, and hence there is no need to expand the existing D10 capacity. This policy will mean that the dumping of combustible waste in landfill will be given up during the period of the National Waste Management Plan.

The policy will be implemented through a combination of positive financial incentives for investment in high-calorie processing capacity and a tax on the dumping of combustible waste. This will make alternatives to incineration as a form of disposal cheaper for high-calorie waste substances.



If everything goes according to the plan…..

In the end, if all succeeds we will reach about 85% recovery instead of present 77%. Waste-to-energy will contribute about 10% of the total recovery target.

# Summary of the Swedish report “Förbränning av avfall – en kunskapssammanställning om dioxiner” (Waste-to-energy, an inventory and review about dioxins)

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Continuous efforts are being made to further improve waste incineration as a means of dealing with household waste and other combustible material, while also producing valuable energy. The main aims are to further reduce the already low emissions to air, and to ensure effective long-term deposition of ashes and other residues from the flue-gas treatment of the waste incineration process.

In order to increase knowledge in this area, the Swedish Association of Waste Management (RVF) has taken the initiative for the biggest study to date into dioxins and waste incineration in Sweden. RVF is a trade association working within the areas of waste management and recycling. The owners of Sweden’s 22 waste incineration plants are all members of RVF. The study has been carried out by engineer Nils Ahlgren, an independent consultant in energy and the environment, and Professor Stellan Marklund of the University of Umeå, who has a doctorate in dioxins and conducts research into incineration technology and environmental effects.

A summary of the report of this study is presented here. The order of the text in this summary follows that of the respective sections in the main report, see below for further explanation.

## 1. The report – outline and content

The main aim of this report is to provide and distribute information about the current situation and developments within the field of waste incineration with particular focus on dioxins. We have endeavoured to structure the way we provide knowledge to ensure it fulfils requirements on clarity and general information, as well as demands on factual reports and other more detailed information. We have therefore chosen to divide the report into a main report and two sub-reports.

The main report begins with a summary, in which we recount the most important results of the study and charting work on dioxins and waste incineration, and give a general outline of developments and the current situation in the field of waste incineration. Taking into account the central role of dioxin-related issues in this work and the great interest in these issues, we have highlighted the results in brief in the first section of this summary. The results are then presented in more detail in the following sections together with various background information as is described below.

The main text in the report begins with a retrospective look at developments within the field of waste, and the role of waste incineration in waste processing and energy generation. This first section also details the current situation at the 22 incineration plants in Sweden that are authorised to incinerate household waste. The second section provides a broad analysis and description of the issues surrounding chlorinated dioxins in society and our surroundings – properties, structure, exposure, formation, incidence etc.

Issues regarding waste incineration and dioxins are brought together and discussed in the following two sections. The third section contains an overview of what has happened since the end of the 1970s when dioxins were discovered in ash from waste incineration, up until the present day situation. In the fourth section we review the degradation, formation and separation of dioxins that occur in waste incineration plants, and discuss the conditions and consequences.

One central task of the investigative work has been to clarify the contents and quantities of dioxins in residues from waste incineration. The fifth section reports the results and conclusions from the studies carried out at the plants during 1999 and 2000. More detailed information can be found in the sub-report entitled “Dioxins in residues from waste incineration. Results from studies in 1999/2000 by Swedish waste incineration plants”.

The main report concludes with a review of and comments on current knowledge levels regarding leaching and degradation of dioxins in ashes. For more detailed information, please refer to the sub-report entitled "Dioxins in ashes from waste-fuelled plants. A review and report of current knowledge levels regarding leaching and degradation".

Since some of the issues treated in the main report and both of the sub-reports are complex in nature, we have, as far as possible, endeavoured to integrate explanations of various conditions into the running text. This is particularly relevant in section 2 (main report), which deals with issues relating to dioxins in society and our surroundings. As a complement, Appendix A contains a glossary of measures, units, abbreviations and chemical denominations.

In the case of dioxins, particular attention should be paid to the fact that there are different ways of assessing poisonousness or toxicity to produce a measure of TCDD equivalents. The most commonly applied and generally accepted method today is the international I-TEQ system, in which the 17 toxic dioxins are assigned a factor indicating their relative toxicity. 'Eadon' is an older method that has been in use for a long time, and is still used quite often in, for example, permits in line with environmental legislation. We have therefore been obliged to use both systems in parallel in our reports.

Briefly, the difference between both methods is that Eadon is based on an assessment of the acute toxicity, while I-TEQ also takes into account other effects of dioxins. The measured values for dioxin content according to Eadon are, as a rule, lower than I-TEQ values, although the differences in figures for flue gases from normal waste incineration, for instance, are not normally particularly great. The differences between Eadon and I-TEQ values are a result of the target object in question and prevailing conditions. There is therefore no universal conversion factor that can be applied to convert figures from one method to the other. Unless otherwise stated, our dioxin quantities refer to Eadon measurements.

# 2. The results in brief

## 2.1 Waste incineration and dioxins – the current situation and development tendencies

The waste treated and used as fuel at the Swedish waste incineration plants in 1999 contained dioxins of varying quantities, depending on the origin and composition of the waste. The information available, however, has not been sufficient for any reliable assessments to be made about the amounts of dioxins involved.

At the high temperatures involved in waste incineration in the plants, 90–95% of the dioxins in the waste are broken down into carbon dioxide, water and hydrogen chloride. A small quantity (5–10 g in 1999) of these dioxins in incoming waste are borne with particles and found in slag and bottom ash (FB plants), which are used as filler or sent to landfill.

When the flue gases were cooled 115–125 g of dioxin was formed, and this went with the raw gases to the flue-gas treatment system. Flue-gas cleaning separated 110–120 g of dioxin and stored it in fly ash, sludge, etc., which was then sent to long-term landfill. Total emissions of dioxins into the air from waste incineration plants in Sweden amounted to just under 3 g.

A major advantage of waste incineration when dealing with the dioxins in society is that the vast majority of the dioxins separated after incineration through flue-gas cleaning are collected and deposited in ash and other residual waste from the flue-gas treatment system. Dioxins in these residues, and to an even higher degree in slag and bottom ash, are solidly fixed to particles, and many studies have shown that separate handling gives rise to practically no leaching at all.

The risk of dioxins in residues from waste incineration leaching out and polluting the environment is therefore very low, provided that the residues from flue-gas cleaning are deposited without coming into contact with other waste, at landfill sites which are designed and dimensioned for long-term disposal of hazardous waste, see following section and section 6 (main report). The question of what would happen to the waste and its dioxin content if it were not incinerated is therefore of interest when discussing the role of waste incineration as a dioxin source, and selecting a method of treating household waste.

Efforts to further improve waste incineration as a method of treating household waste and other waste, and to increase energy production is now continuing as plants expand and modernise. Of course environmental protection is a central aspect in this work, and continued initiatives within the field of dioxins play an important role. The main aims are to reduce the formation of dioxins, to further reduce the already low emissions to air, and to ensure effective long-term deposition of ashes and other flue-gas treatment residues from the waste incineration process.

In our opinion, conditions are also favourable for waste incineration to be made even more effective in reducing the flow of dioxins through society and reducing the health-related and environmental problems this can cause. This applies to all stages of the process, from degradation of dioxins in the waste, reduction of formation, and separation of dioxins, to long-term deposition of waste from flue-gas cleaning.

## 2.2 Leaching and degradation of dioxins in ashes

The aim of the inventory and review carried out has been to chart and report current knowledge levels regarding the degradation and leaching properties of dioxins in ash and other residues from flue-gas cleaning from the waste incineration plants.

The work has encompassed and been based on documentary research, interviews with experts, and reviews of reports and studies etc. It soon became clear that only a few studies and investigations on leaching of dioxins and other persistent organic pollutants have been carried out. To all intents and purposes, there are no proper studies on ashes related to the degradation of dioxins, and we have therefore been referred to investigations into soil types.

The most important conclusions from this charting and review work on the leaching of dioxins from ashes can briefly be summarised in the following points:

- Dioxins and other organic environmental toxins are solidly fixed to particles and it is primarily the small particles in the leachate that carry these pollutants;
- Dioxin in fly ash does not leach at all, or to a very small extent (0.004%) when using distilled water or unaffected natural water as a leaching agent;
- Tests have shown that using different types of solvent as leaching agents results in considerably larger quantities of dioxin leaching;
- Leaching tests have shown that an increased concentration of e.g. detergent or other substances which reduce surface tension in the leaching agent result in increased leaching – tests show that the increase can be 100 times or even more compared to pure water;
- The leaching tests also showed that acidic solutions have a similar effect to solvents, although they involve lower levels of dioxin leaching;
- The higher chlorinated dioxins, which are present in the highest quantities, leach to a greater extent than the low chlorinated toxic dioxins, which are found in lower quantities, despite the latter being more water soluble;
- Background values for dioxins in rainwater and fall-out are at the same level as the dioxin contents in leachate.

These conclusions concur with experiences from previous research and studies. The results both on the dioxins' leaching properties and the factors that affect leaching are also concordant with earlier findings. The quantities and contents measured in tests using different leaching agents also tally well with previous findings.

The following conclusions can be drawn with regard to the degradation of dioxins in ashes.

- Dioxins in ashes are characterised by high stability and low mobility, provided that the ashes are handled separately and isolated from the surroundings;

- Under these conditions, the dioxins in ashes degrade very slowly and the half-life can be several decades;
- Dioxins in contaminated soil can degrade significantly faster than dioxins in ashes, depending on the different composition, the soil's structure, water flow and other factors, which facilitate degradation;
- Dioxins in ashes that are handled separately and isolated from external influence maintain their stability and degrade very slowly – particularly ashes containing unincinerated material.

# 3. Waste incineration

Incineration has a long history as a method of disposing of waste from households, industries and other activities in society. Special plants for incinerating household waste started being developed in Europe at the end of the 19th century. The first waste incineration plant in Sweden started up in 1901 in Lövsta outside Stockholm. However, it would be a long time before incineration plants started being expanded in earnest. Any incineration that did occur took place in open fires on rubbish tips or in simple furnaces.

At the end of the 1960s, environmental issues came to the fore, while waste quantities increased and municipalities had more and more trouble disposing of their waste. In the city regions in particular, investments were made in expanding large waste incineration plants that could process the waste from wide catchment areas. These kinds of plant with a capacity of 150 000–200 000 tons/year were developed in Stockholm, Gothenburg, Malmö and Uppsala.

In the mid-1970s, there were 13 waste incineration plants in Sweden, which dealt with a total of 0.8 million tons of waste. The following years saw rapid expansion and by 1985 there were 27 plants in operation. Collectively they handled just over 1.4 million tons, of which 1.3 million was household waste. By this time waste incineration had become the most common method of handling and treating household waste (Figure 1).

Strict requirements regarding environmental measures soon started being placed on the waste incineration plants, partly as a result of the moratorium in spring

1985 and the ENA inquiry (see main report), and due to subsequent related decisions by the Swedish Franchise Board for Environmental Protection and the Swedish government. This applied to both existing and future plants. The requirements were primarily focused on restricting emissions and other negative effects of heavy metals and dioxins.

One result of the requirements was that in the late 1980s and early 1990s, 20 of the 27 existing plants were rebuilt to improve incineration, and fitted with what were then highly advanced flue-gas treatment systems. The other seven plants were closed for environmental and economic reasons. These reconstructions and the opening of two new plants also increased the incineration capacity to approximately two million tons a year.

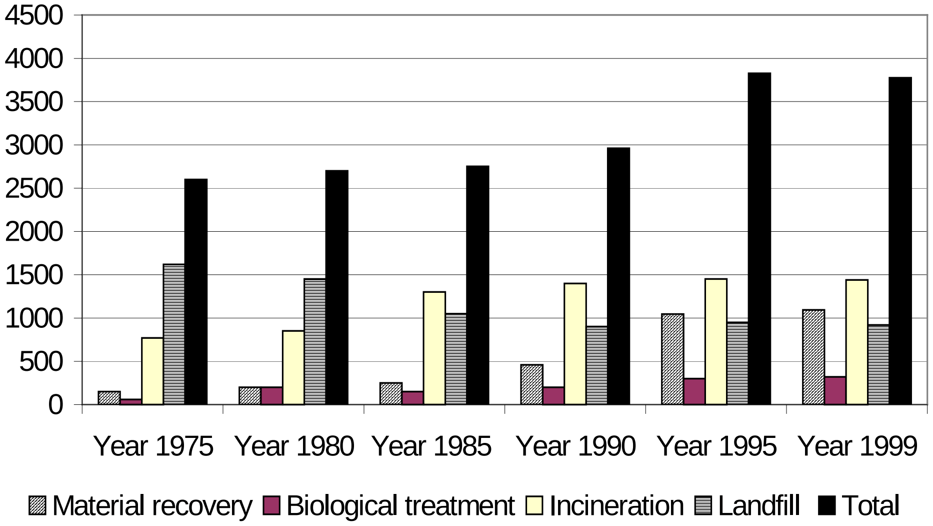

*Figure 1. Treatment of household waste in Sweden 1980–1999, thousands of tons a year.*

The total volume of household waste in Sweden amounted to 3.8 million tons in 1999. As shown in Figure 1, 1.1 million tons or approximately 30% of this was waste collected separately for material recovery in accordance with the producer responsibility charter. The remaining 2.7 million tons or 70% was collected under the direction of the local authorities and passed on for biological treatment, incineration or landfill.

Since 1975, the volume of household waste in Sweden has increased by a total of 1.2 million tons, an average of 50,000 tons a year. It has been possible, for the most part, to handle these increased amounts of waste over this 25-year period by increasing material recovery from 0.15 to 1.1 million tons a year. As regards the treatment of other household waste, incineration has doubled from 0.77 to 1.44 million tons a year, and biological treatment has increased from 0.06 to 0.32 million tons. At the same time, landfill has decreased from 1.62 to 0.92 million tons.

### 3.1 The waste incineration plants

In 1999, the existing 22 waste incineration plants in Sweden dealt with and incinerated a total of 1.9 million tons of waste. Of this, 1.3 million tons was household waste, 0.5 million tons industrial waste and 0.1 million tons waste wood etc.

The different plants vary a great deal in terms of size and capacity, see Figure 2. In 1999, the largest plant incinerated almost 400,000 tons, while the smallest plant handled only 5,000 tons. The five largest plants – Gothenburg, Stockholm, Uppsala, Linköping and Malmö – incinerated just over 1.3 million tons, almost 70% of the total waste incineration in Sweden.

Improved incineration with more efficient energy recovery, along with flue-gas condensation at some plants, has led to a twofold increase in energy production from 2.8 TWh in 1985 to 5.6 TWh in 1999 (Figure 3). This entails an energy exchange of 2.9 MWh per ton of waste, which is comparable with the energy obtained using peat and damp wood fuel. The majority (5.3 TWh) comprised district heating. Waste incineration therefore accounted for 10% of the district heating requirement in Sweden. The remaining 0.3 TWh comprised electricity.

Moving grates dominate incineration technology in the waste incineration plants. The sixteen grate-fired plants also accounted for 90% of waste incineration in Sweden. The other six are fitted with FB boilers for fluidised combustion.

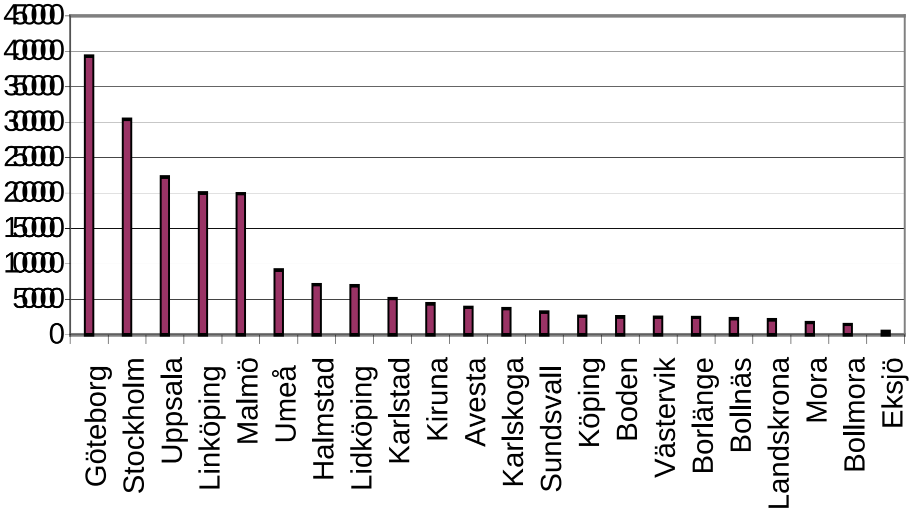

*Figure 2. Waste incinerated at the waste incineration plants in Sweden in 1999, tons.*

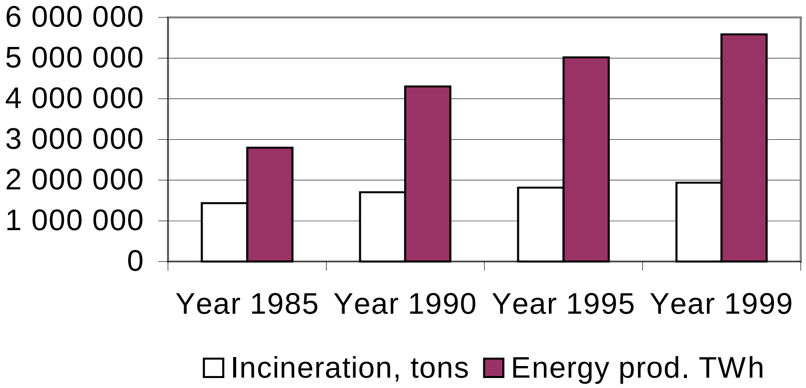

*Figure 3. Waste incineration and energy production at Swedish waste incineration plants 1985–1999 (tons and TWh).*

All Swedish waste incineration plants are fitted with equipment for dry cleaning of flue gases and efficient separation of dust into different electrostatic and/or barrier filters. Half of the plants are equipped with wet cleaning with flue-gas condensation, and several more are being extended or are planned for extension. Equipment to reduce nitrogen oxides is also installed at all plants.

Thanks to the comprehensive environmental protection efforts made at the plants, emissions of pollutants into the air have been dramatically reduced. Discharges of mercury and cadmium decreased by approximately 99% between 1985 and 1999 (Figure 4). During the same period, emissions of lead to air fell from 25,000 kg a year to 35 kg a year, and zinc from 54,000 kg to 90 kg a year. Emissions of dioxins were reduced during the same period from 90 g a year to just below 3 g a year.

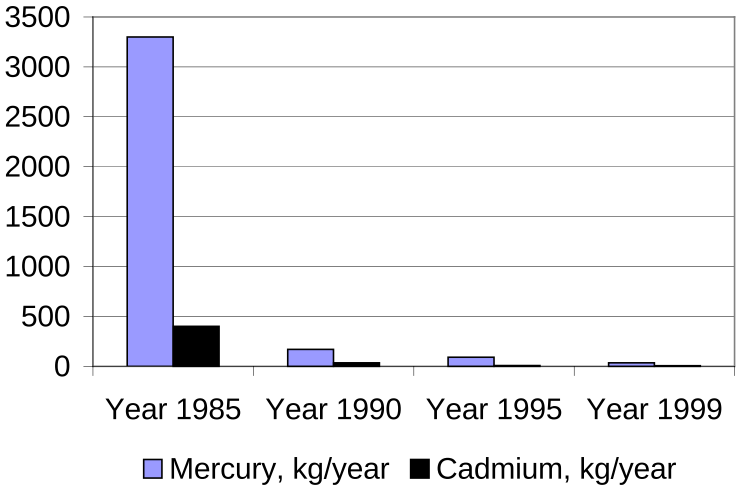

*Figure 4. Discharges of mercury and cadmium from waste incineration in Sweden 1985–1999, kg per year.*

Incinerating waste at the plants in 1999 resulted in 370,000 tons of slag and bottom ash being formed, equivalent to 19% by weight of the original amount of waste. At the grate-fired plants, slag and bottom ash comprised 20% of the additional amount of waste. The corresponding figure for FB plants was 6%.

During flue-gas cleaning, a total of 75,000 tons of ash and other residues from flue-gas treatment was separated, equivalent to 4% by weight of the original amount of waste. These residues consist of electrostatic filter ash, bag filter ash, sludge from water treatment, and lime and activated carbon additives. When FB boilers are used, some bed materials are borne with the flue gases and separated together with the ash. The proportion of flue-gas residues in the grate-fired plants was 3.5% of the original amount of waste. At the plants with FB boilers, the amount of residual waste separated during flue-gas cleaning was considerably higher, amounting to 8.5%.

# 4. Chlorinated and brominated dioxins

Chlorinated dioxins and other substances within the group known as persistent (stable) organic pollutants (POPs) occur and are formed in many different activities and processes, and in many different places within the industrialised countries. Due to emissions and other activities, these substances, which by nature are stable and are enriched in the food chains, have built up in the ecosystems where they cause serious disturbances. Dioxins include the most toxic substances known to mankind. The dioxins have therefore come into focus, and now form the template for dealing with chlorinated organic substances.

‘Dioxins’ is a collective name for 210 different chlorinated dibenzo-p-dioxins and dibenzofurans. Some of these compounds are extremely toxic, while others are practically harmless. In total, 17 of these dioxins are toxic to some degree, and of these 2.3.7.8-TCDD is the most toxic.

The dioxins’ toxicity is given in TCDD equivalents, which are a measure of how the 17 toxic dioxins are distributed in a sample from a flue gas, an ash or another material. Today toxicity is usually reported in the international I-TEQ system, although the older ‘Eadon’ method is still extensively used in parallel.

Brominated dioxins and dibenzofurans form a group of substances with similar properties to the chlorinated analogues (equivalents). The composition, structure and toxicity of both groups are comparable. One crucial difference, however, is that the brominated dioxins and dibenzofurans are not as stable in sunlight as their chlorinated counterparts. Tests have also shown that the rate of degradation of the brominated compounds in nature is significantly faster.

However, only a few studies into brominated dioxins and mixed chlorinated-brominated dioxins have been carried out, and the information basis for assessing incidence, formation, effects etc. is therefore extremely limited and unreliable. In this study on waste incineration and dioxins, we have therefore had to concentrate on issues surrounding chlorinated dioxins and dibenzofurans. It may, however, also be noted that during the investigations carried out, no brominated dioxins were observed in flue gases and ashes. Taking into account the risk of, for example, brominated flameproofing agents appearing to a greater extent in household and other waste, it is important that the issue of brominated dioxins be studied and investigated.

# 5. Enrichment and exposure of dioxins

The main problem with dioxins and other stable organic environmental toxins – apart from their toxicity – is the fact that they are enriched in the food chains (biomagnification). Organisms in sea and lake beds form the first step in this enrichment chain, as the dioxins remain in the organisms. The enrichment process then continues in fish, and the highest contents are found primarily in predatory fish, birds of prey and seals, all of which consume large quantities of fish. High dioxin contents have been measured in wild salmon from the Baltic Sea, for example, while Baltic herring and other fish products from this inland sea also contain dioxins.

As humans we are principally exposed to environmental toxins through what we eat. The size of an individual person's dioxin intake depends both on the content in the food that she/he eats, and the actual amount of food the person consumes. Considering the high content in fish caught in the Baltic Sea, the National Swedish Food Administration has recommended that particularly vulnerable groups, such as pregnant women, limit their consumption of these species of fish. However, by far the largest source of exposure to dioxins for humans is – despite the relatively low dioxin contents – dairy products, for the reason that these products form such a large part of our diet. The dioxin content in air, water and vegetables on the other hand is so low in Sweden that they are not significant sources of direct exposure for humans.

Bearing in mind that some of the dioxins are exceptionally harmful, stringent demands are in place to ensure that people are only exposed to extremely small doses of dioxin. The starting point for these assessments is the highest level at which the dioxins do not affect the organism (NOEL – no observed effect level). The NOEL value obtained is divided by a safety factor of 200, and based on this level, an assessment is made of how much dioxin a human can take in without being affected. World Health Organisation, WHO, recommendations state that an intake of 1–4 picograms (pg) per kilogram of body weight per day is tolerable.

The National Swedish Food Administration has set a limit of 5 picograms per kilogram of body weight per day for dioxin intake. This means that a person weighing 70 kg should not be exposed to more than 350 pg of dioxins (1 pg = 0.000 000 000 001 g) a day.

# 6. Formation of dioxins

Dioxins have never been produced commercially in the same way as polychlorinated biphenyls (PCBs) and polychlorinated naphthalenes (PCNs). Distribution in the environment has only happened via products that have been contaminated with dioxins or through emissions from thermal and chemical/ biological processes.

Dioxins can be formed in a number of different ways. A distinction is usually drawn between two main types of formation: formation in thermal processes and formation in chemical/biological processes.

During thermal processes, dioxins of the elements carbon, hydrogen, oxygen and chlorine are newly formed by the effect of a catalyst, such as copper. Alternatively, dioxins can be formed from precursors (the forerunners of dioxins) in the form of chlorinated organic compounds, such as chlorophenols. This too requires access to a catalyst. A third method of formation entails chlorination from non-chlorinated or low-chlorinated dioxins.

As regards chemical and biological formation at lower temperatures, this can take place in a number of different ways: chemical reactions based on specific chemical compounds, photochemical reactions when using UV light, or exposure of organic material to activated chlorine are just some examples.

It has emerged that conditions for dioxin formation can be found in many different activities and processes in society, and even in nature under both natural and influenced conditions. For example, dioxins can be formed during all types of incineration based on organic material. This is a result of chlorine and catalytically active substances such as copper commonly occurring in all forms of organic material. Precursors can also be found in many materials, which means the conditions are there for dioxin formation.

# 7. Sources of dioxins

Research and studies have shown that there are a great many dioxin sources in the modern industrial society, and new sources are emerging all the time. Dioxin sources are usually divided into three groups according to their formation: handling chemical residues, thermal treatment and natural formation.

An alternative basis for division, which may be easier to link with the development in society, is a division into primary and secondary sources. Primary sources refers to sources where dioxins are formed through chemical/biological and thermal processes. Secondary sources are products and materials contaminated with dioxins, and which may cause health and environmental problems when used or destroyed.

Our reviews and studies have enabled us to establish that the occurrence of dioxin sources in society and their properties are relatively well-charted. However, there is great, and in some cases very great, uncertainty concerning the size of these sources and their significance from a health and environmental perspective. In particular, this applies to the many minor sources within the energy and traffic sectors, and the diffuse emissions from house fires, forest fires and landfill sites etc. Drawing comparisons between different sources mainly relies on information about emissions of dioxins to air from various activities and otherwise on general valuations and assessments.

According to a charting carried out within a research project entitled “The Swedish Dioxin Survey”, emissions of dioxins to air from different activities and areas in Sweden amounted to 20–90 g in 1993. The uncertainty of these assessments is, as shown in Figure 5, quite significant due to large gaps in the foundation material. Waste incineration is an exception here, as a high number of samples have been taken from outgoing flue gases at the plants as part of research work and environmental controls, and these samples have then formed the basis for determining dioxin contents.

According to this charting of emissions to air, industry was a major source of dioxins, emitting between 10 and 31 g of dioxins in 1993. The industries in question are forest industries, iron and steelworks, aluminium and copper works, foundries, the cement industry and lime burning. It should be noted in this context that emissions of dioxins are higher at plants that work with recycled metals and other recovered materials than at plants which base their production on virgin raw materials.

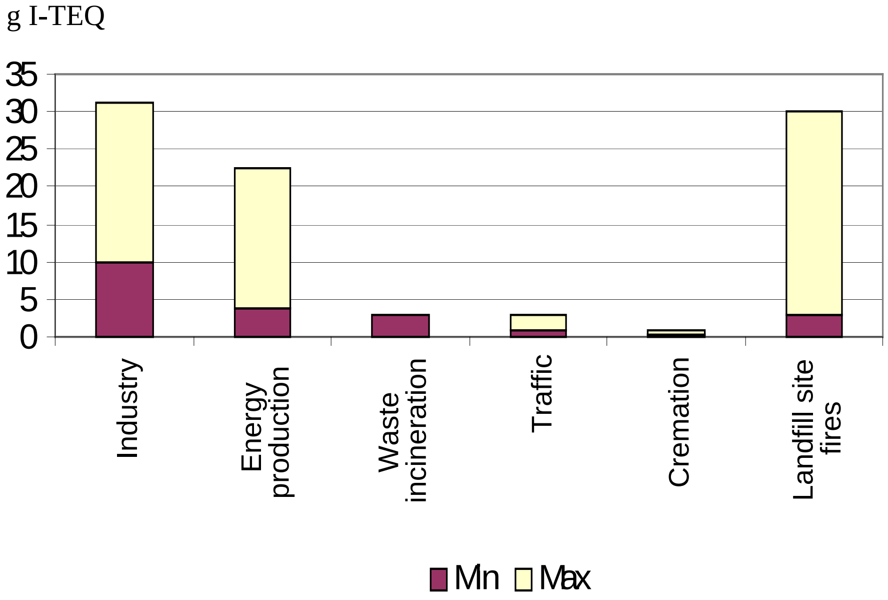

*Figure 5. Emissions of dioxins to air from different areas of activity in Sweden in 1993, g.*

Energy production – excluding waste incineration plants' energy production – is another major source of dioxins, with emissions of dioxin to air amounting to 4–23 g in 1993. According to estimates, the highest emissions are from small boilers, wood-fuelled furnaces etc., totalling 2–10 g.

There is of course a great amount of uncertainty regarding the magnitude of these dioxin emissions from at least a couple of hundred thousand furnaces, as the estimates are based on only a limited number of studies. The studies conducted, however, indicate that small boilers and other small furnaces are important sources of dioxins, since incineration can be uneven and the flue gases are not treated. These problems also apply to small biofuel-powered heating plants without more advanced cleaning. Emissions of dioxins to air from what the study terms 'other biofuel incineration' are estimated to have totalled between 1.5 g and 8 g in 1993.

Emissions of dioxins to air from traffic are considered relatively low, which is probably a result of the introduction of catalytic exhaust cleaning and unleaded petrol, among other things. In total, it was estimated that this sector of society accounted for 1–3 g of dioxin emissions into the air in 1993.

The great uncertainty surrounding emissions of dioxins springs from different forms of fire. In the Swedish study, emissions from fires at landfill sites have been estimated at between 3 and 30 g per year. Forest and land fires were previously considered a significant source of dioxin formation and distribution. Nowadays, however, it is thought that fires in buildings, cars and other objects that contain PVC and other chlorine-containing materials, are a larger source of dioxins.

The role of waste incineration as a source of dioxin has therefore decreased sharply as annual emissions to air have been brought down from 90–100 g in the mid-1980s to 3 g in 1993. Assuming that total emissions in Sweden averaged 50–60 g, waste incineration would therefore have accounted for 5–6% of emissions of dioxins to air.

Household waste contains dioxins to a varying degree, depending on the origin and composition of the waste. Surveys indicate that no degradation of dioxins takes place during composting, but rather that the waste’s dioxin content remains and is transferred to and included in the resulting product – compost. When it comes to issues surrounding dioxin formation the situation is less clear, although it has been observed in studies that biological formation of dioxins from chlorophenols has occurred during composting processes.

# 8. Dioxins in materials and products

The formation and distribution of dioxins mainly during the latter half of the 20th century, means that dioxins are now found in many materials, products, buildings and plants, as well as in the air, water, land, plants and animals.

Chlorophenols and their derivatives were the first products to be identified as containing dioxins as pollutants. Chlorophenol in the form of pentachlorophenol was used, for example, to protect timber against dry-rot. In Sweden, chlorophenols and PCBs were banned as far back as the 1970s, while stringent demands were placed on chlorophenol derivatives. However, there still remains a great deal of chlorophenol-treated timber in buildings and constructions, which could cause problems in demolition and reconstruction work if this waste is not dealt with in an environmentally friendly way.

The rate of turnover for many products and materials in society is often slow, and sometimes very slow. This is particularly true for buildings and plants that can have an economic life of 50–100 years or more. Consequently – despite dioxins being eliminated from various products and materials in Sweden as long ago as the 1970s – the ‘dioxin contamination’ of waste continues while these long-life products and materials become waste.

Another problem related to dioxin was the hormoslyr used frequently during the 1960s and into the 1970s to clear leafy brushwood along embankments and clear-felled areas. The herbicide contained a substance called 2.4.5-T, which was manufactured from chlorophenol and, depending on the production method, could contain the toxic dioxin analogues. The use of hormoslyr was prohibited in Sweden at the end of the 1970s.

Household waste contains varying levels of dioxins, depending on the origin and composition of the waste. Studies carried out in countries such as Germany have shown that the variations can be great, and measurements of content have ranged from a few micrograms per ton to several hundred micrograms per ton. There is not sufficient data on Swedish household waste to make possible any reliable assessments of the dioxin content in the waste dealt with for incineration or other treatment. Bearing in mind the importance dioxin contents in waste can have in the choice of treatment method, for example, we consider it essential that these issues are closely analysed.

# 9. Dioxins in nature and the environment

Small quantities of chlorinated dioxins are present in the air around us. The concentrations are usually higher in towns and industrial areas than in areas of undisturbed nature.

Dioxins emitted into the air are, however, transported long distances by the air streams before they sediment on land or in water. As a result dioxins can now be found all over the globe – in the polar bears of the Arctic and the penguins of the Antarctic.

The groundwater and drinking water in Sweden contain very low quantities of chlorinated dioxins. Water is therefore not a major contributor to human exposure to dioxins.

The majority of the dioxins that reach the earth's surface come from the air through sedimentation or with rainwater. The dioxin contents in soils that have not been contaminated are, as a rule, very low. Studies in the UK have shown contents of 1–5 ng per kg of soil in the countryside and 10–50 ng per kg in industrialised areas.

Plants do not usually absorb dioxins, rather these are adsorbed onto the root-fibres or leaves when they fall. Therefore the dioxin contents in plants are, as a rule, very low. The dioxin contents we reported earlier, however, can be high in animals found high up the food chain.

# 10. Degradation, formation and separation of dioxins during waste incineration

Household waste and other waste generated by modern society are a reflection of production and consumption. These kinds of waste will therefore contain all the types of material and chemicals used in society and the pollutants that form. In particular, this applies to household waste which comprises a heterogeneous material and which contains small amounts of mercury, cadmium, dioxins or other pollutants.

Household and other waste must therefore be treated carefully and dealt with safely to ensure the pollutants do not spread and cause harm to humans and the environment. The aim of waste incineration, however, is not only to break the harmful ecocycle of heavy metals, dioxins etc., but also to close beneficial material and energy ecocycles. Waste incineration with energy recovery, separation of pollutants and handling of residual waste – which is the most common method of treating household and other similar waste – satisfies both these requirements.

A modern waste plant is organised with the following main functions:

- reception, including separation, storage and feed system
- incineration including furnace, boiler and energy recovery

- flue-gas cleaning with dust separation and dry, and at some plants wet, cleaning with flue-gas condensation
- water treatment (with wet flue-gas cleaning)
- production of district heating and in some cases also electricity
- treatment and handling of slag, ash and other flue-gas treatment residues.

Consequently, the incoming waste contains varying amounts of dioxins, depending on the origin and composition. By far the largest proportion of these dioxins is broken down into carbon dioxide, water and hydrogen chloride during incineration at temperatures above 850$^{o}$C. The small quantities of dioxins that have not been broken down are borne with particles into slag and bottom ash. The dioxins are solidly fixed in these materials and there is no risk of leaching. It is estimated that there were 5–10 g of dioxin in the 370,000 tons of slag and bottom ash separated at the waste incineration plants in 1999.

As the hot flue gases are cooled, there is a degree of dioxin formation provided that three conditions are fulfilled. There must be sufficient chlorine in the flue gas for the carbon skeleton to be chlorinated. A catalyst in the form of copper, for instance, must be available in the flue gas. The temperature of the gas must be at least 200°C and no more than 600°C. These conditions are usually fulfilled in the convection part, where the flue gases are cooled and emit heat, which is used in district heat production or as steam in electricity generation.

Dioxins are therefore formed during waste incineration, although there are large variations between different plants, due to differences in factors such as technical design and the composition of the waste. Results from the investigations carried out show that 115–125 g of dioxin may have been formed at the waste incineration plants in Sweden in 1999.

The efficient flue-gas treatment systems at the Swedish plants today have in several cases already reduced the dioxin content in outgoing flue gases to below the EU’s limit value of 0.1 ng/m$^{3}$, and in some cases well below this limit. It should be noted that this limit value will apply for new plants as of the day the EU Directive is implemented in Swedish legislation (December 2002 at the latest) and for existing plants three years after this date. At the majority of the waste incineration plants, over 99% of the dioxins that have been formed and borne with the flue gases from the incineration are separated. Total dioxin emissions from the waste incineration plants in Sweden over the past five-year period have amounted to just under 3 g per year, which means the rate of separation is 98% on average.

Ash and other residues from flue-gas treatment, with their content of dioxins and other pollutants, are classified as hazardous waste and may therefore only be deposited at landfill sites approved for hazardous waste. This means for example that these residues  must be deposited separately from other types of waste, and that special protective measures must be taken to prevent the leaching of dioxins, heavy metals and other pollutants. At several plants, there is also some degree of stabilisation of these residues, through mixing different materials and adding stabilising agents. The total quantity of residues from flue-gas cleaning at the Swedish waste incineration plants amounted to 75,000 tons in 1999. These residues contained a total of 110–120 g of dioxin (Eadon).

# 11. Dioxins in residues from waste incineration

Of course, developments in waste incineration have led to considerable reductions in emissions of dioxins, heavy metals and other pollutants into the air, mainly through the expansion of highly effective flue-gas cleaning. The pollutants that were previously emitted out through the factory chimneys with the flue gases are – to the extent that they are not broken down – stored in ash and other residues from flue-gas cleaning. The focus in the dioxin issues, for instance, has therefore shifted to issues on dealing with and treating these residues. This applies in the industry and among experts, as well as among the general public and in the general debate on environmental issues.

In recent years, the Swedish Association of Waste Management (RVF) has therefore taken the initiative in establishing a series of measures to improve knowledge within these areas, and the information basis for decisions on measures. As part of this work, RVF and the waste incineration companies carried out the presented extensive investigation into dioxins in residues from waste incineration in autumn 1999 and spring 2000. As mentioned above, the main aim of this investigative work was to establish the contents and quantities of dioxins in ashes and other residues from flue-gas treatment.

Samples were taken at 21 of the 22 plants in operation during 1999/2000. The dioxin contents were found to vary within relatively wide limits, with a lowest value of 0.10 ng/g and a highest of 10 ng/g according to Eadon (Figure 6). The corresponding values according to I-TEQ were, as expected, slightly higher with 0.14 ng/g as the lowest value measured and 18 ng/g as the highest.

To some extent, these relatively large variations between plants can probably be explained by differences in technical design, operating conditions, waste composition and other conditions specific to each plant. However, the uncertainty in the individual samples has also played a crucial role. An accuracy of ± 50% in an individual sample can be expected under optimal conditions.

The crucial question, however, is whether the sample taken is representative of the operating conditions over a longer period. Since the samples were taken over one or a few days, there is of course a risk that they continuously "missed the mark", and ended up reflecting periods that were not representative of the operation during an annual cycle.

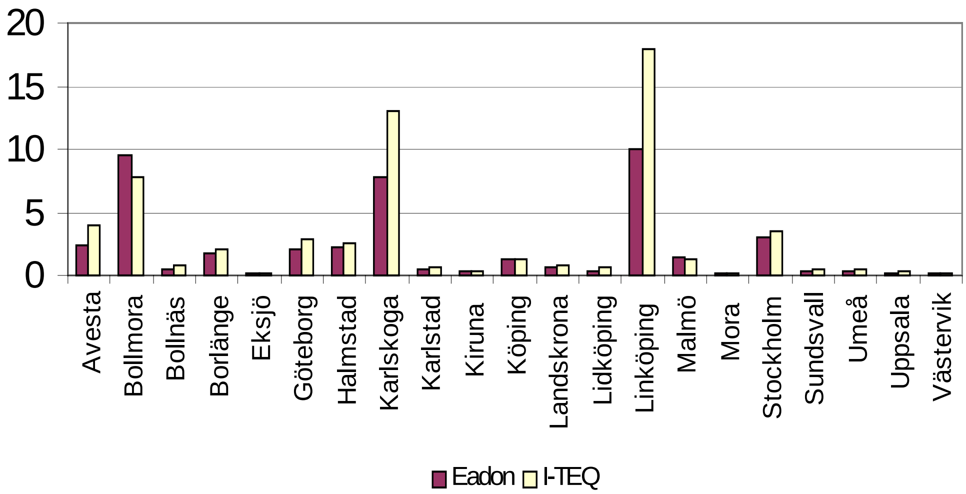

*Figure 6. Dioxin contents in residues from flue-gas cleaning at waste incineration plants in Sweden in 1999, ng/g.*

However, the majority of samples fall quite nicely within a more restricted window. Half of the values within the second and third quartiles lie between 0.35 and 2.0 ng/g according to Eadon and between 0.45 and 2.5 ng/g according to I-TEQ. The median value for both methods is 0.7 ng/g. Based on the total quantities of residues from flue-gas cleaning collected from all plants, the mean value is 2.0 ng/g (Eadon) and 2.8 ng/g (I-TEQ).

In light of these findings and after reviewing documented information, we concluded that an average figure of 2–3 ng/g of dioxin content in residues from flue-gas cleaning for waste incineration in Sweden appeared to be the norm.

The total quantity of dioxins in residues from flue-gas cleaning at the plants in 1999 amounted to approximately 110 g according to Eadon and approximately 160 g according to I-TEQ. A few of the plants account for the great majority of these quantities of dioxin, as shown in Figure 7. It should be observed that when calculating quantities of dioxins for the individual plants there were, in addition to the significant differences in dioxin contents, large variations in the quantities of residues. The largest plant generated 15,000 tons of ash and other flue-gas treatment residues, while the smallest produced just 250 tons.

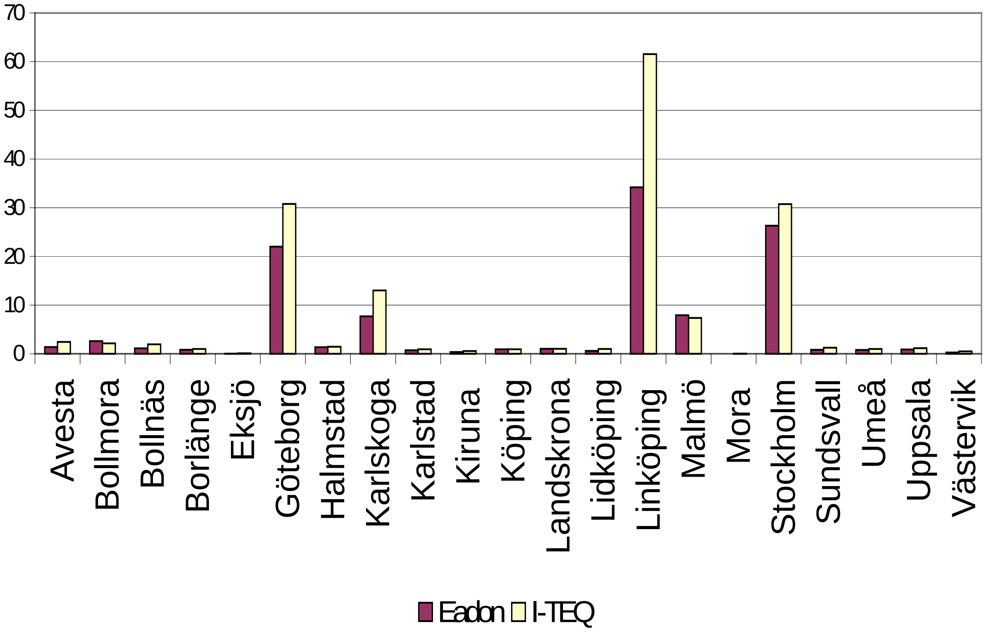

*Figure 7. Quantity of dioxins in residues from flue-gas cleaning at waste incineration plants in Sweden in 1999, g.*

As a basis for continued discussions on dioxin-related issues, we have produced two “key ratios” for dioxin content in residues from waste incineration. The first specifies micrograms of dioxin per ton of incinerated waste, and the second micrograms of dioxin per MWh of energy produced.

In approximate terms, an average of 40–60 µg/ton of incinerated waste during waste incineration can be viewed as the norm for the key ratios linked to the quantity of incinerated waste over a longer period (Figure 8). The corresponding key ratios linked to energy production can be estimated to amount to 15–20 µg/MWh of energy produced.

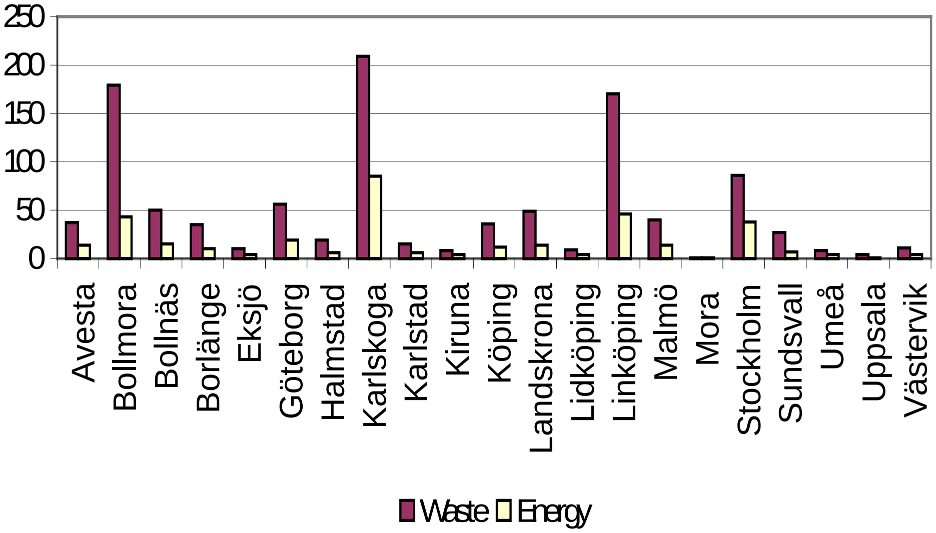

*Figure 8. Dioxins in residues from flue-gas cleaning at waste incineration plants in Sweden in 1999, expressed in µg per incinerated ton of waste and µg per MWh of energy produced.*

In short the results can be summarized as:

The study shows that dioxins found in the residual waste from incineration are solidly fixed. This breaks the ecocycle of the dioxins in the waste. Incineration and energy production using waste as the fuel is a good way of dealing with combustible waste.

# Bottom ash and APC residue management

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## Abstract

The management of residues from waste incineration aims at inertisation of the bottom ashes and minimisation of the amount of hazardous fly ashes and gas cleaning residues while still meeting the emission standards. For economic reasons, this should mainly be reached by in-plant measures. Strategies to produce bottom ash with utilisation properties and to inertise other solid residues are presented. The leaching stability as most important environment related quality parameter is addressed. The costs of the existing treatment and disposal options are discussed.

# 1. Introduction

Some ten years ago the debate about thermal processes was mainly focused on potential risks of air emissions, especially those related to dioxins. Meanwhile the gas cleaning devices implemented in municipal solid waste incineration (MSWI) plants are among the most effective ones found in any technical process and the interest is more directed to the quality of the solid combustion residues. The aims are to produce as far as possible inertised bottom ashes and to enable their utilisation as secondary building materials. This is especially promoted in the Netherlands, Denmark and Germany, recently also in France. A further focus is the inertisation and safe disposal – or even utilisation – of the filter and boiler ashes as well as of the gas cleaning residues.

All kinds of secondary treatment processes have been developed to tailor the residue quality according to special needs. Secondary measures, however, are expensive and hence the better approach is an optimised control of the combustion process to

- guarantee an excellent burnout of carbon compounds
- promote the volatilisation of heavy metals like Hg and Cd out of the fuel bed
- fix lithophilic elements in the silicatic and oxidic matrix of the bottom ash, thus reducing their leachability.

The following discussion of the quality of residues from modern waste incineration plants will follow these objectives. Finally it will investigate, which rational options exist to inertise and eventually utilise filter ashes and flue gas cleaning residues. All considerations base mainly on the results of an international perspective on the characterisation and management of waste incineration residues published by the International Ash Working Group in 1997 [IAWG 1997].

## 2. Mass streams in a MSWI

The basis of all discussions about waste incineration residues is the knowledge of the different mass streams in a municipal solid waste incinerator. Fig. 1 shows average ranges for these streams as found in modern mass burning systems. The air consumption is approx. 4500 $m^3$/Mg of waste.

State-of-the-art plants produce typically between 200 and 300 kg bottom ashes per 1 Mg of burnt waste. Most published numbers include the grate siftings, which are only recently and only in some countries kept separate from the bottom ash. The mass flow of siftings depends on the type of grate and its time of operation. The siftings may increase the amount of unburnt matter in the bottom ash. In view of utilisation, however, the inventory of metallic Al, which drips through the grate voids, is of much higher concern.

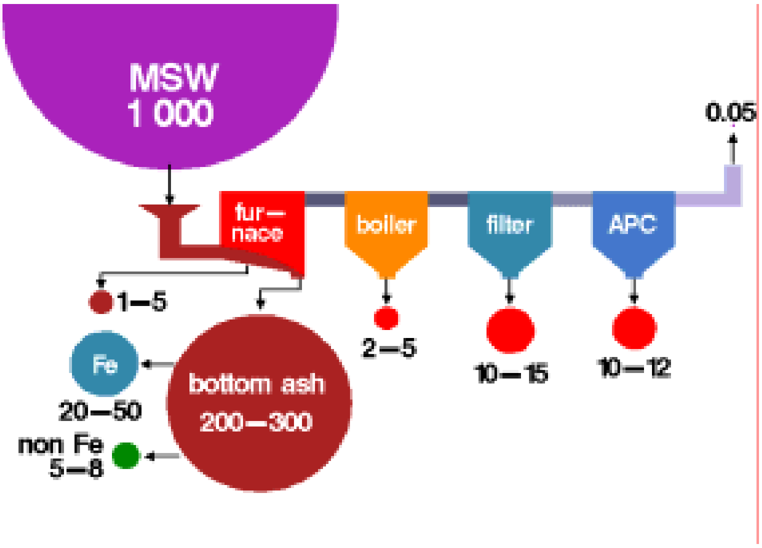

*Fig. 1. Mass balance of a municipal solid waste incinerator (values in kg/Mg waste).*

The production of boiler ash depends on the type of boiler and on the amount of dust originally released from the grate. Boiler ash should be treated together with the filter ash due to its similar level of toxic heavy metals and organics. In some countries this has already been enforced by legislative regulations. The data presented for filter ashes reflect the situation in modern plants, which try to establish a more gentle combustion with dust loads down to less than 2 g/m$^3$ [Vogg 1991].

The mass flow of air pollution control (APC) residues shows actually the highest variation of all residues. The given 10–12 kg/Mg is a mean value for wet systems that operate close to stoichiometry. The number comprises the dry neutral sludge (2–3 kg/Mg) and the soluble salts (8–9 kg/Mg). In semi-dry or dry systems the amount is increased because of unreacted additives.

# 3. Bottom ashes

## 3.1 Disposal and utilisation regulations

Waste incineration is performed to produce an inertised residue, the bottom ash, which meets the respective disposal standards. Many countries aim at utilising this residue stream in order to save space on landfill sites.

*Table 1. Selected German standards for disposal and utilisation of MSWI bottom ash.*

| | Unit | Landfill class 1 | Road construction |
|---|---|---|---|
| LOI | wt% | 3 | |
| TOC | wt% | 1 | 1 |
| DEV S4 | | | |
| Soluble fraction | wt% | 3 | |
| El. conductivity | mS/m | 1000 | 600 |
| Cl | mg/l | | 250 |
| Cu | mg/l | 1 | 0.3 |
| Zn | mg/l | 2 | 0.3 |
| Cd | mg/l | 0.05 | 0.005 |
| Pb | mg/l | 0.2 | 0.05 |

Selected German standards for disposal on landfill class 1 and for utilisation of bottom ash in road construction [LAGA 1994] are compiled in Table 1. The table indicates only a small difference between the requirements for disposal and utilisation, and the challenge is to reach the utilisation quality without further post-combustion treatment.

