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Fuel and energy recovery

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Foreword

This study entitled "Fuel and energy recovery" is the first in a series evaluating sustainable recovery. It aims to contribute to the Waste Strategy of the Commission which clearly prioritises:

Prevention by source reduction > Re-use and recovery > Safe disposal.

The principle of waste prevention and minimisation is clearly the top priority. However, a "Zero-Waste-Society" will not exist and a coherent approach for integration of minimisation and the best possible recovery of the unavoidable waste with the least environmental impact is needed in order to minimise landfill.

Many of today's best available technologies for material recovery and energy recovery, however, are still quite far away from really efficient and clean systems and there is still much room for improvements. After all, material recovery and energy recovery technologies and processes are not independent. They interact in such a complex way that they cannot be optimised independently.

The JOULE-THERMIE programme has successfully demonstrated that significant energy savings and emission reductions can be achieved if energy and material production are integrated. This is true whether the industrial process produces new products from raw materials or from recovered (secondary) products. Life cycle inventories and assessments have shown to be quite complicated because of this complex interaction and dependence.

Optimising the whole industrial production chain for reducing the consumption of energy and raw materials and for reducing the emission of CO_2 and pollutants has been a strong pillar of the JOULE-THERMIE programme (in the sectors of rational use of energy in industry, power production from solid fuels and renewable energies) and is expected to continue in the specific programme "Preserving the Ecosystem" (1998-2002) with an increased importance on the reuse and recovery of used products in the industrial processes or in power supply processes. Additional weight should also be put on improving industrial production so as to reduce the production of wastes at the source.

This report aims at developing a scientifically and technically sound approach of the subset "Fuel and Energy recovery". If successful, further studies should extend this concept to material recovery, then to the interaction of energy and material production processes and ideally to an optimised end-of-life design of products and processes. It could thus guide the Commission in supporting and stimulating the development of new, clean and efficient industrial and power production processes, which in turn could help to better and faster implement the EU waste management, CO_2-reduction and energy policies.

P. de Sampaio Nunes
Director Energy Technologies
THERMIE-programme

Parties involved in consortium

An international consortium supports this study on **fuel and energy recovery** from non-hazardous, combustible waste in the THERMIE programme of DG XVII of the European Commission under contract DIS-1375-97-FI. The parties of this consortium are:
- Association of Plastics Manufacturers in Europe, APME (Belgium);
- Borealis Polymers Oy (Finland, co-ordinator);
- Ciments d'Obourg (Belgium);
- Compania Internacional de Plantas Papeleras, Coinpasa (Spain);
- Finnish Forest Industries Federation, FFIF (Finland);
- Alstom Energy (France);
- Imatran Voima Oy, IVO (Finland);
- Norrköping Miljö & Energi, NME (Sweden);
- NOVEM (Netherlands);
- Tetra Pak Fibre Systems AB (Sweden);
- TNO Institute of Environmental Sciences, Energy Research and Process Innovation (TNO-MEP, the Netherlands, 1st Contractor);
- UK Waste (UK);
- nv VAM (the Netherlands).

Statement by the Project Consortium

The draft report "Fuel and Energy Recovery" was presented and discussed at a Workshop on November 26, 1998 in Brussels, gathering 75 stakeholders. A summary, presentation material and a list of participants are included as Appendix B of this final report.
Based on the presentations and the discussion at the Workshop, where it was generally agreed that legal terminology and definitions need to be improved, the Project Consortium concludes:

A. Position on EU Policy Issues:

1. Waste is a resource that should be utilised in the most rational and economic way by processing into useful products for an open market. The EU energy policy should include wastes as CO_2-neutral fuel and energy resources. Wastes are not always mixed or contaminated. A differentiated regulation for treatment of various wastes should be included in the EU waste management policy, e.g. for pre-use waste vs. post-use waste, untreated waste vs. pre-treated waste and for "waste for recovery" vs. "waste for disposal".