In the case of utilisation as secondary building material additional standards are set for mechanical properties like density, mechanical strength, grain size distribution or freeze-thaw-stability. This aspect, however, will not be discussed here.

## 3.2 Burnout

The burnout is the key parameter for disposal as well as for utilisation of bottom ashes. The German Technical Ordinance Residential Waste sets a TOC (total organic carbon) limit of 1 wt.-% for disposal on a class I landfill. The same number is found in the LAGA memorandum for utilisation in road construction.

In modern well-operated MSWI plants the TOC in bottom ashes is typically well below 1 wt% [Schneider 1994, Bergfeldt 2000]. Special combustion trials in the Karlsruhe test incinerator TAMARA demonstrated that an increasing heating value of the feed and the resulting higher bed temperatures improve the burnout of bottom ash (see Fig. 2) [Vehlow 1994].

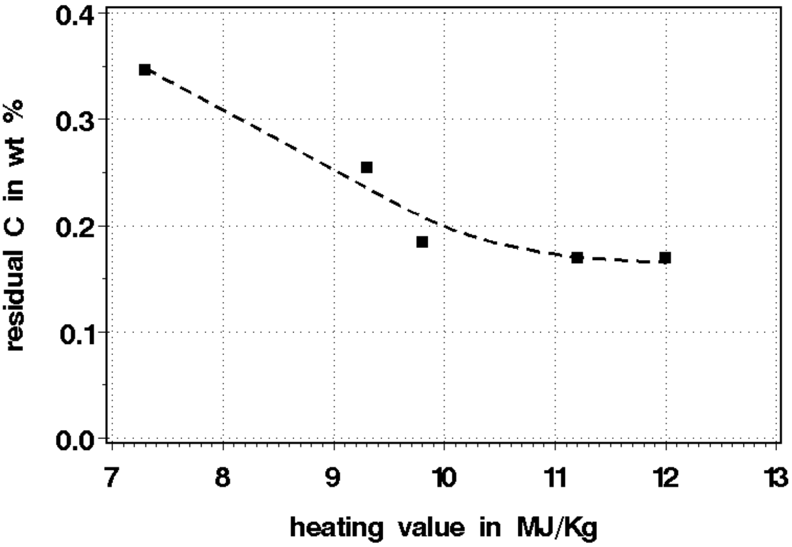

*Fig. 2. Residual carbon in TAMARA bottom ashes versus heating value of the feed.*

The TOC of bottom ashes comprises mainly elementary carbon but to a certain extent also organic compounds are found, which cover the spectrum from short-chain compounds [Köster 1998], up to low volatile species such as PAH or PCDD/F. Typical concentrations of organic compounds in the various solid residues are compiled in Table 2.

*Table 2. Concentration ranges of organic compounds in bottom, boiler, and filter ashes.*

| Parameter | Bottom ash ng/g | Boiler ash ng/g | Filter ash ng/g |
|---|---|---|---|
| I-TEQ | <0.001–0.01 | 0,02–0.5 | 0.2–10 |
| PCB | <5–50 | 4–50 | 10–250 |
| PCBz | < 2–20 | 200–1 000 | 100–4 000 |
| PCPh | <2–50 | 20–500 | 50–10 000 |
| PAH | <5–10 | 10–300 | 50–2 000 |

Only data from modern facilities have been used as basis [Johnke 1995, Schneider 1994, Bergfeldt 1997]. The PCDD/F numbers are given in terms of international toxic equivalence data (I-TEQ). It is evident that the organic pollution is higher in the boiler and fly ashes than it is in the bottom ash. The I-TEQ levels detected in the bottom ashes of modern incineration plants were in the same order of magnitude as found in uncontaminated soils in Germany [Bergfeldt 2000].

## 3.3 Chemical and mineralogical characterisation

The mass and volume reduction of waste incineration causes an enrichment of a number of heavy metals in the bottom ashes compared to their concentration in the waste feed. This is demonstrated by the concentration ranges of selected metals depicted in Fig. 3 [IAWG 1997]. Some heavy metals, e.g., As, Cd, or Hg, are to a great extent volatilised out of the fuel bed and show eventually lower concentrations in the bottom ashes than in the waste. The graph contains the respective concentration ranges in filter ashes, too, and it is evident that – with the exception of the mainly lithophilic Cu – all other selected heavy metals are highly enriched in these materials. For comparison the concentrations in the lithosphere are enclosed, too.

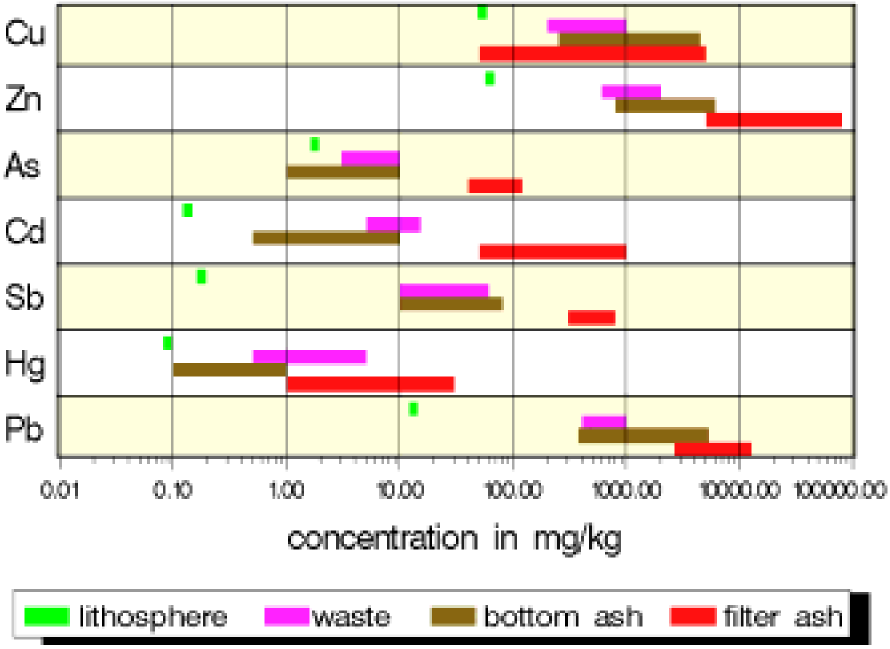

*Fig. 3. Concentration ranges of selected elements in various materials.*

Apart from the chemical analysis a geochemical and mineralogical characterisation provides useful information in view of the long-term behaviour of a material. Bottom ashes can be characterised as a mixture of silicatic and oxidic phases. Some typical mineral phases found in these residues are shown in the micrographs in Fig. 4 [Pfrang-Stotz 1992]. These phases do not only tell about the structure of the bottom ash but can in special cases also supply information about the temperature, the material has been exposed to on the grate. This important number, which controls mainly the fate of elements in the combustion chamber, is widely unknown in full-scale plants. The knowledge of formation temperatures of single phases and the specific search for high-temperature phases are promising ways to obtain better information in this area [Pfrang-Stotz 1993].

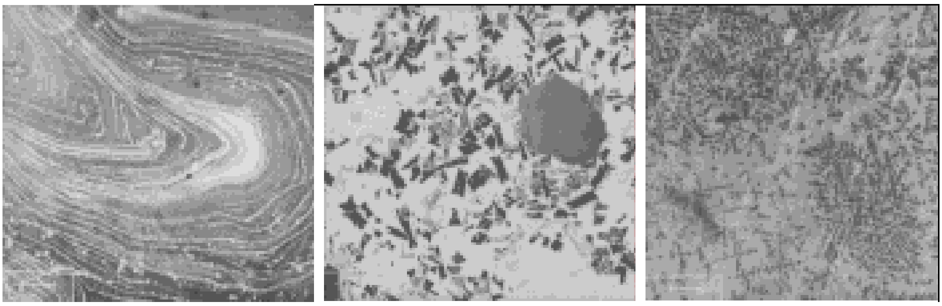

*Fig. 4. Micrographs of minerals in bottom ashes: glass formed during combustion (left), gehlenite* $Ca_2AlAlSiO_7$*, in glassy matrix (centre), magnetite,* $Fe_3O_4$ *(right) [Pfrang-Stotz 1992].*

## 3.4 Leaching stability

### 3.4.1 Leaching fundamentals

The chemical composition of a product does in principle not allow evaluating its environmental impact. This is far more depending on the leaching stability of the material in question. Even if the matrix and the speciation of single elements were known, a reliable theoretical prediction of the short- and long-term behaviour is more or less impossible. The most important parameters influencing the leaching stability of a material are enumerated below:

- chemical composition
- chemical/geochemical/mineralogical speciation
- fraction of a species available for leaching
- particle morphology
- properties of the leachant, especially its pH or the presence of complexing constituents
- liquid-solid ratio (LS) in the leaching system.

It seems evident, that no single – and on top of that – simple test procedure will deliver results that allow a sound evaluation of impacts on the environment. In fact, a large number of different tests have been developed to get detailed information about the leaching properties of residues from waste incineration.

There are two categories of test procedures: extraction tests and dynamic tests. The most common principles of these test categories are comprised in Fig. 5.

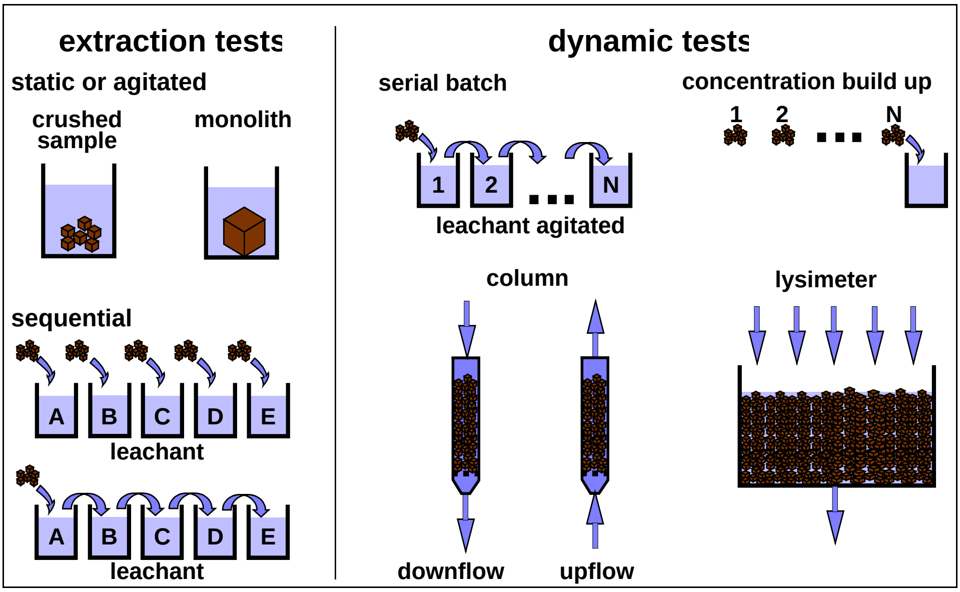

*Fig. 5. Principles of leaching tests.*

Extraction tests allow the determination of leaching equilibria. If the leachate is analysed in time increments before the equilibrium is reached, information on the kinetics of the system can be obtained. An example of such tests is the Dutch tank-leaching test [NEN 7345] for stabilised materials. This test gives also indication of the major parameters controlling the leaching process, e.g., diffusion or solubility. Sequential tests in different leachants of increasing chemical strength are often used to investigate the chemical bond of specific elements in the matrix.

Dynamic tests are applied to reveal the kinetics of the leaching process. A rather common one is the Dutch column-leaching test [NEN 7341] for granular material. This test is typically performed up to an accumulated LS of 10 and enables the modelling of contaminant release during 50–100 years.

In practice, a material in question is subject to a number of different tests, which are selected to model as close as possible the envisaged disposal or utilisation scenario. After the fundamental properties have been acquired, an indicator test – in most cases a standardised test procedure – is chosen to control the quality of an actual sample in short time and with limited effort.

Almost all regulations for the disposal or utilisation of waste products are based on standardised leaching tests, unfortunately different ones in different countries. Hence the testing is done under country-specific conditions and the interpretation of the results of various tests has to take such differences into account.

The most important parameter influencing the results of a leaching test is the pH of the leachant. Fig. 6 gives a schematic overview of the influence of pH of the leachant upon the solubility of metal cations and anions in aqueous solutions. It is well known that most heavy metals show rather low solubility in the weak alkaline range. Their solubility increases with decreasing pH. In the alkaline region different metals behave differently: some (e.g. Cd) stay insoluble with increasing pH. Others, the amphoteric ones, are more or less solubilised if the pH is elevated. The amphoteric metal of highest interest in waste incineration is Pb.

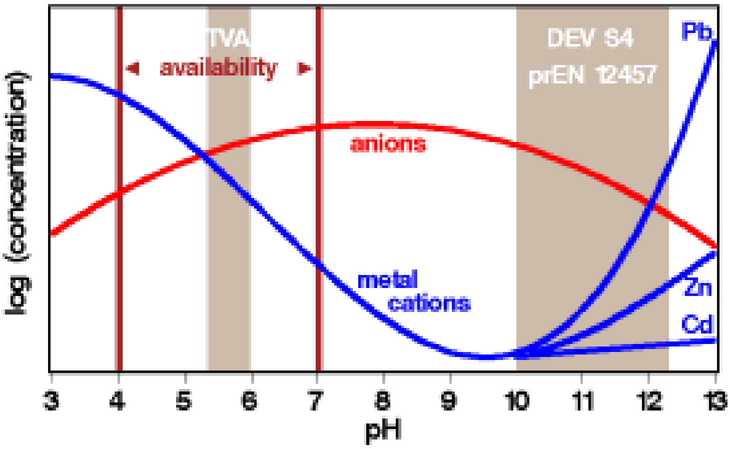

*Fig. 6. Influence of the pH and the solubility of metal cations and anions.*

Metals that tend to form anions in aquatic solutions like V, Cr, or Mo, have their highest solubility close to the neutral point.

The graph in Fig. 6 indicates the ranges of pH that establish in selected leaching tests of bottom ashes. The German DEV S4 [DIN 38 414] (LS = 10, 24 h) shows numbers between 10 and > 12. Almost the same procedure is used in France with the X31-210 AFNOR leach test [Normalisation française 1988]. These varying conditions have severe impacts especially on the test results of Pb.

The Swiss TVA test [Schweizerischer Bundesrat 1990], (2 tests at LS = 10, 24 h each) is characterised by a rather constant pH of 5.5–6 due to the gaseous $CO_2$ bubbling through the test solution.

Constant pH values are used for the Dutch total availability test [NEN 7341], which gives information about the leaching potential under assumed 'worst' environmental conditions. The cation solubility is tested at a pH of 4, that of the anions at a pH of 7. The sample has to be finely ground in order to exclude any inhibition of the leaching by diffusion and the liquid-solid ratio is kept at 100 to avoid saturation effects in the solution.

The standardisation committee of the EU has recently proposed the leaching procedure prEN 12457 for crushed bottom ashes. A 6-h test at LS = 2 is followed by a second leaching for 18 h at LS = 8 [European Committee 1999]. The first part of this test has been adopted by the Danish authorities for quality control of bottom ashes. The test is not pH controlled. For the time being only limited knowledge exists how results from this test compare to other tests.

### 3.4.2 Effect of aging

In order to optimise the total burnout the combustion temperature and with this also the fuel bed temperature has been elevated in MSWI plants during the last decade. As an effect of such operation changes a higher formation of CaO can be seen. The pH value of fresh bottom ashes is often exceeding 12. According to the German LAGA memorandum bottom ashes have to be stored for 12 weeks prior to utilisation in road construction. During this time the uptake of $CO_2$ from the air converts the earth-alkali oxides into carbonates and neutralises part of the alkalinity. Hence aged bottom ashes establish a pH of about 10–11 in the DEV S4 test.

Data from a test program in a German full-scale waste incineration plant illustrate the effect which aging has on the pH of bottom ashes and on the test results obtained by the DEV S4 method [Bergfeldt 1997]. Fig. 7 documents that the pH of the fresh bottom ashes in the DEV S4 test is typically exceeding 12 and drops down by about two units during the aging process. As can be seen in Figure 8, this pH change has no effect on the leaching properties of Mo, which is present mainly as molybdate. The leaching stability of Cu and Zn is moderately improved in the aged material whereas the leaching of Pb is reduced by almost 2 orders of magnitude.

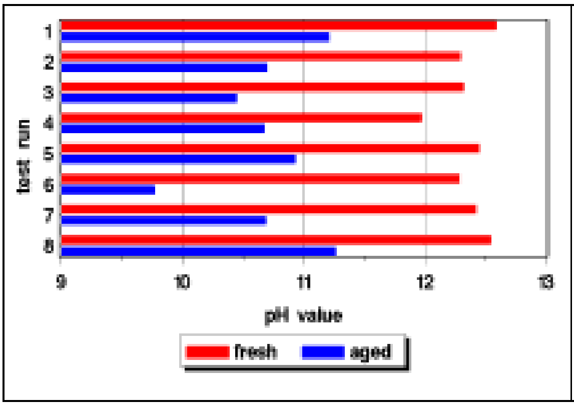

*Fig. 7. pH values of fresh and aged bottom ashes.*

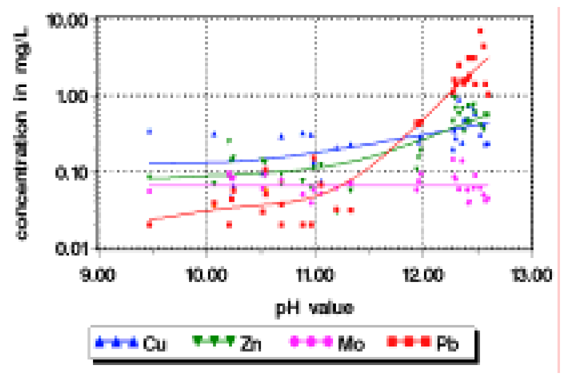

*Fig. 8. pH dependency of metal leaching.*

This strong interdependency is responsible for the strange situation that due to German regulations fresh bottom ashes from some plants do not comply with the landfill standards while after aging they are excellent secondary building materials.

## 3.5 Potential for utilisation

As mentioned above, a number of countries has or is going to set standards for the utilisation of bottom ashes. The major application area is road construction where ashes are used in the support layers mainly under watertight capping. The requirements for leaching stability are more or less of equal stringency in all countries all over the world. The German guideline regulating utilisation in road construction is the above-mentioned LAGA memorandum.

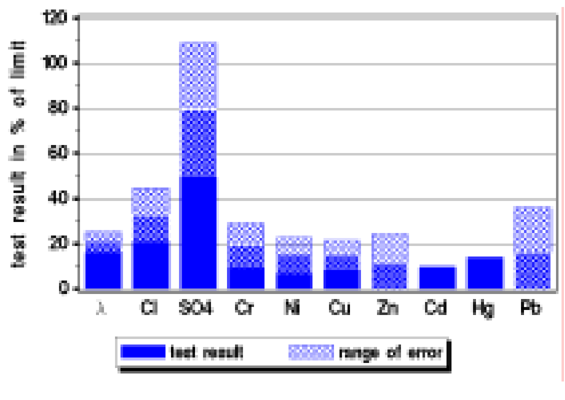

*Fig. 9. DEV S4 results of 26 bottom ash samples standardised to the limits of the German LAGA memorandum.*

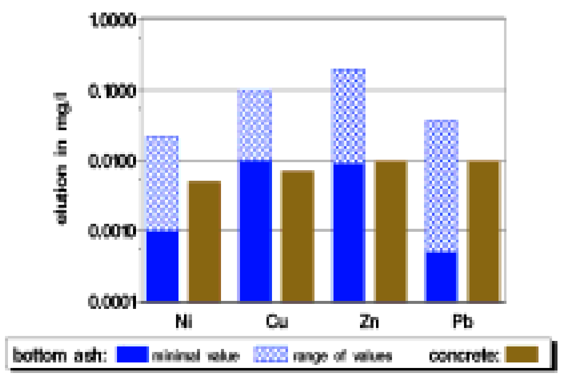

*Fig. 10. DEV S4 results of 26 bottom ashes compared to those obtained on concrete debris from a highway bridge.*

Fig. 9 demonstrates for 26 samples taken routinely during one year on an industrial ash treatment site, that the test results for the environmentally interesting heavy metals were always well below the respective standards [Pfrang-Stotz 1995]. The only component exceeding the limit in few cases was sulphate. This limit has been set to protect concrete structures from corrosion attack. Hence it can be stated, that bottom ashes from modern and well-operated MSWI plants do easily meet the LAGA limits for utilisation

Other constituents of concern are soluble salts, mainly alkali and earth-alkali chlorides and sulphates. Chlorides can be reduced by washing the ashes [Schneider 1994]. The simplest way is a washing in the quench tank, which is already performed in some German plants. The sulphate solubility is controlled by the solubility equilibrium of the predominant earth-alkali sulphates. A stabilisation or removal is hence difficult.

The compliance with standards fulfils the legislative requirements but does not necessarily tell about the acceptability of the environmental impact. To get a clue about this aspect the DEV S4 test was also applied to samples of concrete from a demolished highway bridge. The test results of four metals in terms of concentrations are displayed in Fig. 10 together with those of the 26 bottom ash samples. The bar chart gives evidence that the leaching stability of aged high quality bottom ashes can be kept in the same order of magnitude as that of conventional building materials. Hence there is no reason not to utilise, after careful testing, bottom ashes from modern waste incineration plants.

This is common practice in countries, which have geological conditions hampering the siting of landfills like The Netherlands or Denmark. These countries utilise up to 90% of the bottom ashes [Sakai 1996]. The respective number for Germany is approx. 60% [Johnke 1995]. Some other countries like France are nowadays as well encouraging bottom ash utilisation.

A different strategy is followed by the Swiss authorities. According to their regulations, bottom ashes are categorised as reactive residues. Only stone-like materials are accepted as in building materials and stone-like refers to the concentration and not to the mobility of a single constituent. Since the bottom ashes contain higher amounts of heavy metals than the lithosphere (compare Fig. 3), almost no utilisation is practised. Bottom ashes have to be disposed of or they have to be converted into real stone-like materials by adequate measures.

## 3.6 Quality assurance by sintering

The good leaching stability of bottom ashes presented above needs to be reached permanently and this gives reason to ask, how to guarantee such high quality. The best approach seams to establish a high temperature in the fuel bed for volatilisation of mobile metals and immobilisation of the lithophilic ones by sintering. Since sintering is a solid phase re-speciation, higher residence time improves the effect.

This strategy has been investigated in laboratory scale by sinter experiments using fresh bottom ashes from two German incineration plants [Schneider 1994]. The ashes have been annealed under air atmosphere at temperatures of 850, 1000 and at 1300°C for 30 min each. At the latter temperature the material was melted. The resulting DEV S4 leaching data of the products of these tests are depicted in Fig. 11.

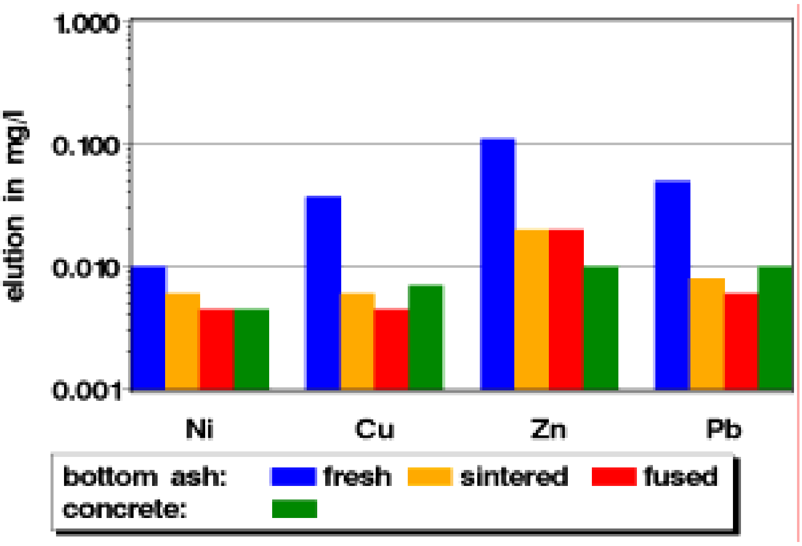

*Fig. 11. DEV S4 results of thermally treated bottom ashes and concrete.*

The graph indicates a significant improvement of the leaching stability of four selected metals by the treatment. At 850 and 1000°C comparable effects were observed. The fusion, however, did not improve the elution stability significantly. This finding is supported by the comparison of test results from bottom ashes with those published for molten residues from high-temperature processes like Thermoselect or the Siemens Thermal Waste Recycling Process [Vehlow 1995].

The stabilisation by sintering could also be validated in semi-technical experiments with fresh bottom ashes from a full-scale incineration plant [Bergfeldt 1997].

Based on these results it can be concluded that a sintering at temperatures of 850°C has a stabilising effect upon heavy metals. The energy consuming – and that means expensive – fusion, however, does not pay since no significant further fixation could be observed. Hence a simple in-plant measure to produce bottom ashes of high leaching stability can be recommended: the bed material should be kept at high temperature at the back end of the grate.

# 4. Filter ashes and APC residues

Filter ashes and to a certain extent boiler ashes, too, carry substantial loads of volatilised heavy metals (as has been documented in Fig. 3) and of low volatile organic compounds (compare Table 2).

Wet and (semi-)dry gas cleaning systems produce different amounts of scrubbing residues, which are different in quality, too. Their major constituents are water-soluble salts derived from the removal of acid gas constituents. The main waste inventory of Hg is discharged along with these residue streams. Furthermore, contaminants like organic compounds and – depending on the quality of fly ash removal – traces of other heavy metals are found.

The filter ashes as well as the scrubbing residues are classified as hazardous waste in almost all legislations and consequently the only safe disposal is that on an adequate special disposal site, preferentially in the underground in old salt mines (as preferred in Germany). The alternative, the inertisation of these residues will be addressed in the next chapter.

# 5. Treatment and costs

## 5.1 Treatment principles

Many efforts have been made to improve the environmental quality of residues from waste incineration by secondary treatment and to recycle or utilise at least parts of specific residues. A compilation of proposed strategies and processes is shown in Fig. 12. The disposal/utilisation in salt mines is a German speciality and will briefly be discussed below.

To assess the usefulness of post-combustion treatment it is necessary, not only to consider the environmental benefits of a measure but also to set the obtained improvement into relation to the spent effort. The measure for the effort should be the cost of the process. In other words: a real eco-balance is needed.

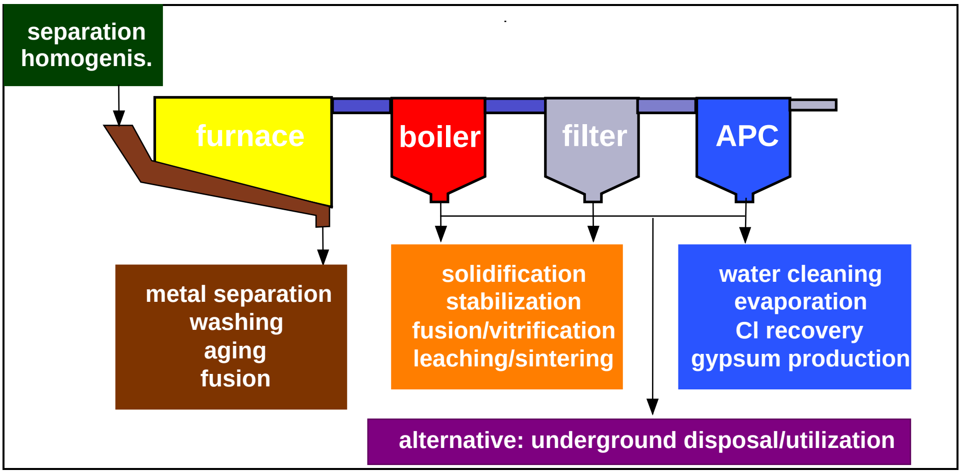

*Fig. 12. Principles of post-combustion treatment of waste incineration residues.*

The International Ash Working Group identified a number of principles that have to be considered when assessing the benefits but also the obstacles of a given treatment measure:

- Does the process result in a significant quality improvement?
- Does the process impose any health, environmental or safety impacts?
- Are there secondary residues and where do they end up?
- Is there a final product of high quality?
- Is there a long-term market for that product?
- What is the cost of the process?

It is not easy to answer these questions in particular, the more so if the respective process has not been tested in full scale. This applies especially for the costs. In view of the total process costs of waste incineration an expensive treatment process might be acceptable for a small residue stream like filter ashes, for the bottom ash, however, even moderate process costs are prohibitive.

## 5.2 Bottom ashes

Especially in Japan, fusion or vitrification of bottom ashes is practised in order to reduce their volume and to improve their environmental quality. In other countries like Germany such processes have been proposed, but did not enter the market for economic reason.

As has been documented above, bottom ashes from modern waste incineration plants have the potential to be utilised as secondary building material in road construction – and there is a permanent requirement for such material. It is also evident, that fusion of bottom ashes from stat-of-the-art MSWI plants does not improve the quality to an extent which would open new markets.

Table 3 compiles estimates of costs of various treatment options for bottom ashes taken from literature [Vehlow 1997]. Considering German conditions it makes sense to utilise bottom ashes, since the expenses for the pre-treatment are similar to those for landfilling. Furthermore, it can be expected that the latter ones will increase with time. Fusion, however, should only be applied if the high costs can be justified by either respective revenues or long-term benefits of other kind.

*Table 3. Cost estimates for land filling and treatment of bottom ashes.*

| | €/Mg of bottom ash | €/Mg of MSW |
|---|---|---|
| Landfill | 35 | 12 |
| Pretreatment for utilisation | 20 | 7 |
| Fusion (fossil fuel, no pretreatment) | 100 | 30 |
| Fusion (fossil fuel, scrap removal) | 130 | 45 |
| Fusion (electric heating) | 120 | 40 |
| Fusion processes in Japan | 100 | 30 |
| Fusion processes estimates (IAWG) | 180 | 60 |

## 5.3 Filter ashes

Boiler and even more filter ashes are classified as special wastes in many legislative regulations and their final destination is in most countries a disposal on special and expensive disposal sites. That is why numerous attempts have been made to detoxify these materials in order to get access to less expensive disposal routes. The applied principles are pointed out in Fig. 12.

A broad spectrum of different processes has been proposed and tested in different scales. Table 4 tries to categorise the various treatment options. Without going into detail it seems evident that solidification or stabilisation does not alter the toxic inventory of the material. The established transformation or diffusion barrier does only last for a limited time. Two processes are in full scale application: the 'Bamberg Model', where filter ashes are stabilised on a landfill by mixing with the sludge of the wet scrubber discharge neutralisation [Reimann 1990], and the Swiss filter ash cement stabilisation after washing [Tobler 1989].

*Table 4. Procedures for treatment of filter ashes.*

| Principle | Process | |
|---|---|---|
| Solidification/ stabilisation | Without additives<br>Cement based systems<br>Waste pozzolanic systems<br>Chemical stabilisation<br>Organic additives or matrix | (Bamberg Model)<br>(Portland cement, alinite)<br>(coal fly ash)<br>(sulphides, TMT 15™)<br>(bitumen) |
| Thermal treatment | PCDD/F destruction<br>Sintering<br>Fusion<br>Vitrification | (Hagenmaier drum)<br>(mineral respeciation)<br>(melting without additives)<br>(melting with additives) |
| Combined process | Acid extraction + sintering | (3R Process) |

Thermal treatment can be performed at moderate temperatures (400°C) to destroy dioxins or at high temperatures (>1300°C) to produce glassy products. The latter option has been tested in many variants during the early nineties. Most processes allow a certain recycling of metals. Vitrification is mainly favoured in Japan. The molten products are distinguished by excellent elution stability. Care has to be taken to avoid air pollution by evaporation of metal compounds. The energy consumption of all of these processes, however, is very high and that is why such processes did not conquer the market in Europe.

A third strategy – more in line with the demand for simple and in-plant measures – is followed by the 3R Process which combines an acid extraction of soluble heavy metal compounds (by use of the acid flue gas cleaning solution) with a thermal treatment of the compacted extraction residues in the combustion chamber [Vogg 1984]. A scheme of the process is shown in Fig. 13. The technical demonstration revealed that the 3R Process is a sink not only for mobile heavy metals but also for toxic organics [Vehlow 1990].

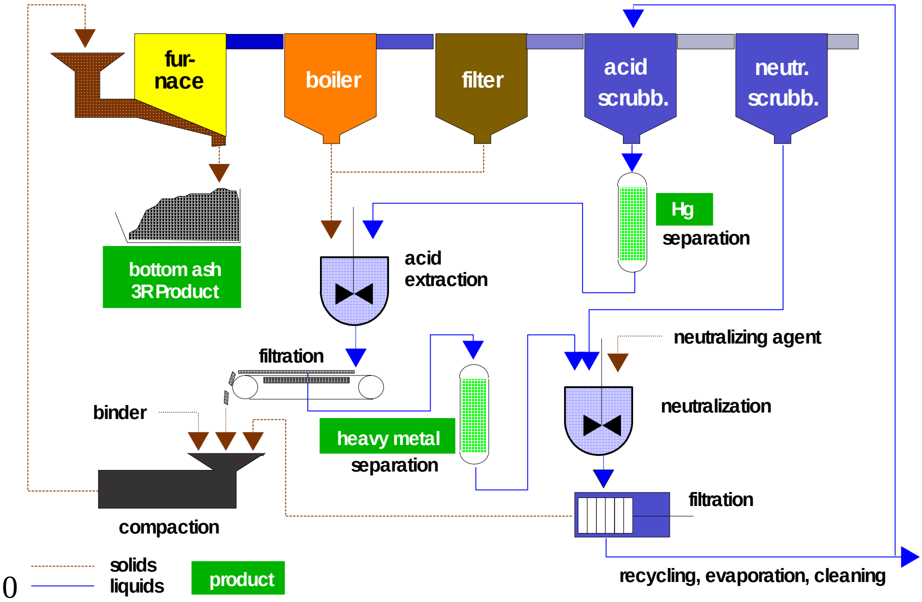

*Fig. 13. Scheme of the 3R Process.*

The costs of the various filter ash treatment options are estimated on the basis of published data in Table 5 [Vehlow 1997]. Again, as in the case of bottom ash treatment, the costs of technical processes should be comparable in most industrialised countries whereas the disposal fees will change from country to country.

The table reveals that the specific costs of the technical measures are rather high, but due to the small residue streams the expenses per ton of waste are low and similar for all disposal strategies. Hence the economy will not be the decisive factor for the selection of a specific process and local conditions like access to adequate disposal sites will be more important.

*Table 5. Cost estimates for landfilling and treatment of filter ashes (* disposal costs not included).*

| | €/Mg of bottom ash | €/Mg of MSW |
|---|---|---|
| Disposal on special landfill | 200 | 3 |
| Utilisation in salt mines | 100 | 1.5 |
| Cement solidification* | 25 | 0.5 |
| Stabilisation* | 80 | 2 |
| Solidification+stabilisation* | 120 | 2 |
| 3R Process | 120 | 2 |
| Fusion/vitrification | 180 | 3 |

## 5.4 APC residues

Flue gas cleaning processes, at least in Germany, are in principle not allowed to discharge waste water and the evaporation of the scrubber effluents is mandatory for wet systems. The resulting residues and those of dry or semi-dry APC systems carry high levels of soluble salts, especially of alkali and earth-alkali chlorides or sulphates. Due to the high solubility a safe disposal can only be guaranteed on special and expensive sites. Attempts have been made to utilise parts of the ingredients of these residues in order to minimize the disposal problem. The challenge is the closing of the chlorine cycle. Different processes to recover NaCl [Karger 1990], HCl [Kürzinger 1989], or $Cl_2$ [Volkman 1991], have been tested. All such processes can only be successful if they end up with high quality products and if there is a long-term market for the products. Today, e.g., in Germany, only few MSWI plants produce HCl.

A different – and finally very cheap – way of disposal of filter ashes (and APC residues) has been opened recently in Germany where authorities enforce the backfilling of cavities in old mines. Salt caverns are already being filled by semi-dry flue gas cleaning residues from MSWI in big bags [Plomer 1995]. This strategy – which is even accepted as 'utilisation' – may be justified with the similar chemical as well as physical properties of the original salt and the disposed residues. However, for likewise activities in old coal mines this argument can hardly be used.

Since the mass flow and properties of residues from gas cleaning depend on the applied strategy, it seems not useful to discuss their specific disposal or treatment costs. Hence the attempt has been made in Table 6 to compare the costs of the respective flue gas cleaning strategies. The base of the data and their validity is the same as in the above outlined cost considerations.

*Table 6. Cost estimates for landfilling and treatment of scrubbing residues.*

| | €/Mg of MSW |
|---|---|
| Dry sorption without residue disposal | 23 |
| Dry sorption with utilisation for backfilling of caverns | 32 |
| Semi-dry sorption | 29 |
| Wet scrubbing with waste water discharge | 25 |
| Wet scrubbing with spray dryer | 28 |
| Wet scrubbing with external evaporation | 29 |
| Wet scrubbing with HCL/gypsum production | 35 |

Like in the case of the filter ashes the economy of the various options does not differ significantly and again local conditions will be decisive for the most adequate strategy. In Germany the underground 'utilisation' looks economically promising. The gate fee has dropped down to approx. 40–70 € per ton of material. As a consequence dry scrubbing processes may be promoted, which is in contradiction to the legislative demand for residue minimization. If the strategy gains wide application, however, it will change the management of residues from APC systems in future at least in Germany, where a great number of old mines is waiting to be filled.

# 6. Conclusions and recommendations

For the optimisation of waste incineration in view of high quality bottom ashes and the safe and sustainable management of filter ashes and APC residues some fundamental strategies are recommended:

- Adequate combustion control and careful sintering of the bed material at the back end of the grate guarantee an excellent burnout and cause a good fixation of heavy metals;

- Simple washing of the bottom ashes, preferentially in-plant in a modified quench tank, reduces the leaching of chlorides to very low levels;
- The resulting products have a high potential for utilisation, e.g. according to German regulations in road construction;
- Post-combustion treatment of bottom ashes increases the incineration cost without improving the elution stability significantly;
- The economy is no decisive parameter for the special treatment of fly ashes and air pollution control residues.

Most problems in the field of residue management are well understood today and in most cases appropriate technologies exist already. It is obvious that primary and in-plant measures have to be preferred rather than secondary post-combustion techniques.

All processes intended for quality improvement have carefully to be analysed whether they result in real ecological benefits, whether all potential impacts upon the environment are taken into consideration, and whether these benefits pay in view of effort and expenses. Especially the last criterion - mentioned as a decisive factor even in the latest German waste directive - is often pushed aside in political discussions.

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# EU Waste incineration and LCP directives, co-firing and practical examples in fluidized-bed boilers/power plants

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## 1. Fluidized-bed combustion

Fluidized-bed combustion is widely used combustion technology, e.g., in forest industries and CHP production, where the fuels include mixtures of

- bark
- wood based production rejects
- other selected wastes
- sludges
- demolition wood
- peat
- coal, etc.

Depending on the fuels co-fired in the boiler, either Large Combustion Plants (LCP) or Waste Incineration (WID) Directives will be applied.

## 2. Requirements set by the directives

LCP directive is applied, when at the power plant:

- thermal fuel input is equal to or greater than 50MW
- fuels include
    - wastes from forestry
    - fibrous waste from virgin pulp and paper production, when co-incinerated at the place of production
    - non-contaminated wood wastes and bark
    - fossil fuels.

WID is applied, when the plant incinerates or co-incinerates wastes. Article 2 of the directive lists the plants that shall be excluded from the scope of the WID.

The directives set requirements to the equipment and operations.

LCP directive sets, e.g., the following requirements:

- $SO_2$, $NO_x$ and particulates emissions control;
- Continuous monitoring of $SO_2$, $NO_x$, particulates and flue gas moisture;
- Continuous monitoring of relevant process operation parameters of oxygen content, temperature and pressure;
- Max. 24 operation is allowed with malfunctioning emission control equipment.

WID sets more stringent control requirements for the following emissions:

- $SO_2$, $NO_x$, particulates
- CO, TOC, HCl, HF
- Cd + Tl
- Hg
- Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V
- PCDD/F.

$SO_2$, $NO_x$, particulates, CO, TOC, HCl, HF and flue gas moisture must be continuously monitored. Heavy metals and PCDD/F shall be sampled periodically. Max 4 hours' operation time with malfunctioning emission control equipment is allowed.

WID sets also technical requirements for combustion:

- combustion temperature must be at least 2 seconds above 850°C;
- auxiliary burners shall be used to ensure the temperature;
- process temperature at a representative point of the combustion chamber, pressure and oxygen concentration and water vapour content of the exhaust gas;
- in the ashes, organic C < 3% or LOI < 5%;
- scrubber water impurities have their own emission limits.

# 3. Examples of boilers under the scope of LCP and WID

Conventional CFB or BFB boilers (Figures 1 and 2) are typically under the scope of LCP directive. These boilers consist of

1. furnace
2. limestone feed for $SO_2$ emission control
3. staged combustion, optionally with recycle gas, for NOx control
4. superheaters, eco and luvo are located in convective pass
5. ESP or baghouse is used for flue gas cleaning from particulates.

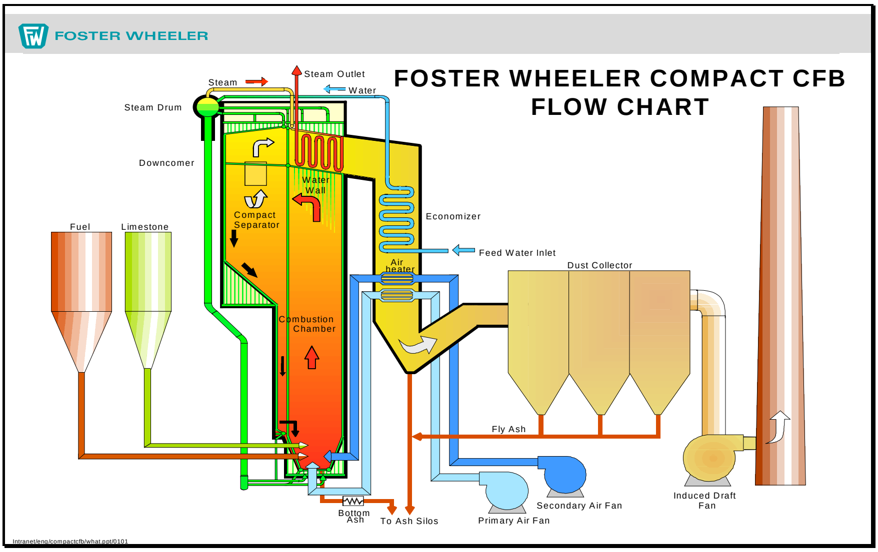
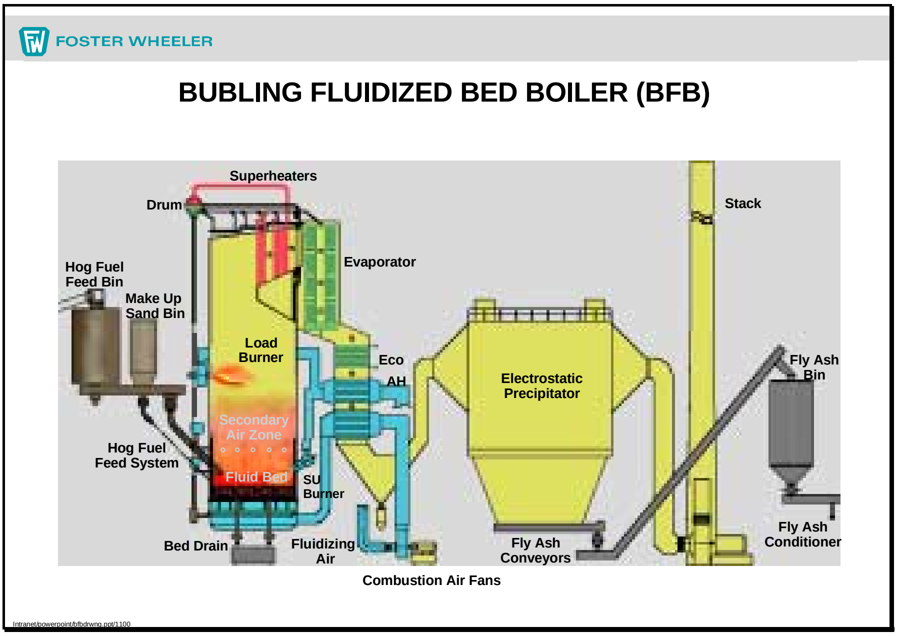


*Figure 1. Compact CFB flow chart.*



FOSTER WHEELER

**BUBLING FLUIDIZED BED BOILER (BFB)**

Intranet/powerpoint/bfbdrwng.ppt/1100

*Figure 2. Bubbling fluidized-bed boiler.*

What changes are then required for waste co-firing? WID with its stringent emission limits sets rather challenging requirements to stability of combustion (indicated by CO and TOC) and flue gas cleaning, in general. Critical emissions are also $SO_2$, HCl, heavy metals and PCDD/F.

The practical means to be considered to reach these challenging targets include at least:

- separate fuel feeding line for waste fuels
- a special fluidization grid design, capable to remove coarses from the furnace (Figure 3)
- baghouse filter
- $Ca(OH)_2$ and activated carbon injection
- auxiliary burners and elimination of corrosion risks.

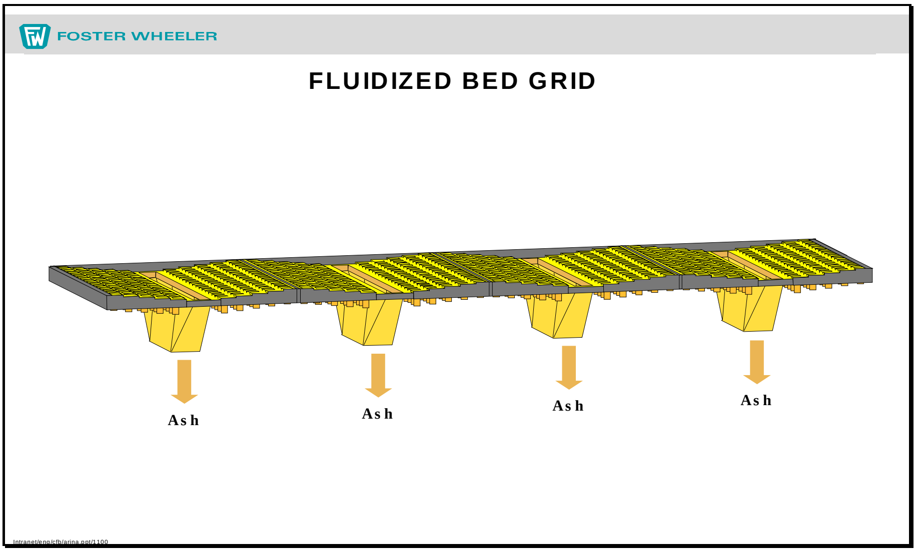


*Figure 3. Fluidized-bed grid.*

Technically, small amounts of wastes may be co-fired with the main fuels in conventional CFB and BFB boilers. Small amounts mean a few percent of the fuel input.

Hornitex Werke Beeskow Kunststoffe und Holzwerkstoffe (Figure 4) is firing wood based production wastes and partly contaminated demolition wood in an 86 $MW_{th}$ CFB boiler (30.5 kg/s, 89 bar, 480°C). The boiler modifications (compared to conventional CFB) include:

- in-bed Intrex superheater
- grid
- fuel preparation
- baghouse with $Ca(OH)_2$ and activated carbon injection.

The concept is applied also in other CFB boilers with similar fuels.

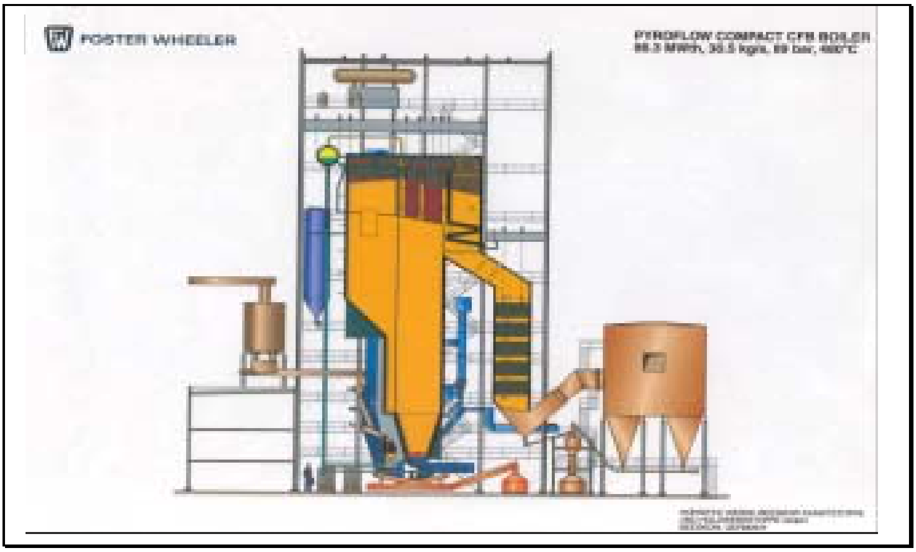
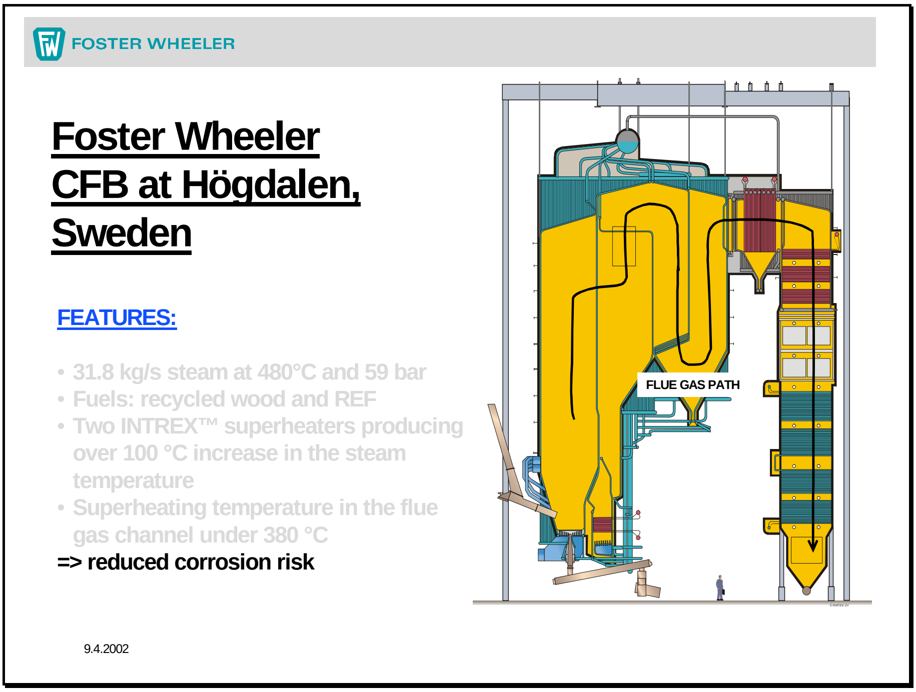


*Figure 4. Pyroflow compact CFB boiler.*

When the fuels contain more difficult fractions like RDF, Stockholm Energi AB Högdalen CFB boiler (31.8 kg/s, 59 bar, 480°C) design shows the trend. The Högdalen boiler is firing demolition wood, PDF and forest wastes. The boiler modifications (Figure 5) include:

- Intrex superheaters
- idle pass
- grid
- SNCR
- NID.



FOSTER WHEELER

**Foster Wheeler CFB at Högdalen, Sweden**

**FEATURES:**

- 31.8 kg/s steam at 480°C and 59 bar
- Fuels: recycled wood and REF
- Two INTREX™ superheaters producing over 100 °C increase in the steam temperature
- Superheating temperature in the flue gas channel under 380 °C

**=> reduced corrosion risk**

9.4.2002

*Figure 5. Foster Wheeler CFB at Högdalen, Sweden.*

# 4. Conclusions

When a conventional CFB or BFB boiler design and a modern boiler design for Waste Co-firing are compared, it is obvious from the examples above that significant changes may be needed. The need of changes depends also on the waste fuel and its amount in the fuel scope.

Demolition wood may require smaller changes than RDF. Anyway, investment costs will increase considerably.

Operation costs will also increase. The items include:

- additives ($Ca(OH)_2$, activated carbon)
- own power consumption
- emission monitoring, sampling and analysis
- maintenance.

The increased investment and operation costs must be covered by cheaper fuel, sometimes a gate fee is possible.

Minor positive benefits may also be listed: process control will be improved by the directive requirements, which will result in all the heat value in the fuel will be recovered. In some countries, like Sweden, $NO_x$ and sulphur emission fees will decrease!

# Experiences of RDF fluidized-bed combustion and gasification, emissions and fuel quality aspects

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(1) Helsinki, (2) Varkaus, Finland

## Abstract

The energy recovery from industrial and municipal wastes has become an important option for waste management and power production. The quality of wastes varies much depending on the origin of waste and pre-treatment of the waste. The differences in the quality of the waste have to be taken into account when designing the method for energy recovery and the equipment. Fluidized-bed combustion and circulating fluidized-bed gasification have been recognized as the most environmentally benign and cost-effective solutions for the energy recovery from RDF. Two projects utilizing a CFB boiler for the combustion of high-energy waste, and one project for using gasification as the fuel pre-treatment method, are presented to highlight the potential of this technology.

The first unit combusting waste with high heating value built by Foster Wheeler in Europe started operation in 1999 in Högdalen, near the centre of Stockholm, the capital of Sweden. The unit generates district heating for the community of Stockholm, and electricity for the local net. The base of the fuel is sorted industrial waste. The Högdalen CFB boiler is in its third year of operation. The unit produced only district heating for the first two operating periods, a new turbine was installed during summer 2001 to improve the plant economy. The plant has attracted visits by several customers from different parts of the world.

The Lomellina Energia Recycling WTE (Waste To Energy) facility is located in Parona, a village in Pavia Province, 30 km from Milan in Italy. The facility started commercial operation in July 2000. As the first installation of its kind in Europe, Lomellina Energia is an integrated facility for recyclable materials recovery and refuse derived fuel (RDF) production, composting and electricity

generation. The plant is capable of treating 200 000 tons of MSW per year. The WTE plant has functioned as expected, and decisions about constructing similar plants in Europe are expected in the near future.

A demonstration project for using a CFB gasifier as the fuel pretreatment unit has been completed at Lahden Lämpövoima Oy, Kymijärvi Power Plant in Lahti, Finland. The project demonstrated commercial-scale direct gasification of biofuels and wastes, and the use of product gas directly in the existing coal-fired boiler. The advantages of this approach include decreased $CO_2$, $SO_2$ and $NO_x$ emissions, low investment and operation costs, and utilization of existing power plant capacity. The second commercial application of the concept is now under construction in Ruien, Belgium. Several similar projects are under evaluation.

# 1. Introduction

Energy generation using recovered fuel fractions with high heating value is attracting growing interest in Europe. Wastes have been mainly treated to reduce their volume and thus minimize need landfill. Energy regeneration has been only a secondary object in these applications. As landfill areas cannot in the future be used for storing material that can be composted or contains combustible fractions, the requirement for more efficient recycling and energy recovery sets special needs for developing technologies that allow combustible fractions to be used with maximum efficiency. The new approach described in this paper includes high efficiency heat recovery by pre-treating waste materials so that the fractions with higher heating value are separated and combusted in a CFB boiler. This technology can utilize the major proportion of waste, but requires additional investment in pre-treatment facilities. Another possibility is to treat the wastes by gasifying them, and then combusting the gas in existing power plants. Several projects are under way to evaluate the potential of atmospheric CFB gasification. Figure 1 illustrates the possible uses of wastes in the future. The fractions shown in Figure 1 may not be proportional to the actual portion the waste contains.

*Figure 1. Different waste fractions and their possible uses.*

## 2. Foster Wheeler CFB in Högdalen, Stockholm

The first unit combusting wastes with high heating value built by Foster Wheeler in Europe started operation 1999 in Högdalen, near the centre of Stockholm, the capital of Sweden. An illustration of the unit is shown in Figure 2. The unit provides district heating for the community of Stockholm, and some electricity.

This boiler is the first modern Foster Wheeler CFB especially designed to minimize the risk of fouling and superheater corrosion in the convection section. The boiler utilizes the compact CFB design with rectangular solids separators, together with two INTREX™ 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, sulfur and alkali metals has been minimized. The Högdalen CFB boiler was commissioned during the fall of 1999, and boiler characteristics have been extensively mapped between 1999 and 2001.

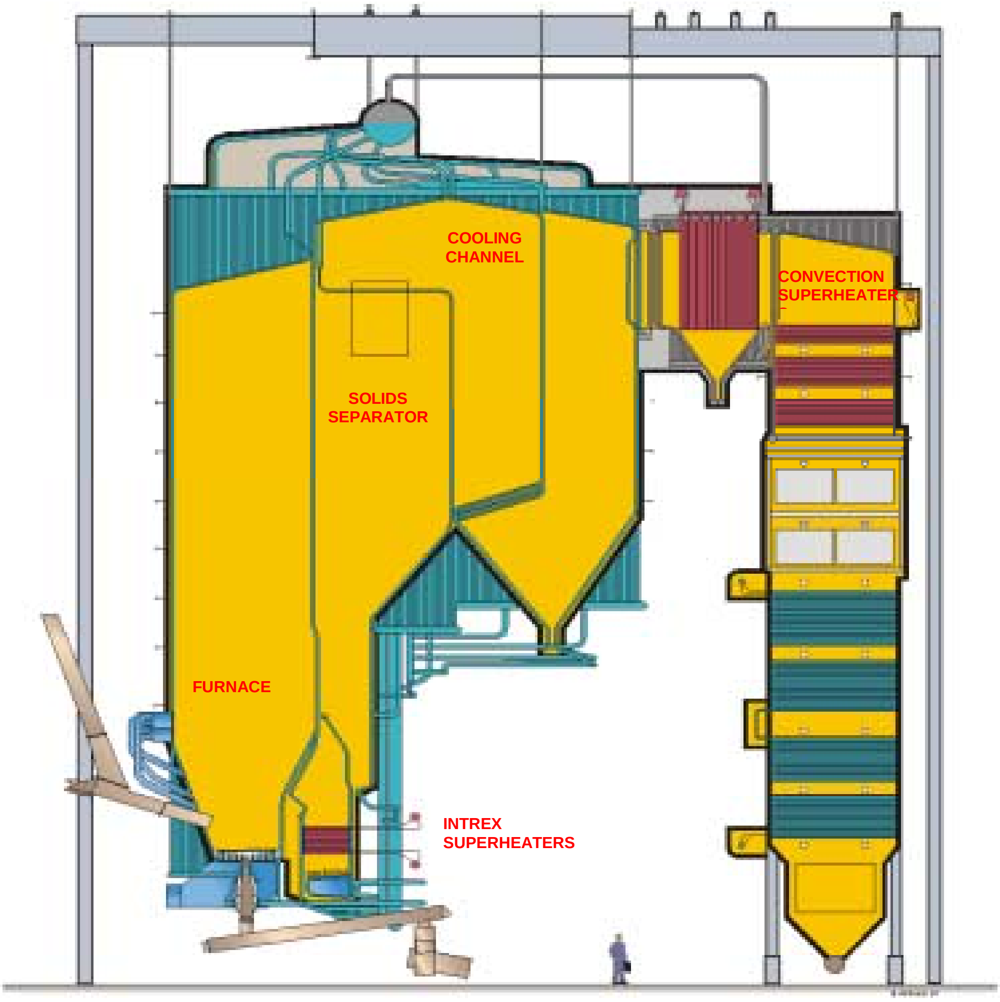

*Figure 2. The Högdalen CFB boiler is especially designed for the combustion of recovered fuels. It has a rated thermal effect of 92 MWth,* $p_{steam}$ *is 60 bar, and* $T_{steam}$ *is 480°C.*

## 2.1 Fuel pretreatment and fuel feeding

The base of the fuel is sorted industrial waste, so no household wastes are combusted in the Högdalen boiler. To achieve optimal fuel, some pre-treatment is carried out. The fuel coming to the pretreatment facilities is provided by several companies. The fuel is treated by manually removing oversize items, and items containing large amounts of metal. The remaining paper, wood and plastics are then crushed with mobile crushers. If needed, some recycled wood is mixed in to provide a more stable heating value. The procedure is shown in Figure 3. Table 1 shows some of the analyzed characteristics of different fuels combusted in the Högdalen CFB boiler.

*Figure 3. Fuel treatment: upper left: industrial waste, upper right: removal of large pieces, lower left: crushed recovered wood, lower right: pre-treated fuel.*

The fuel is brought to the plant and stored at the site in a relatively small warehouse. The plant also has four grate-fired mass burning units, which can handle the fractions not suitable for the CFB boiler: no storage capacity is needed for this type of waste. Some crushing and mixing capabilities are also available at this stage. The fuel suitable for the CFB is transported to two large intermediate silos located outside the boiler house. Final metal separation takes place at this stage. From these silos, the fuel is fed to three day bins located inside the boiler house. Fuel is fed to the boiler by three separate feeding lines, each taking material directly from one bin only. The fuel feeding system does not differ significantly from a system designed for biomass feeding. So far, the only problems in the fuel feeding have been related to long textiles and fastening cords occasionally present in the fuel. These long strings have to be removed manually.

*Table 1. Characteristics of different fuel types combusted in the Högdalen CFB boiler.*

| Component | Recovered Industrial Waste | Forest residue | Recovered wood |
|---|---|---|---|
| Dry solids, % | 79.9 | 59.1 | 75.2 |
| Volatiles, % | 76.9 | 75.2 | 79.8 |
| Fixed C, % | 14.5 | 19.2 | 17.5 |
| Ash, 550 °C, % | 7.55 | 5.85 | 2.85 |
| Ash, 815 °C, % | 7.65 | 5.70 | 2.65 |
| C, % | 47.3 | 49.0 | 49.3 |
| H, % | 5.83 | 5.56 | 5.87 |
| N, % | 0.61 | 0.43 | 0.90 |
| S, % | 0.25 | 0.04 | 0.07 |
| O, % | 38.7 | 39.3 | 41.1 |
| Ca, % | 2.09 | 1.14 | 0.57 |
| Cl, % | 0.28 | 0.02 | 0.13 |
| $K_{total}$, mg/kg | 1124 | 3150 | 685 |
| $Na_{total}$, mg/kg | 1238 | 279 | 448 |
| HHV, MJ/kg | 19.3 | 19.7 | 19.8 |
| LHV, MJ/kg | 18.1 | 18.4 | 18.6 |

a.s. = acetic acid soluble

## 2.2 Boiler characteristics

The CFB boiler at Högdalen is the first compact CFB especially designed for the combustion of industrial waste. The cross-sectional area of the furnace is approximately 40 m², and the furnace height is approximately 20 m. The unit has one compact separator with two separate vortex finders. The re-circulating solids are returned to the furnace via the two INTREX™ superheaters. The fluidization of the bed material is accomplished by primary air introduced into the furnace through a new type of grid. Figure 4 shows the principle of the Högdalen grid consisting of directional nozzles, which create a horizontal jet. Together with large solids discharge openings, this grid design greatly improves the removal of coarse material.

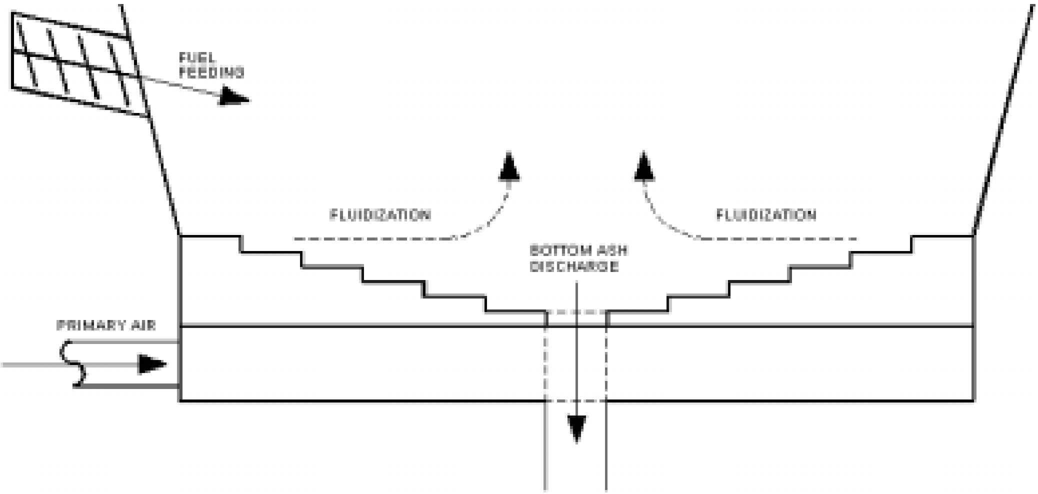

*Figure 4. Operating principle of the grid construction in the Högdalen CFB boiler.*

The bed temperature is controlled with re-circulated flue gas. The $O_2$ level in the flue gas is monitored by two zirconium cells. The two convection superheaters are located after the cooling channel. After the superheater section, the flue gas is cooled with an economizer and cleaned with an extensive flue gas cleaning system shown in Figure 5 prior to entering the stack. Emissions are measured both before and after flue gas cleaning to ensure optimal operation of the CFB boiler.

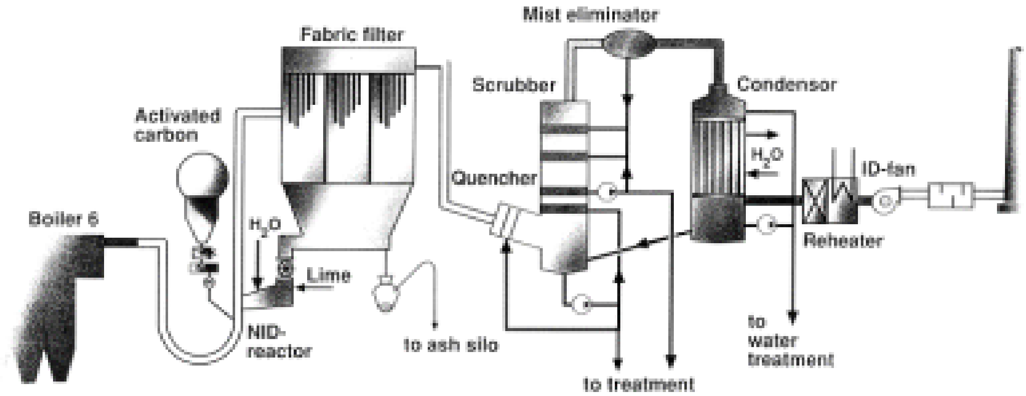

*Figure 5. Flue gas cleaning system at the Högdalen CFB boiler. Courtesy of ABB.*

### 2.2.1 INTREX™ Superheaters

The two INTREX™ superheaters at the Högdalen plant are located in the lower region of the furnace as integrated but separately fluidized chambers. Hot solids are introduced into the heat exchanger from the solids separator. The solids are returned to the lower part of the furnace. The rate of heat absorption can be controlled by adjusting the sand fluidization velocity, and by controlling the solids mass flow through the system. The mass flow of solids entering the heat transfer chamber depends on the boiler load: at high loads, most of the solids bypass the chamber. The main frame of the integrated heat exchanger chamber is constructed of tubes similar to the membrane walls, and the unit is integrated with the separator and furnace. As a result, the whole structure is totally water-cooled. The steam temperature entering the first INTREX™ superheater is kept below 400°C, and the steam temperature after the second superheater is 480°C. A spray de-superheater is located between the units. The heat transfer effect of each superheater at full load is approximately 6 MW. This allows maximal heat recovery with reduced tube material temperature in the convection section.

## 2.3 Boiler operation with different fuels

After the commissioning period, boiler operation with different fuels was verified during a three-week test period in April 2000. Combustion tests at three load levels (50%, 75% and 100% of MCR) were performed. Three different fuels were combusted:

- forest residue
- recovered wood
- recovered industrial waste.

The characteristics of these fuels are shown in Table 1. The corrosion characteristics of each fuel type were measured using an electrochemical corrosion probe located after the solids separator, and these results were verified with conventional corrosion probe tests. The measured relative corrosion risks at different tube material temperatures with different fuels are shown in Figure 6.

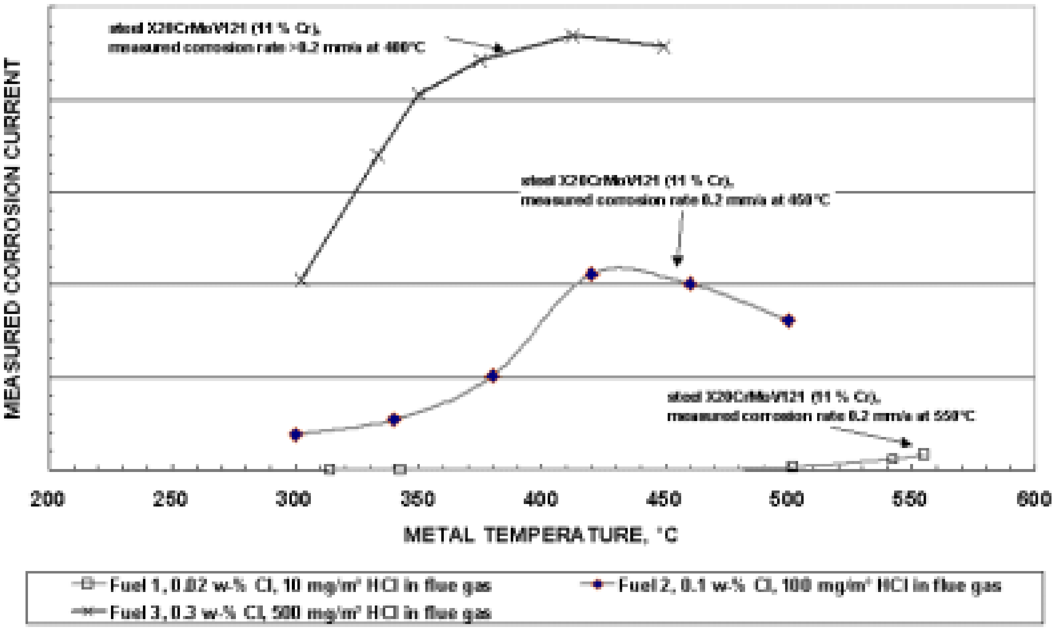

*Figure 6. Measured relative corrosion risks associated with combustion of different fuels at the Högdalen CFB boiler. Fuel 1 is forest residue, fuel 2 is recovered wood and fuel 3 is selected industrial waste.*

The tests show considerable differences between the corrosion behaviour of different fuels. With recovered fuels, the risk of fireside corrosion is evident at as low a temperature as 300°C. With forest residue, the measurements indicated corrosion at temperatures above 500°C. According to the measured corrosion risks, the boiler would not be able to meet the required corrosion resistance without the flue gas cooling channel. With these fuels, the finishing superheater must be of the INTREX™ type, and the flue gas must be cooled prior to entering the vicinity of the convective superheaters. The tests also showed that the boiler operation differs considerably with different fuels. Recovered fuels caused most feeding instabilities, and it was noticed that despite aggressive bed regeneration, the amount of coarse particles in the bed material increased rapidly, indicating a risk of fluidization difficulties. This justifies the special grid construction. With wood-based fuels, boiler operation was outstanding. Recovered fuels also caused increased $SO_2$ and HCl emissions after the boiler. The measured corrosion potential increased as the flue gas HCl content increased.

The Högdalen CFB boiler is now in its third year of operation. Although the unit produced only district heating for the first two operating years, the economics of the plant have been very good. A new turbine was installed during summer 2001 forth improving plant economy. The plant has attracted visits by several customers from different parts of the world, so similar projects are expected in the near future.

## 3. Lomellina WTE Plant

The Lomellina Energia Recycling WTE (Waste To Energy) facility is located in Parona, a village in Pavia Province, 30 km from Milan in Italy. The facility started commercial operation in July 2000. As the first installation of its kind in Europe, Lomellina Energia is an integrated facility for:

- recyclable materials recovery and Refuse Derived Fuel (RDF) production
- composting
- electricity generation

Figure 7 shows the flow diagram of the facility.

The plant is designed to recover material and energy from MSW. The quantity of waste brought to the plant is 200,000 tons per year. About 60% of the MSW can be converted into RDF. The process also separates reusable aluminum, ferrous materials, glass and compost from the waste. The sorting process provides both recycling and production of RDF, a fuel that can be easily burned producing very low quantities of bottom ash. The net power output of the plant is 17 MW. In addition to electricity sales, the MSW is a source of revenues as well. Separate waste delivery agreements have been signed with (a consortia of) municipalities to detail the specific terms and conditions for waste delivery. The contracts are of the put-or-pay type, which means that even if the municipalities deliver less than the agreed committed quantity, they will have to pay an amount based on the agreed gate-fee and committed quantity.

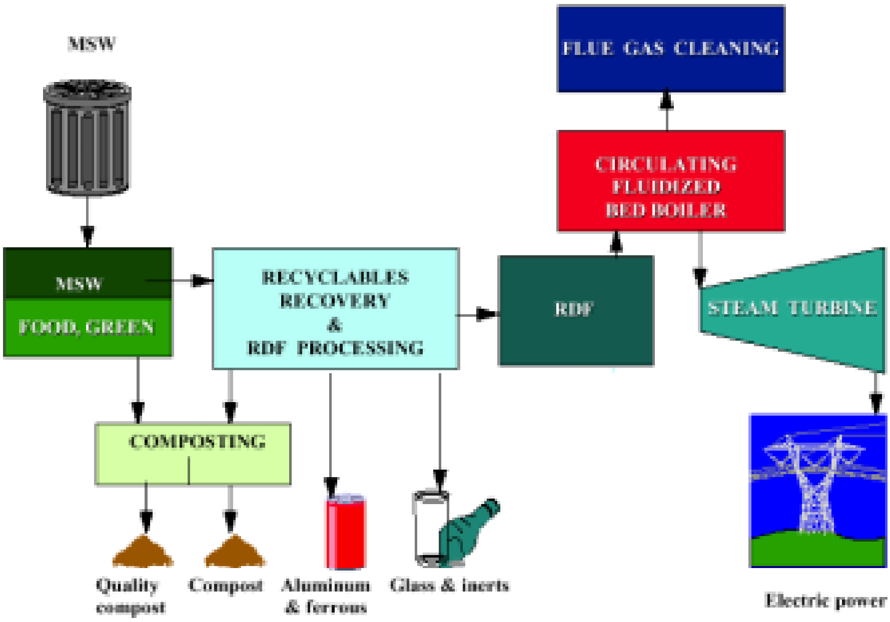

*Figure 7. Flow diagram of the Lomellina WTE plant.*

## 3.1 The recyclables recovery and fuel preparation system

The system was started up in December 1999, six months prior to the scheduled power plant start-up. This was necessary to guarantee the disposal of MSW in a district which is suffering from a major waste problem due to the closure of landfill facilities. The MSW composition is shown in Table 2.

*Table 2. Nominal composition of MSW treated at the Lomellina plant.*

| **Material by % wt.** |
|---|
| Food waste 20.0 |
| Paper and cardboard 27.5 |
| Plastic 13.5 |
| Textiles 3.5 |
| Metals 3.5 |
| Wood 3.5 |
| Yard waste 7.5 |
| Glass 8.0 |
| Screenings 5.0 |
| Other 8.0 |
| LHV 10 MJ/kg |

The waste is brought to the site by truck and dumped in a waste pit, which can store 3 days deliveries. Two bridge cranes equipped with a 6 m³ grapple feed the sorting unit. The recyclables recovery and fuel preparation system consists of three lines, each designed to process 25 t/h of MSW. One line is a spare and can be dedicated to the processing of source-sorted organic material to obtain a quality product after composting. Each processing line is composed of a low velocity shredder, a primary trommel, a secondary trommel, magnetic separators and a hammer mill, as shown schematically in Figure 8.

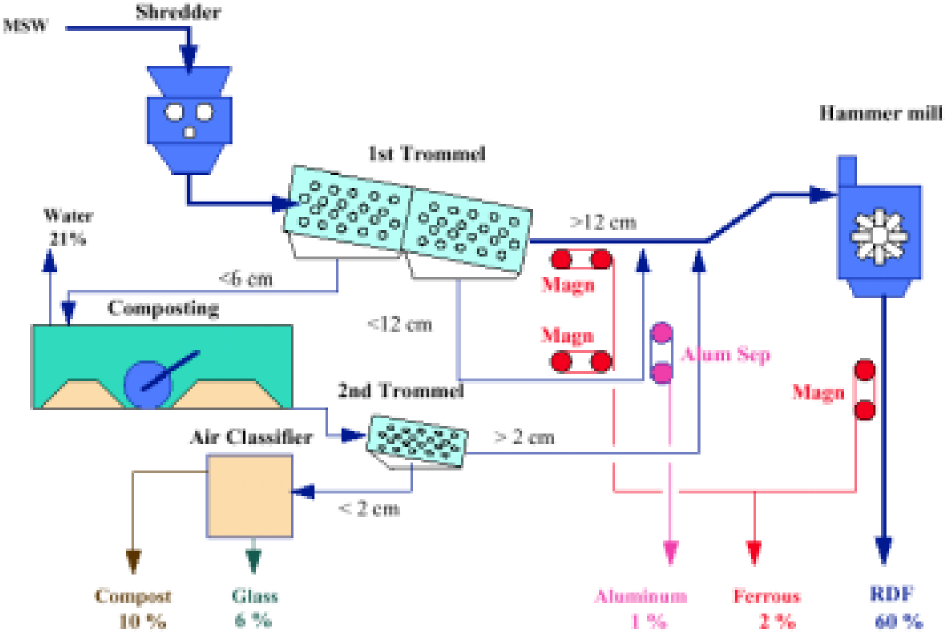

*Figure 8. Material separation and produced material fractions.*

The resulting RDF has the following characteristics:

- organic content: 15% wt. max.
- particle size: 98% lower than 90 mm
- inerts: 2% wt. max.

## 3.2 The Lomellina CFB boiler

The CFB installed for the combustion of RDF is top supported and comprises four sections: the furnace, the cyclone, the idle pass and the heat recovery area. The nominal capacity of the CFB boiler is 19 t/h of RDF with a LHV of 12 MJ/Kg. The plant is capable of handling RDF with a LHV range of 10–18 MJ/Kg. The finishing superheaters are located in the solids return as INTREX™ type fluidized-bed heat exchangers. Figure 9 shows the schematic of the CFB boiler and the flue gas cleaning system.

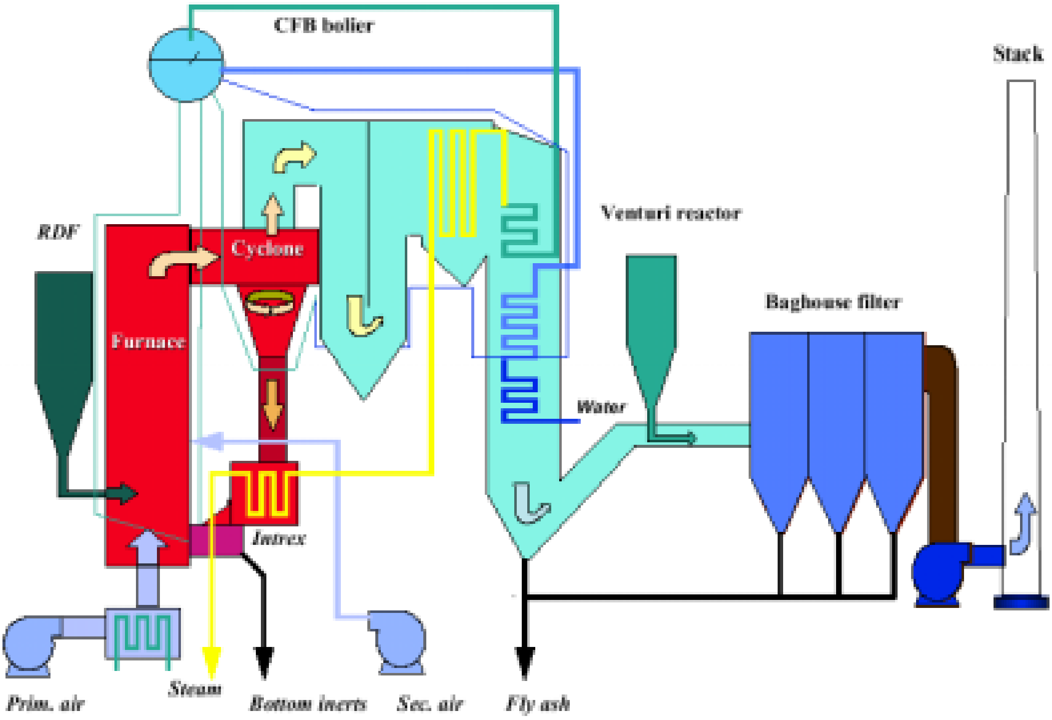

*Figure 9. Lomellina CFB boiler.*

### 3.2.1 RDF feed system

The produced RDF is delivered by auger conveyors into the inlet hoppers of three parallel fuel feed systems. Each fuel feed system is sized for 50% capacity at full load, thus providing complete redundancy. From these hoppers, RDF is fed to a fuel chute, from which it drops into the fuel spout where sweep air is used to transport the fuel into the furnace. A gate valve is used to isolate the furnace during shut down of the fuel spout. The feeders are supplied with variable speed drivers controlled by superheated steam flow.

### 3.2.2 Boiler characteristics

The fuel fed into the 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 single cyclone is completely cooled with saturated steam from the drum. The cyclone separates the entrained solids including unburned carbon from the flue gas, and returns them to the furnace, providing an excellent carbon burn-out. The flue gas flows through the idle pass before entering the convection section, and then through the primary and intermediate superheater sections, followed by the economizer and the flue gas cleaning.

Superheating is sequentially carried out at the cyclone walls, the vestibule walls, the primary superheater, the intermediate superheater and finally at the finishing superheater located in the INTREX™ heat exchanger. This solution enables final superheating to be carried out using reduced-dimension equipment, thanks to the very high heat transfer that can be achieved in a bubbling bed, and above all avoiding the risk of corrosion due to HCl at high temperature. The design steam production is 83 t/h at 443°C and 62 bar(g). The electric power production at generator terminals is 19 MW.

The heavier fraction of the bottom ash is discharged from the rear wall at the bottom of the furnace to two stripper-coolers through two slightly sloped solid drains. Stripper-coolers are used for stripping the fines from the discharged ash and cooling the remaining coarser ash by cold air. Air is also used for channelling the fine ash back to the furnace. Each stripper-cooler is batch fed, so that bed material is admitted when the furnace bed level reaches a set value. Bottom ash, equivalent to about 3% by wt. of the fired RDF, is disposed of in a landfill for non-hazardous waste.

### 3.2.3 Flue gas cleaning

The flue gas cleaning system consists of

- a conditioning tower to control moisture and temperature levels
- a flue gas dry scrubber with injection of lime and active carbon
- a fabric-filter baghouse.

A continuous monitoring system is used to control and record flue gas temperature, $O_2$, dust, CO, HCl, $NO_x$, $SO_2$ and VOC. Thanks to the quality of the combustion process, there is no need for a $DeNO_x$ system. The flue gases exiting the boiler economizer enter the external economizer where they are cooled to some 150°C, and further cooled to some 130°C by finely dispersed water droplets inside the conditioning tower. Flue gases are then sent to the venturi dry reactor where hydrated lime and activated carbon are pneumatically injected to remove acid components and pollutants. The hydrated lime reacts with sulphur dioxide, as well as hydrochloric and hydrofluoric acid, forming the relevant salts, while the volatile heavy metals and organic micropollutants are adsorbed on the surface of the activated carbon. The fly ash, reaction products, activated carbon and unreacted lime are then retained by the bags of the fabric filter and periodically removed by air jet pulses and collected in the filter hoppers.

The fly ash fractions collected in the filter and in the conditioning tower are partially recycled to recover unreacted lime and carbon and partially sent to the storage silos for further processing. The collected fly ash, which represents about 6% by wt. of the fired RDF, is stored in a dedicated silo. 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 poured in 1 $m^3$ bags. These bags are temporarily stored until the concrete solidification is complete.

## 3.3 Operating experiences

After the commissioning of the boiler in the summer of 2000, the boiler was tested for performance. All guarantees were met. Table 3 lists the permitted emissions. The operation record during 2000 and 2001 is shown in Table 4.

It can be noted that the amount of non-processible waste is only less than 1% of the total amount of waste treated. The WTE plant has functioned as expected, and decisions about constructing similar plants are expected in the near future.

*Table 3. Permitted emissions at the Lomellina WTE plant.*

| **Substance** | **Permitted*** | |
|---|---|---|
| Dust, mg/Nm³ | 10 | 30 |
| $SO_2$, mg/Nm³ | 100 | 200 |
| $NO_x$, mg/Nm³ | 200 | 400 |
| HCl, mg/Nm³ | 20 | 40 |
| CO, mg/Nm³ | 50 | 100 |
| HF, mg/Nm³ | 1 | 4 |
| VOC, mg/Nm³ | 10 | 20 |
| Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V+Sn, mg/Nm³ | 0.5 | |
| Cd+Tl, mg/Nm³ | 0.05 | |
| Hg, mg/Nm³ | 0.05 | |
| Aromatic hydrocarbons, mg/Nm³ | 0.01 | |
| Dioxins & Furans, ng/Nm³ | 0.1 | |

* daily average and hourly average, respectively

*Table 4. Operation record of the Lomellina WTE plant.*

| | **4th quarter 2000** | **1st quarter 2001** | **2nd quarter 2001** | **3rd quarter 2001** | **Total** |
|---|---|---|---|---|---|
| MSW received | 40 000 | 3 800 | 42 000 | 33 000 | 158 000 |
| RDF received | 3 200 | 6 700 | 6 100 | 3 500 | 19 000 |
| MSW processed | 40 000 | 42 000 | 47 000 | 38 000 | 167 000 |
| Non-processible | 130 | 960 | 290 | 270 | 1 700 |
| Compost | 5 700 | 8 900 | 6 800 | 5 800 | 27 000 |
| Ferrous | 1 200 | 1 300 | 1 400 | 1 300 | 5 100 |
| Non-ferrous | 43 | 44 | 50 | 46 | 180 |
| Inerts | 1 400 | 190 | 0 | 340 | 2 000 |
| Steam produced | 94 000 | 130 000 | 164 000 | 152 000 | 540 000 |

# 4. Biomass CFB gasifier at Lahti, Finland

To keep energy prices as low as possible, many power plants continuously review the most economical fuel sources, while simultaneously trying to improve the environmental aspects of generation. In order to test the feasibility of using a CFB gasifier as a fuel pre-treatment unit, Lahden Lämpövoima Oy, Kymijärvi Power Plant gasification project was commenced. The project has demonstrated commercial-scale direct gasification of wet biofuel and the use of hot, raw and very low calorific gas directly in an existing coal-fired boiler. The advantages of biofuel gasification include reduced $CO_2$, $SO_2$ and $NO_x$ emissions, low investment and operation costs, and the utilization of existing power plant capacity. Industrial and household wastes with high heating value have been gasified to test the operation of the concept.

In Europe renewable solid fuels with a thermal potential of 30–150 MW are typically available within 50 km from a given power plant, enough to gasify and utilize directly in mid-or large-size coal-fired boilers. Thus, a power plant with a gasifier that is connected to a large conventional boiler with a high-efficiency steam cycle offers an attractive and efficient way of using local renewable sources in energy production.

## 4.1 CFB gasification

The atmospheric circulating fluidized-bed (CFB) gasification system is relatively simple. The system consists of a reactor where gasification takes place, a cyclone to separate the circulating-bed material from the gas, and a return pipe for returning the circulating material to the bottom part of the gasifier. All of these components can be entirely refractory lined. After the cyclone, the hot product gas flows into the air preheater, which is located below the cyclone. The gasification air, blown with a high-pressure air fan, is fed to the bottom of the reactor via an air distribution grid. When the gasification air enters the gasifier below the solid bed, the gas velocity is high enough to convey some of the bed particles out of the reactor and into the cyclone. In the uniflow cyclone, the gas and circulating solid material flow in the same direction – downwards – and both the gas and solids are extracted from the bottom of the cyclone, a difference compared to a conventional cyclone.

### 4.1.1 Fuel feeding and gasification reactions

The fuel is fed into the lower part of the gasifier above the air distribution grid. The operating temperature in the reactor is typically 800–1000°C depending on the fuel and the application. When entering the reactor, the fuel particles start to dry rapidly, and a primary stage of reaction, namely pyrolysis, occurs. During this reaction, fuel converts to gases, charcoal, and tars. Part of the charcoal flows to the bottom of the bed and is oxidized to CO and $CO_2$, generating heat. After the rest of these components flow upward in the reactor, a secondary stage of reactions takes place. These reactions can be divided into heterogeneous reactions where char is one ingredient in the reactions, and homogeneous reactions where all the reacting components are in the gas phase. A combustible gas is produced from these and other reactions, which then enters the uniflow cyclone and escapes the system together with some fine dust.

Most of the solids in the system are separated in the cyclone and returned to the lower part of the gasifier reactor. These solids contain char, which is combusted with the fluidizing air introduced through the grid nozzles to fluidize the bed. This combustion process generates the heat required for the pyrolysis process and subsequent mostly endothermic reactions. The circulating bed material serves as a heat carrier and stabilizes the temperatures in the process. The coarse ash accumulates in the gasifier and is removed from the bottom of the unit with a water-cooled bottom ash screw.

## 4.2 Lahti gasifier unit

The Lahti gasifier has been built to act as a fuel pre-treatment unit for the old PC boiler at the Kymijärvi power plant. The PC boiler is a Benson-type once-through boiler. Originally, the plant was heavy-oil fired, but was modified for coal firing in 1982. The steam data is 125 kg/s 540°C/170 bar/540°C/40 bar, and the plant produces electric power for the owners, and district heat for the city of Lahti. The maximum power capacity is 167 $MW_e$ and the maximum district heat production is 240 MW. 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 1200 GWh/a (180,000 ton/a) of coal and about

800 GWh/a of natural gas. The boiler is not equipped with a sulphur removal system. However, the coal utilized contains only 0.3% to 0.5% sulphur. The burners are provided with flue gas circulation and staged combustion to reduce $NO_x$ emissions. The connection of the gasifier to the existing power plant is shown in Figure 10.

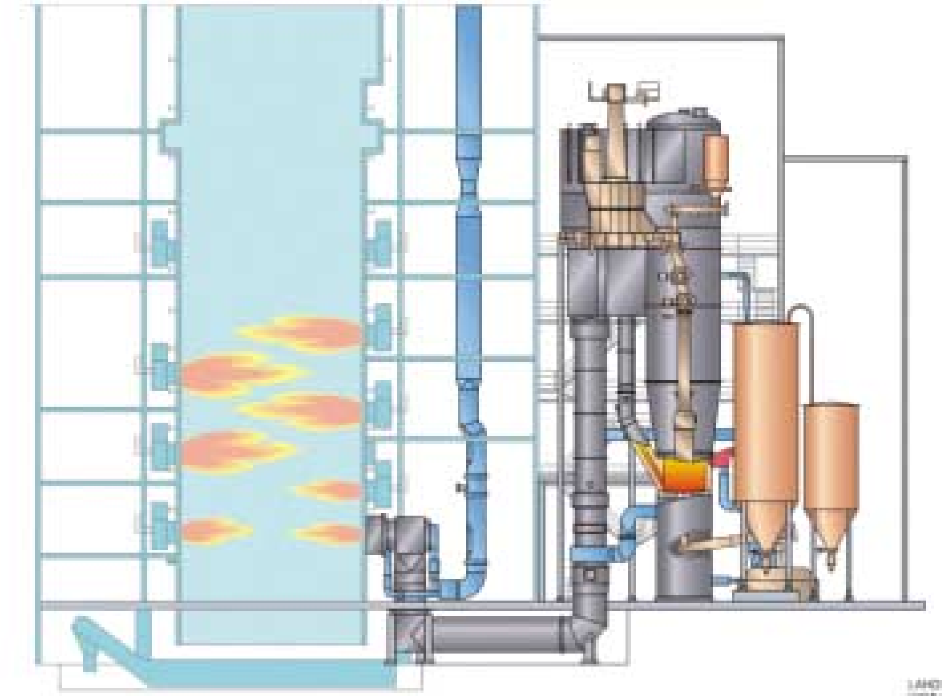

*Figure 10. Integration of CFB gasifier with a PC boiler.*

### 4.2.1 Fuels for gasification

Initially, the Lahti gasifier used biofuels such as bark, wood chips, sawdust and uncontaminated wood waste. Other fuels have also been tested subsequently. System for collecting combustible refuse (REF) was started in the Lahti area at the end of 1997. This REF fuel originates both from households and industry. The amounts of collected REF have been lower than the REF gasification capacity of the gasifier, but it is expected that the amounts and quality of REF will increase in the future. In addition to the above-mentioned fuels, railway ties (chipped on site) and shredded tires have also been used as fuel.

## 4.3 Operating experiences

Generally, the operating gas has been as expected. The quality of the product gas has been close to the calculated values, and the effect of the gasifier on the main boiler emissions has been marginal. Perhaps the most positive phenomenon has been the decrease in the $NO_x$ emissions for the main boiler when product gas is combusted. The main data is as follows:

- commercial operation since March 1998
- operating time 21,000 hours during 1998–2001
- energy produced 1270 GWh
- fuel gasified 394,000 tons

The results from the first operating years are very encouraging. Table 5 lists the operating data for 1998–2001. The opportunity fuel fractions listed in Table 6 have been used during this time.

The effect of gasification on the main boiler emissions has been as follows:

| | |
|---|---|
| • $NO_x$ | decrease by 10 mg/MJ (= 5 to 10%) |
| • $SO_x$ | decrease by 20–25 mg/MJ |
| • CO | no change |
| • HCl | increase by 5 mg/MJ, base level low |
| • particulates | decrease by 15 mg/$m^3$n |
| • heavy metals | increase in some elements, base level low |
| • dioxins, etc. | no change. |

*Table 5. Operating record of the Lahti gasifier.*

| | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|
| Operating hours | 4730 | 5460 | 4727 | 7089 |
| Availability * % | 99.3** | 98.9 | 97.1 | 96.1 |
| Energy produced GWh | 223 | 343 | 295 | 449 |

* heat-up periods excluded, covers operation in gasification mode only
** the second half of the year

*Table 6. Fuels processed at the Lahti gasifier.*

| Fuel | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|
| Biomass % | 71 | 57 | 63 | 61 |
| REF % | 22 | 23 | 29 | 26 |
| Plastics % | – | 13 | 7.4 | 12 |
| Paper % | – | 6.0 | 0.1 | 0.3 |
| Railway ties % | 5.5 | 0.1 | 0.2 | – |
| Shredded tires % | 1.5 | 0.9 | – | – |
| TOTAL ton | 79 900 | 106 200 | 91 800 | 116 100 |

The stability of the steam cycle, coal burners, and product gas burner has been excellent. No signs of abnormal deposit formation on the boiler heat transfer surfaces have been detected either in probe monitoring tests or during summer maintenance inspection. Because of the excellent process behavior of the gasifier and low impact on emissions, the authorities have set no limitations on applicable fuels or utilization of ash. All fuel fractions that have been tested are permitted to be used in the gasifier today.

# 5. Ruien gasification project

Due to the very promising results gathered during the Lahti gasifier demonstration project, the first commercial application of the concept is now under construction for MW Electrabel in Ruien, Belgium. The Ruien site is located near the River Scheldt 10 km from Oudenaarde, and is the largest fossil fuel-fired power station in Belgium. The location and connection to the existing boiler is shown in Figure 11.

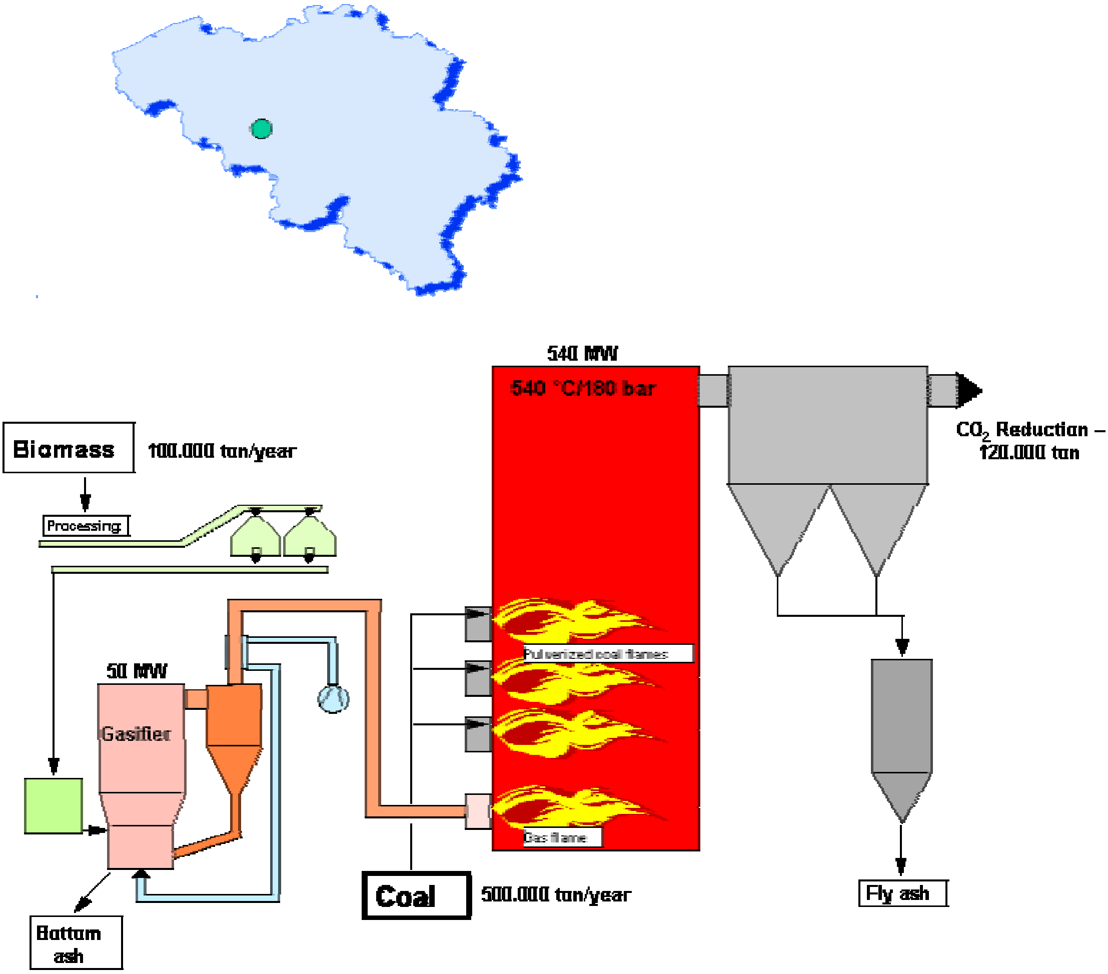

*Figure 11. Location of the Ruien plant and gasifier connection to the existing boiler.*

Installed combustion capacity on the Ruien site is as follows:

- unit 3: 1967, 130 MW coal & fuel fired
- unit 4: 1966, 125 MW coal & fuel fired
- unit 5: 1973, 190 MW on coal, 294 MW on gas or fuel
- gas turbine: 1997, 40 MW direct and 12 MW through re-powering unit 5
- unit 6: 1979, 300 MW gas and fuel.

The gasifier will be delivered by the end of 2002 and will start operation in January 2003. This project is a major breakthrough in the utilization of recovered fuels with a high heating value, and several similar projects are expected in the near future. This approach can easily be taken if the customer has existing capacity for combusting fossil fuels, as no new combustion or energy recovery equipment is needed. The produced gas can be used for replacing a major part of the fossil fuel with a renewable energy source. As demonstrated in the Lahti project, the operation of the existing unit will improve as the amount of gaseous emissions will decrease.

## 5.2 Further development possibilities

The concept of the gasification of recycled fuels can be developed further by adding a product gas cleaning unit prior to combustion. With this approach, clean fuel gas can be produced by treating wastes, which normally cannot be burned very efficiently. The components used in this concept are shown in Figure 12.

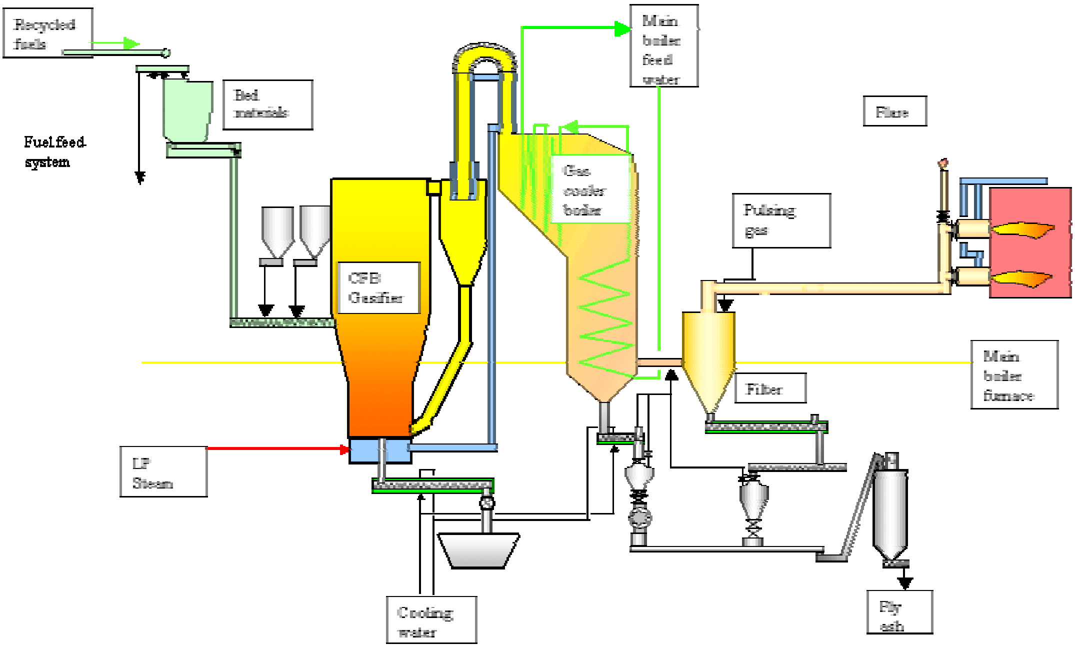

*Figure 12. CFB gasifier with product gas cleaning.*

# 6. Conclusions

The increasing need for more effective energy recovery from different type of waste has led to development of various approaches aiming at increasing the utilization potential of waste fractions with a high heating value. Fluidized-bed combustion and circulating fluidized-bed gasification have been recognized as the most environmentally benign and cost effective solutions. As examples of the potential of these technologies, operating experiences from three projects are presented.

The Högdalen CFB boiler is now in its third year of operation. Although the unit produced only district heating during the first two years, the economics of the plant have been very good. A new turbine was installed during summer 2001 to improved the plant economy. This type of solution has been the focus of several visits by possible customers from different parts of the world.

As the first WTE installation of its kind in Europe, Lomellina Energia is an integrated facility for recyclable materials recovery and refuse derived fuel (RDF) production, composting and electricity generation. The plant has functioned as expected, and decisions about constructing similar plants in Europe are expected in the near future.