Material origin	Raw material	Semi-finished product	Finished product	*Product destiny*
Natural resource	Renewable Fossil		- Material products - **Fuel products** - **End-use energy**	*Market*
Production residues = Scrap = Pre-use waste	Mono-material ***- "Clean waste" with known fuel properties*** Multi-material	*- "Alternative fuel"*	- Material products ***- "Recovered fuel"*** **- End-use energy**	*Market*
Post-use waste	Selected *- Industrial* *- Commercial* *- Household* Mixed	*- "Alternative fuel"*	- Sec. raw material - Material products ***- "Recovered fuel"*** **- End-use energy**	*Market*
"Waste status"	*Untreated waste*	*Pre-treated waste*	*Treated waste* **= Product**	

Key terms regarding Fuel and Energy in production and recovery operations

2. Specified products from mechanical, chemical, thermal or biological recovery operations (waste treatment) should not be subject to waste legislation. Secondary fuels are generally considered to be pre-treated waste (*alternative fuel*). As for any other recovery operation (including recycling), it should also be possible

to process selected non-hazardous combustible waste into standardised "Recovered Fuel" product for the market.

3. *Direct incineration* of mixed MSW with *"recovery of the heat"* for production of end-use energy is an environmentally sensible R1 operation, i.e. *" use principally as fuel.... "*, and so is the use of selected pre-treated combustible waste for high efficiency production of material or energy products *(co-incineration)*. The latter needs to be promoted and not to be restricted by costly technical and monitoring requirements, which are not essential for environmental protection.

4. The first priority for waste management is "prevention by source reduction". The same principle is included in the "Cleaner Technologies" concept for process development. A continuous improvement of overall efficiency and a reduction of overall emissions for all processes is essential for Sustainable Development.

5. Emission limits for energy production plants, including waste incinerators for energy recovery, should be related to output energy in order to promote efficiency. Increased control on input should allow less control on emissions.

6. The 5th Framework programme for RTD of the EU should further support development of advanced recovery technologies with higher efficiency and lower emissions, especially avoiding formation of pollutants at source, not by end-of-pipe cleaning technology.

B. Proposal for action regarding the Draft Waste Incineration Directive (WID):

1. *"Clean wastes"* with known fuel properties (meaning pre-use wastes from production processes), such as e.g. saw-dust, paper/plastic off-cuts and petcoke, should be excluded from the Scope of the draft WID.

2. When permitting the use of selected, pre-treated, non-hazardous combustible wastes as *"alternative fuels"* in combustion plants, the Competent Authorities of Member States should be allowed to grant exemptions with respect to technical and monitoring requirements for the *"co-incineration plant"*, and to prioritise overall efficiency and emissions before isolated single Emission Limit Values.

3. When applying the mixing rule for co-incineration, the strictest resulting Emission Limit Value should be that for dedicated incineration of non-hazardous waste. ELVs should be normalised to the same content of excess oxygen in the flue gas for all combustion plants (if they are not normalised to output energy).

C. Proposal for action with regard to Fuel:

1. The proposed definition of fuel in the draft Directive on Large Combustion Plants needs to be amended to include also waste derived fuels.

2. The production of a storable specified solid, liquid or gaseous *"Recovered Fuel"* product for the fuel market should be seen as a R3 operation, i.e. "*recycling/-reclamation of organic substances which are not used as solvents...*", as defined in the Waste Directive.

3. In order to develop guidelines and minimum requirements for *Recovered Fuel*, the Commission should give CEN a Mandate to explore whether a European Standard could be developed as a tool for authorities and for the fuel market.