In order to test the feasibility of using a CFB gasifier as a fuel pre-treatment unit, a gasification project was commenced at Lahden Lämpövoima Oy, Kymijärvi Power Plant in Lahti, Finland. The project demonstrated commercial-scale direct gasification of biofuels and wastes, and the use of hot, raw and very low calorific gas directly in the existing coal-fired boiler. Generally, the operating gas has been as expected. Product gas quality has been as expected, and the effect of the gasifier on main boiler emissions has been marginal. Perhaps the most positive phenomenon has been the reduction in main boiler $NO_x$ emissions when product gas is combusted. Due to the very promising results gathered during the Lahti gasifier demonstration project, the second commercial application of the concept is now under construction in Ruien, Belgium.

These three examples demonstrate the capability of fluidized-bed technologies offered by Foster Wheeler in the waste-to-energy business, and particularly in efficient heat regeneration using wastes with a high heating value.

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# Norrköping 75 MW CFB plant and biomass RDF combustion in fluidized-bed boilers

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## Scope

The 200,000 t/a CFB boiler under construction for Sydkraft Östvärme AB in Norrköping in Sweden is the latest Energy-from-Waste plant designed by Kvaerner. This report describes the background of the project and the main features of the plant. In addition, operating experiences and detailed performance results are reported from the similar SOGAMA plant in Spain.

# 1. Modern waste combustion

## 1.1 Developments within the waste market

Today there are constantly ongoing changes in waste handling, and thus in the composition of various waste streams, in order to find the environmentally best solutions. In Sweden, a number of governmental instruments of control, such as tax on landfill, prohibition of landfilling assorted combustible material from year 2002 and prohibition of landfilling organic material from year 2005, lead to an increase in the amount of waste suitable for combustion. There is also a trend towards increased diversification of the waste streams. One reason for this is that several fractions of industrial waste that were not earlier classified as waste will today be so. Another reason is that among the assorted waste, some fractions are not suited for material recycling. Sewage sludge is yet another type of waste that needs new treatment technology since the possibility to use it, for instance, as a fertilizer spread on fields is very limited due to its high content of heavy metals and toxic substances. Altogether this makes the fuel flexibility to one of the most important criteria in many waste combustion projects.

## 1.2 CFB for waste combustion

The fuel flexibility with a CFB is illustrated in Figure 1 in the form of an operating window, defined by the span of net calorific value (from 6 to 27 MJ/kg) and moisture content (from 5 to 60%) in the feedstock that is possible to burn in a specific boiler. The location of the operating window in the diagram is chosen so that the anticipated fuel span is covered, the smallest window in the figure. Therefore, the operating window for a boiler aimed for low NCV fuels is shifted downwards to the right hand side and for a high NCV fuel boiler to the opposite corner. The acceptable fuel span easily covers normal industrial waste and MSW and also leaves margins for further changes or additional waste streams.

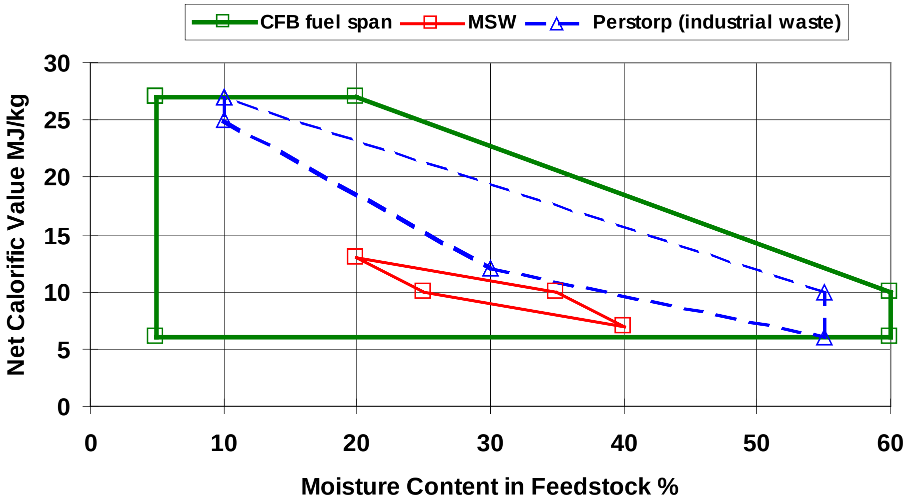


*Figure 1. CFB fuel flexibility. The largest window shows the acceptable fuel design range. In this are the composition of a high NCV fuel, industrial waste (dotted line) and a typical MSW fuel (solid line).*

The steam temperature can be raised higher in a CFB than in other types of boilers thanks to the possibility to locate a superheater in the loop seal between the cyclone dipleg and the furnace, the so called Circulating Loop Cooler (CLC). In this location, the heat transfer rate is extremely high and the atmosphere is much less corrosive than in the back pass, making it possible to increase the material temperature without increasing the risk of corrosion. This type of CLC superheater is used in new CFB plants.

The CFB combustion technology is since long known for its low emissions. The main reasons for this is the low and even combustion temperature combined with the intense mixing of air and fuel. This provides for low $NO_x$ formation, low emissions of CO, hydrocarbons and other organic compounds as well as good burnout of the ashes. The typical content of unburned carbon in the ashes is 0.1% in the bottom ash and 0.5% in the fly ash. The good combustion conditions also results in a low amount of dioxin in the ashes, normally <0.01 ng/g I-TEQ in the bottom ash and <0.5 ng/g I-TEQ in the fly ash and flue gas cleaning product.

## 1.3 Design features for CFB waste combustion

In order to handle demanding waste fuels a number of considerations must be taken, both regarding external equipment and boiler design. In addition to the specific fuel handling, which will be described later, and the flue gas cleaning, the main differences regarding the equipment compared to a plant designed for biomass fuel are:

- The fuel feeding system must be non-compacting in order to get an even feed of the waste fuel;
- An Eddy current separator removes aluminium from the fuel;
- Dolomite is added to the furnace to avoid deposits of aluminium;
- The high ash content and coarse ash particles calls for a high discharge capacity of bed material to keep a good bed quality and secure good fluidization. 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.

There are also a number of differences in the boiler design between a waste fired and a biomass fired boiler, as for example:

- The furnace bottom is equipped with specially designed directional nozzles to provide for good ash transportation;
- The boiler height has to be adjusted according to the regulations regarding retention time at a temperature above 850°C. For a large CFB the boiler height decided by the cyclone will fulfil this requirement;
- The boiler has to be equipped with a support burner, which shall start automatically if the combustion temperature falls below 850°C;
- After the cyclone the flue gas passes an empty radiation cooling pass, which cools the flue gas prior to entering the closely arranged convective cooling surfaces. This minimize both fouling and corrosion;
- The risk of combined corrosion and erosion in the back pass calls for low flue gas velocities and small temperature differences between flue gas and steam/water. This will result in large superheater and evaporator surfaces.

# 2. The power plant at Händelö in Norrköping

## 2.1 History of the Power Plant

The combined heat and power plant at Händelö was built in 1982–1983 (Tables 1 and 2). It became the main plant for power production based on district heat production for the city of Norrköping. The plant comprised twin coal-fired travelling-grate boilers producing steam at 11 MPa and 540°C with a capacity of 262 $MW_{th}$, used for production of 82 MW electricity and 180 MW heat.

In the beginning of the 1990s, the Swedish government introduced taxes and environmental fees on heat produced by fossil fuel. These taxes and fees have since then been increased successively in order to stimulate a transition from fossil fuels to renewable fuels such as biomass and waste. In 1993, Sydkraft Östvärme AB, former Norrköping Miljö och Energi, took into operation a new biomass fired CFB boiler. The main fuel was forest residue, GROT. Three years later, in 1996, one of the coal-fired boilers was retrofitted with a vibrating grate and a spreader designed for combustion of demolition wood waste. The other grate boiler is fired with coal mixed with 25% tyre derived fuel, TDF, which is taxed as a biomass fuel.

*Table 1. CHP plant Händelöverket, boiler history.*

| Year | Boiler | | Retr./ new | Fuel | Thermal | Steam data | |
|---|---|---|---|---|---|---|---|
| | No | Type | | | MW | MPa | °C |
| 1982 | P11P12 | Travelling grate | New | Coal | 125<br>125 | 11 | 540 |
| 1993 | P13 | CFB | New | Biomass, Coal | 125 | 11 | 540 |
| 1996 | P11 | Vibrating grate | Retrofit | Demolition wood waste | 117 | | |
| 2002 | P14 | CFB | New | MSW, industrial waste, sewage sludge, rubber, demolition wood waste | 75 | 6.5 | 470 |

*Table 2. CHP plant Händelöverket, Steam turbine/generator history.*

| Year | Turbine | | Retr./ new | Comment | Electr | Heat | Steam data | |
|---|---|---|---|---|---|---|---|---|
| | No | Type | | | MW | | MPa | °C |
| 1982 | G1 1 | ABB STAL Axial | New | | 82 | 180 | 11 | 540 |
| 1993 | G1 1 | | Retrofit | | 90 | 200 | 11 | 540 |
| 1964 | G1 2 | STAL Radial | New | Moved to Händelö 1994 | 10 | 30 | 6.5 | 470 |
| 2002 | G1 2 | | Retrofit | | 11 | 32 | 6.5 | 470 |

In order to further increase the use of biomass, meet the increasing demand of heat and process steam and the need to renew the production system a project was started in 1999. The aim was to investigate the possible modification or expansion of the existing CHP plant. It was decided to plan for a new boiler for combustion of various types of waste. The main reasons were the trend of increasing price on virgin biomass, increasing amounts of sorted waste on the fuel market and the coming prohibition in Sweden of landfilling of combustible material (January 1, 2002) and of organic matter (January 1, 2005).

The requirements on the new boiler were defined based on own and others experiences and on the local conditions. The boiler shall have good fuel flexibility to be able to treat the existing and the future waste fractions. The main fuel will be sorted household waste and sorted industrial waste. The expected span of fuel quality is described by a net calorific value between 6 and 25 MJ/kg and a moisture content in the range 5 to 60%. The steam data shall be high enough for efficient power production by means of the CHP turbine. Furthermore, the capacity of the boiler shall be optimised, with respect to the amount of waste available in the Norrköping region. It shall be big enough to cover all production of steam and heat during the summer months and yet small enough so that its minimum load is less than the minimum demand during the summer period. The boiler shall operate all over the year with an annual revision period of three weeks.

## 2.2 Reasons for choosing the CFB for waste combustion

Sydkraft Östvärme AB concluded that the best solution for their needs is a CFB boiler designed for waste firing. The reasons for this are as follows:

- Good experiences of biomass combustion in the CFB boiler taken into operation on the plant in 1993;
- Better fuel flexibility with the fluidized-bed technology, which increases the possibility to meet future changes in type and quality of waste fractions;
- Better steam data with the superheater location in the loop seal;
- Lower investment and maintenance costs;
- Shorter time of delivery;

- Co-ordination advantages of fuel preparation with other parts of the plant, for instance regarding demolition wood waste.

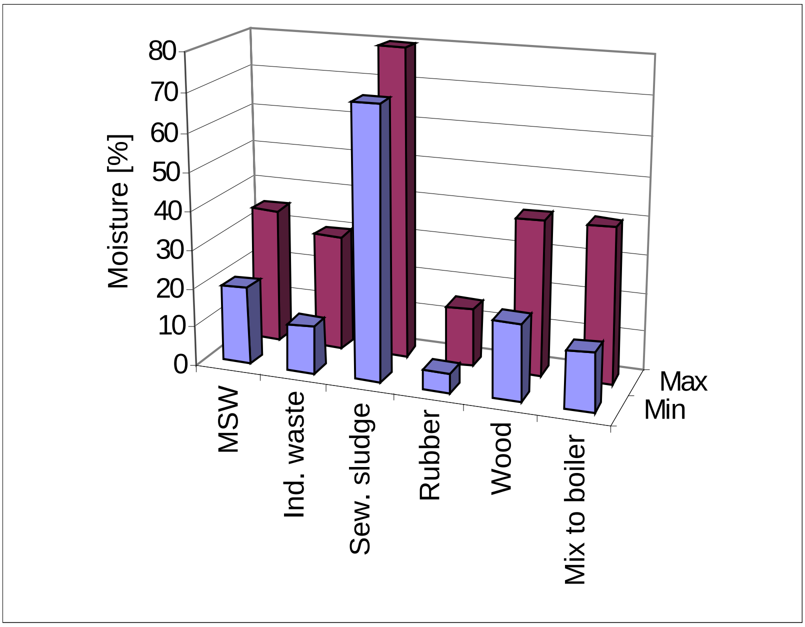
In addition to this, the low formation of emissions like $NO_x$ and dioxin and the good burnout of the ashes were appreciated.

The optimum capacity of the boiler was found to be 75 $MW_{th}$ with steam data 6.5 MPa and 470°C to fit an existing turbine. The inquiry documents for boiler and flue gas cleaning were issued in June 2000 and the bidding time was set to three months. Kvaerner Pulping was selected as the boiler supplier based on its long experience on fluidized-bed combustion of waste and the content of the bid, which fitted well with the inquiry. The contract was signed in December 2000. Alstom Power AB was selected as the supplier of the flue gas cleaning plant, a NID unit. That contract was signed in January 2001.

Next phase was the design of the fuel preparation plant. Attempts were made during year 2000 to find a turnkey contractor for the fuel preparation plant, but with poor response. Also, after having visited a number of plants it was concluded that none of them corresponded completely with the planned Norrköping fuel preparation plant. Therefore, it was decided to make an in-house design of the plant and order the pieces separately.

## 2.3 Fuel mix

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 range of variation for the different waste fractions are illustrated in Figure 2, and the span for the fuel mix to the boiler is shown in the combustion diagram (Figure 3). The corresponding analysis is given.



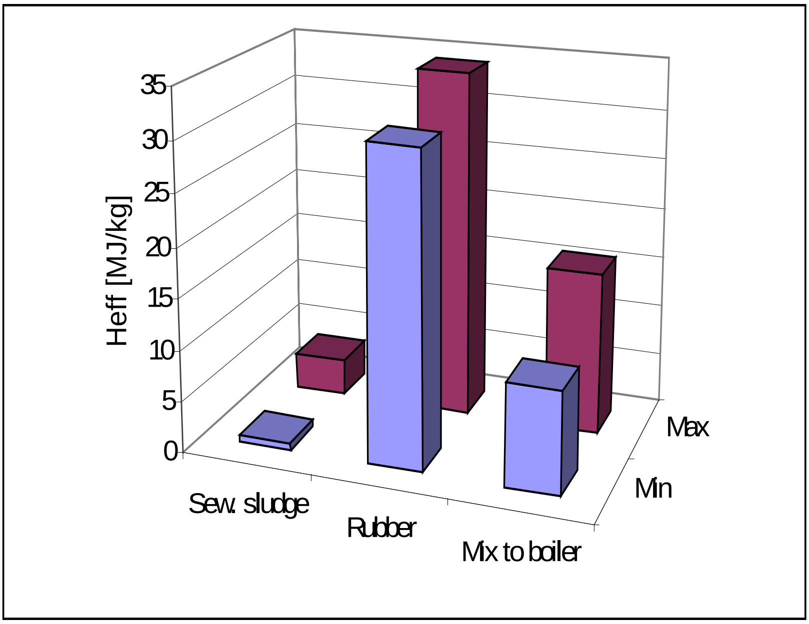


*Figure 2. Range of variation for different waste fractions, Norrköping.*

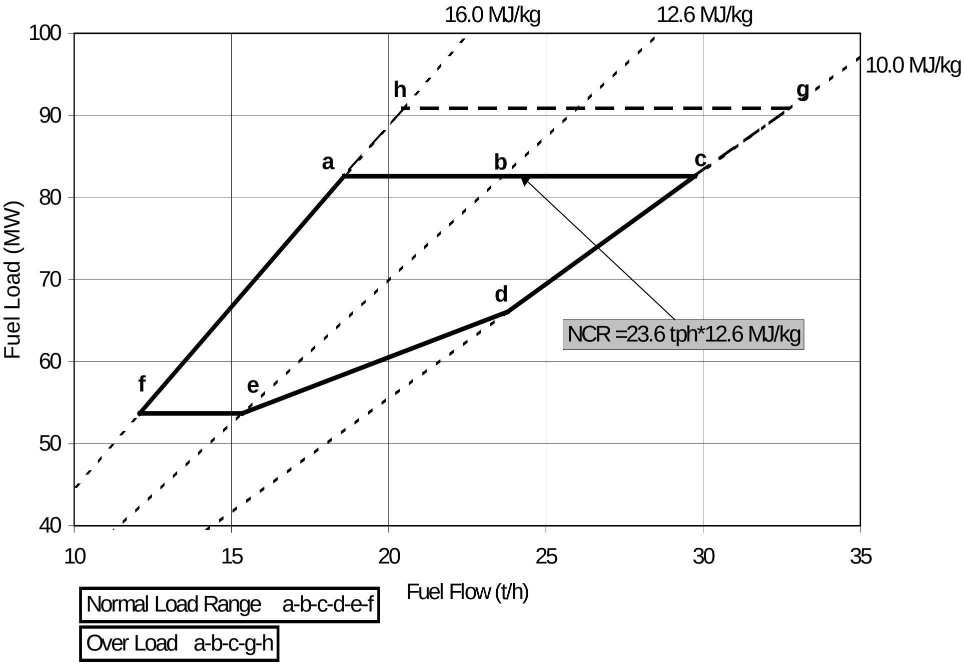


*Figure 3. Combustion diagram for the Norrköping CFB showing waste heat input versus waste feed rate. Normal operation area: a-b-c-d-e-f, overload area a-b-c-g-h.*

## 2.4 Solid fuel preparation

Waste delivered to the plant is tipped into a bunker, 78 m long, 12 m wide and 8 m deep. It has the capacity to store enough fuel for 4 days full boiler load operation. Two cranes then feed two low-speed shredders from which the fuel is conveyed to two hammer mills (Figure 4). Magnetic separators are located both before and after the mills, for removal of ferrous material from the fuel before it is transported to the main storage, the A-barn. It has a volume of 10,000 m$^3$ corresponding to 3 days of full boiler load operation. All preparation and storage thus takes place indoors. The fuel is transported from the A-barn, via a third magnet, up to three silos at the top of the boiler, prior to being fed to the furnace for combustion.

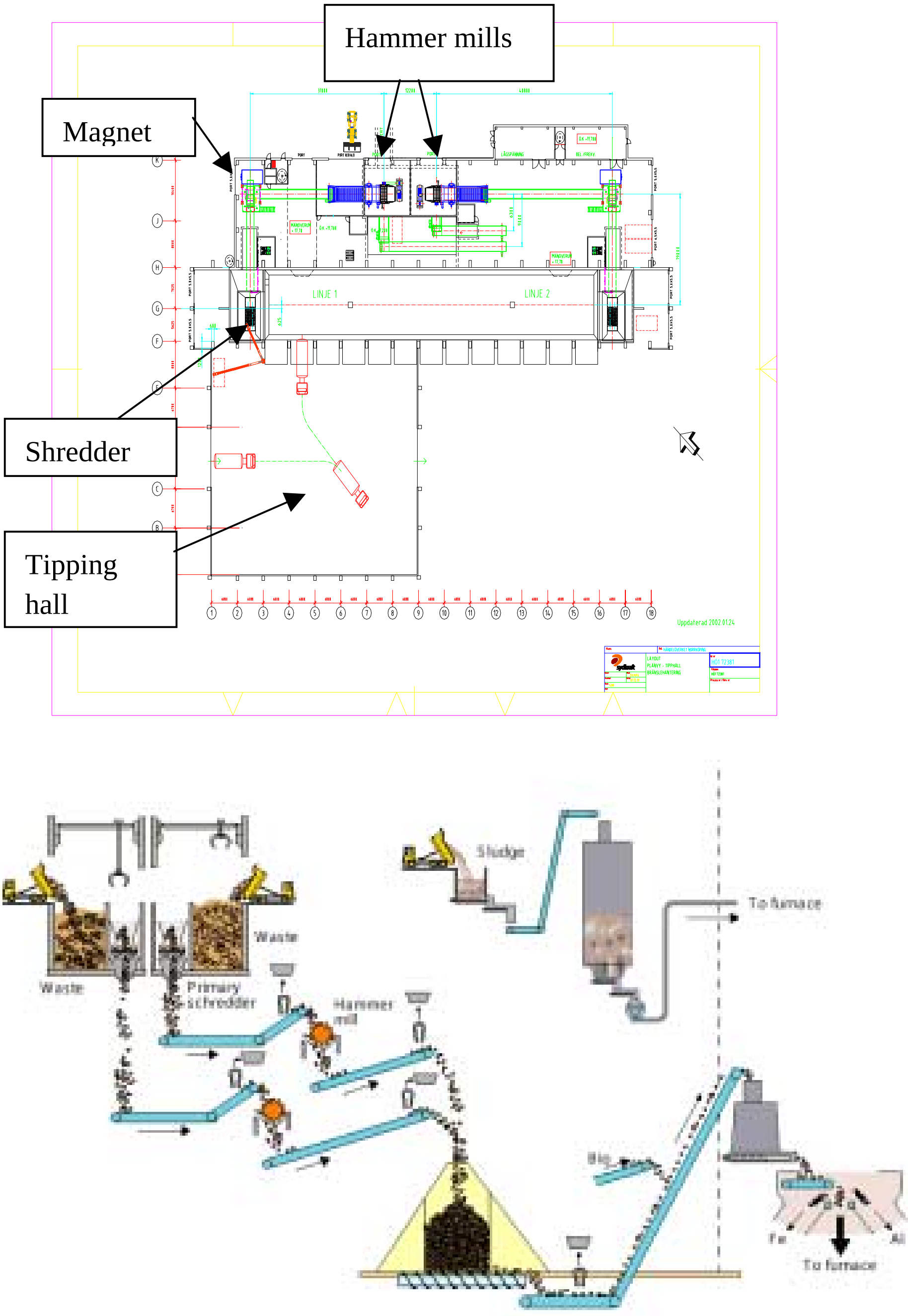


*Figure 4. Fuel preparation plant.*

The plant has an extra discharge possibility below one of the two hammer mills and an extra dosing hopper after the A-barn. It is also possible to feed one of the mills directly by means of a front loader. Thus, the design of the fuel preparation is fairly simple, flexible and robust since it is based on heavy-duty equipment. Commissioning is planned for June 2002 allowing for a marginal of two months before the boiler start-up.

## 2.5 Sludge

Kvaerner has built a number of fluidized-bed boilers for different types of sludge, the first delivered in 1974. However, this fuel mix, consisting of RDF and sewage sludge, combined with the strict emission limits is new. Also, the Norrköping plant will be the first plant in Sweden to burn sewage sludge on a regular basis. Preparatory tests were conducted both at a 10 $MW_t$ BFB boiler in Västervik and in the Chalmers University 12 $MW_t$ CFB boiler.

The tests in Västervik showed that the co-combustion of sewage sludge with waste in a fluidized-bed resulted in good combustion performance and controlled emissions. More extensive tests at Chalmers [Åmand *et al.* 2002], where sewage sludge were co-combusted with coal and biomass, resulted in the following main observations:

- The high content of ash in the sludge (around 45% of dry substance) results in increased fly ash flows;
- Although the concentration of alkali metals in the sludge is high the level is not crucial and no tendency to deposits in the boiler was observed;
- The flow of trace elements increases with increasing fraction of sludge in the fuel mix. However, the emission of heavy metals with the flue gas was well below the EU limits;
- The $NO_x$ emission increases with increasing sludge fraction when wood is the base fuel. If coal is the base fuel the pattern is the opposite. The $NO_x$ levels can be lowered if advanced air staging is applied, i.e. when the secondary air is added after the hot cyclone.

- A CFB boiler can be operated flexibly with fuel mixes containing more than 40% energy fraction of sludge without exceeding the EU emission limits. The only additional equipment needed, compared to the Chalmers boiler, is lime injection for $SO_2$ abatement and an SNCR-system to reduce the emission of $NO_x$.

In Norrköping, the sewage sludge is delivered to a 45 $m^3$ receiving bin and transported immediately by a conveyer to a 200 $m^3$ storage silo (Figure 5). From the storage silo, the sludge is pumped by one pump, with the capacity range 2–16 $m^3/h$, to the two feeding points, one in each cyclone loop seal.

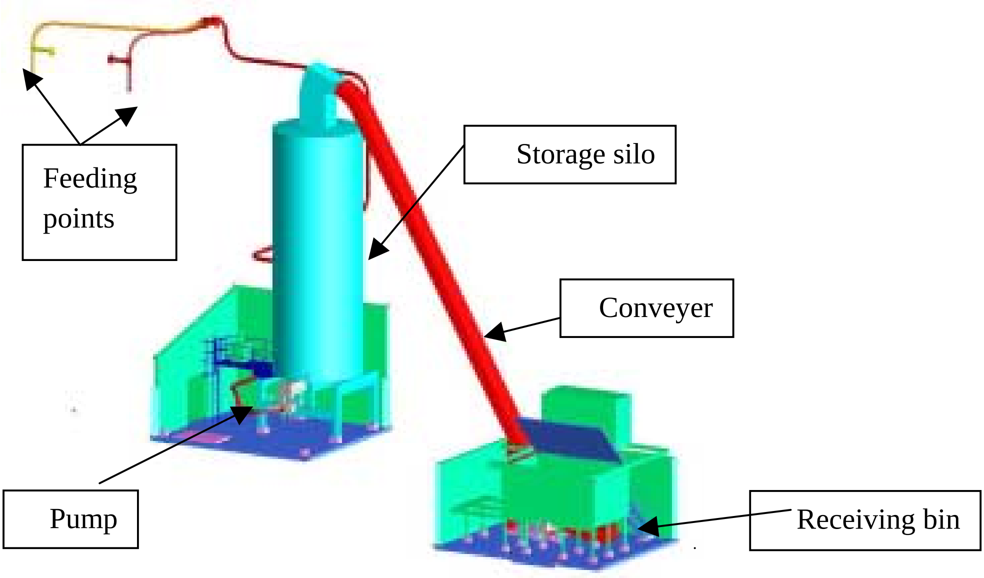


*Figure 5. Sewage sludge handling.*

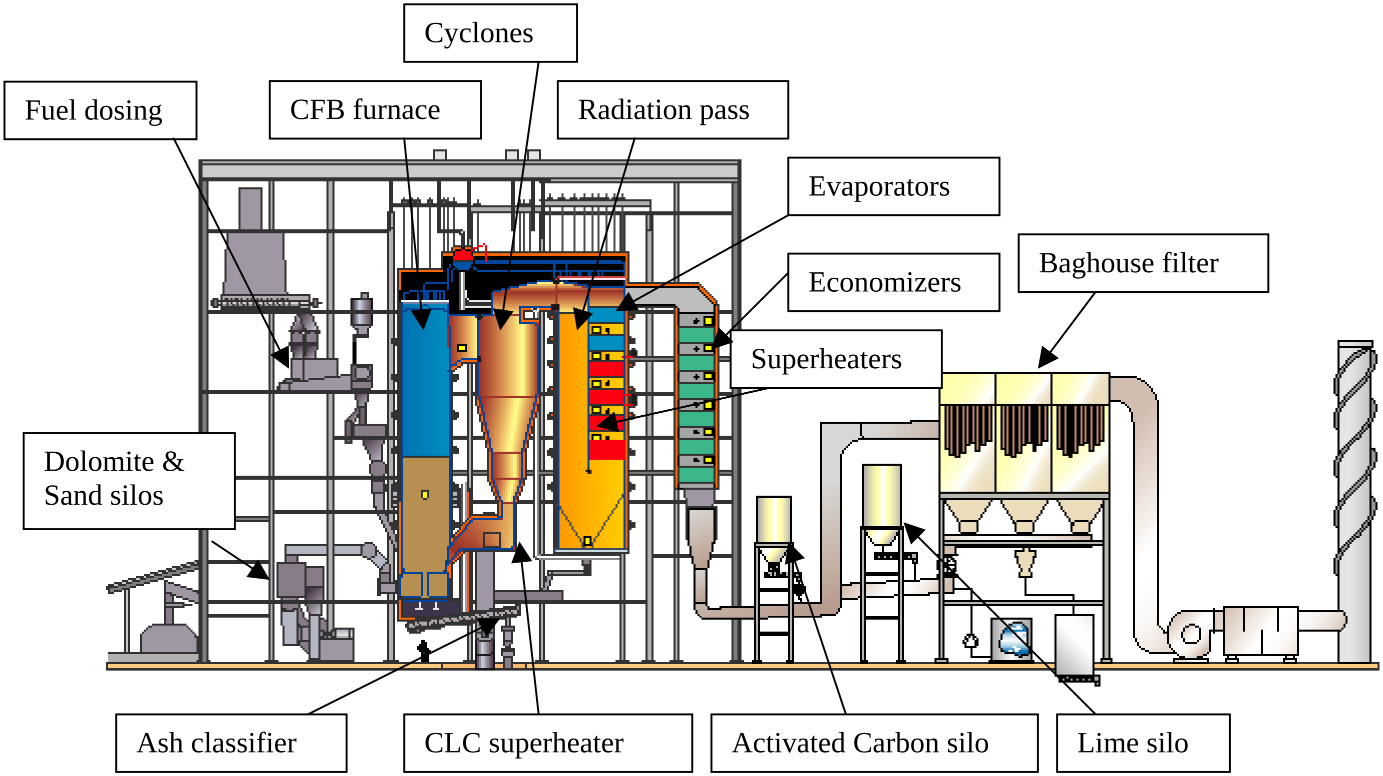


*Figure 6. Side view of the Händelö/Norrköping P14 CFB boiler.*

## 2.6 The boiler

The Händelö P14 CFB boiler is capable of utilising up to 200,000 tons of waste a year. The main parts of the plant are the RDF preparation facility, the CFB boiler and the flue gas treatment system, Figure 6. The boiler produces steam, primarily used for production of district heat energy and industrial process team, but it can also be used to drive a turbine for electric power production. The boiler is similar to the two boilers in SOGAMA, Spain, taken into operation in 2000, but with higher steam data (470°C / 6.5 MPa). The fuel analysis and the main boiler data for the two boilers are shown in Tables 3 and 4.

The boiler is designed for fuel flexibility, using a fuel mix of 30–50% combined household waste, 50–70% classified industrial waste and up to 20% sewage sludge. Co-firing of sewage sludge represents an economical sound environmental solution for which the boiler has been specifically designed.

*Table 3. RDF analysis: Design (Des.), Span, Measured average (Meas.).*

| | Norrköping | | Sogama | | |
|---|---|---|---|---|---|
| | Des. | Span | Des. | Span | Meas. |
| ***Main elements:*** | | | | | |
| Carbon (% dry basis) | 45.0 | 35–55 | 44.8 | | 42.7 |
| Hydrogen (% dry basis) | 5.8 | 4–9 | 6.28 | | 5.65 |
| Oxygen (% dry basis) | 27.3 | 25–45 | 29.5 | | 26.1 |
| Nitrogen (% dry basis) | 1.0 | ≤1.0 | 1.15 | ≤1.2 | 1.34 |
| Sulphur (% dry basis) | 0.4 | ≤0.5 | 0.25 | ≤1 | 0.39 |
| Chlorine (% dry basis) | 0.8 | ≤0.8 | 0.83 | ≤1.08 | 0.57 |
| Inert materials (% dry basis) | 19.7 | 12–23 | 17.1 | 12–22 | 23.3 |
| Moisture (%) | 28.9 | 15–40 | 28.0 | 20–35 | 25.7 |
| Net calorific value (MJ/kg) | 12.6 | 10–16 | 12.5 | 9.2–16.7 | 11.1 |
| ***Heavy metals:*** | | | | | |
| Al (g/kg dry fuel) | | ≤ 10 | 10 | ≤+30% | |
| Pb (mg/kg dry fuel) | | ≤ 500 | 200 | ≤+30% | |
| Cr (mg/kg dry fuel) | | | 50 | ≤+30% | |
| Cu (mg/kg dry fuel) | | | 150 | ≤+30% | |
| Mn (mg/kg dry fuel) | | | 150 | ≤+30% | |
| Ni (mg/kg dry fuel) | | | 20 | ≤+30% | |
| As (mg/kg dry fuel) | | | 10 | ≤+30% | |
| Cd+Hg (mg/kg dry fuel) | | | 10 | ≤+30% | |
| Pb+Cr+Mn+Zn+V+ Co+Sn+Ti+Sb (mg/kg dry fuel) | | | 1200 | ≤+30% | |
| Zn (mg/kg dry fuel) | | ≤ 800 | | | |
| Cd (mg/kg dry fuel) | | ≤ 2.0 | | | |
| Hg (mg/kg dry fuel) | | ≤ 0.6 | | | |

*Table 4. Boiler data.*

| | N[*] | S[**] |
|---|---|---|
| ***Furnace*** | | |
| Height (m²) | 22.6 | |
| Cross-sectional area (m²) | 34 | |
| Gas velocity at MCR (m/s) | 5.4 | |
| ***Boiler exit*** | | |
| Gas temperature (°C) | 165 | 145 |
| Unburned in bottom ash (%) | <1 | |
| ***Water/steam*** (MCR) | | |
| Feed water temp (°C) | 135 | 140 |
| Steam flow (kg/s) (per boiler) | 27.5 | |
| Steam pressure (MPa) | 6.5 | 4.4 |
| Steam temperature (°C) | 470 | 450 |
| ***Miscellaneous*** (MCR) | | |
| Boiler efficiency (%) | 89.9 | 89.5 |

[*] N = Norrköping, [**] S = Sogama

## 2.7 Flue gas cleaning

The plant is equipped with a Kvaerner SNCR system using ammonia for $NO_x$ reduction. The main component in the external flue gas treatment system is an Alstom/NID system with a mixer, reactor and bag filter. Lime is mixed with water and introduced to the mixer along with fly ash from the boiler and more water. The thus moistened particles are then injected into hot flue gas in the reactor, in which activated carbon is also added. The reactor ensures an even distribution of particles in the gas flow. The flue gas then passes through a 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 heavy metals. Some of the fly ash is deposited in a silo, but most of it is re-circulated through the mixer and reactor to give the additives enough time to do their work.

# 3. The SOGAMA Plant

The SOGAMA Energy-from-Waste plant is located near the town of Cerceda in Galicia, Northwest Spain. The plant, owned by Sociedade Galega do Medio Ambiente (SOGAMA), is designed to process approximately 650,000 tonnes of MSW annually to 400,000 tonnes of RDF to be used for combustion and generation of electric power. The combustion technology is the Kvaerner's Circulating Fluidized-Bed boiler system. The main purpose of the SOGAMA plant is to recover useful materials, generate electricity from the RDF and to reduce the final volume for the landfill. Fuel analysis and main boiler data are shown in Tables 3 and 4.

## 3.1 Operating experience

The SOGAMA boilers were fired on RDF first time in December 2000. The plant availability during the first few months was poor, mainly due to problems with the fuel preparation plant. Numerous of oversized fuel particles caused frequent plugs in the fuel feeding system as well as in the ash removal system. After modifications of the fuel preparation plant and enhancements of the fuel feed and ash removal systems the availability was improved. The client took over the plant in June 2001 and the technical performance tests were performed in early September 2001. Today, end of February 2002, the boilers have been in operation on RDF approximately 6800 hours and the operation confirms the good combustion characteristics typical for a CFB, resulting in good burnout and emissions performance within the fuel span. Typical operational data are shown in Figures 7 and 8.

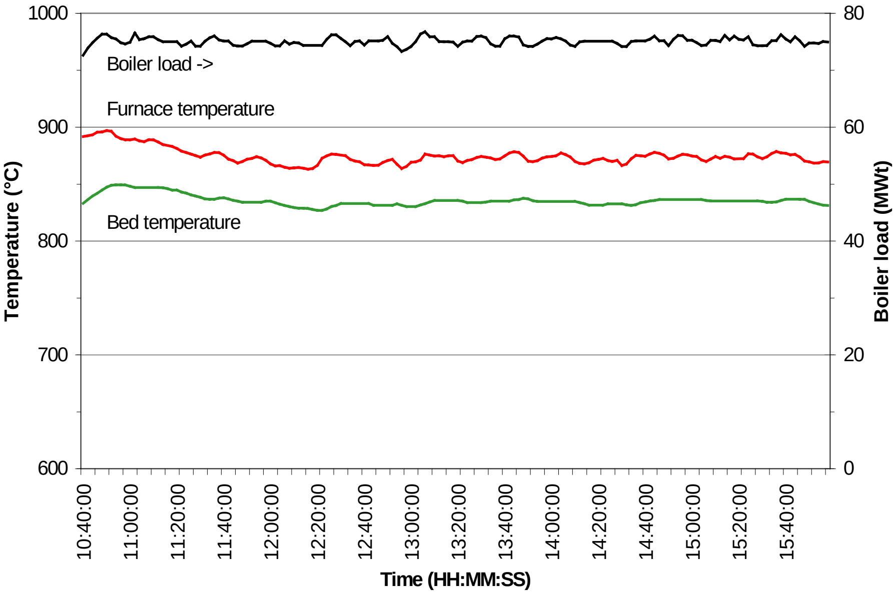


*Figure 7. Typical combustion temperatures at full boiler load. SOGAMA plant.*

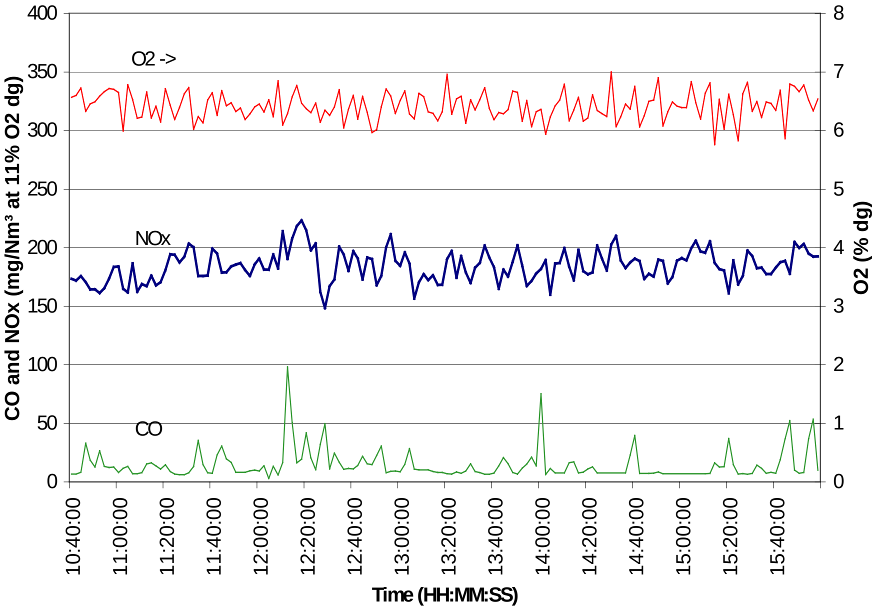


*Figure 8. Typical emission data at full boiler load. SOGAMA plant.*

## 3.2 Performance test results, emissions and ashes

Table 5 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's evident from the table that the emissions are well below all these limits. Also, the requirement of 2 seconds 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.

*Table 5. Gaseous emissions. Ref.cond.:273 K, 101.325 kPa and 11% $O_2$ vol. dry gas. SOGAMA plant.*

| Compound | Unit | Directive 2000/76/EC | Guarantee SOGAMA | Perf. test SOGAMA | Guarantee Norrköping |
|---|---|---|---|---|---|
| Particulates | mg/Nm³ | 10 | 10 | 2 | 1) |
| Org. comp., as TOC | mg/Nm³ | 10 | 10 | <1 | 10 |
| CO | mg/Nm³ | 50 | 50 | 10 | 50 |
| $NO_x$ | mg/Nm³ | 200 | 300 | 180 | 120–150 2) |
| HCl | mg/Nm³ | 10 | 10 | <1 | 1) |
| HF | mg/Nm³ | 1 | 1 | <0.3 | 1) |
| $SO_2$ | mg/Nm³ | 50 | 50 | <1 | 1) |
| As+Co+Ni+ Pb+Cr+Sn+ Cu+Mn+V+Sb | mg/Nm³ | 0.5 | 0.5 | 0.35 | 1) |
| Cd+Tl | mg/Nm³ | 0.05 | 0.05 | <0.02 | 1) |
| Hg | mg/Nm³ | 0.05 | 0.05 | <0.002 | 1) |
| Dioxin | ng TEQ/ Nm³ | 0.1 | 0.1 | 0.002 | 1) |
| $NH_3$ | mg/Nm³ | | | | 10 |
| $N_2O$ | mg/Nm³ | | | | 40 |

1) Not within KP delivery
2) Differs over the load range. With SNCR.

The good combustion performance is also shown by the low concentration of dioxins before the flue gas cleaning. During the performance test, dioxin was sampled both before and after the baghouse. The result shows that the dioxin content in the flue gas before the flue gas cleaning was in the range 0.2–1 ng/Nm$^3$ (TEQ, 11%$O_2$ dg) (Table 6).

Not only the emissions to air, but also the ash quality is dependent on good combustion performance. The amount of unburned carbon in the ashes is extremely low (Table 7).

*Table 6. Dioxin concentration in the flue gas before and after the baghouse filter, ng/Nm$^3$. Ref.cond.:273 K, 101.325 kPa and 11% $O_2$ vol. dry gas. SOGAMA plant.*

| | Boiler A | | Boiler B | |
|---|---|---|---|---|
| | Test 1 | Test 2 | Test 1 | Test 2 |
| Before baghouse | 0.84 | 0.92 | 0.26 | 0.22 |
| After baghouse | 0.01 | 0.004 | 0.014 | 0.003 |

*Table 7. Unburned carbon and dioxin in the ashes. SOGAMA plant.*

| Type of ash | Sampling temperature °C | Unburned C, % | Dioxin ng/g, TEQ |
|---|---|---|---|
| Bottom ash | 850 | < 0.1 | <0.01 |
| Boiler ash | 650 | < 0.1 | <0.01 |
| Filter ash | 150 | Not analysed | 0.15 |

# 4. MBM

In addition to the ordinary waste streams, a minor portion of meat and bone meal (MBM) has been burned in the plant. The possibility to take care of this waste in a proper way is highly needed due to the latest developments regarding BSE infected carcasses. After the initial successful test runs with this fuel, the operator now has built a new preparation plant for MBM (Figure 9). Today the fuel mix contains approximately 2.5% MBM.

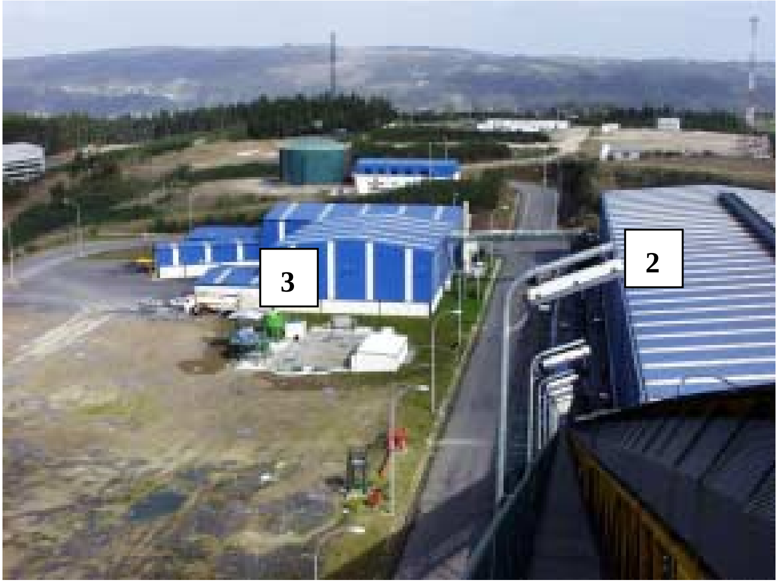


*Figure 9. The Sogama plant including the boiler house (1), the RDF storage (2) and the MBM factory (3). The upper picture was taken before the MBM factory had been erected.*

# 5. Summary

The background for choice of Energy-from-Waste technology in Norrköping is described. Special attention is paid to the design of the fuel preparation plant, the main parts of the CFB boiler and the dry flue gas treatment facility. Also, the environmental performance of the similar SOGAMA boilers, which have been in operation since December 2000, is reported based on the measurements conducted by independent consultants. All the guaranteed emission values were met, in most cases with a margin of one order of magnitude. The concentrations of unburned carbon and dioxin in the ashes and in the flue gas were found to be remarkably low.

# Reference

Åmand, L.-E, Leckner, B., Lücke, K. & Werther, J., Advanced air staging techniques to improve fuel flexibility, reliability and emissions in fluidized-bed co-combustion, VärmeForsk AB and VGB PowerTech E.V., 2002.

# Future mix of energy: contribution by non-regular/recovered fuels – energy and emissions

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## Abstract

A conference on “Power production from waste & biomass” includes the need to discuss and observe several fields of evaluation and technical considerations, of which I choose the following to be the highlights of my presentation:

The achievements in waste-to-energy in the past (“waste incineration plants as sinks”), energy and emissions, waste from “integrated waste management to “Waste-to-energy” (WtE) under Material Flow Management criteria, the contribution of “non-regular fuels” to the security of supply of energy in the EU, the definition of “recovered fuels from wastes” and the establishment of quality control criteria and the monitoring thereof.

What are the targets we have to achieve to ensure that WtE from solid recovered fuels (SRF) is not only the intended but also factual solution?

ASSESS DATA (on a national basis for the EU15) on combustible fuels as feed for SRF (amounts, heating values, other physical and chemical features, sources of such fuels).

SIMPLE RULES to make sure we all talk about the same, to avoid market distortions across the EU, to not “hunt” for 157 000 key numbers of undefined wastes with regard to their chemical composition.

ENSURE SRF go to WtE PLANTS and not to the cheapest hole.

ENSURE that WtE-PLANTS are CAPABLE of HANDLING the INPUT by FUEL QUALITY CONTROL and PROCESS MONITORING: process control and emissions permit to avoid fouling and corrosion of plants and diffuse emissions: this asks for standardization and formulation of quality controlled classes of fuels whereupon an operator can base his planning for energy, plant safety, and emissions liabilities in picking fuels from the market as feed for this plant.

ACHIEVEMENT of SUSTAINABILITY, i.e., the fulfillment of economical and environmental goals by making vast amounts of wastes usable as fuels in industry and thereby enlarge the energy independence of the EU15.

## Discussion of slides shown

The following slides show the dilemma between goals of DG TREN to introduce Waste-to-Energy on a large scale in Europe, also in the light of increased energy dependence in conventional fuels. The goals to be achieved on the one hand are sustainable usage of waste and biomass as a fuel in increasing amounts. To be able to achieve this we have to have harmonized rules and goals within the EU 15 and a good database with regards to “combustible fuels”: calorific value, but also other data. Fluidized-bed incineration may provide a win-win solution for industry in its quest for energy from recovered fuels from wastes.

There is also shown some data so far collected in Austria and Germany, with respect to amounts, calorific value and ingredients, also including an evaluation from source. The method applied is “material waste flow analysis” (Prof. Brunner, TU Vienna).

A few highlighted examples for waste-to-energy use with industrial solutions in the fluid bed incineration – both bubbling and circulating type – application and the fuels checked already are being presented.

The willingness by DG ENV to think seriously about a solution in the field of “solid recovered fuels” (cf. also the newly founded CEN TC 343 “solid recovered fuels from wastes”), the necessity of doing more in this field (1500 tons of Cadmium per year are “lost” in Germany!, only 82 tons go to a waste incineration/waste-to-energy plant (acting as a sink) out of 3000 tons annually entering. All this in the light of having to expect increasing amounts of Cd-containing PVC entering the high-calorific waste fuel market in the coming years this is not influenced by a future ban on Cadmium in new products, of course).

### Standardization for Solid Recovered Fuels

Opening Remarks from the Chair
**Kyriakos MANIATIS**
**Energy from Biomass & Waste**
**DG Energy and Transport, European Commission**

**A PUZZLE OF DILEMMAS**

- **The PRODUCER's DILEMMA**
- **relevant quality-control, material or energy recovery, large markets to be created**
- **The USER's DILEMMA**
- **limited experience, liberalization confused**
- **The STAKEHOLDER's DILEMMA**
- **diverging interests (public/private, global/local)**
- **The GOVERNMENT's DILEMMA**
- **harmonized legal framework, clear, adequate and decisive control monitoring, bridging local and national interests**

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### *SUSTAINABLE DEVELOPMENT*

**DEFINITION IN "OUR COMMON FUTURE":**
**REPORT BY WORLD COMMISSION**
**FOR ENVIRONMENT AND DEVELOPMENT**
**TO GENERAL ASSEMBLY OF UN 1983**

**"….development that meets the needs of the PRESENT**
**without compromising the ability**
**of FUTURE generations**
**to meet their own needs"**

## Non-regular /Recovered Fuels for ENERGY RECOVERY: what are they?

•<u>*COMBUSTIBLE WASTES : MIXTURE of LEGAL POLTICS & TECHNICALITIES*</u>

***•Waste, Household Wastes, Commercial Waste, Refuse Derived Fuel, Recovered Fuels, Secondary Fuels, Waste Fuels, Substitute Fuel, Industrial Waste Fuels, Solid Recoverd Fuels, Waste for Recovery (R1), Waste for Disposal (D10), dry stabilized waste, recycling/shredder wastes, in-company wastes..***

***•Renewables, biomass, biofuels, wood residues, impregnated wood residues, saw dust, bark, waste wood, wood wastes...***

***•Agricultural wastes, new biomass fuels (cynara thistle, fast growing biomass, olive pits, shells)….***

***•„Green fossils“ : peat, landfill gas….***

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### NON-Regular/Recovered FUELS BENEFITS: SUMMARY

- **Sustainable development=waste/energy minded**
- **EU <u>security of energy supply</u> improved**
- **EU <u>harmonized energy & environment goals</u>**
- **Private market forces, public control**
- **Local energy/labor needs - global benefits**
- **Fluidized Bed application on large scale**

### NON-Regular/Recovered FUELs FURTHER STEPS to SUCCESS

- **Harmonization between mixed and separatedwaste streams markets: more DATA**
- **Harmonization for waste definitions, recovery//disposal action: more DATA**
- **Harmonization of control monitoring (SRF/emissions control): more DATA**
- **Agreed quality classification of SRF, creation of credibility between producers/consumers; public/private; MSWI/industrial co-incinerators:more DATA**

## FUTURE MIX FUTURE MIX of of THERMAL ENERGY - THERMAL ENERGY - D: Annual Waste Waste-to-Energy is 101 million tpy /1200 kg

Abfallstatistiken 1996 und 1998/9 für Deutschland/Reimann

| **Übersicht** | | **Mio. Mg/a** | **Mio. Mg/a** |
|---|---|---|---|
| **Aufkommen von Primärabfällen (1996)**<br>verteilt auf:<br>Bauabfälle, Abbruch, Bodenaushub<br>Unbehandelte Bergmaterialen aus dem Bergbau<br>**Abfälle aus dem produzierenden Gewerbe/Industrie**<br>Siedlungsabfälle | | **335,954** | <br><br>176,582<br>67,814<br>56,948<br>~34,000 |
| **Siedlungsabfälle (1998/9)**<br>Einschl. ~10 Mio Mg/a hausmüllähnlicher Gewerbeabfall, Sperrmüll, Kehricht | Davon:<br>Abfallbeseitigung<br>Abfallverwertung | **44,008** | <br>24,678<br>19,330 |
| **Siedlungsabfall (1998/9) in öffentlicher Verantwortung**<br>(endienungspflichtig) | Davon:<br>Zur Verbrennung<br>Zur Deponierung | **24,678** | <br>11,000<br>13,678 |

## FUTURE MIX of THERMAL ENERGY

**A: but the 9,7 mio tpy contain environmentally relevant ingredient" !**

| Calorific value | Mass of Comb.<br>Wastes to recovery | Cl | Cd | Hg | Pb | Zn |
|---|---|---|---|---|---|---|
| | | To Recovery | | | | |
| MJ/kg | % | % | % | % | % | % |
| ➤ 5 | 80 | 100 | 98 | 82 | 97 | 95 |
| ➤ 8 | 77 | 97 | 95 | 74 | 92 | 89 |
| ➤ 11 | 54 | 59 | 51 | 23 | 38 | 55 |
| ➤ 14 | 42 | 48 | 48 | 22 | 36 | 49 |
| ➤ 17 | 13 | 40 | 38 | 8 | 11 | 30 |
| ➤ 21 | 8 | 16 | 19 | 5 | 7 | 29 |

## Stoffkonzentrationen in den brennbaren Abfällen/conc. in comb. wastes A

| | C | N | S | Cl | Pb | Zn | Cd | Hg |
|---|---|---|---|---|---|---|---|---|
| | [g/kg TS] | | | | | | [g/kg TS] | |
| Durchschnitt Abfälle/mean | 450 | 9,1 | 2,3 | 4,3 | 0,23 | 0,52 | 5,7 | 0,8 |
| Min. Konz. | 100 | 0,2 | 0,06 | 0,01 | >0,001 | 0,001 | 0,01 | 0,001 |
| Max. Konz. | 900 | 670 | 17 | 480 | 4 | 16 | 500 | 10 |
| Restmüll-MSW | 240 | 7 | 4 | 8,7 | 0,81 | 1,1 | 11 | 2 |

**MODERN WASTE INCINERATORS: MATERIAL FLOW MANAGMENT& HIGH SUBSTANCE CONCENTRATION EFFICIENCY& HIGH ENERGY RECOVERY**

- **-- HAZARDOUS SUBSTANCES**
- **CONCENTRATED**
- **-- PLANT FUNCTIONS AS SINK FOR**
- **HAZARDOUS SUBSTANCES**
- **-- CHP (combined heat & power)**
- **GUARANTEES HIGH ENERGY RECOVERY**

## Fuels investigated in the AE-Pilot Plants

- Waste wood
- Car shredder material (various sources)
- Bagasse (sugarcane etc.)
- Refuse derived fuel RDF
- Natural gas (start-up and auxiliary fuel)
- Chipboard waste
- Fibre sludge
- Fibre boards
- Fuel oil
- Industrial sewage sludge
- Municipal sewage sludge
- Lignite (Austrian origin)
- Concentrate from fibreboard production
- Petrol coke
- Coal dust (Lausitzer fine coal)
- Visbreaker residues
- Tetra Pack
- Wood chips
- Oil ashes
- Brown coal
- Waste tires (steel and textile cord)
- Rejects (various sources)
- Bark
- RDF
- Bituminous coal (Polish)
- Straw
- Residues from leather production
- Waste plastics (sorted)
- **Special applications**
- Regeneration of casting-sand
- Regeneration of contaminated
- soil- material (oil, cyanide)

## Fuels fired in the BBP - Commercial plants

- **Fossil Fuels:**
- Bituminous coal
- Brown coal
- Coal dust (undried &dried)
- Fuel oil (light, heavy)
- Lignite
- Natural gas
- Oil ashes
- Anthracite
- Pet coke
- **Renewable Fuels:**
- Bark
- Chicken droppings
- Straw
- Wood chips

- **Residues & Wastes:**
- Bagasse (sugarcane etc.)
- Various fibreboard wastes
- Garbage
- Ginding dust
- Industrial & Municipal sewage sludge
- Paper sludge
- Petrol coke
- Refuse derived fuel (RDF)
- Rejects (various sources)
- Residues from leather production
- Saw dust
- Waste plastics (sorted)
- Waste tires (steel and textile cord)
- Waste wood

## Our references

| | **BFB** | **FICB** | **CFB** |
|---|---|---|---|
| **No. of installations** | 26 | 5 | 43 |
| **Largest capacity (t/h)** | 70 | 80 | 400 |
| **Largest capacity (Mwe)** | 20 | 20 | 120 |
| **Countries** | A, S, GER, ROK, FIN, UK | A, CH, I, JP | A, CZ, GER, JP, ROK, PRC, RP, S, TH, US |

## Waste incineration plant PV-Lenzing:

•over 20,000 operating hours firing 100% waste fuels

•range of LHV: 6,5-31 MJ/kg, extremely high flexibility on various waste materials

•use of exhaust air (fibre production) for combustion

•extremely good emissions

•high thermal efficiency due to integration in energy supply system of Lenzig AG

## CFB plant RVL Lenzig (Austria)

**Steam data:** 129 t/h; barü, 500 degrees Celcius

**Main fuels:** packaging material, screen overflow, waste wood, rejects, sewage sludge

**Additional fuels:** bituminous coal, heavy fuel oil, natural gas

**Combustion air:** polluted with $H_2S$ and $CS_2$

| | **Guarantee values** |
|---|---|
| Max. continuous rating using residual matter | 110 MWth |
| Max. continuous rating using coal | 110 MWth |
| Max. continuous rating using residual matter | 55 MWth |
| Availability | 92% |
| Range of low heating powers | 6,5-31 MJ/kg |
| Emissions: ref. To 11% $O_2$ in the flue gas, dry | |
| CO | 45 mg/Nm3 |
| Corg | 5 mg/Nm3 |
| $SO_2$ (after flue gas cleaning) | 50 mg/Nm3 |
| Nox (after flue gas cleaning) | 70 mg/Nm3 |
| HCl (after flue gas cleaning) | 7 mg/Nm3 |
| PCDD (TE acc. To ITEFF), (after flue gas cleaning) | 0,1 ng/Nm3 |

## Selected BBP Fluidised Bed Reference Plants

SICET: 80 t/h, wood, bark

WESTFIELD: 47 t/h, chicken litter

FUNDER: 39 t/h, residuals, used wood, etc.

VERA: 3x11,2 t/h, sewage sludge

HAINDL: 80 t/h, residuals, waste wood, etc.

RENI: 18 t/h, sewage sludge, waste wood, etc.

## European Waste Forum - Brussels, 21 June 2001 Speech by Mrs M. Wallström/European Commissioner for the Environment

**"Future Directions for European Waste Policy"**

**ON WASTE MANAGEMENT HIERARCHY:**
**"Clearly, prevention, reuse, recycling and energy recovery have to serve the objectives of environmental protection and sustainability."**
**"hierarchy is not a bible…there may be a valid argument for some flexibility on a case-by-case basis"**
**"The key question is therefore where to draw the line between RECOVERY & DISPOSAL"**
**ON WASTE QUANTITITES, QUALITIES & TARGETS:**
**"we should therefore base targets first on a clear and transparent analyses that everybody can understand…"**
**waste quantities are not the *real* problem…it is the environmental impact"**
**ON SUSTAINABLE USE OF RESOURCES/SUSTAINABLE DEVELOPMENT**
**"We will not hesitate to propose legislation.This concerns in particular haz. substances in products"**
**ON DEFINITION OF WASTE/MARKETS FOR WASTE**
**"...env'l advantages can only be secured if the markets for secondary materials is stabilized and supported by clear targets" - "WASTE is not a good like any other"**
**ON ENVIRONMENTAL RULES AND STANDARDS**
**"our env'l rules and standards shoud continue to provide a stimulus for techno. Innovation"**
**"there needs to be a balance between…functioning of the market and the need for control"**

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## WASTE INCINERATION DIRETIVE 2000/76/EC
## Article 11: Measurement requirements

**2. The following measurements of air pollutants shall be carried out in accordance with Annex III at the incineration and co-incineration plant:**
**(a) continuous measurements of the following substances: NOx, provided that emission limit values are set, CO, total dust, TOC, HCl, HF, SO2;**
**(b) continuous measurements of the following process operation parameters: temperature near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority, concentration of oxygen, pressure, temperature and water vapour content of the exhaust gas;**
**(c) at least two measurements per year of heavy metals, dioxins and furans; one measurement at least every three months shall however be carried out for the first 12 months of operation. Member States may fix measurement periods where they have set emission limit values for polycyclic aromatic hydrocarbons or other pollutants.**

**6. Periodic measurements as laid down in § 2© of HCl, HF and SO2 instead of continuous measuring may be authorised in the permit by the competent authority in incineration or co-incineration plants, if the operator can prove that the emissions of those pollutants can under no circumstances be higher than the prescribed emission limit values.**

# MSW source separation and REF production – experiences

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## 1. Introduction

When part of MSW is processed to REF – recovered fuel, the aim is to obtain an advantage in energy production. This target is reached in two ways: For REF advanced combustion technology can be applied that makes it possible to reach low emissions at lower costs and, secondly, to achieve higher efficiency in electricity production.

MSW has traditionally been collected and handled in one mixed fraction, as there has been no incentive to separate different fractions, when MSW was dumped to a landfill or incinerated. However, the source-separation system and collection systems applied in Finland have a significant effect on the quality of the recovered energy fractions. Further, in REF production, most fuel properties of the recovered energy fraction can be improved.

As generally known, MSW comprises three main fractions: household waste, commercial waste from shops, offices and companies, and also process waste from small enterprises. In many countries, the process waste from small enterprises is included in MSW, 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. Figure 1 presents an estimate of the composition of the combustible part of the main waste fractions in the Helsinki area (Mäkinen et al. 2000:10).

Properties of these different fractions and possibilities to improve the dry fraction of household waste by applying different source-separation systems are discussed.

*Table 1. Properties of various REF fractions.*

| | | Commercial waste | Construction waste | Household waste |
|---|---|---|---|---|
| Combustible waste volume | t/a | 115 000 | 80 000 | 85 000 |
| Lower heating value as received | MJ/kg<br>MWh/t | 16–20<br>4.4–5.6 | 14–15<br>3.8–4.2 | 13–16<br>3.6–4.4 |
| Annual energy content | GWh/a | 530 | 285–315 | 360–440 |
| 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% | < 0.1–0.2 | <0.1 | 0.3–1.0 |
| Storage properties | wt% | good | good | good as pellets or baled |

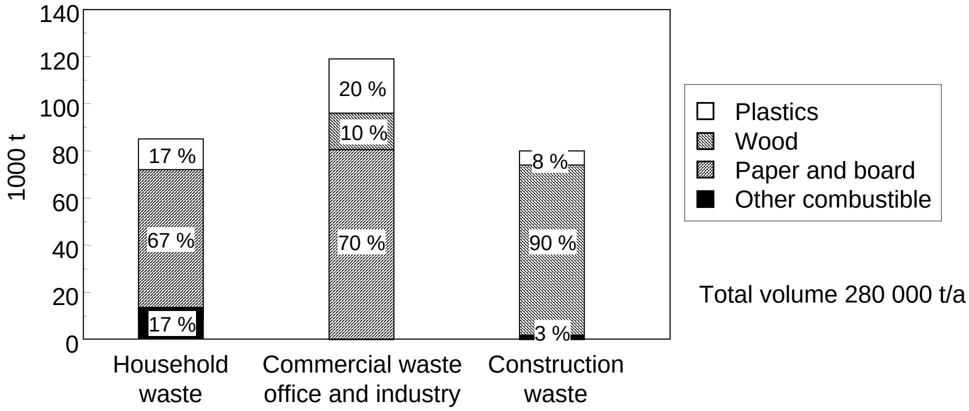

*Figure 1. Combustible waste fraction in Helsinki.*

# 2. Commercial waste

As all MSW was previously transported to landfills or mixed waste incinerators, commercial waste was collected together with household waste. However, the separate collection of this cleaner, in many ways higher-grade commercial waste, actually raw material, causes only a minor increase in collecting costs.

What makes commercial waste better? The greatest difference is the much lower content of PVC and NaCl. The chlorine content is 70–90% lower than that of the dry fraction of household waste. The reason for the low PVC content is that there is no point to use PVC in transportation packages. Fancy colours or easy printability are not needed in transport packages. There are only a few applications of PVC (tapes, labels, transparent hard plastic plates, etc.) that cause PVC waste in commercial waste stream but these can be eliminated.

It is also much easier to separate biowaste in companies than in homes. Consequently, commercial waste has normally no bad smell. Neither do metal and glass cause problems in this fraction.

Hence, the waste coming from shops, supermarkets, department stores, etc., is a good raw material for high-grade recovered fuels – REF. The waste from industrial companies is, of course, very different. Companies producing problematic waste streams are, however, fairly few and identifiable, and the problems associated with these wastes controllable. Difficulties with household waste are more diverse and concern the whole population.

All these aspects mean that a much better fuel can be produced from commercial waste than from household waste.

# 3. Construction waste

Construction waste is, in fact, not municipal solid waste, but in many cases, it is mixed with MSW. In Finland, we have a lot of wood construction and even 40–50% of combustible construction waste is as clean that it can be considered clean wood (untreated wood) and hence is beyond the scope of the waste incineration directive.

If construction waste is mixed with MSW, it deteriorates even mixed MSW. This is due to cables, plastic pipes, flooring materials, etc., which consist mostly of PVC. The metal and glass contents are also high.

High-grade REF can be produced from construction waste. When the waste is properly treated in a sorting plant, like that of L&T Oy in Kerava, Finland, the results of long-term analysis indicate that the quality of wood waste is good even for high efficiency power plants operating at high steam temperatures. For example, the chlorine content is around 0.1%.

# 4. Household waste

The problems in converting waste to energy are mostly related to household waste. It has a high chlorine content, in Finland about 1.0%, which can be reduced with a good source separation system. Its aluminium content is high, even 1%. It has also high moisture content, in ready-made REF 25–35%. The heavy metal content is usually high due to pigments and printings, and PVC (when the chlorine content is high, the content of heavy metals is also high). The worst disadvantages are the occupational problems. Waste workers exposure, for example, to microbes, dusts and VOC -compounds.

Technically, there is also a great difference in the fouling tendency of the boiler, when commercial/construction REF or household REF is burnt. Fouling of the heat exchange surfaces of the boiler results in high-temperature corrosion. These problems are caused by combination of chlorine, different alkali metals, aluminium, etc. in the REF.

Can the quality be improved by processing? According to everyday experience of household REF production in Finland and tests made by VTT, the quality can be improved. However, in most cases the quality of REF produced from household waste is not good enough to be used in high-efficiency power plants. The chlorine content can be reduced by processing, but not down to 0.1–0.2% required for use in normal power plants, for example, in co-combustion with biomass fuels. It is very likely that the household waste should be dried to be able to really improve the quality. This should make it possible to use PVC detectors and Eddy Currents to remove chlorine compounds and non-ferrous metals.

# 5. Alternatives of improving the quality of household waste by different source separation systems

Following results refer to a project called "Effect of source separation system on the quality of REF, trial runs at REF production plants" (Juvonen & Hyvönen, 2002). It is a comparative study of different source separation systems and the properties of recovered fuels carried out at VTT.

Co-combustion, gasification and REF boiler technology of recovered fuels is developed in Finland. The starting point was classifying of waste at source and processing of combustible waste fraction to homogeneous recovered fuel. Combustible waste includes sorted energy waste or dry waste recovered by sorting and screening other waste fractions from the waste batch. When energy waste is separately source separated, there is also a landfill waste fraction. An example of the composition of household waste in different sorting systems is presented in Table 2.

*Table 2. Composition of household waste in two different sorting systems.*

| **5-waste fraction separation "Energy waste"** | **wt%** | **5-fraction separation "Dry waste"** | **wt%** |
|---|---|---|---|
| Biowaste | 27 | Biowaste | 20 |
| Cardboard and paper package waste | 3 | Metals | 1 |
| Waste paper | 24 | Glass | 1 |
| Landfill waste | 32 | Waste paper | 29 |
| **Energy waste** | **14** | **Dry waste** | **49** |
| **Total** | 100 | **Total** | 100 |

The landfill waste fraction comprised 54 wt% of combustible waste and 46 wt% of other materials.

The compositions of energy and dry waste fractions are presented in Table 3. The results indicate that some consumers do not sort their household waste, although the real estate company had separate waste containers for different fractions. Unintentional wrong sorting of wastes also occurred. Especially the large amount of biowaste and other incombustibles among dry waste is worth of attention. Corresponding impurities were also found in separately sorted energy waste.

*Table 3. Compositions of energy waste and dry waste.*

| Material | Energy waste,wt% | Dry waste, wt% |
|---|---|---|
| Fibre products | 49 | 23 |
| Plastics | 35 | 15 |
| Wood | 4 | 4 |
| Other combustibles | 4 | 23 |
| Biowaste | 6 | 24 |
| Glass | 1 | 3 |
| Metals | 1 | 3 |
| Other impurities | – | 5 |
| Total | 100 | 100 |

Analytical results obtained for combustible fractions of energy waste and dry waste are presented in Table 4. Separate collection of energy waste improved the quality of recovered fuel, but it does not sufficiently consider the quality requirements of existing boiler plants. On the other hand, the fluidized-bed boilers especially designed for recovered fuels, and gasification technology tolerate better detrimental substances, and hence the quality of the recovered fuel produced from dry waste is sufficient for these.

Greater part of substances harmful in energy use (i.a., chlorine, metallic aluminium, heavy metals) originates from products and materials, and these substances are very difficult to separate at source. On the other hand, the amount of mechanical impurities (i.e., glass, metals, sand and stones, household appliances) can be reduced by source-separation.

*Table 4. Analytical results of combustible fractions of energy and dry wastes (fibres, plastics, wood and other combustibles). The content is given for dry matter.*

| **Element/Property** | **Unit** | **Dry waste** | **Energy waste** |
|---|---|---|---|
| Chlorine (Cl) | wt% | **1.03** | **0.65** |
| Sulphur (S) | wt% | **0.18** | **0.06** |
| Nitrogen (N) | wt% | **1.45** | **0.7** |
| Potassium (K) + sodium (Na) | wt% | **0.65** | **0.19** |
| Aluminium, metallic (Al) | wt% | **0.48** | **0.23** |
| Mercury (Hg) | mg/kg | **0.5** | **<0.1** |
| Cadmium (Cd) | mg/kg | **5.2** | **5.3** |
| The lower heat value as received, $Q_{net, ar}$ | MJ/kg | **15.24** | **15.11** |
| Moisture as received, $M_{ar}$ | wt% | **31.5** | **33.9** |
| Ash content, $A_d$ | wt% | **7.6** | **6.6** |

The quality of recovered fuel can be improved, at the cost of yield, by collecting energy waste separately. By collecting energy waste separately, 68% of household waste is recovered and 32% (more than half being combustible materials) is disposed to landfills.

Separate collection of energy waste has been the first step in starting the energy use of wastes in many localities. Energy waste, as well as dry waste, will be included in the Waste Incineration Directive. Furthermore, the possible prohibition of landfill disposal of combustible wastes will also involve a separate treatment of the landfill fraction as well. This is also included in the future restrictions concerning the disposal of biodegradable waste and untreated waste to landfills.

# 6. Conclusions

To achieve the highest energy efficiency and the lowest environmental investments, different fractions of MSW and also construction waste should be, at least in most cases, utilised separately.

Commercial waste is good raw material for high-grade recovered fuels – REF. It contains mainly plastics, dirty paper and cardboards, wood etc.

Construction waste is in many cases mixed for example with energy waste, which is coming from households. In Finland, we have a lot wood construction and even 40–50% of combustible construction waste can be considered as untreated wood.

The quality of REF produced from the energy fraction of household waste is superior to that produced from dry waste. However, the extensive and safe utilisation of both these fuels requires the control of fuel mixtures, volumes and quality, and special solutions for handling and combustion technologies. REF produced from energy waste increases the amount of landfill fraction strongly.

Source separation may reduce mechanical and occupational impurities in REF production, while it cannot reduce the contents of determinable elements in REF combustion technologies to any greater extent. In addition to waste containers, information services and waste fees that support separation are required to intensify source separation. It is also important to avoid mixing different fractions when the material is collected.

The quality waste can be improved but simultaneously the amount of landfill fraction increases strongly. Source separation of household is a good system only if it is possible to dispose the residual fraction to a landfill. Should also this fraction be recovered, there seems to be no point in separating two different fractions from dry household waste.

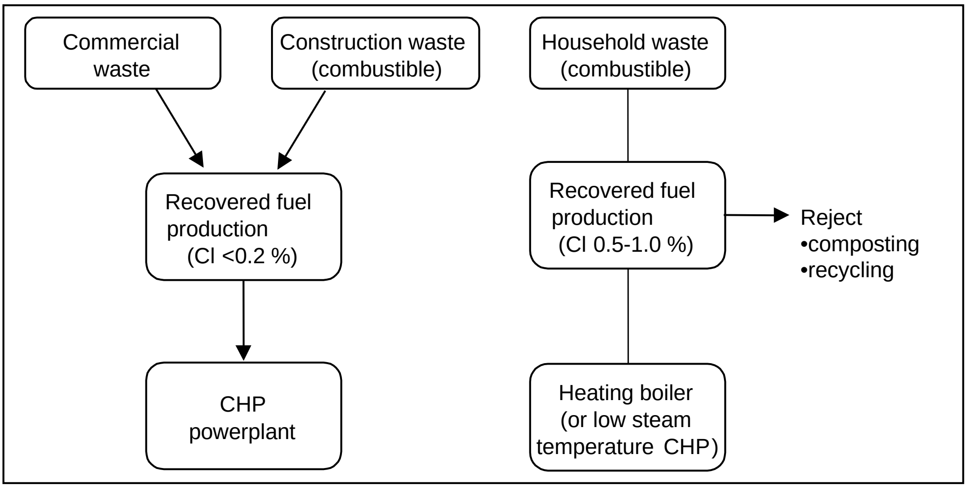

*Figure 2. MSW – waste to energy.*

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# Biomass CFB gasifier connected to a 50 MWth steam boiler fired with coal and natural gas - THERMIE demonstration project in Lahti, Finland

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## 1. Introduction

The Kymijärvi power plant represents the common power plant concept, i.e. the pulverized coal-fired steam boiler producing high-pressure steam for the steam turbine. These power plants are rather large and the steam cycles in the plants are quite efficient.

Biofuels as well as waste-derived fuels are local fuels. The energy density in fresh biofuel is only about 2.5 GJ/$m^3$ (in coal 30 GJ/$m^3$). Therefore, transporting of biofuels or REF from long distances is not an attractive option in an 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 are always much higher in small plants than in large plants. In addition, in small plants the power production efficiency is typically lower.

In Europe, it is typical that about 30–150 MW biofuel energy is available within 50 km from the power plant. This amount is possible to be gasified and utilized directly in the mid- 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 sources in energy production.

# 2. Atmospheric CFB gasification

The atmospheric CFB gasification system is very simple. The system consists of a reactor where the gasification takes place, of a uniflow cyclone to separate the circulating bed material from the gas and of a return pipe for returning the circulating material to the bottom part of the gasifier. All the components mentioned above are entirely refractory lined. Typically, after the uniflow cyclone hot product gas flows into the air preheater, which is located below the cyclone. The atmospheric CFB gasifier train is presented in Figure 3.

The gasification air, blown with the high-pressure air fan, is fed to the bottom of the reactor via an air distribution grid. When the gasification air enters into the gasifier below the solid bed, the gas velocity is high enough to fluidize the particles in the bed. At this stage, the bed expands and all particles are in rapid movement. The gas velocity is so high, that a lot of particles are conveyed out from the reactor into the uniflow cyclone. The fuel is fed into the lower part of the gasifier above a certain distance from the air distribution grid. The incoming biofuel contains 20–60% water, 78–39% combustibles and 1–2% ash.

The operating temperature in the reactor is typically 800–1000 °C depending on the fuel and the application. When entering the reactor, the biofuel particles start to dry rapidly and the first primary stage of reaction, namely, pyrolysis occurs. During this reaction fuel converts to gases, charcoal and tars. Part of the charcoal goes to the bottom of the bed and is oxidized to CO and $CO_2$ generating heat. After this, as these aforementioned products flow upwards in the reactor, the secondary stage of reactions take place, which can be divided into heterogenous reactions, where charcoal is one ingredient in the reactions, and homogenous reactions, where all the reacting components are in the gas phase. Due to these reactions among with other reactions combustible gas is produced, which enters the uniflow cyclone and escapes the system together with some of fine dust. Most of the solids in the system are separated in the cyclone and returned to the lower part of the gasifier reactor. These solids contain charcoal, which is combusted with the air that is introduced through the grid nozzles to fluidize the bed. This combustion process generates the heat required for the pyrolysis process and subsequent mostly endothermic reactions. The circulating bed material serves as heat carrier and stabilizes the temperatures in the process.

The heat energy in the gas is in three forms: as chemical heat (combustion), as sensible heat (hot gas) and as carbon dust (combustion). In the normal operation, the fuel feed rate defines the capacity of the gasifier and the air feed rate controls the temperature in the gasifier. Coarse ash is accumulated in the gasifier and is removed from the bottom of the gasifier with a water-cooled bottom ash screw.

The first commercial gasifier application supplied by Foster Wheeler Energia Oy has replaced fuel oil in the lime kiln since 1983 at Wisaforest Oy, Jakobstad, Finland. Since then, similar gasification plants of the same basic technology have been installed at two pulp mills in Sweden and at one mill in Portugal. These gasifiers produce lime kiln fuel from bark and waste wood, and they also utilize a part of gas generated in drying plants.

# 3. Kymijärvi power station

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$^{o}$C/40 bar, and the plant produces electric power for the owners, and district heat for the Lahti city. The maximum power capacity is 167 MWe and the maximum district heat production is 240 MW.

The operating hours of the boiler total 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 operated at low capacity, with natural gas as the sole fuel.

In 1986, the plant was furnished with a gas turbine connected to the heat exchanger preheating the boiler feed water. The maximum energy output of the gas turbine is 49 MWe, when the outside temperature is –25°C.The boiler uses about 1,200 GWh/a (180,000 ton/a) coal and about 800 GWh of natural gas. The boiler is not equipped with a sulphur removal system. However, the coal utilized contains only 0.3–0.5% sulphur. The burners are provided with flue gas circulation and staged combustion to reduce $NO_x$ emissions.

# 4. Kymijärvi gasification plant

## 4.1 Gasifier fuels

As stated previously in this paper, it has been evaluated that presently about 300 GWh/a of different types of biofuels and refuse fuels are available in the Lahti area. On an annual basis, the available amount of biofuels and refuse fuels is enough to substitute for about 15% of the fuels burned in the main boiler equaling max 30% of coal. Table 1 presents a summary of the available biofuels.

*Table 1. The available local fuels on annual basis in the Lahti area.*

| Fuel | Amount, wt% of total | Moisture, wt% |
|---|---|---|
| Sawdust | 10 | 45–55 |
| Wood residues (bark, wood chips, wet and fresh wood residues) | 40 | 45–55 |
| Dry wood residues from the wood-processing industry (plywood, particle board, cuttings, etc.) | 30 | 10–20 |
| Recycled fuel (REF) | 20 | 10–30 |

The recycled fuel, REF, is produced from refuses classified at source, i.e., in households, offices, shops and construction sites. A municipally owned waste management company (Päijät-Hämeen Jätehuolto Oy) started processing of REF in 1997. Besides the fuels listed in Table 1, peat, demolition wood waste and shredded tires are also used as fuels in the gasification plant.

Table 2 presents the REF composition.

*Table 2. The composition of the recycled fuel (REF).*

| Component | wt% |
|---|---|
| Plastics | 5–15 |
| Paper | 20–40 |
| Cardboard | 10–30 |
| Wood | 30–60 |

## 4.2 Fuel handling

Fuels are transported to the power plant by trucks. There is one receiving hall for REF and one receiving station for incoming biofuels. The REF hall is equipped with a receiving pit having a lamella feeder. The lamella feeder controls the flow to a crusher. Coarse biofuel, which is originates mainly from the woodworking industry, is also fed in through the REF system. The trucks tip the REF and coarse biofuels on the floor of the hall or directly into the pit. The REF and coarse biofuel are crushed in a slowly rotating crusher. The underground conveyor from the first receiving bunker transports the REF and the biofuels from the crusher further.

The other receiving station is made for finer biofuel and peat. This biofuel is transported to the site by special trucks. The transport platforms of the trucks are furnished with conveyors. These conveyors discharge the biofuel and peat from the trucks and the fuels fall through a screen down onto a chain conveyor at the bottom of the bunker. This conveyor is underground. The coarser particles separated by the screen are moved to REF hall for crushing.

The underground conveyor lifts the fuels to a belt conveyor, which has a magnet separator above it. The belt conveyor transports the fuels onto a disk screen. The coarse fuel fractions from the disk screen fall into the final crusher. The fine fractions from the screen and the crushed biofuel are transported with the conveyor to two fuel storage silos.

The gasification plant is furnished with one storage silo for fuels. Besides as a storage silo, this silo is used for homogenization of the fuel mixture before it is transported into the gasification building. The discharger of the silo has variable speed controls. The biofuel handling process is an important and innovative step in this gasification process (Figures 1 and 2).

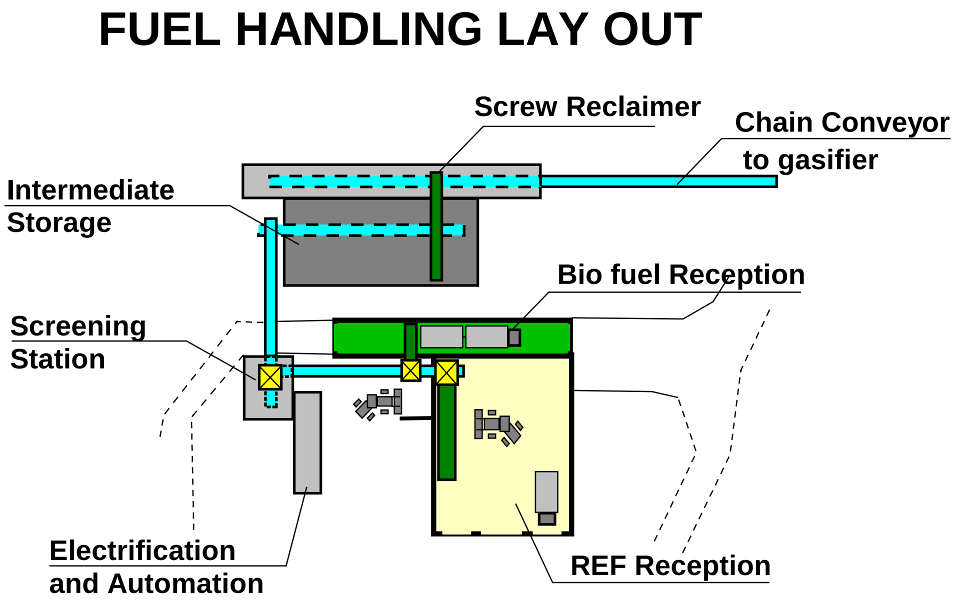

*Figure 1. Fuel reception.*

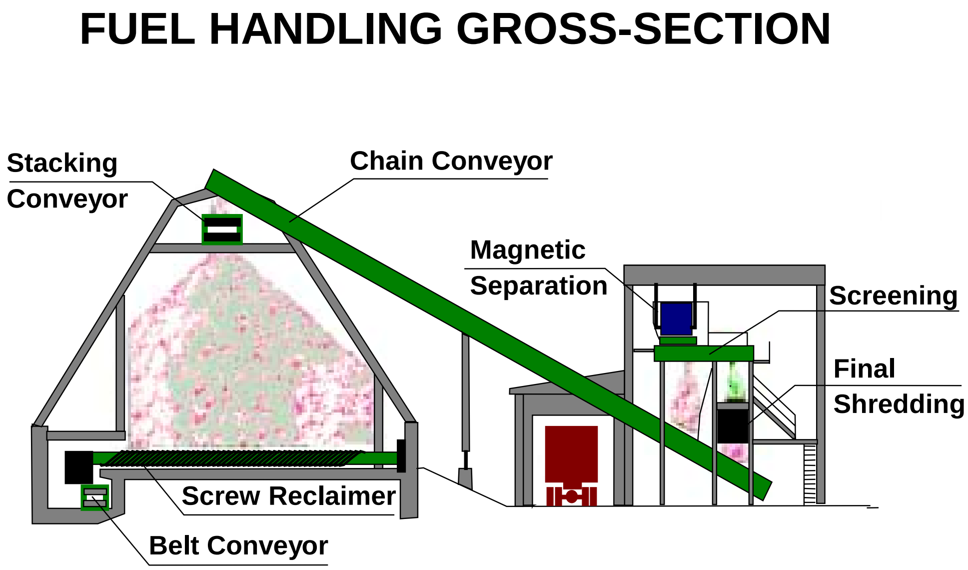

*Figure 2. Intermediate storage.*

## 4.3 Gasifier concept

The CFB gasifier consists of an inside refractory-lined steel vessel, where fuel is gasified in a hot fluidized gas-solid particle suspension. In the gasifier, biofuels and REF are converted to combustible gas at atmospheric pressure and at the temperature of about 850°C. The hot gas flowing through the uniflow cyclone is cooled down in an air preheater before feeding into the main boiler. Simultaneously, the gasification air is heated up in the air preheater before feeding it into the gasifier (Figures 3 and 4).

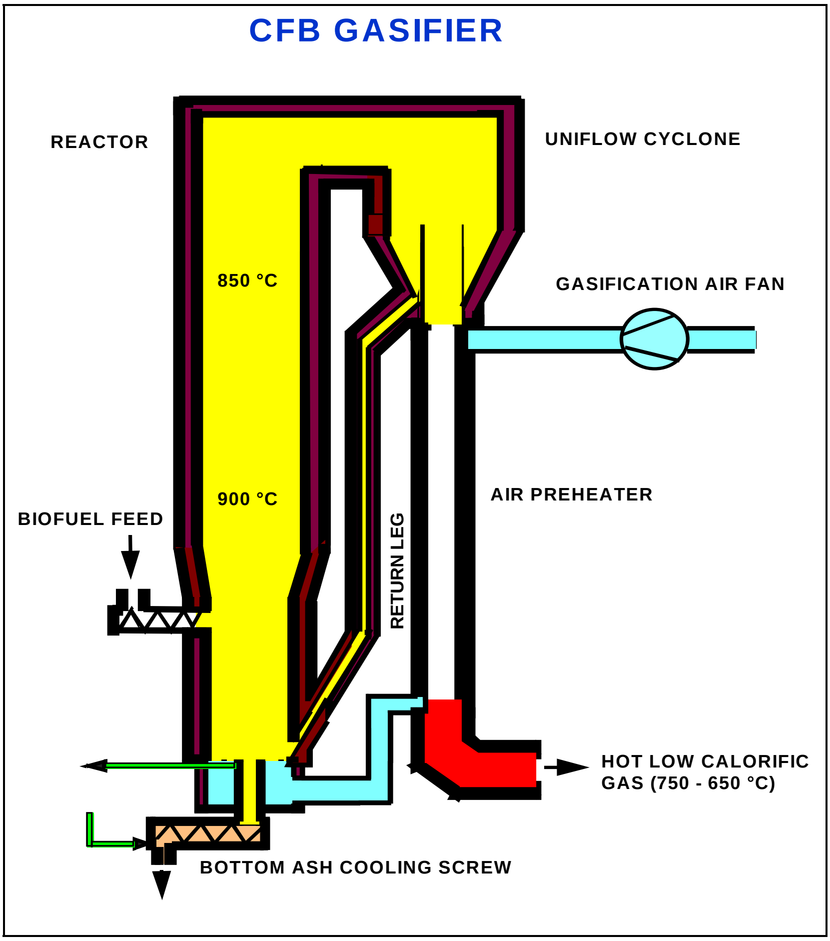

*Figure 3. Foster Wheeler Energia Oy CFB gasifier.*

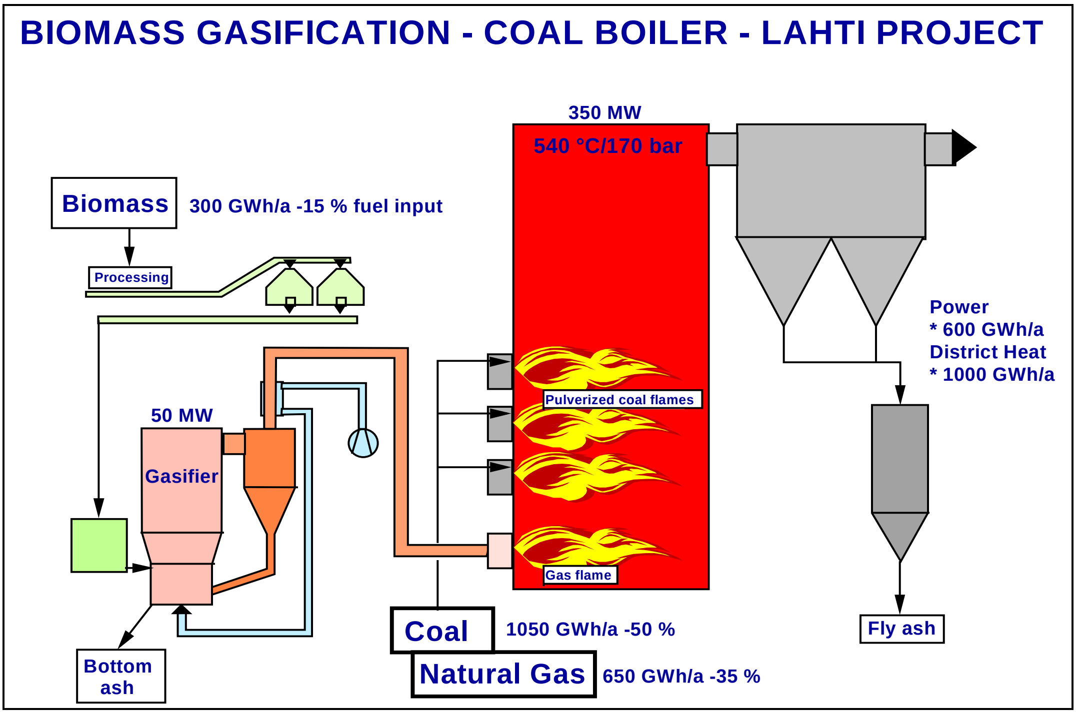

*Figure 4. Lahden Lämpövoima Oy biofuel gasifier connected to pulverized coal-fired boiler.*

From the process point of view, the major difference compared to the gasifiers supplied in the mid-1980s is that the fuel is not dried in this application, but the moisture content of fuel can be up to 60%. However, no considerable changes have been made in the design of the gasifier, the air preheater and the gas pipe line, but the design is heavily based on that of those commercial-scale atmospheric biomass gasifiers supplied by FWE Oy in the mid-1980s. From the mechanical and the piece of equipment point of view some changes compared to the standard atmospheric biomass gasifiers have been made. This is due to the special nature of some of the fuel components to be used in the gasifier. For example, fuels like REF, some wood wastes and shredded tires contain different types of solid impurities (nails, screws, metal wires, concrete), due to which, e.g., the air distribution grid and the bottom ash extraction system have been designed in a different way compared to the standard design.

As regards the product gas combustion, the hot gas 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 used in boiler. 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 appr. 2.2 MJ/kg. The design of the product gas burners is unique and heavily based on both the pilot scale combustion tests and the CFD modelling work.

The process scheme of the concept is presented in Figure 4 and the gasifier lay-out in Figure 5.

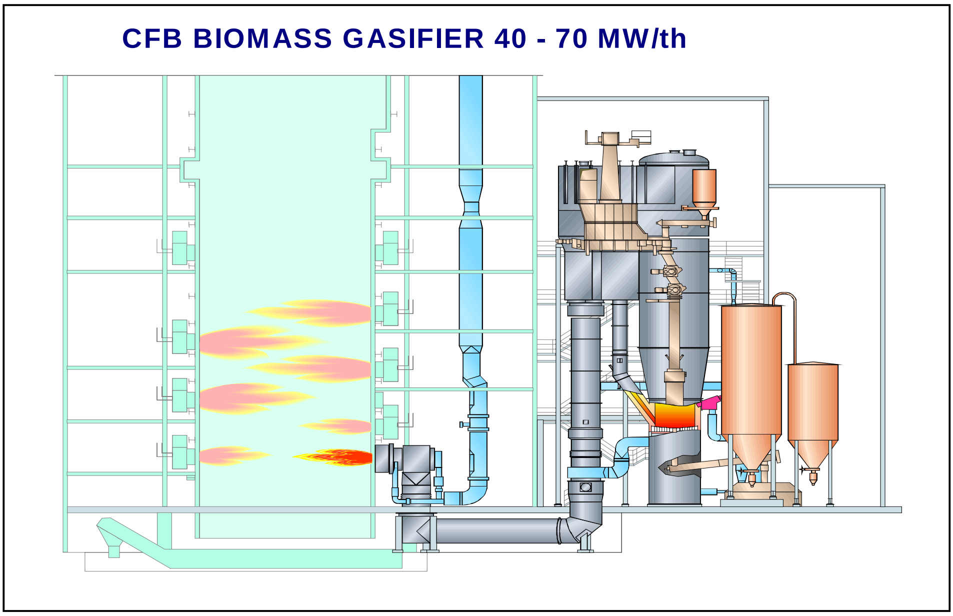

*Figure 5. CFB biomass gasifier of 40–70 MW.*

# 5. Operating experiences

The gasifier was connected to the main boiler on 7 December 1997, and after the refractory lining warm-up the first combustion tests with solid fuel were performed on 9 January 1998. The very first gasification tests were carried out on 14 January 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 into operation only in the beginning of September and the gasification plant two weeks later, i.e., 21 September 1998. During the first operating year, about 4 730 hours of operation in the gasification mode were achieved and the availability of the gasification plant was more than 81 per cent. There has been no shutdawn of the main boiler due to the gasifier in the whole operation time of the gasifier.

In the beginning the gasifier fuel consisted mainly of biofuels like bark, wood chips, sawdust and non-contaminated wood waste. Later on, other fuels have also been used. A collection system of combustible, source-classified refuses (REF) has been started in Lahti area. However, the amounts of collected REF have so far been lower than the REF gasification capacity of the gasifier. It is expected, that in the future the amounts will increase and also the quality of REF will improve. In addition to the fuels mentioned above, railway sleepers (chipped on site) and shredded tires have also been used as fuel in the gasifier. In Table 3, a summary of the operation during the first operation year is presented, and in Figure 6, the distribution of the fuel in the years 1998–2000 is shown.

The emission measurements were carried out according to the programme by the test run period 1998. On the basis of these measurements, the final permission to use waste materials as fuel was given.

*Table 3. Summary of operation in the year of 1998.*

| **Summary of the operation 1998** | |
|---|---|
| | |
| **Commissioning** | **7.1.1998** |
| **First time gasification mode** | **14.1.1998** |
| **Pure wood fuel** | **14.1.-28.2.98** |
| **Testrun with REF fuel** | **1.3.-2.6.98** |
| **Testrun with tyres** | **16.3.-29.4.98** |
| **Testrun with railway sleepers** | **1.3.-2.6.98** |
| **Emission measurement I** | **27.-29.4.98** |
| **Emission measurement II** | **26.-27.5.98** |
| **Shut-dawn of the main prosess** | **3.6.-13.9.98** |
| **The final permission** | **16.9.1998** |
| **Commercial working of the gasifier** | **21.9.-31.12.98** |
| | |
| **The total operation time** | **4736** |
| **The calender time** | **5793** |
| **The availability of the gasfier** | **81,8** |
| | |
| **Some reasons for the disturbances** | |
| **- fault in fuel reception** | |
| **- fault in fuel feeding** | |
| **- lack of fuel** | |
| **- fuel quality, chip size, moisture** | |
| **- blockage in ash outlet** | |
| **- fault in automation or elektrification** | |

The dust content of flue gas after the ESP decreased by 10–20 mg/m$^3$n. 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 by about 10 mg/MJ, equalling a decrease of 5 to 10% from the base level. Furthermore, because of the extremely low sulphur content of biofuels, the SO$_x$ emission of the main boiler decreased by 20–25 mg/MJ. However, due to the very low chlorine content (0.01%) of the main boiler coal, the HCl content of flue gas increased by about 5 mg/MJ when the gasifier was in operation. The reason for this was the use of REF fuel and shredded tires in the gasifier. Both these fuels are known to contain chlorine. As regards the CO emission of the main boiler, no changes were seen.

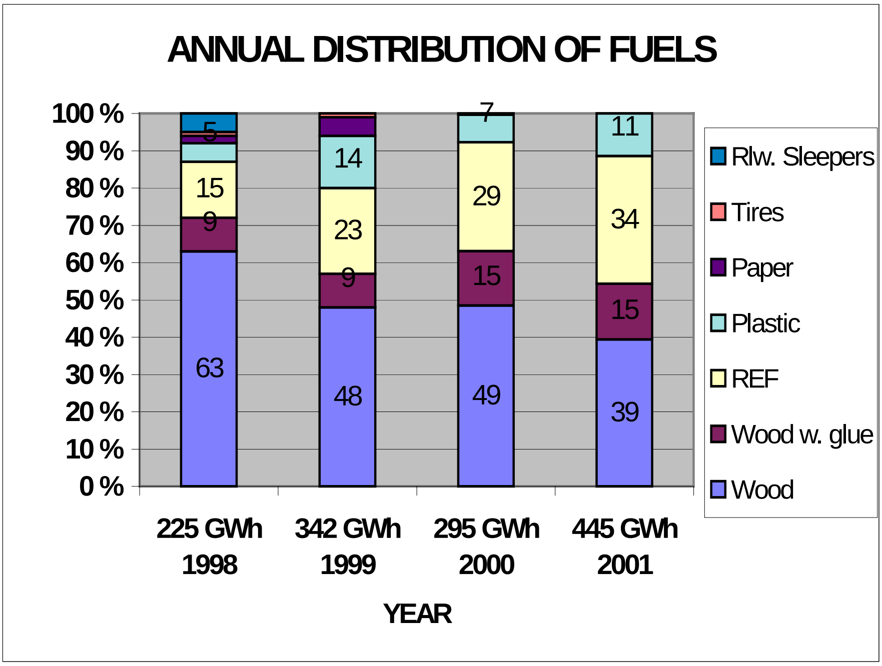

*Figure 6. The fuel distribution in the years 1998–2001.*

As regards heavy metal stack emissions, a slight increase in some elements was seen, but because of the very low base levels in coal combustion, the changes measured were in practice very small. Furthermore, changes in the filter ash quality of the main boiler were small. Increases in some elements were seen, but because the share of gasifier fly ash in the total filter ash of the main boiler is small, only 3–5%, it is obvious that the effect of gasifier fly ash on the filter ash quality of the main boiler is small.

As regards dioxins, furans, polyaromated hydrocarbons, chlorinated phenols and chlorinated benzenes, no changes were seen compared to the results of coal combustion (Table 4).

*Table 4. The effect of gasifier on the main boiler emissions.*

| Emission | Change caused by the 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 | “ |

* Low-chlorine coal in main boiler and REF + shredded tires used in gasifier.

Concerning the monitoring of possible deposit formation and corrosion in the main boiler, reference probe tests were carried out by Foster Wheeler Energy Oy’s Karhula R&D. No corrosion was found. The whole superheater area was inspected in detail during the summer maintenance, and no abnormal deposit formation or erosion / corrosion was found.

# 6. Conclusions

Today, technologies employing biofuels in the heat and power production are of great interest. Biofuels have many environmental benefits compared to fossil fuels: utilization of biofuels is one solution to reduce $CO_2$ emissions in the power production. The growth of biofuel binds $CO_2$ from the atmosphere. The sulphur and nitrogen contents of biofuels are low. This involves low $SO_x$ and $NO_x$ emissions. Part of recycled wastes is suitable only for energy recycling. When the waste contains mainly paper, wood, cardboard and plastics, these recycled fuels have the same nature as fresh biofuels. This is a way to reduce the need for dumping grounds.

However, due to the low bulk density, the feasible transport distance for biofuels is typically only 30–80 km. This means that the amount of available biofuels within this range is limited. The power plant based on the utilization of biofuels only will be small, i.e., the construction of new biofuel-based power plants is an expensive solution. Instead, the concept of this project offers an attractive solution for the use of different types of biomass and recycled refuse in the heat and power production. This gasification project at Lahden Lämpövoima Oy's Kymijärvi power plant demonstrates direct gasification of wet biofuel in an atmospheric CFB gasifier and the co-firing of hot, raw and very low-calorific gas directly in an existing coal-fired boiler.

This concept offers an efficient way to utilize biofuels and recycled refuse fuels, low investment and operation costs, and utilization of the existing power plant capacity. Furthermore, only small modifications are required in the boiler and possible disturbances in the gasifier do not shut down the whole power plant.

The total costs of this project, including fuel preparation, civil works, instrumentations and control as well as eletrification, are about € 12 million. This project has received a support of € 3 million from the THERMIE Programme.