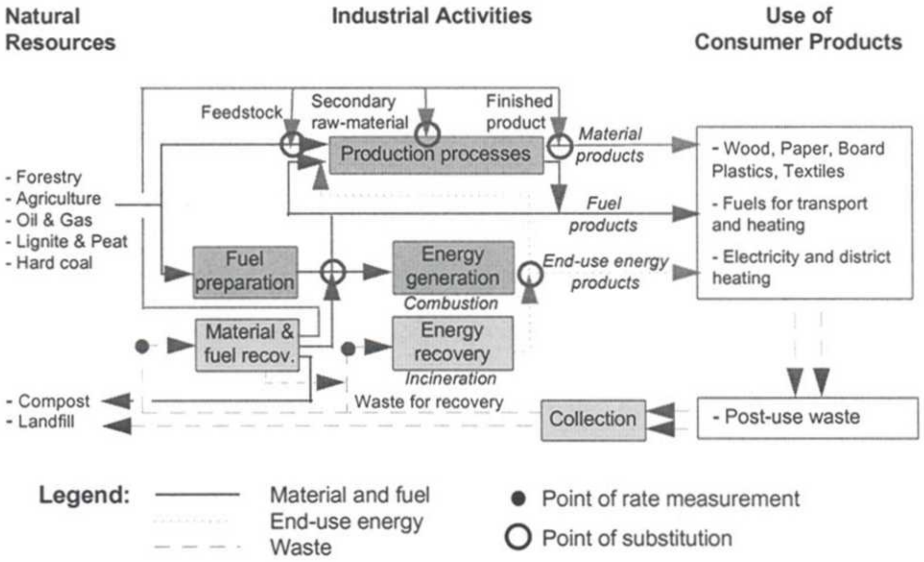

Figure 1 *Life cycles of organic materials.*

Executive Summary

The study, aim and approach

“Fuel and Energy Recovery” is a study on the production of a fuel from waste which can more sensibly be recovered for its energy value than for any other purpose (Figure 1). Specified recovered fuel can be used in existing or specifically built energy installations to substitute regular solid fuels, in a fuel mix or as the main fuel.
Possible installations for recovered fuel are power plants, heating plants, industrial boilers and industrial material production processes such as cement kilns. A typical case is the co-combustion of recovered fuel as a 5 to 30% substitute for coal.

The study is based on an overview of ongoing activities in Europe. It proposes a terminology whereby fuel recovery can be positioned as a relevant recovery option. The study proposes procedures based on which a regulation could be developed both for the production and for the use of recovered fuels. The potential of the concept of fuel recovery from waste is explored for fossil fuel saving. Its incorporation in efficient waste and resource management schemes is discussed for different situations.

Climate change

Organic materials consist mainly of carbon, hydrogen and oxygen. Carbon and hydrogen are the valuable components of fuels. Landfilling of organic materials is a waste of carbon and may lead to emissions of landfill gas, a mixture of methane (CH_4) and carbondioxide (CO_2). Utilisation of the energy content in waste contributes to the reduction of emissions of landfill gas and of CO_2, when the energy produced replaces the use of fossil fuel.

Fuel recovery contributes to fossil fuel saving and CO_2 emission reduction. Counting only combustible, non-hazardous waste that presently is disposed of in landfill, it is estimated that the potential fossil fuel saving in the European Union can be in the order of 30 million tonnes of oil equivalent per year, or 3% of the solid fuel consumption. Counted as CO_2, this could result in a reduction of 2 to 3 % of the current level. It thus contributes significantly to the achievement of the Kyoto targets.

Competitive fuels

To be acceptable for end-users, all fuels have to meet specifications, determined by the combustion system, the requirements for reliability and availability of the plant and by applied emission standards. The cases demonstrate that the different recovered fuels meet the specifications of the relevant end-user at a competitive price, depending on local circumstances.

Energy efficiency and emissions

Recovered fuel is a storable product which can be used for the production of energy or materials such as cement at equal combustion efficiency compared to the fuel it substitutes. As coal will remain the dominant solid fuel, co-conversion of recovered fuel with coal is a long term option.

The studied cases and theoretical considerations show that co-conversion of recovered fuel is as efficient as regular solid fuel conversion and that overall emissions are within existing legislation and permits, and do not increase compared to primary fuel use alone. The cases demonstrate that there is no need for additional costly flue gas treatment equipment, nor for a change in existing emission monitoring procedures.

Cost-effective waste management

The cases show a wide variety of options for fuel recovery. Implementation of fuel recovery in existing local waste management results in cost-effective solutions that can utilise existing infrastructure in the region. Supported by a gate fee competitive with local disposal costs, the production of recovered fuel can be a long term business, producing a competitively priced fuel for the local market. This new business creates industrial jobs in the waste management sector.