# Gasification of waste-derived fuels – R&D activities at VTT

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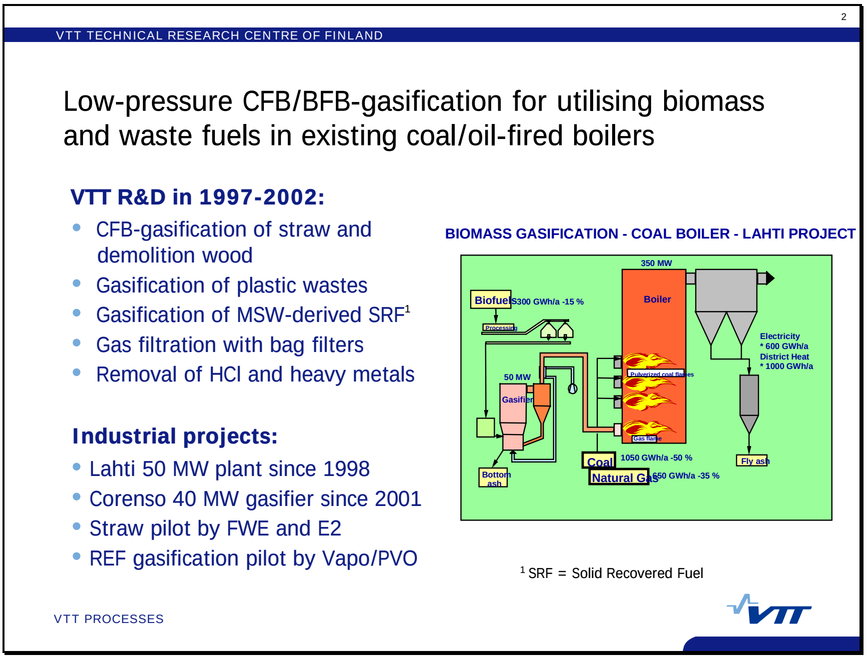
Espoo, Finland



## Low-pressure CFB/BFB-gasification for utilising biomass and waste fuels in existing coal/oil-fired boilers

**VTT R&D in 1997-2002:**

- CFB-gasification of straw and demolition wood
- Gasification of plastic wastes
- Gasification of MSW-derived SRF[1]
- Gas filtration with bag filters
- Removal of HCl and heavy metals

**Industrial projects:**

- Lahti 50 MW plant since 1998
- Corenso 40 MW gasifier since 2001
- Straw pilot by FWE and E2
- REF gasification pilot by Vapo/PVO

BIOMASS GASIFICATION - COAL BOILER - LAHTI PROJECT

[1] SRF = Solid Recovered Fuel

# Why gasification of waste-derived fuels ?

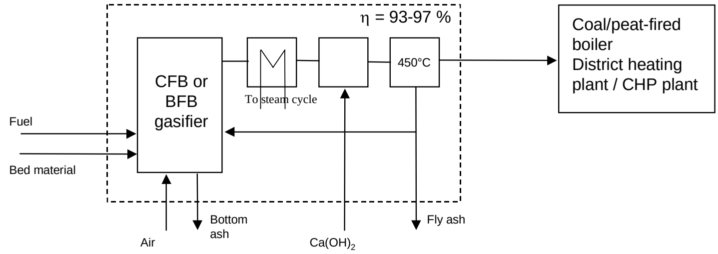
- Makes it possible to use waste-derived fuels and biomass residues also in pulverised coal-fired boilers
- High power to heat ratio due to large-scale power plant technology (compared to small-scale biomass plants)
- Investments only to gasification and gas cleaning
- Effective emission control:
    - no dioxin formation in reducing atmosphere of gasifiers
    - 90...99 % of chlorine is removed before gas combustion
    - heavy metals are removed before gas combustion
    - effective flue gas cleaning after large-scale boiler
- Clean waste-derived gas is comparable to biomass fuels
- Waste ash is not mixed with the coal ash of the main boiler

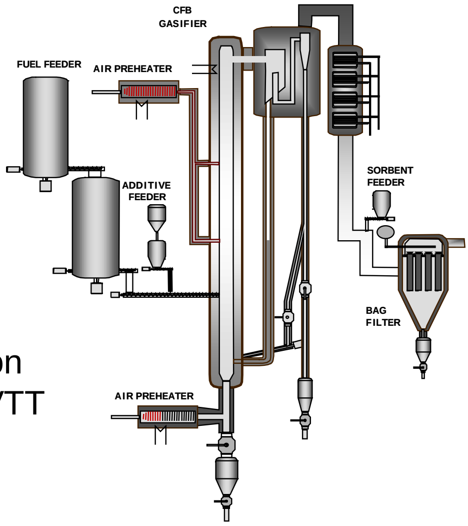
---

# Co-firing concept based on atmospheric-pressure CFB/BFB gasification

- suitable size range: 20 - 100 $MW_{fuel}$

*Basic case:* DRY CLEANING AND CHLORINE REMOVAL





## PDU-scale CFB gasification test facility of VTT

(since 1996)

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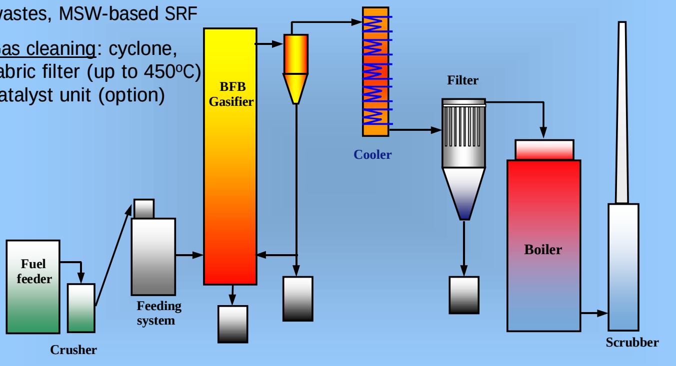
## Fluidised-Bed Gasification Pilot-plant (since 2001)

Thermal capacity: 1 MW
Fuels tested: wood wastes, MSW-based SRF

Gas cleaning: cyclone, fabric filter (up to 450ºC) catalyst unit (option)



# Feedstocks used in the low-pressure fluidised-bed gasification test campaigns in 1997-2002

- *Biomass residues:*
  - saw dust
  - different forest residues
  - wood pellets
  - wheat straws
  - pine & spruce bark
  - (over 20 types of different biomass residues have been characterised in bench-scale reactors)
- *Waste-derived fuels:*
  - demolition wood (CFB)
  - pelletised REF III (CFB)
  - loose crushed MSW-based SRF (CFB and BFB)
  - mixtures of wood and sewage sludge-fuels (CFB and BFB)
  - aluminium-containing industrial plastic reject (CFB and BFB)
  - de-inking sludges
  - other industrial wastes (incl. different plastics)

**=> knowledge to design and operate fluid-bed gasifiers with fuels having different gasification behaviour**

---

# Extended-time CFB-gasification test with 70 % Ewapower SRF + 30 % Wood

| Operation conditions: | |
|---|---|
| - gasifier temperature | 890 °C |
| - air ratio | 0.25 |
| - filter temperature | 395 °C |
| - $Ca(OH)_2$ injection | |
| Carbon conversion -to gas + tars | 97.2 % |
| Tars and benzene | 33 g/m³n |

| | **vol-%** |
|---|---|
| **CO** | **10.6** |
| **$CO_2$** | **14.5** |
| **$H_2$** | **9.8** |
| **$CH_4$** | **4.8** |
| **$C_2H_2$** | **0.55** |
| **$C_2H_4$** | **2.60** |
| **$C_2H_6$** | **0.04** |
| **$C_3$-$C_5H_x$** | **0.06** |
| **$N_2$** | **55.9** |

| | **vol-ppm** |
|---|---|
| **$NH_3$** | **2300** |
| **HCN** | **92** |

## Example of the cleaned waste-derived product gas:

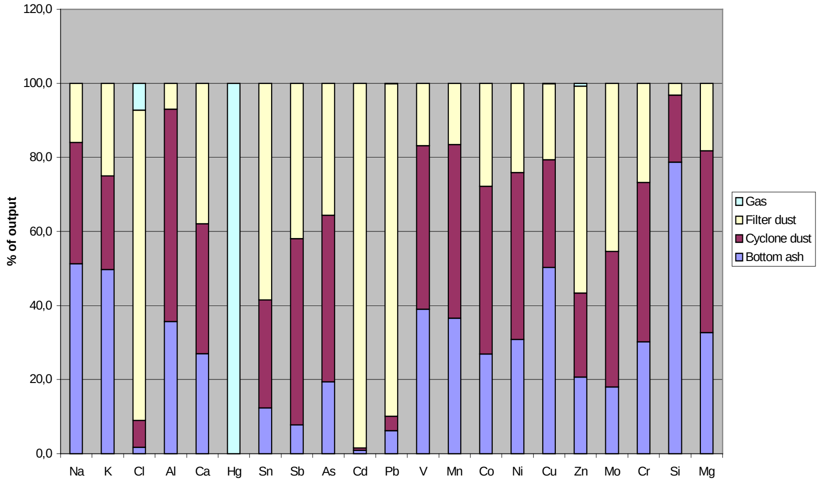
- SRF pellets + 30 % wood
- Ca(OH)$_2$-injection
- gas filtration at 395 °C
- emission measurements after filter
- good material balance closure

**Feesdtock**

| | |
|---|---|
| Moisture | 5.5 % |
| Ash | 8.7 % |
| Chlorine | 4130 ppm-m |
| Sodium | 2490 ppm-m |
| Potassium | 1800 ppm-m |
| Aluminium | 9400 ppm-m |

| | Vapour |
|---|---|
| | phase |
| **Na, ppm(m)** | 0,0 |
| **K, ppm(m)** | 0,0 |
| **Cl, ppm(m)** | **109,0** |
| **Al, ppm(m)** | 0,0 |
| **Ca, ppm (m)** | 0,0 |
| **Hg, ppm(m)** | **0,025** |
| **Sn, ppm(m)** | 0,0 |
| **Sb, ppm(m)** | 0,0 |
| **As, ppm(m)** | 0,0 |
| **Cd, ppm(m)** | 0,0 |
| **Pb, ppm(m)** | **0,024** |
| **V, ppm(m)** | 0,0 |
| **Mn, ppm(m)** | 0,0 |
| **Co, ppm(m)** | 0,0 |
| **Ni, ppm(m)** | 0,0 |
| **Cu, ppm(m)** | **0,11** |
| **Zn, ppm(m)** | **0,51** |
| **Mo, ppm(m)** | 0,0 |
| **Cr, ppm(m)** | 0,0 |
| **Si, ppm(m)** | 0,0 |
| **Mg, ppm(m)** | 0,0 |

## Fate of chlorine and trace metals in CFB gasification of SRF



Results from 1999 test run with
REF from Ewapower

## Estimation of the effects of co-combustion of SRF-derived gas in boilers

- Composition of the SRF-derived gas from the measurements of the CFB test runs carried out with Ewapower SRF pellets
- 40 MW and 80 MW gasifier capacity
- 300 $MW_{th}$ coal-fired boiler and 150 $MW_{th}$ peat-fired boiler
- two different coals (“normal” and “low S + low Cl”)
- Flue gas cleaning after the boiler by ESP or by ESP and wet deSOx
- Flue gas cleaning efficiency was taken from published literature
- Examples of the results in the following slides

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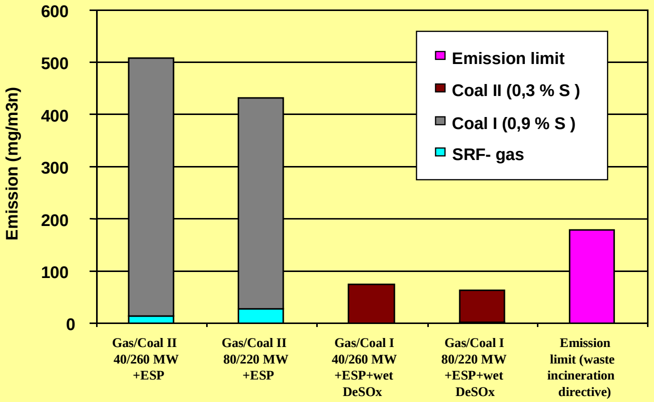
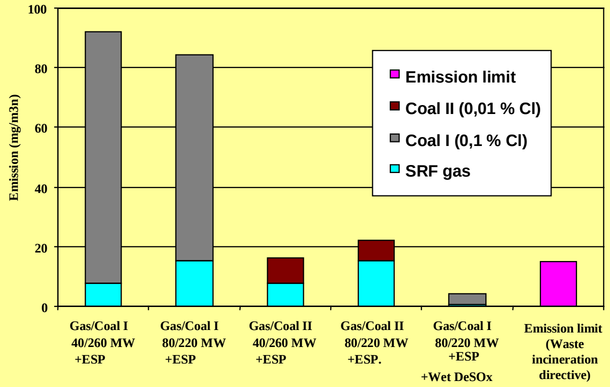
## Effect of SRF derived gas co-combustion on $SO_2$ emissions ($300\ MW_{th}$ coal fired power plant)



## Effect of SRF derived gas co-combustion on HCl emissions (300 MW$_{th}$ coal fired power plant)



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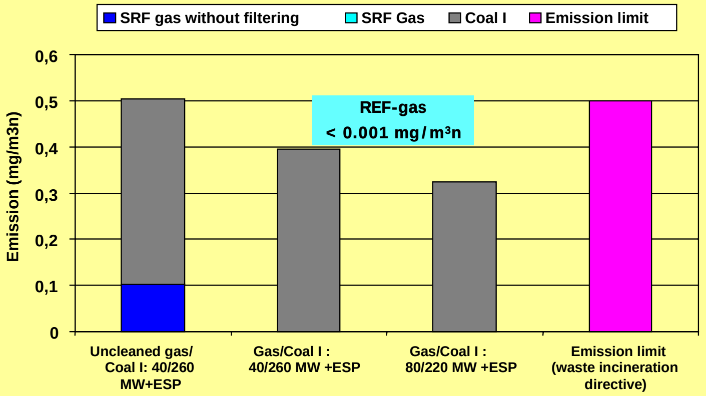
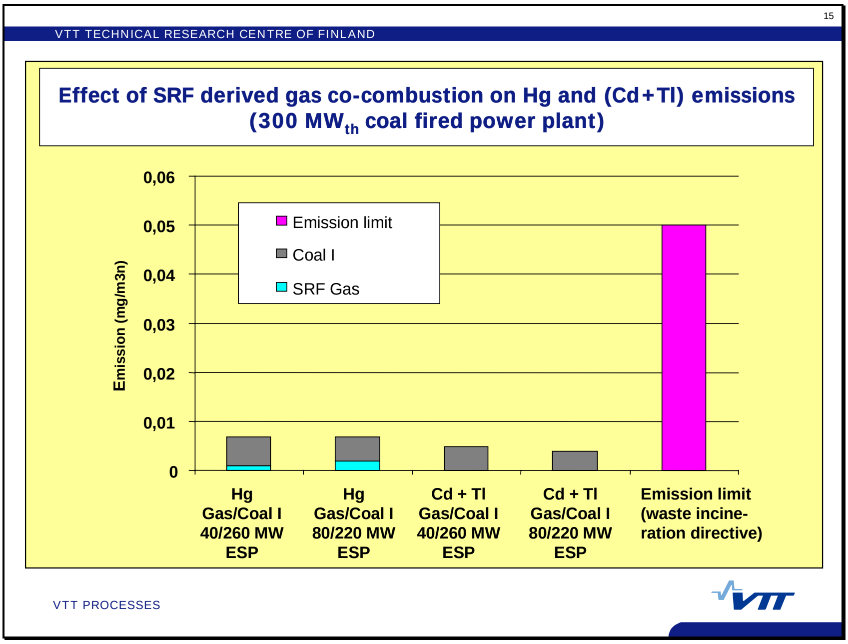
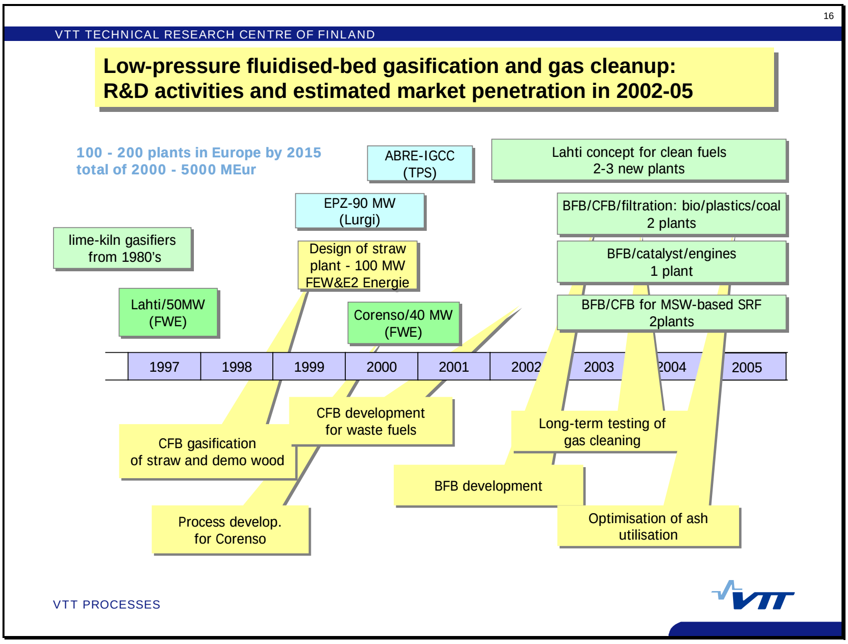
## Effect of SRF derived gas co-combustion on As+Pb+Mn+Ni+Cr+Cu+Co+V+Sb emissions

(300 MW$_{th}$ coal fired power plant)





## Effect of SRF derived gas co-combustion on Hg and (Cd+Tl) emissions (300 $MW_{th}$ coal fired power plant)



## Low-pressure fluidised-bed gasification and gas cleanup: R&D activities and estimated market penetration in 2002-05

100 - 200 plants in Europe by 2015
total of 2000 - 5000 MEur

ABRE-IGCC (TPS)

Lahti concept for clean fuels
2-3 new plants

EPZ-90 MW (Lurgi)

BFB/CFB/filtration: bio/plastics/coal
2 plants

lime-kiln gasifiers from 1980's

Design of straw plant - 100 MW FEW&E2 Energie

BFB/catalyst/engines
1 plant

Lahti/50MW (FWE)

Corenso/40 MW (FWE)

BFB/CFB for MSW-based SRF
2plants

CFB development for waste fuels

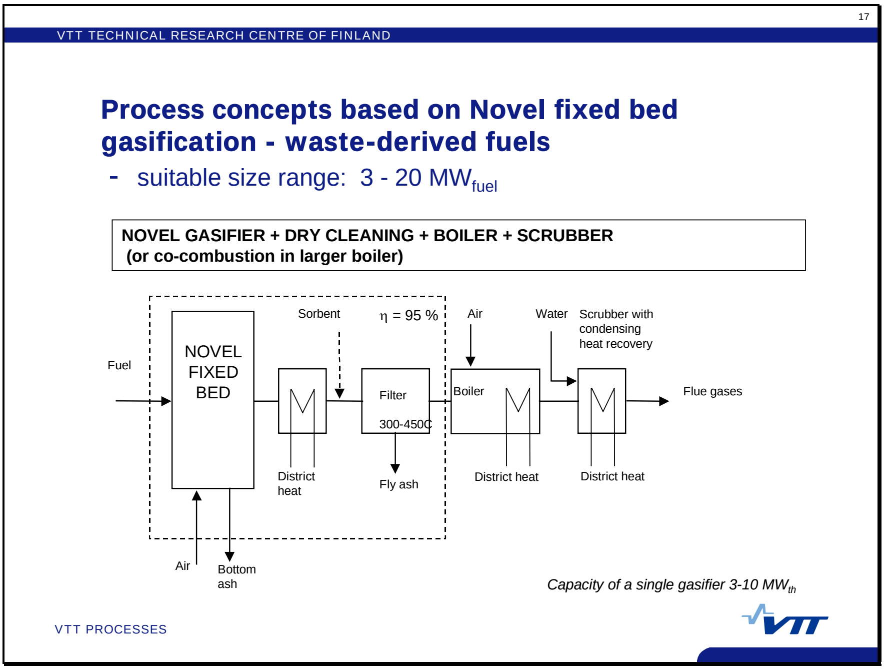
Long-term testing of gas cleaning

CFB gasification of straw and demo wood

BFB development

Process develop. for Corenso

Optimisation of ash utilisation



VTT TECHNICAL RESEARCH CENTRE OF FINLAND

## Process concepts based on Novel fixed bed gasification - waste-derived fuels

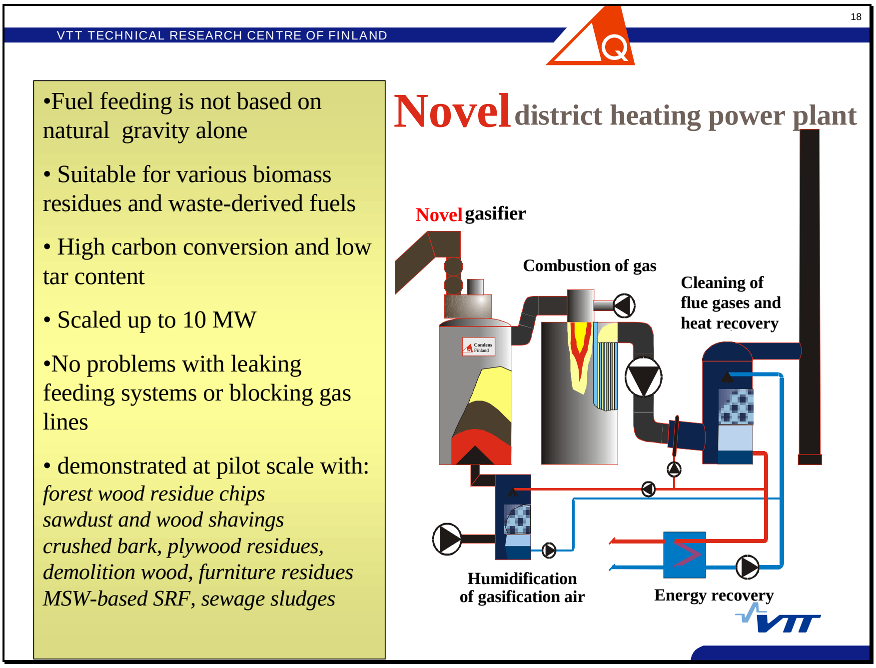
- suitable size range: 3 - 20 $MW_{fuel}$

**NOVEL GASIFIER + DRY CLEANING + BOILER + SCRUBBER**
**(or co-combustion in larger boiler)**

Fuel
NOVEL FIXED BED
Air
Bottom ash
Sorbent
$\eta$ = 95 %
District heat
Filter
300-450C
Fly ash
Air
Boiler
District heat
Water
Scrubber with condensing heat recovery
District heat
Flue gases

*Capacity of a single gasifier 3-10 $MW_{th}$*

VTT PROCESSES



VTT TECHNICAL RESEARCH CENTRE OF FINLAND

•Fuel feeding is not based on natural gravity alone

• Suitable for various biomass residues and waste-derived fuels

• High carbon conversion and low tar content

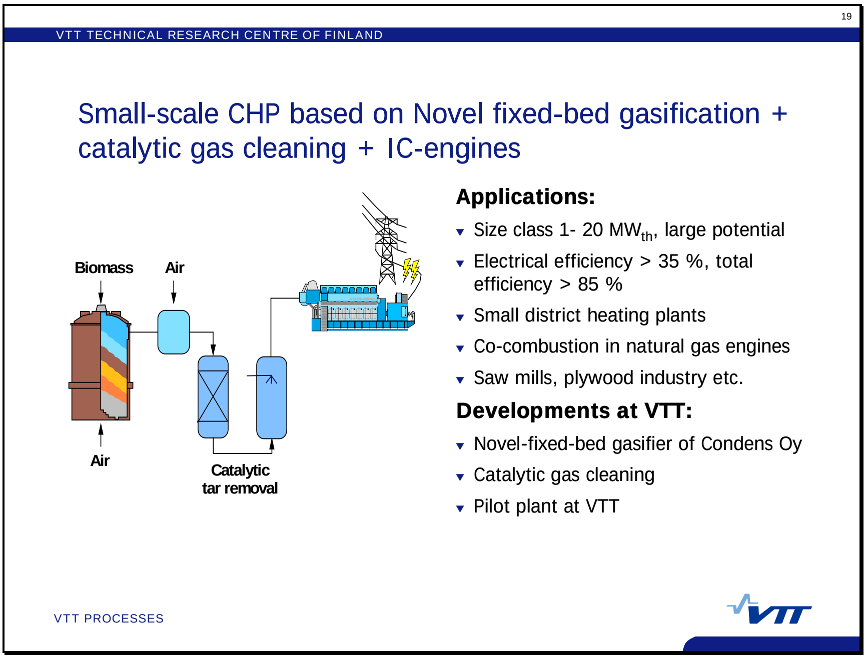
• Scaled up to 10 MW

•No problems with leaking feeding systems or blocking gas lines

• demonstrated at pilot scale with:
*forest wood residue chips*
*sawdust and wood shavings*
*crushed bark, plywood residues,*
*demolition wood, furniture residues*
*MSW-based SRF, sewage sludges*

## Novel district heating power plant

**Novel gasifier**
**Combustion of gas**
**Cleaning of flue gases and heat recovery**
**Humidification of gasification air**
**Energy recovery**



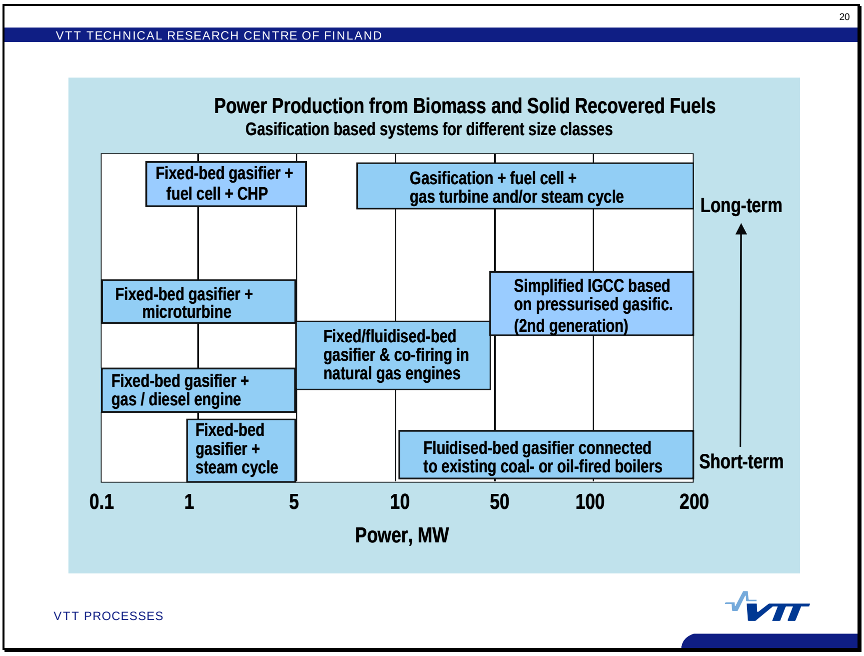
## Small-scale CHP based on Novel fixed-bed gasification + catalytic gas cleaning + IC-engines

**Applications:**

- Size class 1- 20 $MW_{th}$, large potential
- Electrical efficiency > 35 %, total efficiency > 85 %
- Small district heating plants
- Co-combustion in natural gas engines
- Saw mills, plywood industry etc.

**Developments at VTT:**

- Novel-fixed-bed gasifier of Condens Oy
- Catalytic gas cleaning
- Pilot plant at VTT



### Power Production from Biomass and Solid Recovered Fuels

Gasification based systems for different size classes

# MSW and biowaste handling, REF quality improvement for advanced energy production by gasification

Kari Mutka
Vapo Oy Biotech
Jyväskylä, Finland

## 1. Background

### 1.1 EU targets and legislation

EU has set a target to increase the share of renewable energy from 6% to 12%. The largest sources of renewable energy potential in EU countries have been seen to be biomass and waste. This means that the use of waste as a source of energy has to be strongly developed. The Kyoto protocol and the strategy to decrease the greenhouse gases are also boosting the use of waste to replace fossile fuels as a source of energy. Waste management should also develop quickly, since there are many new directives, which give guidelines for waste management. Among the most important are landfill directive, waste incineration directive, and biological waste directive, which is still under process. The member countries have given their own specific targets for waste management, like targets for recycling, landfill taxation, and non-organic and burnable waste cannot be taken to landfill any more after some years’ time. This all means that the handling of waste will be much more expensive than until now and the use of waste as a source of energy will be of great importance in near future. New technologies are needed to make it possible to replace fossil fuels by energy from waste.

### 1.2 Finnish approach

There is only one, in European scale relatively small, mass incineration plant in Finland. There have been attempts to use industrial and district heating power plants also as co-combustion plants for waste-derived fuels (REF or RDF). The plants are fluidized or bubbling-bed boilers, which can burn different types of mixed fuel. There are such plants almost in every town in Finland. A standard (SFS 5875) for quality control system has been prepared for co-combustioning of solid recovered fuels. The aim was to work out strict requirements and specifications for REF, so that the quality of the fuel would be known before combustion. Therefore, we cannot speak about waste incineration any more.

By combusting REF, fossile fuels could be replaced relatively easily and the need of building incineration plants would be smaller. Today, there are some power plants that have started to co-combust a small proportion of source-separated clean REF I class fuel (Cl < 0.15 m-%) without problems. However, there have been a lot of problems in those power plants trying to co-combust REF II and III class fuels (Cl <0.5 and <1.5 m-%) produced from household waste. The main problems have been due to Cl corrosion and metallic aluminium. The boilers have also been fouled by alkaline metals. This has prevented the use of REF III class fuel totally. The Waste Incineration Directive will also make it more difficult to use fuels of waste origin, because the flue gas cleaning and gas monitoring and measurements shall be much more strict and expensive than without waste fuels. If the share of waste fuel is small, the cost of measurements and gas cleaning is too high.

# 2. The gasification project of Vapo Oy and Powest Oy

Because of problems discussed above Vapo Oy and Powest Oy (a subsidiary of Pohjolan Voima Oy) decided to initiate an extensive R&D project to solve these problems. The main target was to develop a chain from household waste via gasification to energy use in coal-fired power plants replacing coal or other fossil fuels.

The other targets were as follows:

- to develop a gasification process of fuels prepared from household waste (REF III)
- to develop the cleaning of syngas
- to develop and set fuel specifications for REF utilized in gasifiers.

Vapo and Powest are jointly responsible of gasification and gas cleaning. The technology partner is VTT Processes, who made laboratory tests first in PDU (Process Development Unit) scale and later built a 1 MW pilot plant for further tests. The test runs have been very promising in all stages. The gas cleaning has proceeded very well and the fuel impurities of the gas have been comparable with those of wood fuels. The new gasification process has also operated very well over relatively long periods of time and there has been no blocking or fouling in the gasifier.

The first demonstration plant shall be built beside the Vantaan Energia Oy’s Martinlaakso coal-fired power plant. The size of gasifier shall be 80 MW and it shall replace 30% (in energy) of the coal used in Martinlaakso power plant. The gasifier shall use 100 000–200 000 t of REF/year. This is equal to 170 000–200 000 t of household waste per year. The environmental impact assessment has been carried out and environmental permits are under process. The target is to make the investment decision during year 2002.

Vapo’s responsibility is to develop solid waste processing, which produces REF for gasification. This work is being done in Vapo’s environmental technology research unit in Jyväskylä. There are two full-scale tunnel reactors, which can each process 10–20 t of waste per test run depending on the properties of the input waste material. The research unit has been doing research on composting, biothermal drying, sludge handling and MSW processing. Development on solid waste processing is done in close co-operation with gasification development. The ideal target is to integrate solid waste processing plants to produce a desired quality of REF, which will be gasified and the cleaned syngas will replace fossil fuels in a high efficient CHP process.

## 3. Integrated waste treatment plant (MBT-plant)

The basic idea is to use the most difficult material, household waste, for fuel production. The mechanical-biological treatment plant (MBT plant) consists of two main phases, the mechanical part and the biological part, which can operate either independently or integrated. The mechanical part has normal shredding devices, screening and sieving devices, metal separation, etc. The main outputs of the mechanical process are fuel fraction, fines (mostly biological materials), large mechanical impurities, and metals. If the input to the treatment process comprises source-separated burnable waste (so-called energy fraction) from trade and industry, the fuel fraction is clean and can be used for gasification or direct combustion. If the input to the treatment process comes from households, the fuel fraction is wet, which lowers its heating value and causes hygiene and odour problems. To upgrade the fuel fraction good enough for gasification or recycling, it has to be dried in a biological system (Wastech biothermal drying process).

In the Wastech biothermal drying process the moisture content can be reduced from 35–50% to less than 20% and simultaneously, the heating value rises from 3.5 MWh/t up to 5.0 MWh/t. The treated material is hygienized because of the relatively high temperatures kept in the Wastech biothermal process. This benefits greatly the storing, handling and utilization of stored REF, e.g., during and after sometimes long summer breaks of power plants. In other words, the production of REF can continue without time-outs throughout the year.

The biological part of waste is put to Wastech biological process. The proposal for Biological Waste Directive expects that the waste taken to landfill has to be treated in a way that the biological activity is less than 5 mg$O_2$/gTS (AT4). The German and Austrian standards also require that the production of gas should be less than 20 l/kgTS (GB21). This means that it takes a long time to process fines in a way that meets the standards. It is possible to screen some fuel fraction from fines so the material for landfilling is minimized.

The Wastech biological/biothermal treatment plant can also process source-separated biowaste (organic waste) and sludge and therefore operates as a regular composting plant. The sludge can be dried biothermally and used as sludge fuel in the gasification process. According to tests the heating value is 1.5–2.0 MWh/t of dried sludge with additive material (bark for example). The energy use of sludge may be necessary in the future, because there may be overproduction of composting material in many areas.

The integrated Wastech biological/biothermal treatment plant is very flexible and can be operated smoothly with different waste materials and different end user needs. Recycling of waste materials can be maximized and at the same time the existing and coming EU Directives and standards can be met.

# 4. Conclusions

The consortium Vapo Oy, Powest Oy and VTT Processes succeeded to develop the whole production line from household waste to cleaned gas to replace coal. The production chain looks very promising, because it fills all the targets of EU to increase the use of renewable energy sources and to replace fossile fuels, to decrease the greenhouse effect and to handle all parts of waste according to directives. At the moment, it looks like that this can also be done at reasonable costs. The technology has been tested in pilot-scale. The next step will be to construct demonstration plants in the near future.

# European standardisation of solid recovered fuels

Martin Frankenhaeuser
Chairman CEN BT/TF 118 Solid Recovered Fuels
Borealis
Porvoo, Finland

On 13 March 2002, the Technical Board of the European Committee for Standardisation (CEN) established Technical Committee 343 *Solid Recovered Fuels*. The decision is based on proposal of CEN BT/TF 118 *Solid Recovered Fuels* (resolution 9). The European Commission, especially DG TREN (formerly DG XVII), actively supports the use of waste as an alternative source of energy and is presently considering a Mandate for the required standardisation work.

TC 343, the secretariat of which is held by the Finnish Standards Association, SFS, will meet for the first time at the Joint Research Centre of the European Commission in Ispra on 5 June 2002. All CEN Members are invited to nominate delegates to the meeting (susanna.virkajarvi@sfs.fi).

*********

The establishment of TC 343 is the result of a process that started in 1996 when an industrial consortium (13 partners from 7 Member States) filed a project proposal *Fuel and Energy Recovery* within the Commission's THERMIE program (contract DIS-1375-97-FI). The results of the study were presented at a workshop in Brussels on 26 November 1998. The report is available at TNO (jan.zeevalkink@mep.tno.nl).

In 1999, an industrial consortium (15 partners from 7 Member States) filed a project proposal *Waste to Recovered Fuel* with the Commission's Fifth Framework Programme (contract number NNE5-1999-533) in order to facilitate CEN standardisation of solid recovered fuels, and to elaborate a Cost-Benefit Analysis. The scope of the CBA was Fuel Recovery and Energy recovery vs. state-of-the-art Landfilling. The results were presented and discussed at a

Workshop on 29 May 2001. The Workshop was jointly organised by the European Recovered Fuels Organisation, ERFO, and the European Commission. The study is available at www.gua.at Aktuelle Studien.

In April 2000, on proposals from SFS and the European Commission, CEN BT decided to establish Task Force 118 in order to develop a technical report on *Solid Recovered Fuels* and a Work Program for a TC to be established, i.e. a list of needed standards. Delegates from 12 Members States have participated in the work. At its fourth meeting on 23 January 2002, TF 118 adopted both the Technical Report, part II of which was drafted by the Joint Research Centre Ispra on request of the European Commission DG ENV, and the Work Program.

The main conclusions drawn from the information presented in Parts I and II of the report are:

1. Solid recovered fuels can be derived from household waste, commercial waste, industrial waste and other non-hazardous, combustible waste streams;

2. European Standards for solid recovered fuels are important for
    - the facilitation of trans-boundary shipments (in accordance with the European Regulation 259/93 and the OECD Green List or Appendix B of the Basel Treaty)
    - access to permits for the use of recovered fuels
    - cost savings for co-incineration plants as a result of reduced measurements (e.g., for heavy metals)
    - the rationalisation of design criteria for combustion units, and the cost savings for equipment manufacturers that go with it
    - guaranteeing the quality of fuel for energy producers;

3. A survey of solid recovered fuel producers in 2001 has concluded that
    - there is a large variation in the standards applied for the sampling, digestion and analysis of solid recovered fuels and harmonisation is required urgently
    - the wide ranges in the analytical results reported justify the need for a fuel standard with limit values

- more detailed information is required about the waste input to the production process
- there is sufficient information available to justify the drafting of a Standardisation Mandate to be issued to CEN by the European Commission for developing European standards for solid recovered fuels (RDF, etc.).

The development of the Work Program was made in close liaison with CEN TC 335 Solid Biofuels and it consists of 27 Work Items grouped in six fields:

1. terminology, definitions and description
2. fuel specifications, classes and quality assurance
3. sampling and sample reduction
4. physical/mechanical tests
5. chemical tests
6. other tests, i.e., Method for the determination of biogenic material

Field 6 is included for the application of solid recovered fuels in the support systems of the RES-E Directive (on the promotion of electricity from renewable energy sources), although the letter of the Directive addresses *biodegradable* material. It is foreseen that standards in fields 4 and 5 (after validation) can be adopted from CEN TC 335

*Solid Biofuels*

Corresponding work has been conducted at national level. In January 2000, the Finnish Standards Association published the national standard SFS 5875 *Solid recovered fuel – Quality control system*. In June 2001, the German Institute for Quality Assurance and Certification published RAL-GZ 724 *Quality Assurance of Solid Recovered Fuels*.

# Public perception of MSW and energy recovery. Waste has a chance of a second life

Raymond Ross
NIPO BV
The Netherlands

## 1. Introduction

### 1.1 Aim of the study

The aim of this study was and is to make a (postive) contribution to the enlargement of the social base for energy obtained from and the improvement of the market position for MSW. Therefore, the study should result in recommendations for the communication strategy with regard to those two topics.

In order to be able to realise these objectives the study had to generate insight into (amongst others) the judgement of the Dutch people on AVI’s. Dutch people in various roles: as an energycomsumer, as a neighbour, as a responsible citizen and as a political actor, closely associated with the decision process on many political levels.

### 1.2 Short description of the method used

We had planned to use what we call at NIPO the learning process. This means that every phase provides information for the next phase. We distinguished the following 4 phases:

- Phase 1: Some desk reasearch
- Phase 2: Qualitative research on four levels
  (internal experts, external experts, government, consumers)

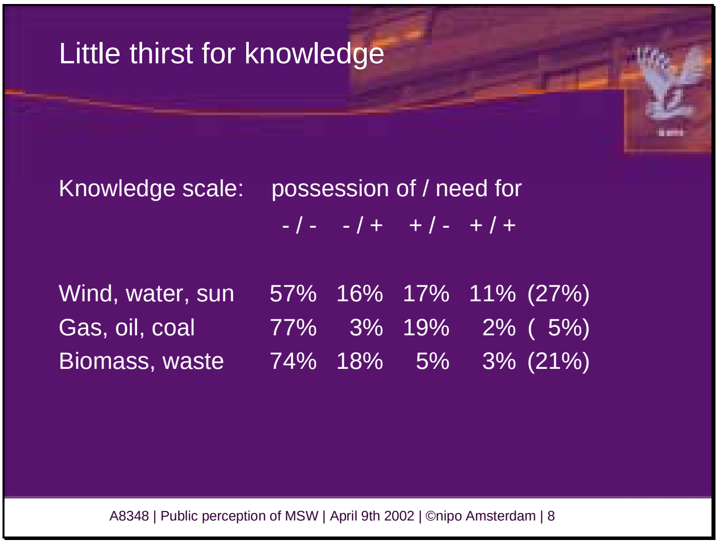
- Phase 3: Quantitative reaserach at two levels
  (random consumers, consumers living in the neighbourhood)
- Phase 4: Formulation of the consequences for strategy.

# 2. Survey results in a nutshell

## 2.1 Consumer knowlegde, attitude and behaviour

In eight short sections the main conclusions from the consumer studies will be reviewed. These sections will be about:

- knowlegde of forms of energy
- what do consumers think of when we are talking waste
- dissimilarity in perception of the different forms of energy
- energy from MSW as a problemsolver and a problemcauser
- image of energy from MSW
- the future we are heading for
- the government
- “normal” consumers versus neighbours.

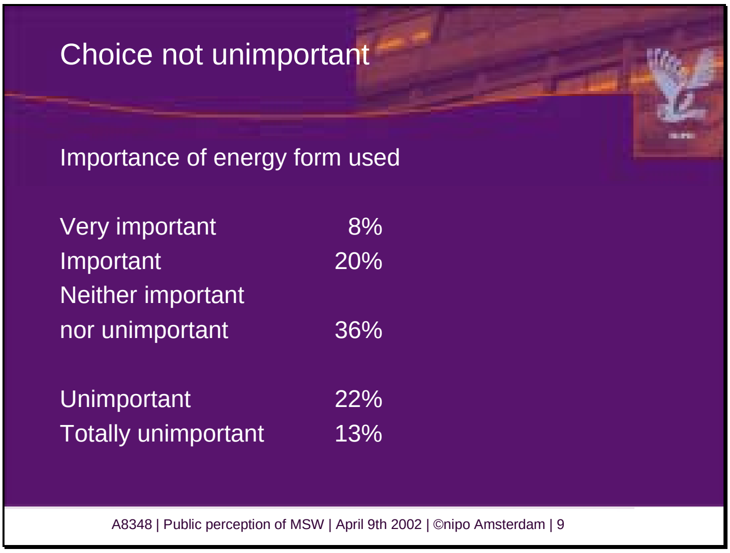


## Little thirst for knowledge

Knowledge scale: possession of / need for

| | - / - | - / + | + / - | + / + | |
|---|---|---|---|---|---|
| Wind, water, sun | 57% | 16% | 17% | 11% | (27%) |
| Gas, oil, coal | 77% | 3% | 19% | 2% | ( 5%) |
| Biomass, waste | 74% | 18% | 5% | 3% | (21%) |

A8348 | Public perception of MSW | April 9th 2002 | ©nipo Amsterdam | 8



## Choice not unimportant

Importance of energy form used

| | |
|---|---|
| Very important | 8% |
| Important | 20% |
| Neither important nor unimportant | 36% |
| Unimportant | 22% |
| Totally unimportant | 13% |

A8348 | Public perception of MSW | April 9th 2002 | ©nipo Amsterdam | 9

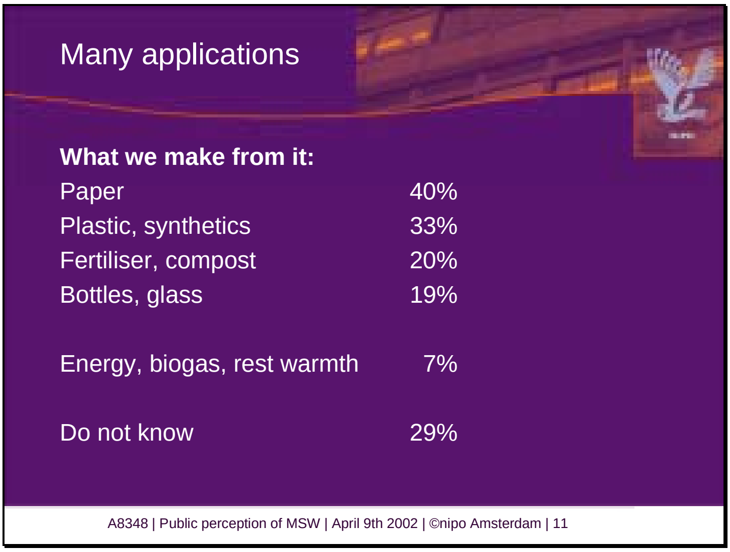
## Talking waste, what is it?

**First thought**

| | |
|---|---|
| What is thrown away, not reusable | 35% |
| "Household" waste | 30% |

**Waste is for me:**

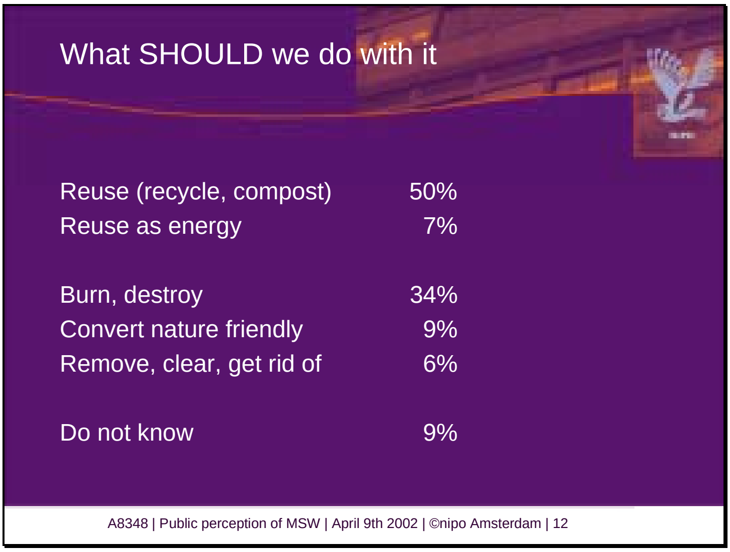
| | |
|---|---|
| Everything not (re)usable | 30% |
| "Household" waste | 28% |
| What is thrown away, redundant | 22% |
| Rest material, packaging | 15% |



## Many applications

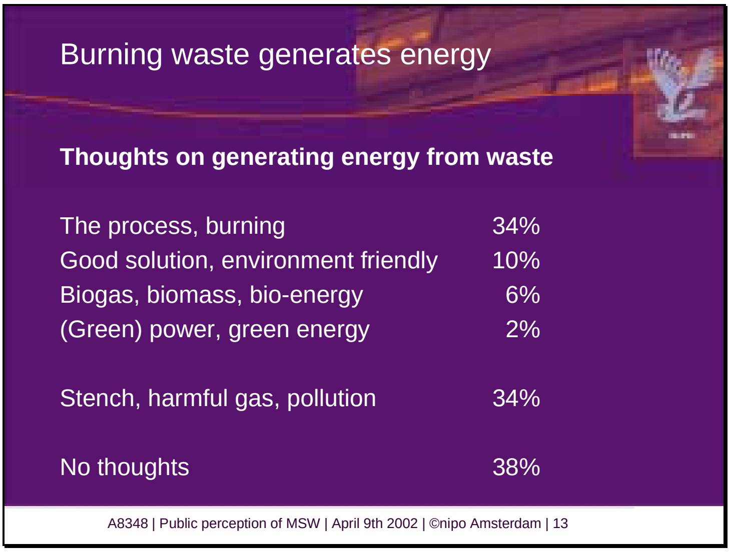
**What we make from it:**

| | |
|---|---|
| Paper | 40% |
| Plastic, synthetics | 33% |
| Fertiliser, compost | 20% |
| Bottles, glass | 19% |
| Energy, biogas, rest warmth | 7% |
| Do not know | 29% |



## What SHOULD we do with it

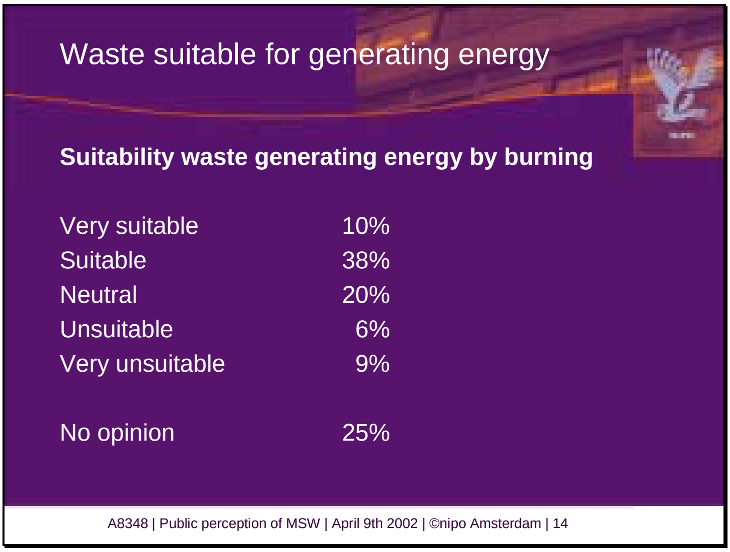
| | |
|---|---|
| Reuse (recycle, compost) | 50% |
| Reuse as energy | 7% |
| | |
| Burn, destroy | 34% |
| Convert nature friendly | 9% |
| Remove, clear, get rid of | 6% |
| | |
| Do not know | 9% |



## Burning waste generates energy

**Thoughts on generating energy from waste**

| | |
|---|---|
| The process, burning | 34% |
| Good solution, environment friendly | 10% |
| Biogas, biomass, bio-energy | 6% |
| (Green) power, green energy | 2% |
| | |
| Stench, harmful gas, pollution | 34% |
| | |
| No thoughts | 38% |



## Waste suitable for generating energy

**Suitability waste generating energy by burning**

| | |
|---|---|
| Very suitable | 10% |
| Suitable | 38% |
| Neutral | 20% |
| Unsuitable | 6% |
| Very unsuitable | 9% |
| | |
| No opinion | 25% |

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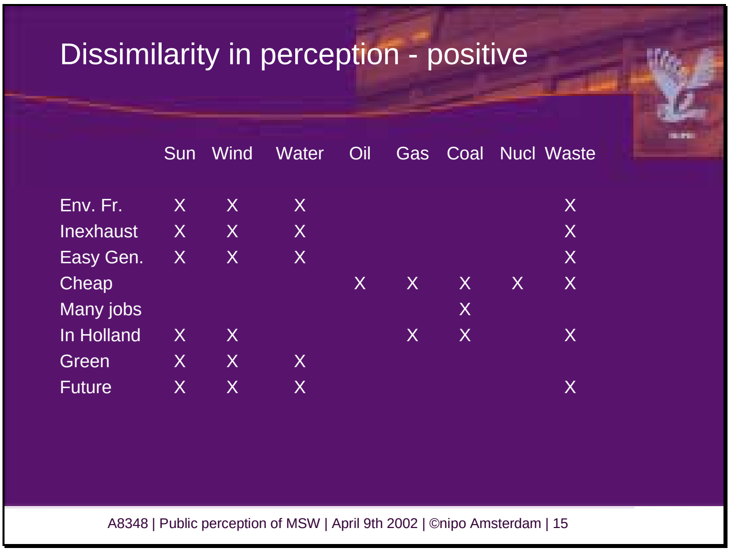

## Dissimilarity in perception - positive

| | Sun | Wind | Water | Oil | Gas | Coal | Nucl | Waste |
|---|---|---|---|---|---|---|---|---|
| Env. Fr. | X | X | X | | | | | X |
| Inexhaust | X | X | X | | | | | X |
| Easy Gen. | X | X | X | | | | | X |
| Cheap | | | | X | X | X | X | X |
| Many jobs | | | | | | X | | |
| In Holland | X | X | | | X | X | | X |
| Green | X | X | X | | | | | |
| Future | X | X | X | | | | | X |

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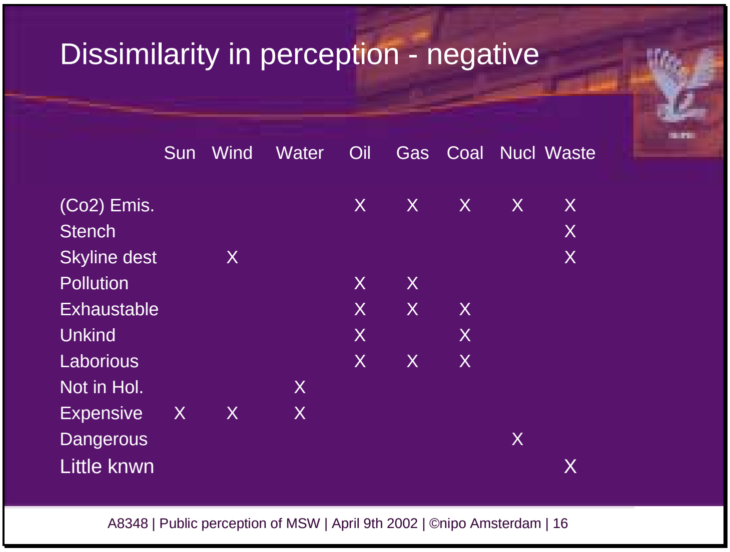

## Dissimilarity in perception - negative

| | Sun | Wind | Water | Oil | Gas | Coal | Nucl | Waste |
|---|---|---|---|---|---|---|---|---|
| (Co2) Emis. | | | | X | X | X | X | X |
| Stench | | | | | | | | X |
| Skyline dest | | X | | | | | | X |
| Pollution | | | | X | X | | | |
| Exhaustable | | | | X | X | X | | |
| Unkind | | | | X | | X | | |
| Laborious | | | | X | X | X | | |
| Not in Hol. | | | X | | | | | |
| Expensive | X | X | X | | | | | |
| Dangerous | | | | | | | X | |
| Little knwn | | | | | | | | X |

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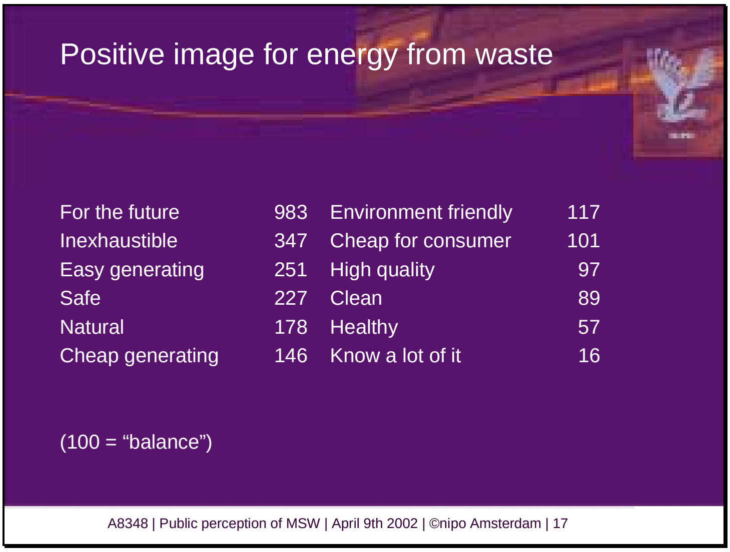

## Positive image for energy from waste

| | | | |
|---|---|---|---|
| For the future | 983 | Environment friendly | 117 |
| Inexhaustible | 347 | Cheap for consumer | 101 |
| Easy generating | 251 | High quality | 97 |
| Safe | 227 | Clean | 89 |
| Natural | 178 | Healthy | 57 |
| Cheap generating | 146 | Know a lot of it | 16 |

(100 = “balance”)

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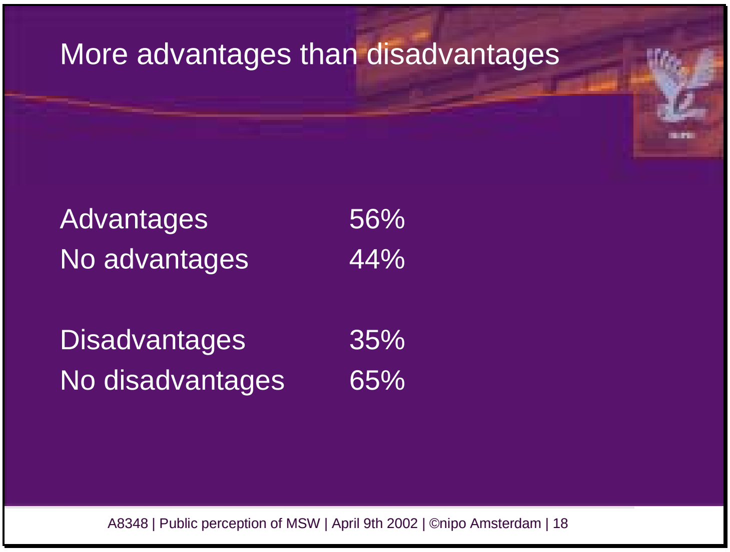
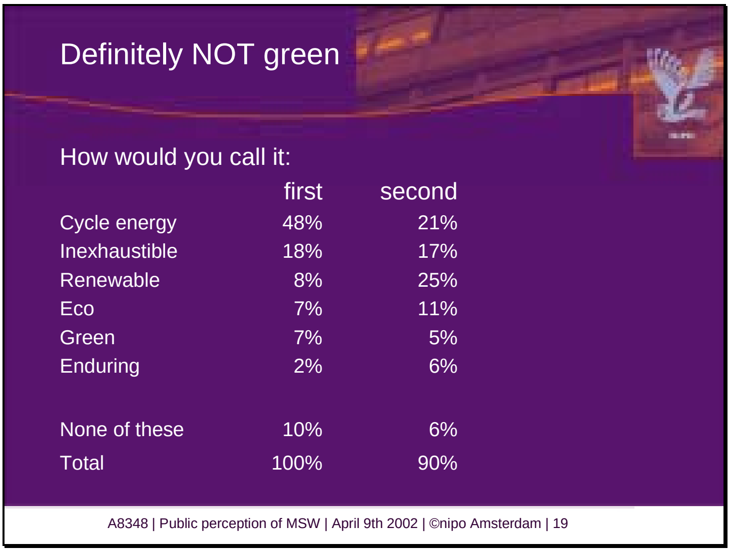


## More advantages than disadvantages

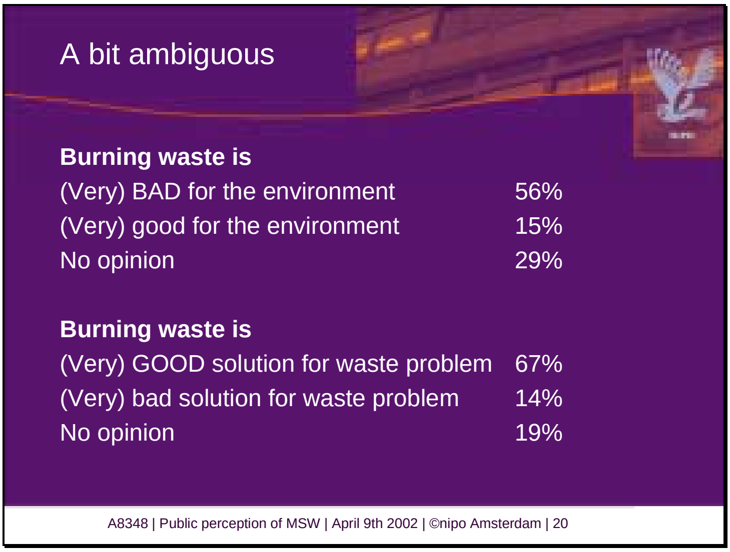
| | |
|---|---|
| Advantages | 56% |
| No advantages | 44% |
| | |
| Disadvantages | 35% |
| No disadvantages | 65% |



## Definitely NOT green

How would you call it:

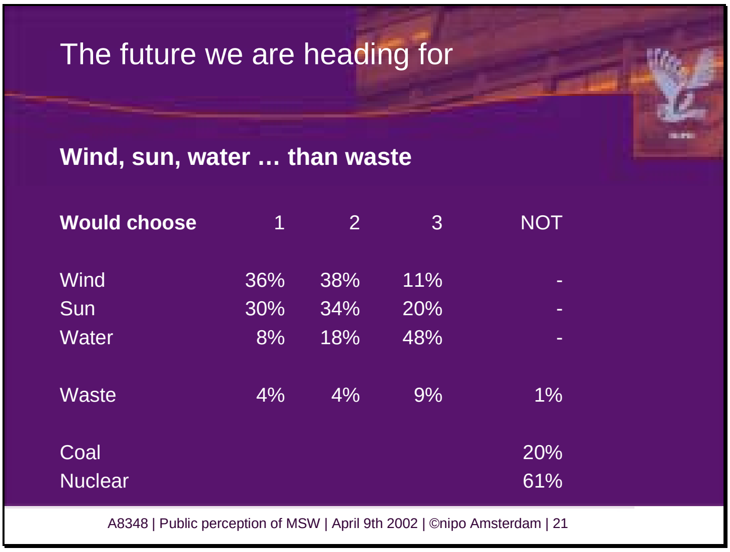
| | first | second |
|---|---|---|
| Cycle energy | 48% | 21% |
| Inexhaustible | 18% | 17% |
| Renewable | 8% | 25% |
| Eco | 7% | 11% |
| Green | 7% | 5% |
| Enduring | 2% | 6% |
| None of these | 10% | 6% |
| Total | 100% | 90% |



## A bit ambiguous

| **Burning waste is** | |
|---|---|
| (Very) BAD for the environment | 56% |
| (Very) good for the environment | 15% |
| No opinion | 29% |

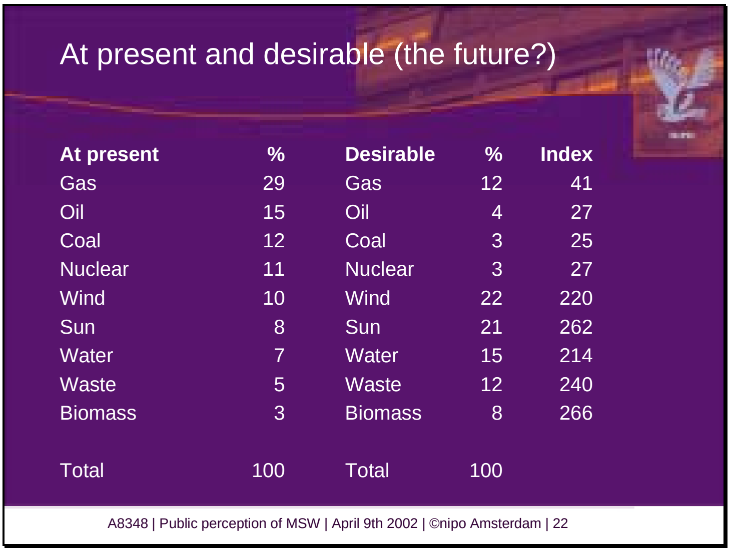
| **Burning waste is** | |
|---|---|
| (Very) GOOD solution for waste problem | 67% |
| (Very) bad solution for waste problem | 14% |
| No opinion | 19% |



## The future we are heading for

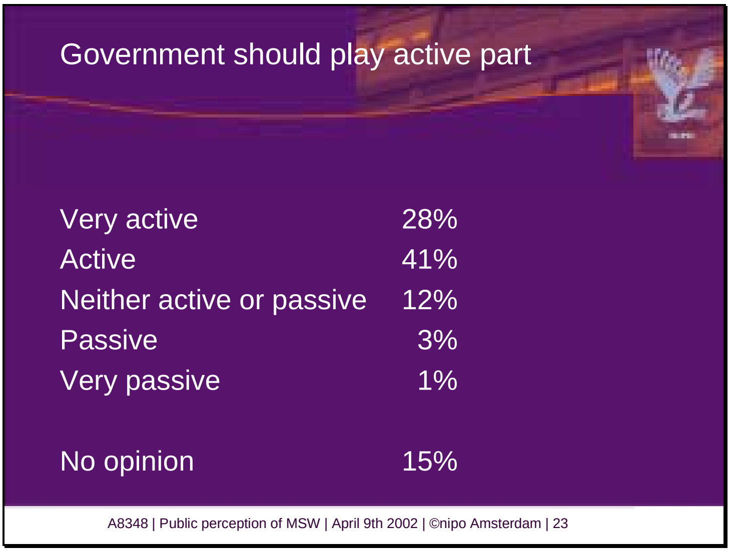
**Wind, sun, water … than waste**

| **Would choose** | 1 | 2 | 3 | NOT |
|---|---|---|---|---|
| Wind | 36% | 38% | 11% | - |
| Sun | 30% | 34% | 20% | - |
| Water | 8% | 18% | 48% | - |
| Waste | 4% | 4% | 9% | 1% |
| Coal | | | | 20% |
| Nuclear | | | | 61% |



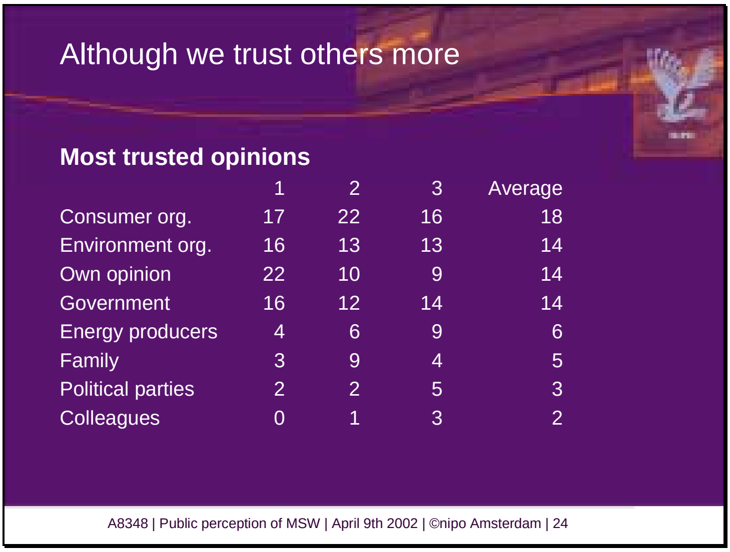
## At present and desirable (the future?)

| At present | % | Desirable | % | Index |
|---|---|---|---|---|
| Gas | 29 | Gas | 12 | 41 |
| Oil | 15 | Oil | 4 | 27 |
| Coal | 12 | Coal | 3 | 25 |
| Nuclear | 11 | Nuclear | 3 | 27 |
| Wind | 10 | Wind | 22 | 220 |
| Sun | 8 | Sun | 21 | 262 |
| Water | 7 | Water | 15 | 214 |
| Waste | 5 | Waste | 12 | 240 |
| Biomass | 3 | Biomass | 8 | 266 |
| Total | 100 | Total | 100 | |



## Government should play active part

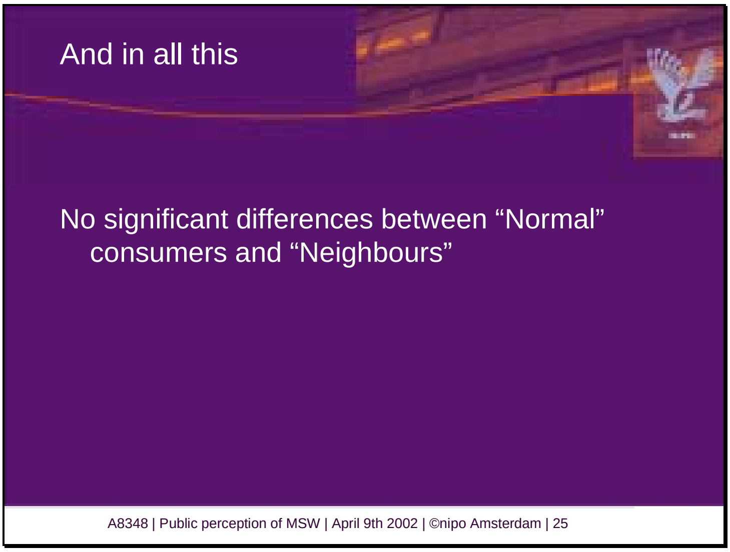
| | |
|---|---|
| Very active | 28% |
| Active | 41% |
| Neither active or passive | 12% |
| Passive | 3% |
| Very passive | 1% |
| No opinion | 15% |



## Although we trust others more

**Most trusted opinions**

| | 1 | 2 | 3 | Average |
|---|---|---|---|---|
| Consumer org. | 17 | 22 | 16 | 18 |
| Environment org. | 16 | 13 | 13 | 14 |
| Own opinion | 22 | 10 | 9 | 14 |
| Government | 16 | 12 | 14 | 14 |
| Energy producers | 4 | 6 | 9 | 6 |
| Family | 3 | 9 | 4 | 5 |
| Political parties | 2 | 2 | 5 | 3 |
| Colleagues | 0 | 1 | 3 | 2 |

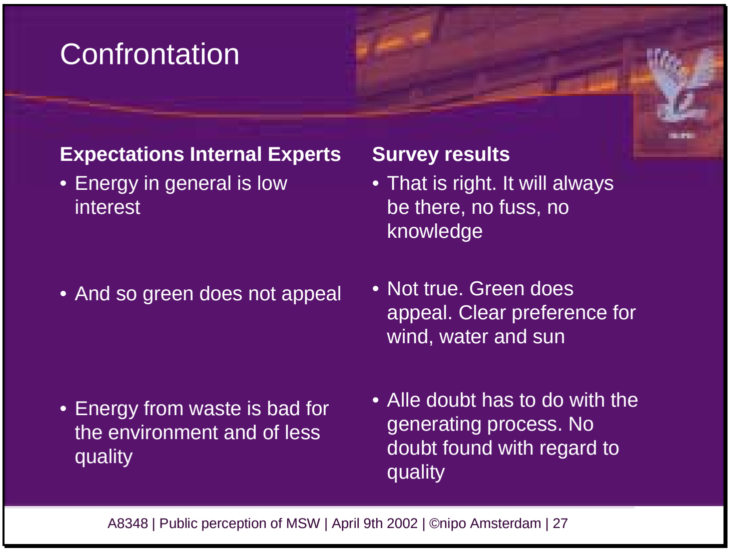


## And in all this

No significant differences between “Normal” consumers and “Neighbours”

# 3. Conclusions

In this final chapter we will confront the opinions of the internal experts with the views of the other groups. This is the first step to the formulation of a strategy.



## Confrontation

| Expectations Internal Experts | Survey results |
|---|---|
| • Energy in general is low interest | • That is right. It will always be there, no fuss, no knowledge |
| • And so green does not appeal | • Not true. Green does appeal. Clear preference for wind, water and sun |
| • Energy from waste is bad for the environment and of less quality | • Alle doubt has to do with the generating process. No doubt found with regard to quality |

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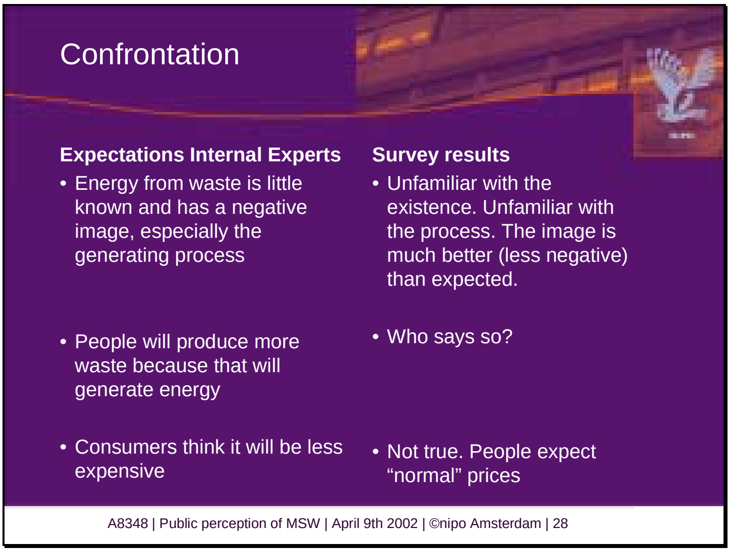

## Confrontation

| Expectations Internal Experts | Survey results |
|---|---|
| • Energy from waste is little known and has a negative image, especially the generating process | • Unfamiliar with the existence. Unfamiliar with the process. The image is much better (less negative) than expected. |
| • People will produce more waste because that will generate energy | • Who says so? |
| • Consumers think it will be less expensive | • Not true. People expect “normal” prices |

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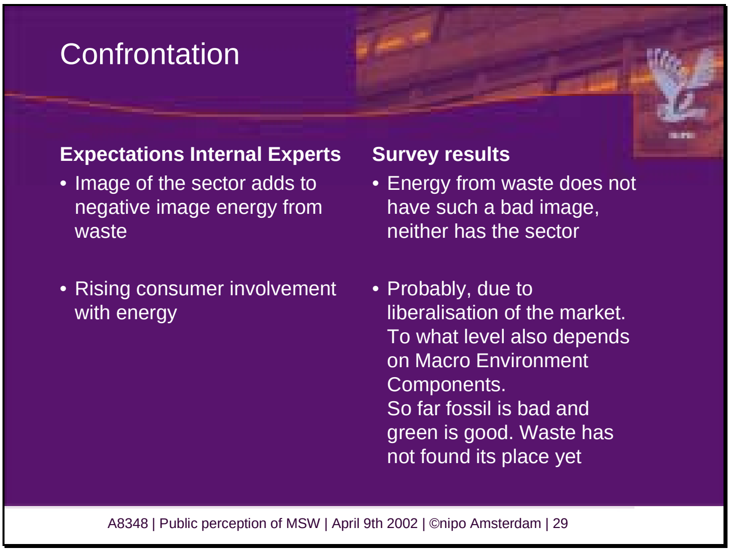
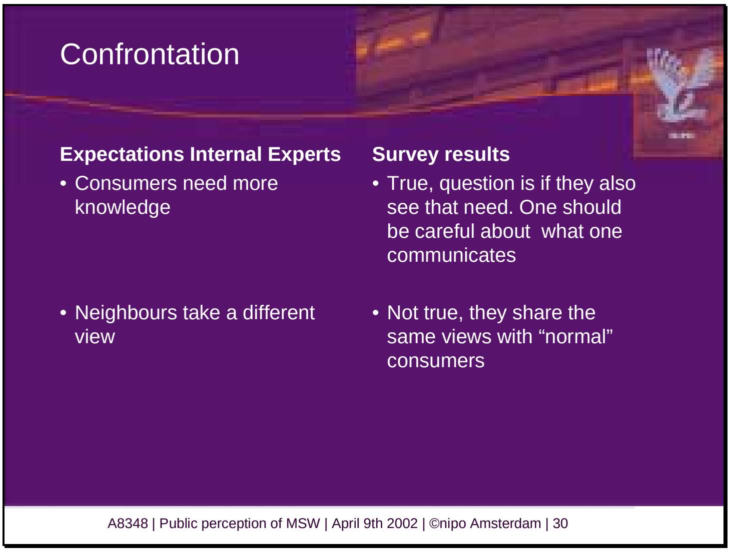


## Confrontation

| Expectations Internal Experts | Survey results |
|---|---|
| • Image of the sector adds to negative image energy from waste | • Energy from waste does not have such a bad image, neither has the sector |
| • Rising consumer involvement with energy | • Probably, due to liberalisation of the market. To what level also depends on Macro Environment Components.<br>So far fossil is bad and green is good. Waste has not found its place yet |

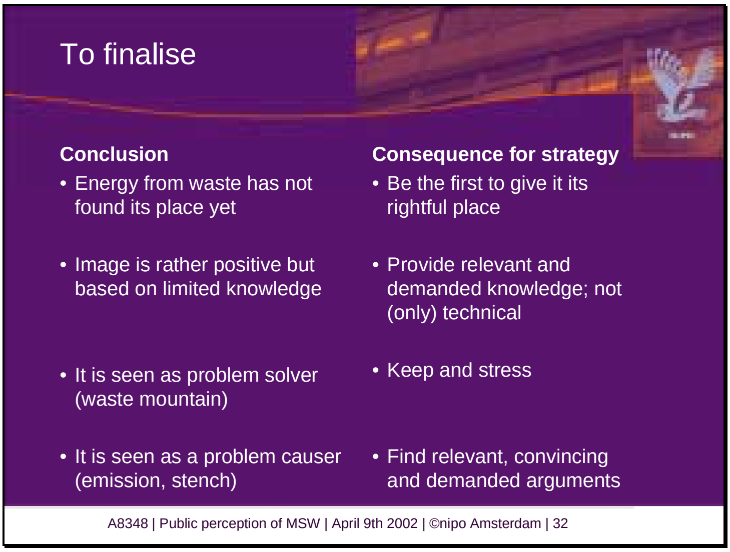


## Confrontation

| Expectations Internal Experts | Survey results |
|---|---|
| • Consumers need more knowledge | • True, question is if they also see that need. One should be careful about what one communicates |
| • Neighbours take a different view | • Not true, they share the same views with “normal” consumers |

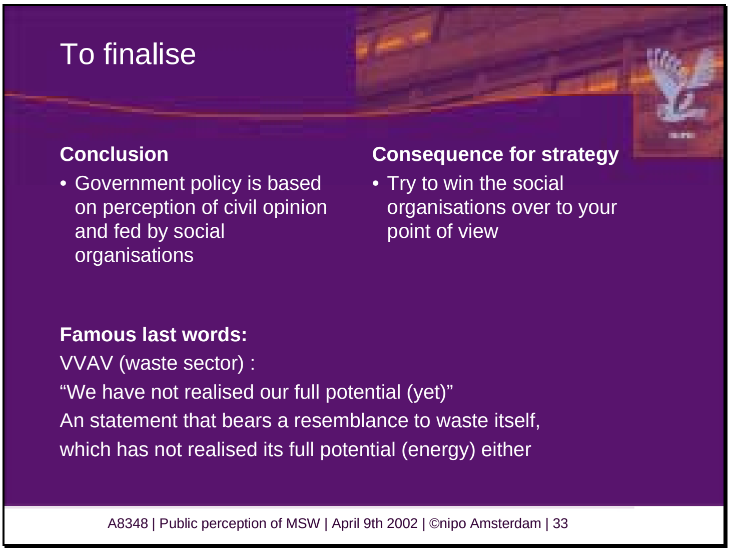
## Confrontation

| Expectations Internal Experts | Survey results |
|---|---|
| • Ministry of Environment is unwilling to look upon energy from waste as green | • True, neither do consumers. The definitions of green and flanking concepts are however vague and should be made more clear |
| • Energy from waste is a threat to the Ministry of Finance | • Only if they do not succeed in reallocation of levies |
| • Ministry of Economic Affairs sees opportunities | • True, first contacts have been made |



## To finalise

| Conclusion | Consequence for strategy |
|---|---|
| • Energy from waste has not found its place yet | • Be the first to give it its rightful place |
| • Image is rather positive but based on limited knowledge | • Provide relevant and demanded knowledge; not (only) technical |
| • It is seen as problem solver (waste mountain) | • Keep and stress |
| • It is seen as a problem causer (emission, stench) | • Find relevant, convincing and demanded arguments |



## To finalise

**Conclusion**

- Government policy is based on perception of civil opinion and fed by social organisations

**Consequence for strategy**

- Try to win the social organisations over to your point of view

**Famous last words:**

VVAV (waste sector) :

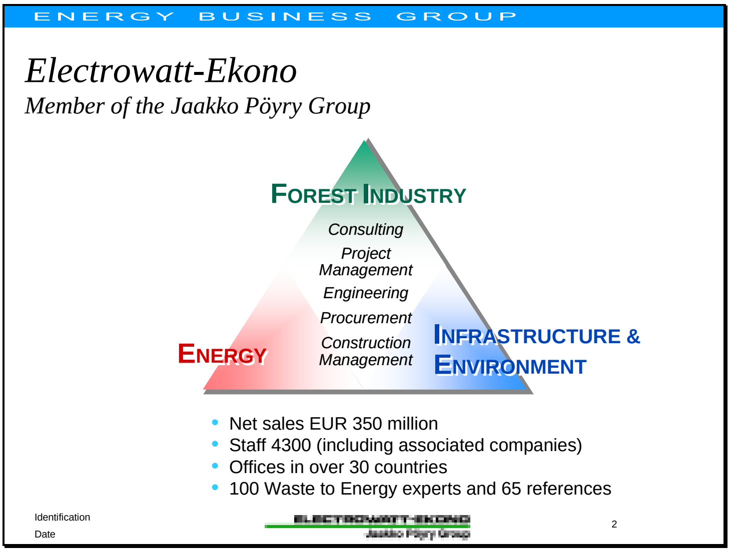
“We have not realised our full potential (yet)”

An statement that bears a resemblance to waste itself,

which has not realised its full potential (energy) either

# Waste to energy markets and trends

Petri Väisänen
Electrowatt-Ekono
Finland



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*Electrowatt-Ekono*

*Member of the Jaakko Pöyry Group*

- Net sales EUR 350 million
- Staff 4300 (including associated companies)
- Offices in over 30 countries
- 100 Waste to Energy experts and 65 references

Identification
Date

ELECTROWATT-EKONO
Jaakko Pöyry Group

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## Market drivers and trends (1)

- Increasing legislative backing and economical incentives
- Rising waste volumes in general
- From small scale to large scale operations
- From mixed waste to dedicated fractions
- From integrated waste management to sustainable resource management
- Transition from low cost landfill disposal to mechanical / biological and WtE

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ENERGY BUSINESS GROUP

## Market drivers and trends (2)

- Privatisation of the waste management
- Deregulation and privatisation of the energy market
- Consolidation of operators and WtE contractors
- Promotion of RES and CHP

## *Market Restraints*

- Lack of environmental legislation or enforcement
- Restricted investment capability of municipalities
- Market inconsistency and low profit margins for equipment suppliers
- Slow market penetration for new technologies
- Pressure from environmental groups and difficulties to obtain permits
- Major share of the market value is in collection and transportation services, few consolidators dominate

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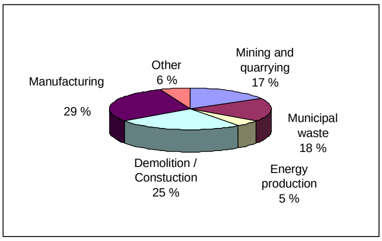
## *Waste management market in Western Europe*

- **Waste generation in the EU 1400 Mt/a and 3,5 t/a per capita excluding agricultural wastes**
- **Increased by 15% between 1995 and 1998**
- **Manufacturing and demolition / construction dominant by mass**
- **MSW dominant by market value**



# *MSW statistics - Europe*

| | MSW total 1000 t | Household 1000 t | per capita kg/capita | per capita kg/capita |
|---|---|---|---|---|
| Austria | 4,100 | 2,775 | 510 | 340 |
| Belgium | 4,852 | - | 480 | |
| Denmark | 2,951 | 2,776 | 560 | 530 |
| Finland | 2,100 | 870 | 410 | 170 |
| **France** | 28,800 | 20,800 | 480 | 350 |
| **Germany** | 36,976 | 35,402 | 460 | 440 |
| Greece | 3,900 | - | 370 | |
| Ireland | 2,032 | 1,325 | 560 | 370 |
| **Italy** | 26,605 | - | 460 | |
| Luxembourg | 193 | 100 | 460 | 250 |
| **Netherlands** | 8,716 | 7,471 | 560 | 480 |
| Portugal | 3,800 | - | 380 | |
| **Spain** | 15,307 | - | 390 | |
| Sweden | 3,200 | - | 360 | |
| **UK** | 28,000 | 26,000 | 480 | 440 |
| Czech Rep. | 3,200 | 2,600 | 310 | 250 |
| Hungary | 5,000 | 3,350 | 500 | 330 |
| **Poland** | 12,183 | 8,169 | 320 | 210 |
| Slovak | 1,800 | 1,100 | 340 | 200 |

**Source: OECD 1999, or latest available year**

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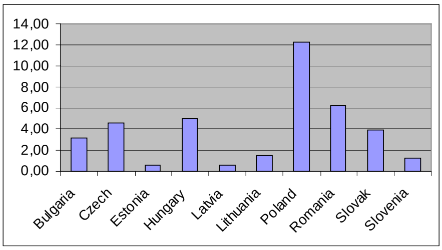
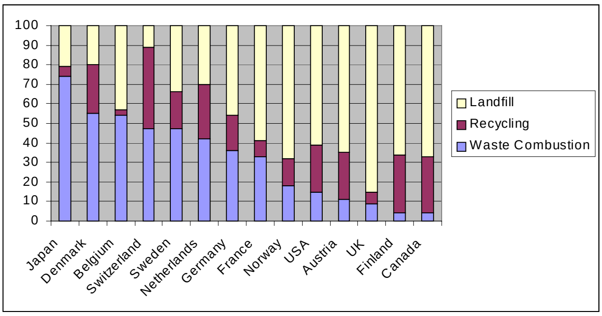
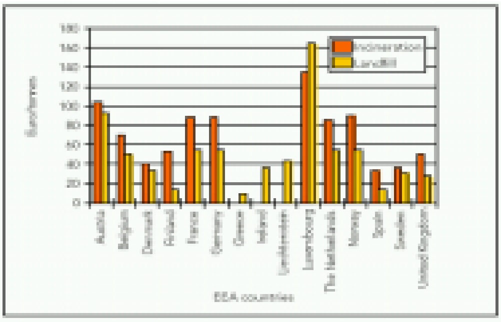
# *MSW generation in CEE countries [Mt/a]*



## *MSW management methods*

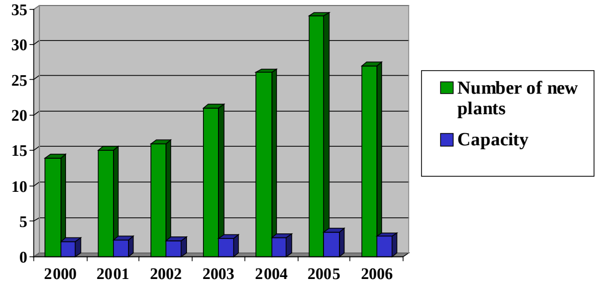


## *Waste treatment costs in Europe*



Average treatment prices (excl. VAT and waste taxes) for landfilling and incineration of non-hazardous waste. Source EEA

## Waste to Energy market in Europe



New technologies (CFB, BFB, Gasification & pyrolysis) 30 % market share ?

Source: Frost & Sullivan 1999

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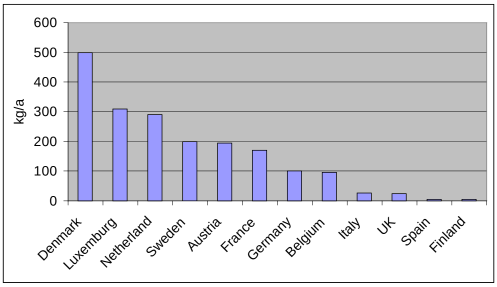
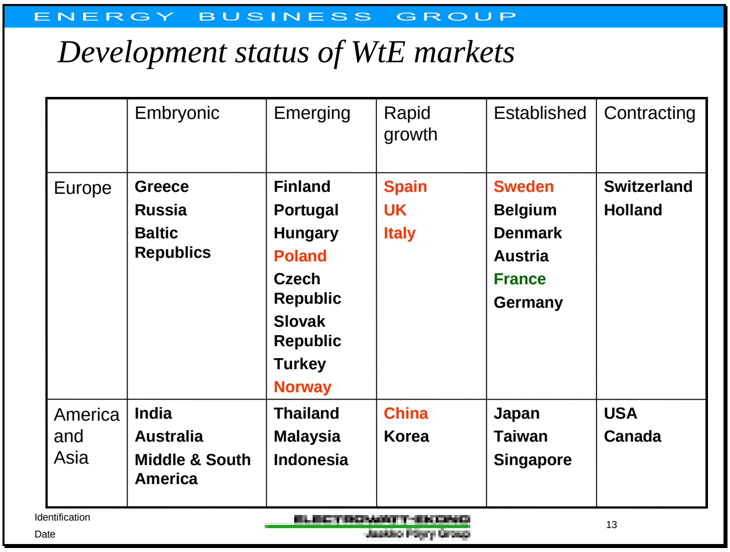
## Waste combustion capacity per capita in EU



Source: EEA



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## *Development status of WtE markets*

| | Embryonic | Emerging | Rapid growth | Established | Contracting |
|---|---|---|---|---|---|
| Europe | **Greece**<br>**Russia**<br>**Baltic Republics** | **Finland**<br>**Portugal**<br>**Hungary**<br>**Poland**<br>**Czech Republic**<br>**Slovak Republic**<br>**Turkey**<br>**Norway** | **Spain**<br>**UK**<br>**Italy** | **Sweden**<br>**Belgium**<br>**Denmark**<br>**Austria**<br>**France**<br>**Germany** | **Switzerland**<br>**Holland** |
| America and Asia | **India**<br>**Australia**<br>**Middle & South America** | **Thailand**<br>**Malaysia**<br>**Indonesia** | **China**<br>**Korea** | **Japan**<br>**Taiwan**<br>**Singapore** | **USA**<br>**Canada** |

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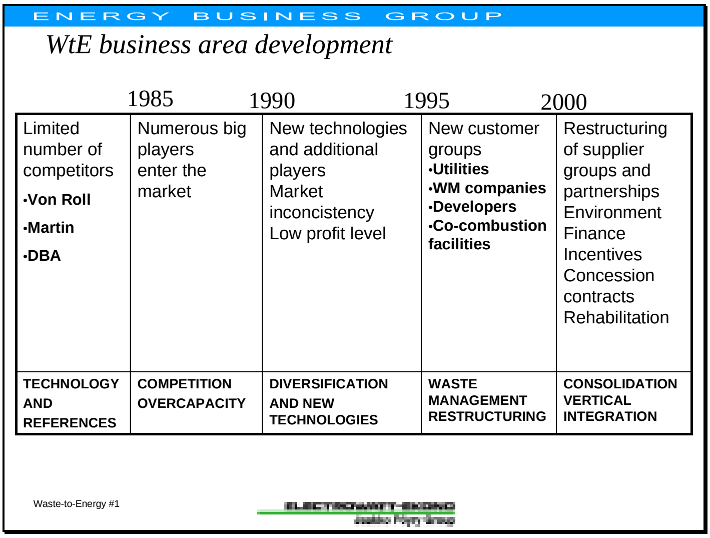

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## *WtE business area development*

1985 1990 1995 2000

| | | | | |
|---|---|---|---|---|
| Limited number of competitors<br>**•Von Roll**<br>**•Martin**<br>**•DBA** | Numerous big players enter the market | New technologies and additional players<br>Market inconcistency<br>Low profit level | New customer groups<br>**•Utilities**<br>**•WM companies**<br>**•Developers**<br>**•Co-combustion facilities** | Restructuring of supplier groups and partnerships<br>Environment<br>Finance<br>Incentives<br>Concession contracts<br>Rehabilitation |
| **TECHNOLOGY AND REFERENCES** | **COMPETITION OVERCAPACITY** | **DIVERSIFICATION AND NEW TECHNOLOGIES** | **WASTE MANAGEMENT RESTRUCTURING** | **CONSOLIDATION VERTICAL INTEGRATION** |

Waste-to-Energy #1

ELECTROWATT-EKONO
Jaakko Pöyry Group

# EXTENDED POSTER PRESENTATIONS

# Improving the modelling of the kinetics of the catalytic tar elimination in biomass gasification[†]

José Corella[*], José M. Toledo & Maria-Pilar Aznar[+]
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University of Saragossa, 50006 Saragossa, Spain

## Abstract

A single one-lump first order reaction for the catalytic elimination of tar present in the flue gas from biomass fluidised-bed gasifiers is not good enough for some applications. A new and more advanced reacting network and microkinetic model has been generated and is here presented. It is based on two lumps, the more and the less reactive tar species, and has four kinetic constants. Each lump reacts (disappears) by both catalytic and thermal reactions. The microkinetic model is applied to results obtained, at around 840 ºC and at small pilot plant level, with two very different solids: silica sand and a commercial (ICI 46-1) nickel-based steam-reforming catalyst. The values found for the four kinetic constants are self-consistent, fit well the results and mean a clear step forward in the modelling of the catalytic tar abatement.

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[†] This paper is dedicated to the memory of Prof. A.A.C.M. (Tom) Beenackers of the University of Groningen (NL), good worker in this field, who recently passed away. He would have probably discussed its content, but surely enjoyed it too.

# 1. Introduction

Tar elimination in flue gas from biomass gasifiers is a key aspect for obtaining a technically feasible advanced gasification process. Hot gas cleaning methods for tar elimination are usually preferred with respect to wet ones because they really destroy the tars (transferring their energetic content to the flue gas as $H_2$, CO and $CH_4$ mainly) instead of transferring them to a liquid waste flow of very difficult disposal. Hot gas clean up is made with calcined dolomites, CaO-MgO, (or related materials) or with steam reforming (nickel-based) catalysts, which usually contain CaO or MgO as well.

These two kinds of solids indeed have very similar catalytic behaviour (1), i.e. they catalyse several tar elimination reactions (refs. 2,3,4,5,6) by similar mechanisms.

A simplified reaction network for the tar catalytic removal is shown in Figure 1. In such a simple reaction network all tar components were grouped in just only one lump, and assumed to disappear by several simultaneous reactions of (steam-, dry- hydro-, thermal-...) reforming, cracking, etc. The overall rate of tar disappearance was thus given by the sum of the rates of all the elementary individual reactions involved in the network. If all individual reactions are considered as first order with respect to tar disappearance, the resulting overall rate is also of first order too and has only one parameter ($k_{app}$):

$$\begin{aligned} -r_{tar} &= k\cdot C_{tar} + k'\cdot y_{H2O}\cdot C_{tar} + k''\cdot y_{H2}\cdot C_{tar} + k'''\cdot y_{CO2}\cdot C_{tar} + \ldots \\ &= (k + k'\cdot y_{H2O} + k''\cdot y_{H2} + k'''\cdot y_{CO2} + \ldots)\cdot C_{tar} \qquad (1) \\ &= k_{app}\cdot C_{tar} \end{aligned}$$

This approach has been accepted by many (if not all) institutions working worldwide in catalytic hot gas cleaning (in biomass gasification). To compare data on catalyst activities (for tar elimination) from different institutions is then very easy using $k_{app}$. When the catalytic reactor is isothermal and there is plug flow, $k_{app}$ can be calculated (refs. 7 and 8) by:

$$k_{app} = \frac{-\ln(1-X_{tar})}{\tau} = GHSV\left[-\ln(1-X_{tar})\right] \qquad (2)$$

$k_{app}$ is thus an easy-to-calculate parameter that is directly related to the catalyst activity and to the "reactivity" of the tar to be destroyed. One problem in using Eq. (2) is that tar conversion ($X_{tar}$) depends on how tar is sampled, analysed, measured or defined (9,10). Consequently, if two different tar-sampling methods are used, the same gasification-gas cleaning test can provide two different values for $X_{tar}$ and $k_{app}$. This problem is the same for all kinetic models and can be solved by using standardised (being agreed nowadays, ref. 21) methods for tar sampling and analysis.

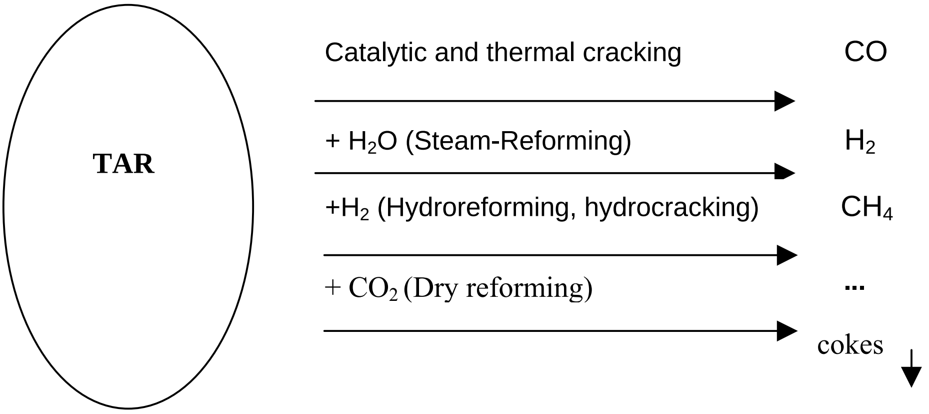

*Figure 1. 1-lump model used till date for tar elimination from flue gas in biomass gasification [from ref. 7].*

A lot of work has been made and published during the last few years that demonstrates the usefulness of the $k_{app}$ parameter and of the single 1-lump $1^{st}$-order reaction approach. Nevertheless, going deeper into catalytic tar removal, problems soon started to appear indicating that the above said approach was not good enough in many ways, and that both the reaction network shown in Figure 1 and the kinetic model (Eq. 1) should be improved. At least two main important problems appeared.

First, $k_{app}$ defined by Eq. (1) should depend only on the bed temperature. For an isothermal catalytic reactor (and a given catalyst) it should have then only one value. Nevertheless, Figure 2 obtained with calcined dolomites (located downstream from the biomass gasifier) by Perez *et al.* (ref. 5) show how $k_{app}$ is high at the reactor inlet zone and decreases with reactor length. From such data it was concluded that there were some more reactive (or "easy-to-destroy") tar components (high $k_{app}$ values), and other less reactive (or "hard-to-destroy") species, which only reacted after relatively long residence times in the catalytic reactor (generating low $k_{app}$ values). The word and lump "tar" (called from now "A") is not enough in itself thus to understand well such results. Other new empirical lumps (like "easy–" and "hard-to-destroy tars") had to be envisaged and used.

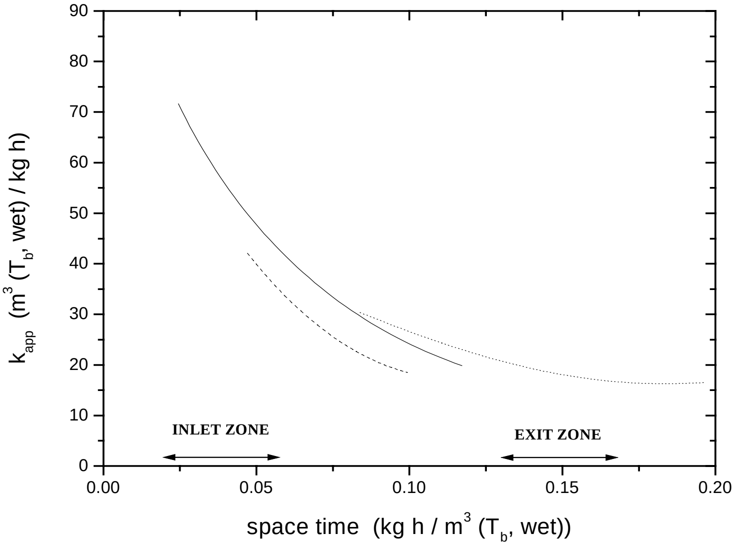

*Figure 2. Unacceptable variation with space-time (or location in the isothermal reactor) of the apparent ($1^{st}$ order, one lump for tar) kinetic constant for tar elimination over calcined dolomite at 840 ºC (from ref. 5. Each line in this figure corresponds to a different particle size of the dolomite or $H_2O/O_2$ value).*

Second, $k_{app}$ for catalytic tar elimination has been calculated by several authors, using Eq. (2), at different temperatures and for different catalysts. Using the Arrhenius equation, the apparent activation energy (for the $1^{st}$-order kinetic approach), $E_{app}$, was further calculated. $E_{app}$ values found by several authors and catalysts are shown in Figure 3. It is a well-known fact that (for the same reaction) the apparent activation energy decreases with increasing catalyst activity. This principle has been confirmed in the tar elimination reaction too, as seen in Figure 3. An improvement in catalyst activity resulted in a lower value for $E_{app}$. Some institutions (18,19), after working on this subject for more than ten years, arrived at very active catalysts (for tar destruction) that generated apparent activation energies as low as 40 ± 10 kJ/mol. These $E_{app}$ values are very low, even considering that their calculations included some internal diffusion control (analysed in refs. 5 and 17, e.g.). Nevertheless, the confidence of such low $E_{app}$ values was confirmed several times by applying error analysis theory (22,23).

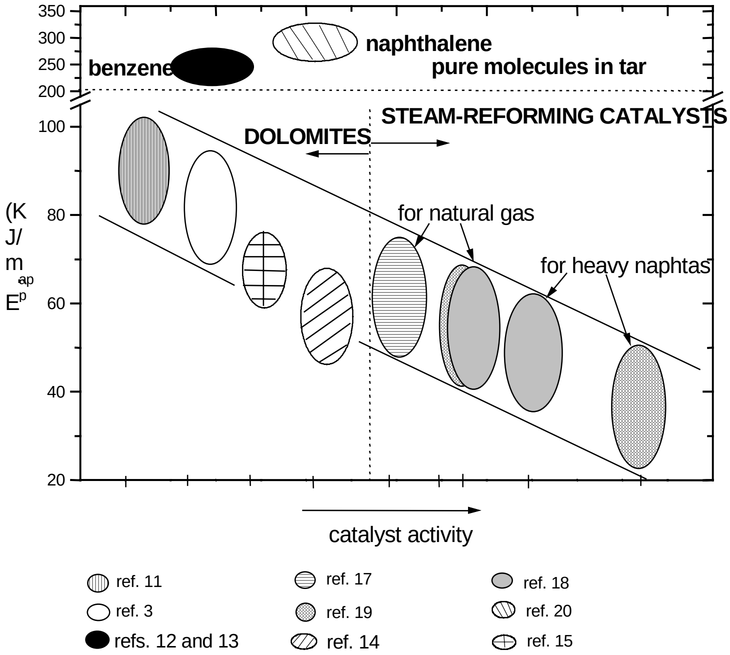

*Figure 3. Values of apparent energy of activation for the overall 1-lump and first-order reaction of tar elimination over calcined dolomites and steam-reforming (nickel based) catalysts.*

Activation energies for pure and key substances ($E_a$) present in tar like benzene, toluene and naphthalene are much higher, between 170 and 320 kJ/mol (12, 13, 24, 25), than the afore mentioned values of 40–60 kJ/mol. These significantly different (deviating) values for the activation energy were already analysed by

Juntgen and van Heek (26), who theoretically demonstrated that when a set of overlapping, independent, first-order reactions (case of the overall tar removal) are approximated by a single first-order expression, the $E_{app}$ and pre-exponential factor tend to converge on the lower value in the set. An example of this effect was given by Anthony and Howard (27), who found $E_a$ to be around 200 kJ/mol for each of a set of steps but obtained an overall figure of 40 kJ/mol for the same data in a single-step correlation. Vargas and Perlmutter (28) also found the same effect when interpreting coal tar pyrolysis kinetics.

The too low values found before for $E_{app}$ using the single 1st-order approach for the fresh tar catalytic removal, and the difference in the values of the activation energy between pure molecules and a fresh tar were the second reason which induced to think that the one-lump, first-order single reaction approach (and thus Eq. 2) was not good enough and that the kinetics of the tar decomposition reaction had to be studied in more detail. Of course, the technical feasibility of the catalytic hot gas clean up may not depend on the kinetic model used for the tar elimination reaction, but a good and improved model may help to solve the hot gas clean up problem in the overall biomass gasification process. This is then the main objective of the present paper: to obtain a more accurate reaction network for the catalytic elimination of tar at elevated temperatures (750–900ºC).

## 2. Kinetic data used

Among the abundant existing data on tar conversion under different conditions (catalysts, temperatures, space-velocities, gasifying agent, ...) published by Corella and co-workers, the authors have selected those shown in Figure 4 because they cover a relatively wide interval for the space-time. Most of the experimental points in such Figure 4 come from the work of Caballero et al. (29), but a few more tests were made at very low space-times just for the modelling work presented in this paper. These new points are included in such Figure 4 together with the former ones.

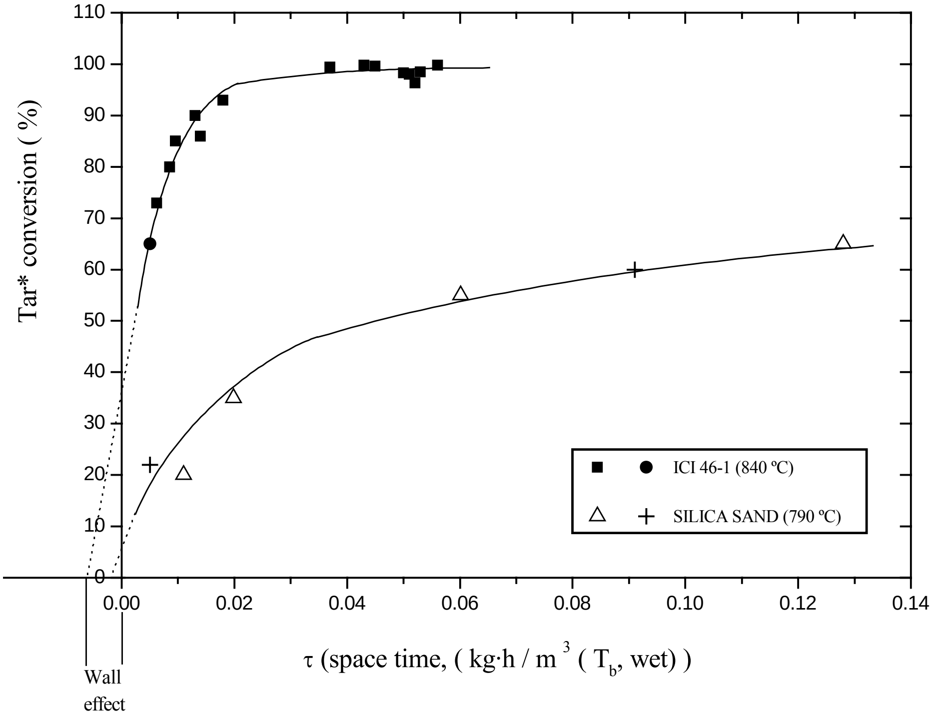

*Figure 4. Tar* conversion at different gas space-times in the catalytic reactor [dp catalyst = 7–14 mm; dp silica sand = 1.0–1.6 mm. ■ and Δ points come from ref. 28; ● and +: new experiments].*

The data on tar conversion shown in Figure 4 were obtained in gasification with air of pine wood chips in fluidised bed at small pilot plant scale. Equivalence ratio (ER) used in these tests was between 0.19 and 0.35. In each experiment 3–5 samples were taken at the inlet and exit of the catalytic reactor at different times-on-stream. Not only the tar conversion ($X_A$) was measured then but also the interval of error in this measurement which is high for $X_A > 0.98$ due mainly to fluctuations in the feeding and flow rates. This interval of error for very high values of $X_A$ has to be remembered to understand some fittings in Figures 6 and 7. More details about how $X_A$ vs τ data were obtained can be found in (29).

For modelling of the kinetics of tar elimination, some key aspects in Figure 4 are:

I. Some tests were made using only silica sand in the catalytic reactor placed downstream from the biomass gasifier. Even with this silica sand, which was supposed not to be a catalyst, an important or noticeable tar conversion is detected (see Figure 4).

II. With a good (for this application) nickel-based catalyst (ICI 46-1) very high tar conversions are obtained even at very low space-times ($\tau$). This high tar conversion is due to both catalytic and thermal reactions (which can not be forgotten by the above said results with silica sand).

III. A careful analysis of the $X_{tar} - \tau$ curve obtained with the nickel catalyst shows how there is something like a breaking at around $\tau = 0.02$ kg·h/m$^3$. The overall $X_{tar} - \tau$ curve seems like the addition of two different exponential curves. The authors deduce then that some tar species react (disappear) faster (f) and that other ones react more slowly (s).