Depending on the local waste management system and the energy production system, fuel recovery will:

- reduce the waste volume to be disposed of in landfill in scarcely populated areas, where waste incineration with energy recovery is uneconomic;
- complement the biological treatment of the wet organic waste fraction;
- reduce the required capacity and investment cost of waste incineration in regions where incineration with energy recovery is planned to be introduced;
- increase energy utilisation where MSW incinerators for energy recovery are fully loaded;
- reduce the use of solid (fossil) fuel.

Key issues

Successful implementation of the recovered fuel concept depends on:

- improvement of the public acceptance of recovered fuel and confidence in its use;
- assessment of recovered fuel as a product and a regulation of the use of recovered fuel as for regular fuels.

Recommendations

The main proposals for solving the key issues are:

- Further development and demonstration is needed with respect to fuel quality and co-conversion in different technologies in order to give further evidence on the technical, economical and environmental effects and on the long-term reliability and availability of heat and power generation from recovered fuels.
- Further LCA and economic assessment studies should be conducted for fuel recovery, material recovery and energy recovery involving different combustible materials as well as the substituted products (Figure 1) in order to evaluate the environmental and economic impacts of all relevant recovery options.
- Suggested criteria for the assessment of the transfer from waste to a recovered fuel product are summarised in Table 1. These could, based on a Mandate from the Commission, be further developed and formalised in a CEN standard for solid recovered fuel.

Table 1. Criteria proposed as a base for a management standard on Recovered Fuels.

- Recovered fuel shall be produced to meet certain minimum requirements which are set by the user and documented in a public specification, approved by the permitting authority.
- Recovered fuel shall be safe and hygienic to handle and to store. This imposes requirements on the input waste material, the recovery process and the physical form and the chemical composition into which the fuel is produced. The fuel recovery facility shall operate according to a documented quality assurance system.
- Production and use of the recovered fuel shall be contractually ensured for the long term.
- The use of recovered fuel should be permitted on the condition that overall emissions from the combustion process stays within existing limits applicable to the use of regular fuels. The use and/or disposal of solid residues shall be maintained.

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Terms and abbreviations used in this report

Note: Legal definitions ar denoted with a bullet, proposals with a dash.

1. Waste to product

- **Waste** shall mean any solid or liquid waste or sludge as defined in Article 1(a) of Council Directive 75/442/EEC as amended (Re. Draft WID).
  It is proposed to distinguish between wastes of different origin, e.g. *pre-use* and *post-use wastes* as well as between *waste for recovery* and *waste for disposal.*
  - Mixed **municipal solid waste** (MSW) includes waste generated in households (HH), household waste (HHW), and similar waste generated in commercial and small industrial operations which is collected in the same system.
  - **Other waste** includes specific wastes from e.g. industry, construction or demolition.
  - **Pre-use production residues** (clean wastes) are well defined side-streams from industrial operations.
  - **Post-use wastes** are substances or objects which have performed in their intended purpose. They are differentiated as wastes either for recovery or for disposal.
- **Waste management** shall mean the collection, transport, recovery and disposal of waste including the supervision of such operations and after-care of disposal sites (Re.: 75/442/EEC as amended by 91/156/EEC).
- **Collection** shall mean the gathering, sorting and/or mixing of waste for the purpose of transport (Re.: 75/442/EEC as amended by 91/156/EEC).
  - **Separate collection** is any collection scheme gathering segregated waste streams.
  - **Kerbside collection** is any system collecting waste at household level.
  - **Bring system** is any system where the holder brings segregated waste to a point for centralised collection, e.g. a container park.

It is proposed that:

- **Waste treatment** is any mechanical, chemical, thermal or biological *recovery* or *disposal operation*.
- **Pre-treatment** is any operation to make waste more suitable for recovery or disposal.