IV. This breaking in the $X_{tar} - \tau$ curve can also be appreciated in the results obtained with silica sand. Some tar-species elimination thermal reactions are then faster than some other ones.

V. The above said inferences from results in Figure 4 allow to conclude that not all species present in tar disappear by the same rate. Some ones are more reactive than other ones. The lump tar (A) may be splitted then in two lumps or 'classes' of species: $A_1$ (more reactive tar-species, giving faster reactions) and $A_2$ (less reactive tar-species, generating slower elimination reactions).

VI. It is assumed that the two lumps or classes of tar ($A_1$ and $A_2$) are present in the flue gas at the catalytic reactor inlet, and that they react in parallel. But $A_1$ might generate $A_2$ too, in a in-series or sequential mechanism, as indicated in Figure 5. This consideration is true but would require the use of another kinetic constant (for the reaction $A_1 \rightarrow A_2$), which, by now, will not be used.

VII. Tests with nickel catalyst were made at 840 ºC. The wall was hot (red) then and its inner side also catalysed or induced some tar elimination reactions. Without neither silica sand nor nickel catalyst in the catalytic reactor, at a space-time ($\tau$) = 0, some tar conversion exists thus, as it can be appreciated in Figure 4. The catalytic effect of the wall (inner side) has also to be taken into account to understand and fit the results in Figure 4. The value for the space-time used from now will be called $\tau'$ and will be the addition of $\tau$ and the hot wall effect shown in Figure 4.

# 3. Kinetic modelling

Shamsi (15, 16) and Aznar et al. (18) already had splitted the overall rate of tar removal in two different contributions, thermal and catalytic. Based in such previous findings, the following kinetic equation was considered initially to fit the results:

$$(-r_A) = k_{th} A^{n_{th}} + k_{cat} A^{n_{cat}} \tag{3}$$

This equation was checked with several values for $n_{th}$ and $n_{cat}$. Values for n higher than 1 had been found and explained (ref. 30) for lumps including several species (values of n = 2 would not surprising thus) but Eq. 3 was not able of fitting well the results in Figure 4. After this not good first attempt, the reacting network shown in Figure 5 was considered. Such network has two lumps ($A_1$ and $A_2$) for the tar and four kinetic constants: two for the elimination of $A_1$ and two for the elimination of $A_2$. Supposing first order in each one of the four reaction involved in the network, the corresponding microkinetic model is:

$$-\frac{dA_1}{d\tau'} = k_{f,th} \cdot A_1 + k_{f,cat} \cdot A_1 \tag{4}$$

$$-\frac{dA_2}{d\tau'} = k_{s,th} \cdot A_2 + k_{s,cat} \cdot A_2 \tag{5}$$

with:

$$A_1 + A_2 = A \tag{6}$$

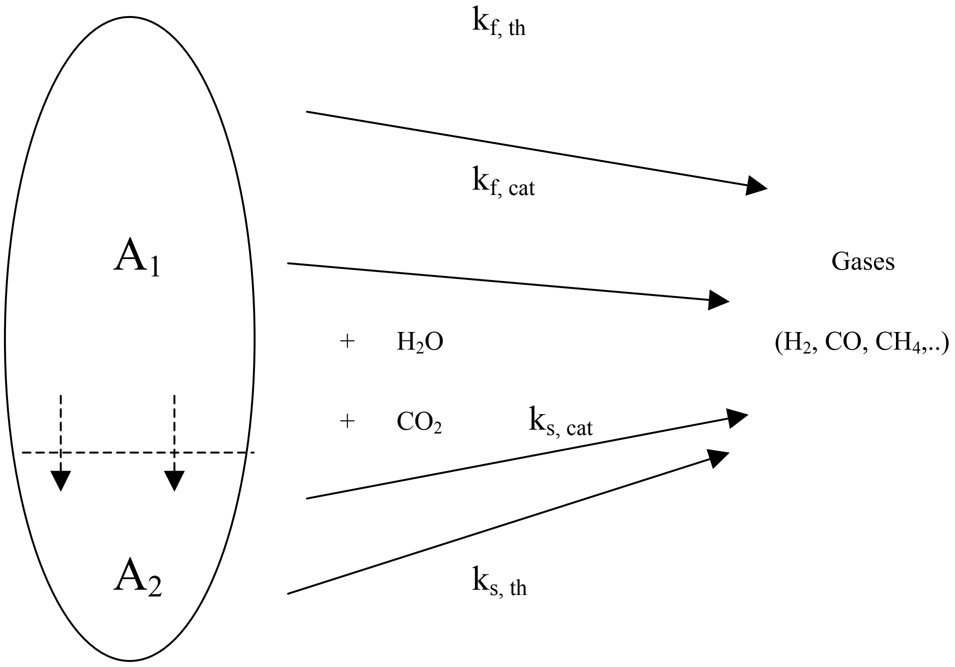

*Figure 5. The 2-lump model with four kinetic constants here presented for the catalytic elimination of tar derived from gasification.*

## 4. Checking of the microkinetic model

From Eqs. 4 and 5 it is deduced that:

$$\frac{A_1}{A_{1,0}} = e^{-\left(k_{f,cat}+k_{f,th}\right)\tau'} \tag{7}$$

$$\frac{A_2}{A_{2,0}} = e^{-\left(k_{s,cat}+k_{s,th}\right)\tau'} \tag{8}$$

from which:

$$A\left[=A_0\left(1-X_A\right)\right]=A_1+A_2=A_{1,0}\cdot e^{-\left(k_{f,cat}+k_{f,th}\right)\tau'}+A_{2,0}\cdot e^{-\left(k_{s,cat}+k_{s,th}\right)\tau'} \quad (9)$$

or:

$$\left(1-X_A\right)=\frac{A_{1,0}}{A_0}\cdot e^{-\left(k_{f,cat}+k_{f,th}\right)\tau'}+\frac{A_{2,0}}{A_0}\cdot e^{-\left(k_{s,cat}+k_{s,th}\right)\tau'} \quad (10)$$

This equation is going to fit well the results in Figure 4. The values of the four kinetic constants involved in it, as well as the ($A_{1,0}/A_0$) and ($A_{2,0}/A_0$) ratios, can be calculated from such fitting.

For fast reaction(s) only ($k_{s,\ cat}$ and $k_{s,\ th}$ = 0), when there is no nickel-catalyst (results with silica sand at 790 ºC thus), $k_{f,cat} = 0$, Eq. 10 becomes:

$$\ln\,(1-X_A)\equiv\ln\,(A_{1,0}/A_0)_{790}-k_{f,\ th,\ 790}\cdot\tau' \quad (11)$$

and with nickel-catalyst ($k_{f,\ cat} \neq 0$ thus):

$$\ln\,(1-X_A)=\ln\,(A_{1,0}/A_0)_{840}-(k_{f,\ cat}+k_{f,\ th})_{840}\cdot\tau' \quad (12)$$

which are checked in Figure 6 (Eq. 11 apply to the full triangles in such figure and Eq. 12 to the full squares). From the slopes of the two lines it is deduced that:

$$k_{f,\ th,\ 790} = 14 \pm 2\ m^3\ (T_{b,\ wet})/kg\cdot h \quad (13)$$

$$(k_{f,\ cat}+k_{f,\ th})_{840} = 94 \pm 5\ m^3/kg\cdot h \quad (14)$$

$$k_{f,\ cat,\ 840} \approx 80 \pm 10\ m^3\ (T_{b,\ wet})/kg\cdot h \quad (15)$$

and from the ordinates in the origin:

$$\left(\frac{A_{1,0}}{A_0}\right)_{790°C}=0.60\pm0.10 \qquad \left(\frac{A_{1,0}}{A_0}\right)_{840°C}=0.92\pm0.08 \quad (16)$$

Since $(A_{1,0} + A_{2,0})_{790} = A_{0,790}$, and $(A_{1,0} + A_{2,0})_{840} = A_{0,840}$, it is further deduced that:

$$\left(\frac{A_{2,0}}{A_0}\right)_{790^\circ C} = 0.40 \pm 0.10 \qquad \left(\frac{A_{2,0}}{A_0}\right)_{840^\circ C} = 0.08 \pm 0.05 \tag{17}$$

Calculation of $k_{s,\ cat}$ and $k_{s,\ th}$ can be now made with Eq. 10. To this concern Levenspiel taught (30) how to manage an equation just like this one. Eq. 10 (at 840 ºC) can be modified to:

$$\ln\left[(1 - X_A) - 0.92\left(e^{-94\tau'}\right)\right] = \ln(0.08) - \left(k_{s,cat} + k_{s,th}\right)\tau' \tag{18}$$

which is checked in Figure 7. From such fitting it is deduced that:

$$k_{s,\ cat} = 35 \pm 10\ m^3/kg\cdot h \tag{19}$$

$$k_{s,\ th} = 6 \pm 3\ m^3/kg\cdot h \tag{20}$$

Figures 6 and 7 validate thus the kinetic model given by Eqs. 4, 5 and 6. Values of the corresponding kinetic parameters are given by Eqs. 13, 15, 19 and 20, which are self-consistent.

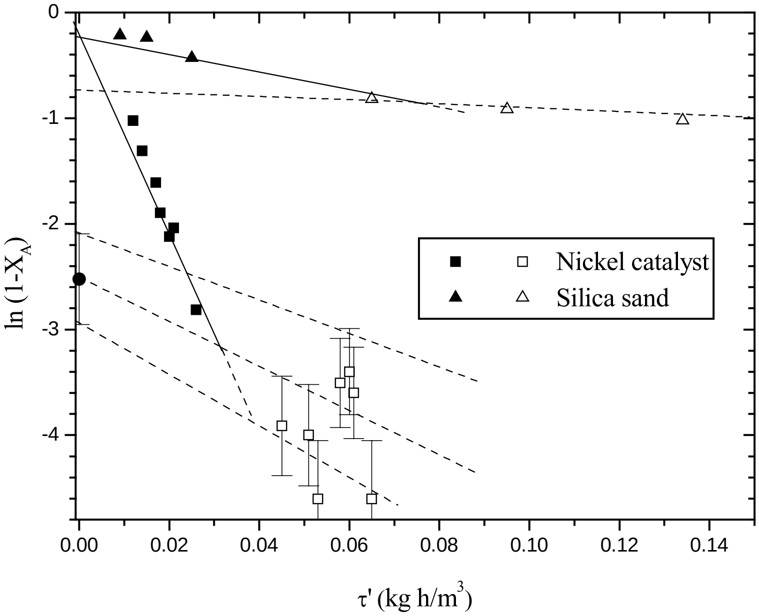

*Figure 6. Checking of equations 10, 11 and 12 (● point = ln [1 – $(A_{1,0}/A_0)_{840}$] = ln (1 – 0.92)).*

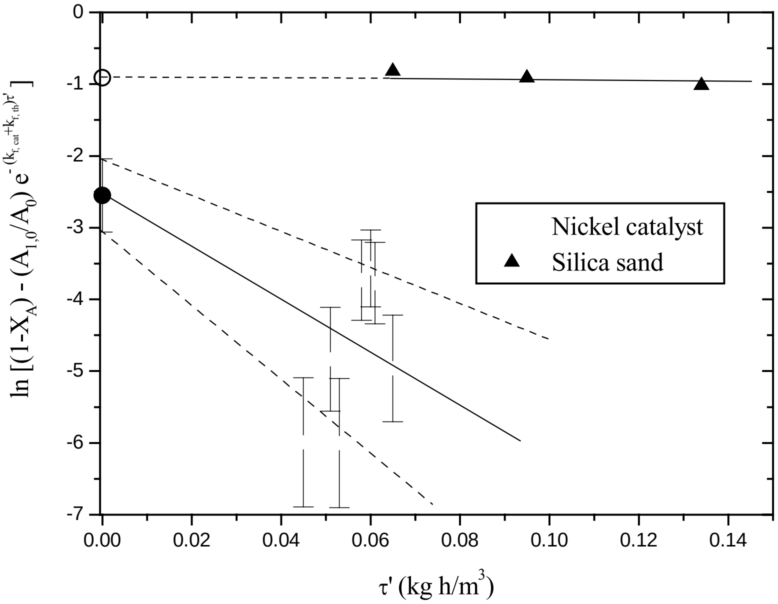

*Figure 7. Checking of Eq. 18 [● point = ln (0.08); o point = ln (0.40))].*

# 5. Deficiencies in this modelling

Some deficiencies in the analysis here presented are:

- In the experiments carried out with silica sand the temperature (~790 ºC) in the bed was somewhat lower than when nickel-catalyst was used (840 ºC). Wall effect was not the same in both sets, as it can be seen in Figure 4.

- Particle size of the silica sand (1.6–1.0 mm) was clearly lower than that of the nickel catalyst (14–7 mm, commercial full size). Some effects based on the external surface (such as thermal transfer) for a given space-time are different for both solids, thus. It is higher in the solid of smaller particle size (higher external surface by unit of mass), silica sand, than in the nickel catalyst.

This b) effect compensates in part the effect indicated in a) and it is thought that the overall modelling, the values of the kinetic parameters and the following main conclusions, may be accepted.

- The reactivity of tar, which is going to generate the values of the four kinetic constants involved in this model, depends on the tar composition, which in turn depends on gasifier design and operation. To avoid this dependence, a kinetic model based on tar composition similar to that recently presented by Corella et al. (32) should be used. A model more complex than the one here presented would have a more universal application. It is recognized, of course, but such type of models requires a deep knowledge of the evolution of the tar composition with space-time, which in turn requires complex experiments and a careful tar characterization before and after the catalytic reactor. It might be out of the possibilities of many laboratories or institutions and might not worth the effort.

The model here presented has some limitations thus, but some advantages too: this 2-lump model is not very difficult to understand and use, and it means a small but clear step forward in the modelling of the catalytic tar abatement.

# 6. Conclusions

The kinetic constants, with units of $m^3_{(Tb,\ wet)}$/kg·h, of the elimination reaction(s) of the easier-to-destroy tars (here called $A_1$) and the more difficult-to-destroy tars ($A_2$) are then:

| | $k_{fast}$<br>($A_1$) | $k_{slow}$<br>($A_2$) |
|---|---|---|
| catalysed<br>(ICI 46-1) | 80 ± 10 | 35 ± 10 |
| thermal | 14 ± 2 | 6 ± 3 |

The difference between $k_{f,\ cat}$ and $k_{s,\ cat}$ is not very big, but it exists and it is important. To split the one-lump tar (A) in two lumps or 'classes' of species ($A_1$ and $A_2$) is a small but clear improvement, thus.

The above said conclusion can be applied to the thermal reactions too although the difference is not so big as for the catalysed reactions. The kinetic constants of the thermal (elimination) reactions of $A_1$ and $A_2$ indicate again a slightly different thermal behaviour of such lumps.

When the values of the kinetic constants for the thermal reactions (both for $A_1$ and $A_2$) are compared with those for the catalysed ones it is observed how such kinetic constants are not so different as one might have thought initially. The value of 14 respect to (80 + 14) means a noticeable contribution of the thermal reactions. It might be further concluded that the silica sand is not so inert or that the catalyst is not so active as it was thought but it has to be remembered that these concrete values are probably due to the big particle size of the commercial catalyst here used which in this case implies a very low effectiveness factor.

Finally, Eqs. 16 and 17 indicate that the relative amounts of $A_1$ and $A_2$ present in tar (A) are not a constant but they depend on the reaction temperature. For instance, the percentage of the less reactive tars ($A_{2,\ 0}/A_0$) decreases from 40 % to 8 % (Eq. 17) when the temperature is increased from 790 to 840 ºC, which is easy to understand.

# Acknowledgement

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# Nomenclature

| | |
|---|---|
| A | Tar content in the flue gas (g/m$^3$) |
| $A_0$ | Concentration of tar at the inlet of the catalytic reactor (g/m$^3$) |
| $A_1$, $A_2$ | Concentration (in the flue gas) of the first (easy-) and second (hard-to-destroy) lump in tar, respectively (g/m$^3$) |
| $A_{1,0}$, $A_{2,0}$ | Ditto, at the inlet of the catalytic reactor |
| $C_{tar}$ | Tar content in the flue gas (g/m$^3$) |
| dp | Particle size (mm) |
| $E_a$ | Activation energy (Arrhenius law) for the catalytic removal of a pure substance related to tar (kJ/mol) |
| $E_{app}$ | Apparent activation energy for the overall tar removal (kJ/mol) |
| ER | Equivalence ratio, defined as the air-to-fuel ratio used in the gasifier divided by the air-to-fuel ratio for the stoichiometric combustion, dimensionless |
| GHSV | Gas hourly space velocity [m$^3$/kg h] |
| k, k', k'', k''' | Kinetic constants for reactions in network shown in Figure 1 |
| $k_{app}$ | Apparent kinetic constant for tar removal [(m$^3$ ($T_{b,\ wet}$)/(kg cat.h))] |
| $k_{th}$, $k_{cat}$ | Kinetic constants for thermal and catalytic, respectively, elimination of tar, [m$^3$ ($T_{b,wet}$)/kg cat h] |
| $k_f$ | Kinetic constant for the fast disappearance of $A_1$, defined by Eq. 4, [m$^3$ ($T_{b,wet}$)/kg cat h] |

| | |
|---|---|
| $k_s$ | Kinetic constant for the slow disappearance of $A_2$, defined by Eq. 5, [$m^3$ ($T_{b,wet}$)/kg cat h] |
| n, $n_{th}$, $n_{cat}$ | Order of a reaction, for the thermal reaction and for the catalysed reaction, dimensionless |
| Q | Gas flow rate [($m^3$($T_{b, wet}$)/h)] |
| $T_b$ | Temperature measured in the centre of the catalytic bed (ºC) |
| ($-r_A$), ($-r_{tar}$) | Reaction rate of the overall disappearance of tar [g tar/kg cat. h] |
| $X_{tar}$ | Tar conversion, dimensionless |
| $y_{H2O}$, $y_{H2}$, $y_{CO2}$ | Weight fractions of $H_2O$, $H_2$ and $CO_2$, respectively, in the flue gas, dimensionless |
| W | Weight of catalyst (kg) |

*Greek symbols*

| | |
|---|---|
| $\tau$ | Space time, defined as W/Q [kg h / $m^3$ ($T_b$,wet)] |
| $\tau'$ | Space time including the effect of the hot wall: $\tau$ + wall effect [kg h/$m^3$ ($T_b$,wet)] |

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# Characterisation of waste fuels with TGA

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## Abstract

In this study an attempt is made to develop a method to determine the composition of an unknown waste mixture. The basic idea is that the waste fuels are composed of some major components, e.g. paper, plastic, textile and biomass. These single components and waste mixtures are characterised by thermogravimetric analyser (TGA). The measured weight loss curve (TG-curve) or its differential (DTG-curve) is used as a fingerprint of each material. To obtain the composition of an unknown waste mixture the fingerprints of single components are correlated with that of the mixture. It is assumed that the mixture curve is obtained as a weighed sum of the curves of its single components – in other words that no interaction takes place between the single components when they are mixed.

Synthetic four-component mixtures with a known composition were prepared. The weighed-sum method was first applied to the TG curves and then to the DTG curves. The results show that modelling with the DTG curves distinguishes better between materials decomposing in a narrow temperature range. However, the decomposition temperature must differ with tens of degrees before the model can set two materials apart. Therefore, another approach is required. Instead of trying to distinguish between all single waste components, one could divide the single components into classes based on their chemical structure and DTG curves. This will be studied closer in the future.

*Keywords:* waste, characterisation, TG, DTG, thermogravimetry

# 1. Introduction

(Co)-combustion of waste in large-scale boilers is an attractive alternative to reduce the amount of waste disposed on the landfills. In the Netherlands, most waste streams are already combusted but in waste incineration plants, which achieve considerably low energy conversion efficiencies (20–28 $\%_{el}$). By co-combusting waste in large-scale boilers one can achieve higher efficiencies and simultaneously contribute to the requirements of Kyoto agreement. However, co-firing with waste fuels can cause the power plant operator many operational problems like slagging, fouling and high-temperature corrosion in the boiler, increased emissions, and more difficult utilisation of by-products. Some of these problems might be prevented, if the composition of the secondary fuel was available. This would in turn make it possible to predict the combustion behaviour of the waste fuel.

The goal of this study is to develop a method for determining the composition of an unknown waste mixture. The basic idea is that waste fuels are composed of some major components. These single components are characterised with a thermogravimetric analyser (TGA), which measures the loss in sample weight when the sample is heated in controlled atmosphere. The weight loss curve (TG) or its differential (DTG) is used as a fingerprint of each component. Fingerprints of single components are correlated with that of a mixture in order to find out the composition of the mixture. It is assumed that the single components do not react with each other when they are mixed, i.e. the TG or DTG curve of a mixture is obtained as a weighed sum of the curves of its single components (Cozzani et al. 1995).

Synthetic mixtures with a known composition were prepared and the weighed sum method was applied. The measured single component mass fractions were compared with the modelled values. It was found out that DTG curves could better distinguish between materials that decompose in a narrow temperature range. In the presence of PVC, the weighed sum method failed due to interactions that take place between PVC and cellulose. For example, the mixture of PVC/newspaper reacts at lower temperatures than either of its components alone. In section 2 the experimental procedure and the weighed sum model are described. The results are discussed in section 3 and the conclusions are drawn in section 4.

# 2. Experimental procedure and used model

The single components studied were separated from the every-day waste stream in Delft, and some samples were obtained from the University of Stuttgart (Germany). The thermal decomposition curve, which was used as a fingerprint of each material, was measured by a thermobalance SDT 2960. Samples obtained from Stuttgart were received already grinded to a sample size of 1.5 mm and those from Delft were cut into pieces of 1–2 mm. 10 mg of sample material was evenly distributed on an open alumina sample pan. The samples were heated at a constant heating rate of 20K/min up to 900 °C while the thermobalance was continuously purged with nitrogen at 100 $\mathrm{ml_N}$/min.

## 2.1 Weighed-sum method (WSM)

The simplest approach to correlate the thermal decomposition curve of a mixture with the curves of its single components is the Weighed-Sum Method (WSM). It assumes that a mixture behaves as a sum of its components. Mathematically this is formulated as (Cozzani et al. 1995)

$$Y_{mix} = x_1 y_1 + \ldots + x_n y_n = \sum_{i=1}^{n} x_i y_i \tag{2.1}$$

where

$Y_{mix}$ = Predicted remaining weight fraction of the mixture: $\mathrm{m_{mix}(T)/m_{mix,0}}$
$x_i$ = Mass fraction of component *i* in the mixture: $\mathrm{m_i/m_{mix}}$ (=constant)
$y_i$ = Measured remaining weight fraction of component *i*: $\mathrm{m_i(T)/m_{i,0}}$.

Subscript *mix* refers to a waste mixture, *i* to one single component, and *n* is the number of single components taken into account. To solve the weights of this sum ($x_i$), i.e. the mass fractions of the single components, the least squares method is used. It minimises the error between the measured and the modelled values. To avoid the cancelling of negative and positive errors, the sum of squared residuals $S_R$ is minimised:

$$S_R = \sum_{N_{data}} \left[ y_{mix} - Y_{mix} \right]^2 = \sum_{N_{data}} \left[ y_{mix} - \sum_{i=1}^{n} x_i y_i \right]^2 \tag{2.2}$$

Equation (2.2) is summed over all the *N* data points.

WSM is applied separately to TG and DTG curves. A built-in template in Microsoft's Excel called Solver is used to solve the mass fractions. It can solve minimise/maximise problems by changing values in certain cells of the spreadsheet. In our case, the sum of the squared residuals $S_R$ (2.2) is minimised by changing the mass fractions of single components ($x_i$).

# 3. Results

A wide range of single waste components was characterised with the TGA. To test the WSM, synthetic mixtures were prepared. Their thermal decomposition behaviour was also analysed by the TGA and the WSM was applied. Several synthetic mixtures were analysed but only two of them are discussed here due to the limited space.

The first mixture consisted of banana peel, newspaper, PET, and HDPE. The results are shown in Figure 1. The bar graph on the top shows the measured mixture composition in percentages. In the case on the left-hand side more or less 25% of each component was mixed, whereas in the case on the right almost 50% of the mixture was banana. Besides the measured composition, TG- and DTG-modelled mixture compositions are shown. Below the bar graphs, measured and modelled TG- and DTG-curves of both cases are drawn. In addition, a "calculated" curve is plotted. It is calculated based on the measured single component curves and mass fractions.

In the case on the left, both TG and DTG curves predict the single component mass fractions quite well. In the case on the right-hand side, modelling with TG-curves results in no newspaper but an increased share of banana. This might be because the beginning of the weight loss curve of banana and newspaper has the same shape; only that banana starts decomposing about 30 °C earlier. However, the DTG curves predict the mass fractions properly. Modelling with DTG curves can thus better distinguish between banana and newspaper whereas modelling with TG-curves cannot set them apart in all cases. This suggests that DTG-curves are more suitable for the modelling.

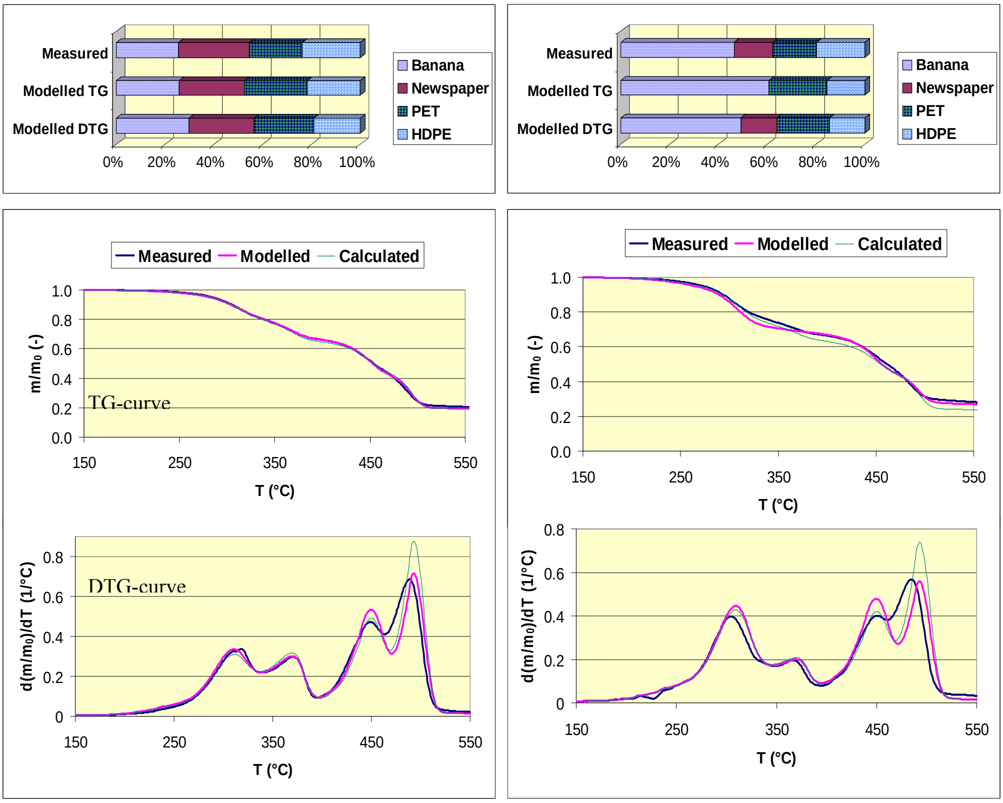

*Figure 1. Two cases of banana-newspaper-PET-HDPE mixture modelled based on TG- and DTG-curves.*

PET in the four-component mixture was replaced with PVC and the measurements were repeated (Figure 2). The "calculated" mixture curve is the theoretical mixture DTG-curve if there was no interaction between PVC and other components. Figure 3 shows the single components of this mixture. The DTG-peak of pure newspaper occurs after 350 °C but in the mixture in Figure 2 this has disappeared. Figure 3 also shows a clear shoulder on the right-hand side of the first PVC DTG-peak, around 350 °C. This peak does not exist in the mixture. Interaction between PVC and cellulose has also been observed by McGhee et al. (1995) and Matsuzawa et al. (2001).

In the case on the left-hand side (Figure 2), both TG and DTG models under-predict the share of newspaper and over-predict that of banana. The amount of PVC is also over-predicted. In the case on the right-hand side the fraction of banana was increased to more than 40%. Using the TG curves in the modelling cannot distinguish between banana and newspaper and results in no newspaper but increased share of banana. DTG curves predict a small share of newspaper but the share of banana is again over predicted.

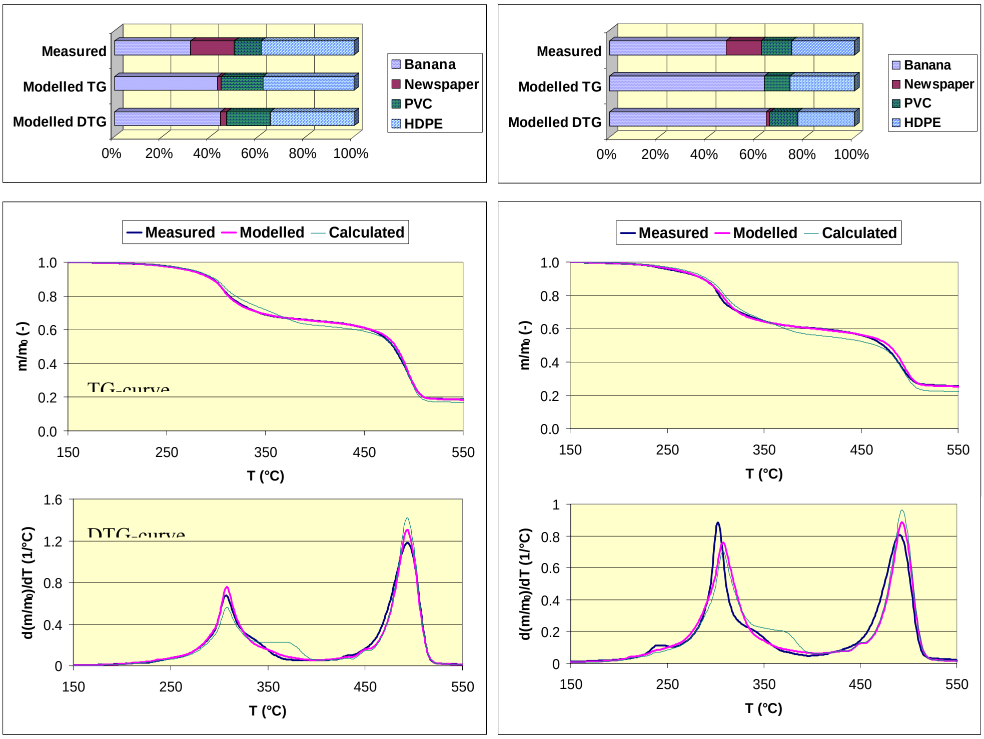

*Figure 2. Two cases of banana-newspaper-PVC-HDPE mixture modelled based on TG and DTG curves.*

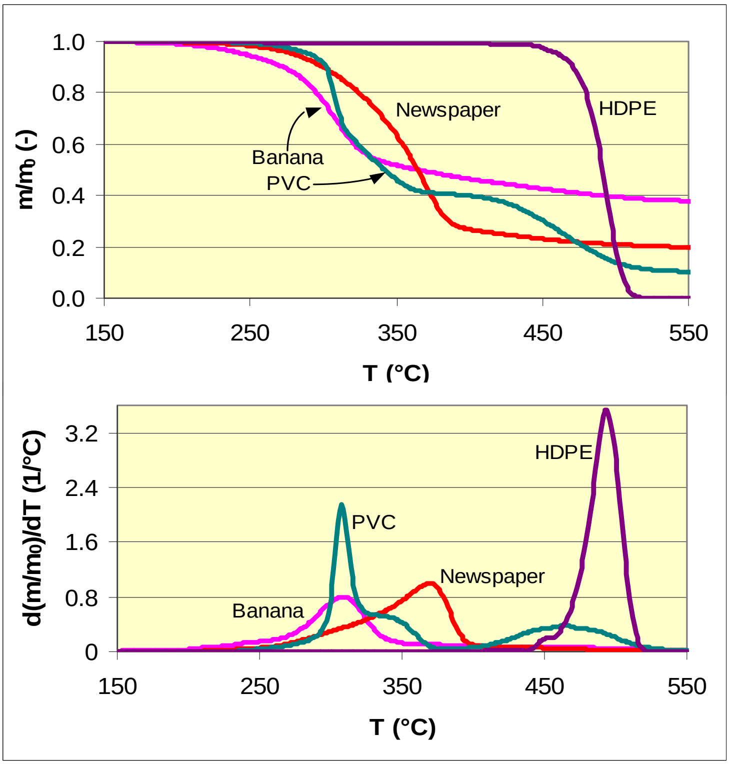

*Figure 3. TG and DTG curves of single components from mix in Fig. 2.*

## 4. Conclusions

These examples show the limitations, but on the other hand the possibilities to use the WSM to predict the composition of a mixture. The method can distinguish between materials, whose TG or DTG curves differ from each other significantly. This means that if the decomposition curves of two materials are of the same shape, then the decomposition temperatures must differ with tens of degrees. Modelling with the DTG curves gives better results than modelling with the TG curves. WSM fails if the single components interact with each other when mixed. Splitting the materials into more rough classes might be a useful approach. Instead of trying to distinguish between all single waste components, one could divide the single components into classes based on their chemical structure and DTG curves. One class could be for example “wood and its derivatives”. This will be studied closer in the future.

# Acknowledgements

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# Optimisation of two-stage combustion of high-PVC solid waste with HCl recovery

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## Abstract

A process for two-stage combustion of high-PVC solid waste with HCl recovery is being optimised at Helsinki University of Technology, based on experimental evidence that PVC can be decomposed into HCl and a low-chlorine or chlorine-free residue by heating to temperatures of around 300–350°C. A theoretical analysis suggested that the process may have a thermal efficiency of ~ 37% and nearly full recovery of the HCl, depending on pyrolysis temperature, PVC content in the solid waste and the moisture content in the solid waste. Results from these process simulations were used to construct a lab-scale test facility at our lab in Otaniemi, Espoo. The facility (approx. 40 kW fuel input) contains two fluidised-bed reactors plus heat exchangers and other side equipment. In a bubbling fluidised-bed pyrolysis reactor operated with nitrogen at ~ 350 °C the drying and dehydrochlorination of PVC takes place, and in a circulating fluidised-bed combustor operated at 800 ~ 850 °C the char from PVC plus the other fractions of the fuel are combusted. Product gases from both reactors are analysed on-line (using FT-IR) in order to evaluate process performance and especially to detect HCl from the second reactor. The first results from this experimental assessment study, which was part of the Finnish National Research Programme "Waste to REF and Energy" (1998–2001), are reported in this paper.

# 1. Background and objectives

Energy recovery from combustion of solid wastes with high concentrations of chlorine is complicated considering both technical and environmental aspects. In general, waste-derived fuels should contain less than 2 wt% chlorine in order to avoid problems with the operation of an incinerator, or combustor or gasifier. Fortunately, PVC, a major source of chlorine in most waste streams, behaves different from most other plastic materials. Due to a relatively low activation energy for thermal degradation, PVC is devolatilized (pyrolysed) at a lower temperature than most other plastics, which maybe explains, why PVC forms a 'char'/cokes'-like residue. Presumably, in the temperature range of 200 to 400 °C the only process taking place during pyrolysis of a waste-derived fuel is the decomposition of PVC into HCl and a 'char'/'cokes' like-residue. This chlorine-free residue can then be burned as a usual waste-derived solid fuel. Many tests showed that 90% or more of the chlorine of PVC is released as HCl at a temperature of 350–400 °C, see, e.g. [1]. If the pyrolysis temperature increases over 400 °C, a second stage of degradation will break down the intermediates produced after dehydrochlorination, giving benzene and many other hydrocarbons.

The objective of this work is to demonstrate a process for two-stage waste combustion [2] that makes use of these properties of PVC. In short, the two-stage process involves the following chemistry:

at low temperature:

$$\text{PVC} + \text{energy E1} \rightarrow \text{HCl} + \text{hydrocarbon residue} \qquad \text{(R1)}$$

at high temperature:

$$\text{hydrocarbon residue} + \text{air} \rightarrow \text{energy E2} + CO_2 + H_2O \qquad \text{(R2)}$$

Other components in the waste fuel mixture are to remain unchanged during process (R1), apart from vaporisation of moisture, to be combusted together with the char residue from PVC at higher temperature. A process scheme based on this principle, composed of two fluidised bed reactors plus heat recovery is given in Figure 1.

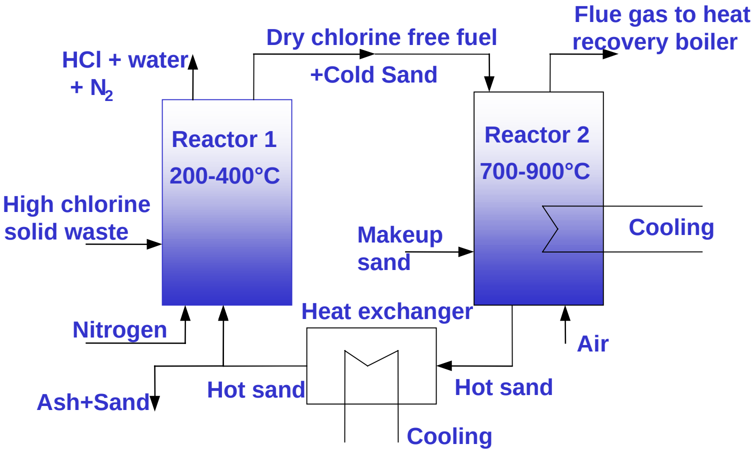


*Figure 1. Simplified process diagram.*

Dehydrochlorination of the fuel takes places in a bed of hot sand, fluidised with nitrogen in the first reactor at 200–400 °C. Using an oxygen-free fluidisation gas blocks the chemical routes to dioxins and furans. Chlorine is released as a gaseous mixture of HCl with the moisture from the solid waste. The solid mixture of sand and chlorine-free waste-derived fuel is fed to the second reactor where the chlorine-free waste-fuel is burnt at 700–900 °C. This heats up the sand and gives additional heat for steam generation. The hot sand is fed back to the first reactor after heat exchange, reducing its temperature to what is needed in the first reactor. Major advantages of this process are that no hot HCl-containing gases have to be handled, and problems related to calcium-based sorbents for HCl capture are circumvented. HCl is recovered for further use.

Energy efficiency optimization analysis using a Process Simulation Program (PROSIM$^{®}$) [3] for various mixes of (wet) PVC and (wet) wood gave a theoretical thermal efficiency of approx. 36%, depending on pyrolysis temperature and PVC content. The heating value of the chlorine-free char residue from a typical PVC is approx. 38 MJ/kg (LHV) [1]. HCl recovery can be above 90% at pyrolysis temperatures above 310 °C, combined with low uncontrolled HCl emissions that may be below legislative emission limits. That work was followed by a project aiming at further optimising the process from a theoretical and, more importantly, an experimental assessment point of view. Further theoretical studies involved a comparison with conventional waste incineration – see, e.g. [4]. The experimental assessment involved the design, construction and testing of a lab-scale facility in our lab at Otaniemi. The test facility and some first experimental results are described below.

## 2. The experimental facility

A test facility was built in Otaniemi, based on 1) kinetic data on de-hydrochlorination for a typical PVC and combustion of PVC-char and wood and 2) the process optimisation calculations for a 40 $MW_{thermal}$ plant design case [3], down-scaled to 40 kW thermal fuel input. A schematic design, with measurement points for temperature, pressure, pressure drop, flow velocity and pH is shown in Figure 2. Reactor 1 is a bubbling FB reactor (i.d. 0.4 m, height 0.8 m) fluidised with nitrogen.

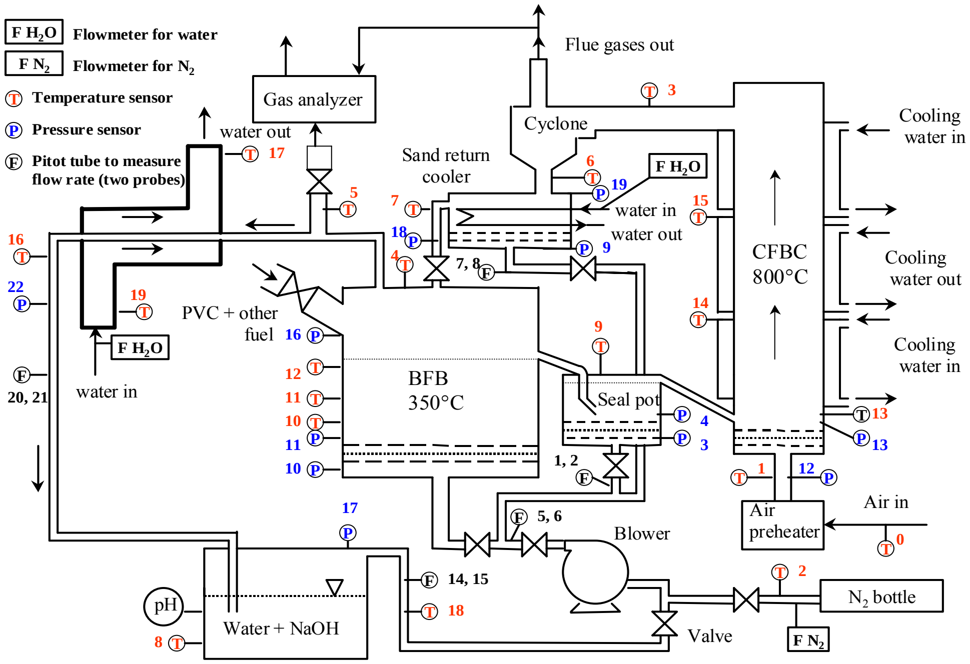


*Figure 2. Process diagram of the test facility including measurement points.*

This BFB is operated in the temperature range 300–400 °C; 350 °C may be the optimum temperature for producing low-chlorine or chlorine-free fuel in this dehydrochlorination reactor, at a solids residence time of approx. 30 minutes, without significant pyrolysis of other combustible matter [1]. Silica sand (mean particle size 0.3 mm) is used as bed material. Reactor 2 is a circulating FB combustor (i.d. 0.11 m, height 2.3 m). The fluidizing gas is air; the reactor operates at a temperature of 800–850°C. Combustion air is preheated to approx. 600°C by heating coils until char from the first reactor can provide sufficient combustion heat. The water cooling system of this CFBC is divided into three parts in order to cool separate parts of the reactor when necessary. The distributor plates used in both FB reactors are of a perforated type, *i.e.* two perforated plates sandwiching a metal screen.

Heating coils mounted around the BFB reactor heat up the bed during a cold start. The sand is collected from the CFBC exit gas by a cyclone operated at about 15 m/s inlet velocity, and is cooled (with water) to below 400 °C before returning to the BFB in an FB heat exchanger fluidised with nitrogen. This heat exchanger will also prevent pyrolysis gases from passing to the flue gas exit. A seal pot-type non-mechanical valve between the BFB reactor and the CFBC prevents flow of gases between the two reactors. The pyrolysis gases from the BFB are cooled to 80 °C by heat exchange with water and then fed to an NaOH/water solution to trap the HCl, giving NaCl and water (on a larger scale, HCl is recovered as hydrochloric acid). By measuring the pH of the solution the HCl concentration can be followed.

Concentrations of HCl and several other species in the pyrolysis gas from the BFB pyrolyser and in the flue gases from the CFBC were measured with a Fourier transform infrared (FT-IR) spectrometer, Gasmet Instruments type Temet DX-4000. This analyser was calibrated for $H_2O$, $CO_2$, CO, HCl, $CH_4$, HBr and NO, $NO_2$ and $N_2O$. Later, other compounds were added to the signal analysis database, most importantly benzene, $C_6H_6$. Figure 3 gives an impression of the test facility showing (at the front) the blower for the fluidisation gas for the bubbling bed reactor, the exhaust gas pipe from the top of the cyclone, left from the cyclone the CFBC, and the two gas sampling and cooling lines.

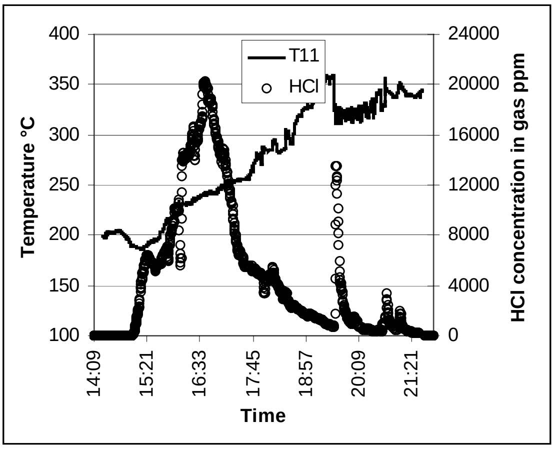
*Figure 3. Impression of the test facility May 15, 2002.*

## 3. A test result: PVC pyrolysis, 4 April 2002

This pyrolysis test involved pyrolysis of a bottle-grade PVC in nitrogen. The chemical composition of this PVC was analysed to be 42.51% C, 5.35% H, 1.08% O, 50.93% Cl, 0.17% Sn (dry wt%). This PVC contains small amounts of Sn-based stabiliser and some MBS stabiliser. A bed of 72 kg sand was heated up during fluidisation with nitrogen. When the temperature had reached 190 °C, 728 g of PVC (*i.e.* 1 wt% of the total bed) was fed to the bed. At that point the concentration of $H_2O$ and $CO_2$ were approx. 5 vol% and a few 100 ppm-vol, respectively. The gas flow through the BFB was approx. 10 liter/s (at 30 °C). The temperature in the BFB was increased at about 30ºC/h until around 350 ºC. Unfortunately, stray currents and zero looping, giving small electric currents in the NaOH solution, made it impossible to obtain a useful on-line pH signal. Thus, repeated samples had to be taken. During the whole test the temperature of the NaOH/water solution was below 50 °C.

The following gases were included in the FT-IR data analysis: $H_2O$, $CO_2$, HCl, HBr, $CH_4$, CO, NO, $NO_2$, $N_2O$, $C_6H_6$ and $C_2H_2$. It was found that only the gases HCl, benzene ($C_6H_6$) and CO were present in significant amounts. For $CO_2$ and $H_2O$ the concentrations were measured to be zero over the whole time interval. The release of HCl is plotted together with temperature in Figure 4. It shows that when at around time 19:40 some HCl is released, apparently from some PVC that was not properly mixed with the rest of the bed, a sudden decrease in temperature is measured. This may be due to the endothermic dehydrochlorination of PVC: it is seen also around time 15.00.

Comparing the release of HCl with that of CO and benzene shows that the release of HCl is always one or two orders of magnitude higher than that of CO or benzene. On average, for every 1 mole of HCl released, the releases of CO and $C_6H_6$ are 0.034 and 0.059 moles, respectively. The oxygen needed for CO formation apparently comes from PVC; no other oxygen-containing compounds were detected. It is possible that CO and benzene circulate in the loop BFB → NaOH/water tank → recirculation blower → BFB, being much less water soluble than HCl. This implies that the measured concentrations overestimate the release of CO and benzene. The release of HCl from the PVC was also followed by the neutralisation with NaOH and following the pH in the aqueous solution. Based on pH and consumption of NaOH for neutralisation, the cumulative release of HCl, i.e. the fractional dehydrochlorination of the PVC could be followed, see Figure 5. Unfortunately no pH data point was obtained after the sudden HCl release at around 19:40, which would have brought the release of HCl from PVC to a higher value than the 75% shown. A more detailed analysis of the results is ongoing – it appears that very small amounts of styrene and butadiene (from the MBS stabiliser) are present in the product gases as well. Two samples of char particles from the bed after the test were sent for chemical analysis (C, H, Cl). This showed a chlorine content of less than 0.1 wt% in the residue at a chlorine to carbon mass ratio < 0.001 kg Cl / kg C.



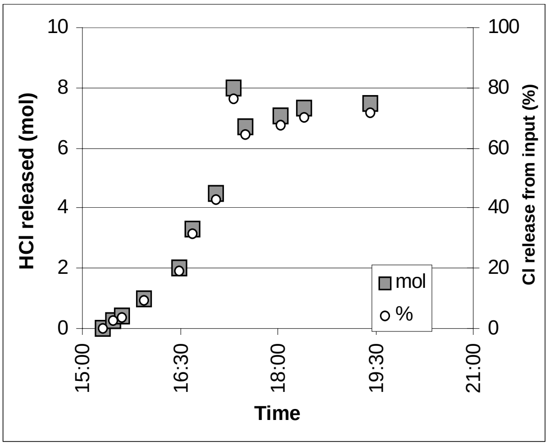


*Figure 4. Release of HCl and BFB reactor temperature $T_{11}$ versus time.*

*Figure 5. Release of HCl and fractional release of chlorine from pH measurement & neutralisation (NaOH.)*

# 4. Conclusions

A lab-scale test facility for two-stage combustion of high-PVC solid waste [2] was built and taken into operation. The pyrolysis test with 100% bottle-grade PVC shows that char with a chlorine content of less than 0.1 wt% (Finnish REF-1 class recovered fuel) can be produced, whilst HCl may be recovered. Testing of the total system is ongoing.

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# Power production from waste and biomass IV

## Advanced concepts and technologies

Abstract

The seminar on Power Production from Waste and Biomass IV, with emphasis on advanced concepts and technologies, was held on 8–10 April 2002 in Espoo, Finland. The meeting was organised by VTT Processes in co-operation with EC DG TREN, Novem (from the Netherlands), IEA Bioenergy Task 36, Tekes and the Finnish Ministry of Trade and Industry.

Overviews of the European waste policies, waste management and waste-to-energy practices were given. Most of the relevant directives were presented including the directive concerning integrated pollution prevention and control (IPPC). The directive on waste incineration and its practical implications for fluid bed combustion and gasification of solid recovered fuels were discussed actively in the meeting. An overview of traditional massburning of mixed waste was given. The main focus, however, was on advanced process concepts and technologies. For example, in Finland, recovered fuel production and cofiring, based on either direct combustion in fluid bed boilers or pregasification, have been introduced successfully at several power plants. Fuel specifications are controlled by the Finnish recovered fuel standard. In Europe, a project for preparing the future CEN standard was presented and discussed. Experiences and R&D activities in the areas of fluid bed combustion and gasification, including gas cleaning and monitoring practices, were presented.

Modern waste-to-energy concepts will play an important role in advanced waste management business concepts. Future integrated waste recycling and energy production concepts, based on source separation and recovered fuel production, were presented. New R&D results were also presented concerning additional paper and plastic recovery from commercial and industrial waste, typically packaging waste.

National waste management policies and practices in the Netherlands and in Finland were presented based on the bilateral information exchange between Novem of the Netherlands and Tekes of Finland. The proceedings include the presentations given by the key speakers and other invited speakers, as well as papers based on some of the poster presentations.

Keywords

bioenergy, municipal solid waste, residues, recovered fuels, combustion, gasification, cogeneration, cofiring, emissions control, recycling

Activity unit

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The expert meeting on Power Production from Waste and Biomass IV, with emphasis on advanced concepts and technologies, was held on 8–10 April 2002 in Espoo, Finland. The meeting was organised by VTT Processes in co-operation with EC DG TREN, Novem, IEA Bioenergy Task 36, Tekes and the Finnish Ministry of Trade and Industry.

In Europe, several directives will set targets for future waste policy. The directive on landfilling will reduce significantly the volumes of combustible fractions. On top of traditional massburning of mixed waste, there is a need for advanced concepts with higher material recovery and higher efficiency in energy production. In the future, instead of mixed municipal solid waste, quality controlled recovered fuels will be produced and used as such or co-fired in existing power plants. The target of increasing renewable energy production in Europe from 6 to 12% by 2010 will boost R&D, future investments and business opportunities. Modern waste treatment practices will have an important role to play in meeting the goals of the Kyoto Protocol.

Indicative of the interest in power production from waste and bioenergy was the participation of about 160 specialists from 19 countries. Industrial companies were well represented, indicating the existence of good business opportunities in this field. The next meeting on power production from waste and biomass will be organised in 2005.

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