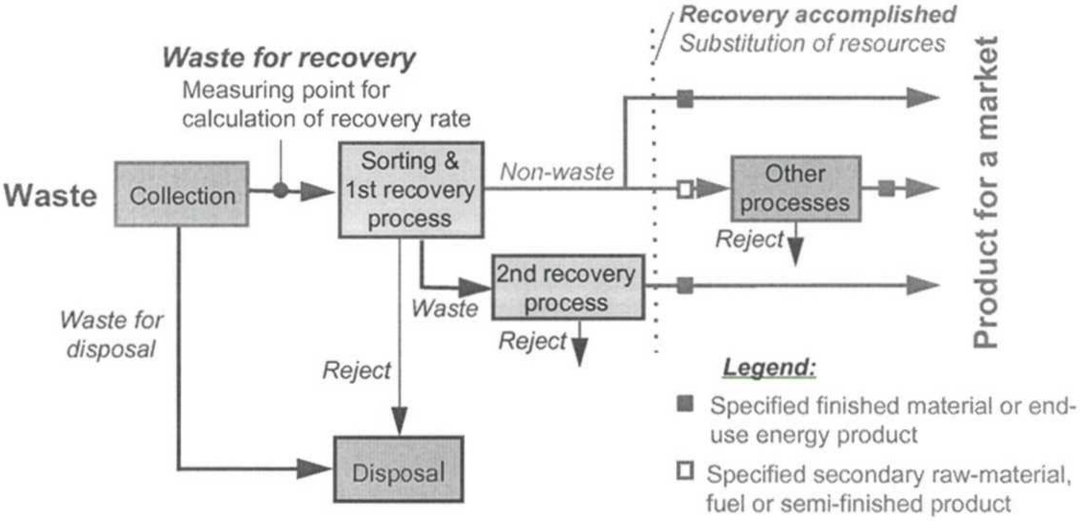

Figure *Waste to product*

- **Recovery** shall mean any of the operations provided for Annex II. B of Directive 75/442/EEC as amended by 91/156/EEC and 96/350/EC.

  Note: Annex IIB lists:
  R 1 Use principally as a fuel or other means to generate energy.
  R 3 Recycling/reclamation of organic substances which are not used as solvent. (including composting and other biological transformation processes)

  It is proposed that
  - **Recovery process** is any operation where *waste* is intentionally converted to a useful material and/or end-use energy product.
  - **Material recovery facility** (MRF) is any installation separating recoverable materials from waste.
- **Recycling** shall mean the reprocessing in a production process of the waste materials for the original purpose or for other purposes including organic recycling but excluding energy recovery (Re.: 94/62/EC).

  It is proposed that
  - **Recycling process** is any operation where *waste* is intentionally converted to a useful material product.
- **Energy recovery** shall mean the use of combustible (packaging) waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat (Re.: 94/62/EC).

  It is proposed that
  - **Energy recovery process** is any operation where *waste* is intentionally converted to a useful end-use energy product.

  and further that:
  - **Fuel recovery process** is any operation where *waste* is intentionally converted to a useful solid, liquid or gaseous fuel product.
- **Disposal** shall mean any of the operations provided for in Annex II. A of Directive 75/442/EEC as amended by 91/156/EEC and 96/350/EC.

Note: Annex IIA lists:
D 1 Deposit into or onto land (e.g. landfill, etc.)
D 10 Incineration on land.

It is proposed that incineration should be seen as pre-treatment of waste before depositing solid residues into or onto land.

2. Fuel to energy

– **Fuel** shall mean any solid, liquid or gaseous combustible material used to fire the combustion unit with the exception of waste within the meaning of Directives 75/442/EEC, as amended by 91/156/EEC, and 91/689/EEC as well as Council Decisions 94/3/EC and 94/904/EC (Re.: Draft Directive on LCI).
  - **Fuels** are specified products of consistent combustion properties.
  - **Recovered fuel** (RF) is a product of uniform quality which meets public user-oriented specifications. It is prepared from selected pre- and post-use, non-hazardous combustible waste in a dedicated process applying a quality assurance system.
  - **Refuse derived fuel** (RDF) is a product mechanically separated from mixed MSW.
  - **Fuel input** is the energy input to a combustion unit. It is calculated on lower heating value (LHV) which is the same as net calorific value (Q_{net}).
  - **Combustion** is a process of complete oxidation.
  - (e.g. burning *fuel* for the purpose of energy generation or production of material products).
  - **Incineration** is the combustion of waste.
  - (i.e. for the main purpose of burning to ash).
  - **Co-combustion** is the combustion of a mixture of fuels.
  - **Co-incineration** means the combustion of waste together with fuels. (Co-incineration with other waste is incineration although support fuel may be needed).
  - **Gasification** is the transformation of organic material by partial oxidation
  - into a gaseous fuel or a synthesis gas.
  - **Combustion technology** is any process used to convert the chemical energy of a fuel in a combustion installation (CI) or other industrial process (IP) into useful process heat, steam or hot water, e.g.: pulverised fuel combustion (PF); grate firing (GF); rotary kiln firing (RK); bubbling fluidised bed (BFB) or circulating fluidised bed (CFB) combustion and pressurised fluidised bed firing (PFB).
  - **Energy generation** is converting natural resources to useful end-use energy.
  - **End-use energy** is the output product of a combustion installation, i.e. process heat, steam, hot water and/or electricity.
  - **Energy conversion technology** is any process used to convert the energy content of a fuel into useful energy, (process)heat or electricity. This includes the power plant as a whole, e.g.: condensing steam cycle; combined

heat and power production (CHP) and integrated gasification combined cycle (IGCC) applying both gas and steam turbine.
- **Net Calorific Gain** (NCG) or energy output is the sum of net electricity and heat outputs as well as utilised process heat. Gross Calorific Gain (GCG) includes also the energy consumed in the process.

3. Efficiencies

- **Efficiency** is the relation between input and output of a process. Improving efficiency of any industrial operation is a key issue for Sustainable Growth and Development.
- **Combustion efficiency** is a measure on the completeness of oxidation of organic carbon in fuel.
- **Boiler efficiency** is the ratio between heat transferred to the steam cycle and fuel input.
- **Overall plant efficiency** is the ratio between net calorific gain and fuel input.
- **Power-to-heat ratio** is the ratio between electricity output and heat output.
- **Availability** is the ratio between actual and planned annual operation time.

4. Emissions

- **Emission** is the release of substances or heat from the combustion installation to the air, water or land. Minimising emissions in relation to overall plant efficiency is a key issue for environmental performance.
- **Emission Limit Value** (ELV) is the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time. Emissions to air are measured in mass/volume flue gas and are for power plants usually expressed as mass/MJ fuel input.
- **Overall emissions** is an expression for total environmental impact which may be assessed as influence on e.g. Climate Change, Acidification, Eutrophication or as “externality costs”.

1. Introduction

1.1 General introduction and goal

A major goal of modern waste management is to contribute to a sustainable development by the conservation of natural resources, including saving of fossil fuel. As a consequence, according to the EU directives, waste treatment, recycling and energy recovery should be promoted.

In this study, the option is elaborated of recovery of a fuel product from non-hazardous waste for which recycling as a material is not viable, for economic or technical reasons. Such a recovered fuel could, depending on the fulfilment of many conditions, be combusted or co-combusted in a combustion installation, e.g. for power production, district heating, cement production or otherwise. A typical case is the co-combustion of recovered fuel as a 5 to 30% substitute for coal. Important advantages of such an approach would be the higher energy efficiency and important savings in investment compared to processing in waste incineration installations; or compared to a reduction in landfill capacity if landfilling is the alternative disposal method to compare with.

The goal of this study is:

- to explore options for the production of recovered fuel and its use and to formulate criteria for the recognition of recovered fuel as a non-waste fuel that can be (co-)combusted in installations under normal regulations for solid fuels;
- to demonstrate the feasibility of and to propose the basis for an economically, technically and environmentally sound recovery route for non-hazardous combustible waste that is positioned within the energy industry and that will create new jobs in SME;
- to identify the structural aspects of the relevant industries and the need for further development and demonstration of fuel recovery from non-hazardous waste.

1.2 Relationship with the waste strategy and energy policy of the European Commission

The European Industry as well as municipalities wish to minimise both their costs of energy and of waste management and disposal. Throughout the union, industry is committed to the principle of Sustainable Growth and Development and to the basic hierarchy of resource management: Prevention by Source Reduction, Recovery of Discarded Products and Safe Final Disposal of Waste.

Product and Market

Industrial products are refined natural resources for specialised open markets (see Figure 1.1). Recovered products are introduced either for the same purpose in the original market or, which is more often the case, as a substitute for other products in other markets. These include the huge fuel market.

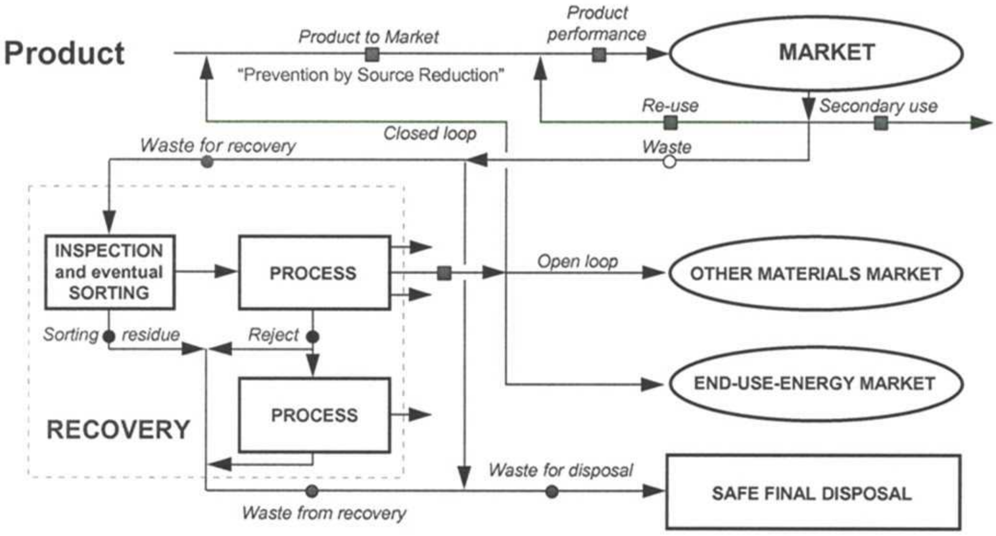

Figure 1.1 Elements of Integrated Resource Management.

Prevention

Effective prevention by source reduction, e.g. in the packaging sector, is often obtained by a combination of lightweight materials in laminates. These may be difficult to recover as material but have a high fuel value. The need to consider the utilisation of discarded combustible products for their potential as sources of energy will become paramount, as will the need to consider formulating products in such a way as to enhance the value of energy that can be recovered from the used product.

Recovery

Recovery of waste is another option in the overall strive for Sustainable Development. It diverts waste from final disposal and thereby helps conserve natural resources. Fuels and raw materials are often from the same origin. Fuels are refined specified products. Recovery processes are of a mechanical, chemical, thermal or biological character. They can all produce material and/or fuel products. Combustion of fuels and incineration of waste generates heat that is used for supply of end-use energy.

Mixed Municipal Solid Waste, MSW, is the design fuel of Waste-to-Energy plants. Refuse Derived Fuel, RDF, which is mechanically separated from mixed MSW has been under development for a long time. Because of certain drawbacks, such as odour and limited storability, it has not been commercially competitive. New efforts to develop efficient and affordable recovery options have indicated the possibilities of source separation of dry combustible fractions of MSW, to be combined with comparable agricultural and industrial waste fractions for processing to Recovered Fuel (RF). This fuel is considered a renewable, indigenous source of energy and its use as a fuel substitute in different energy generating or consuming systems is considered CO_2-neutral.

Figure 1.2 shows the general scheme for recovered fuel production from different non-hazardous waste materials.

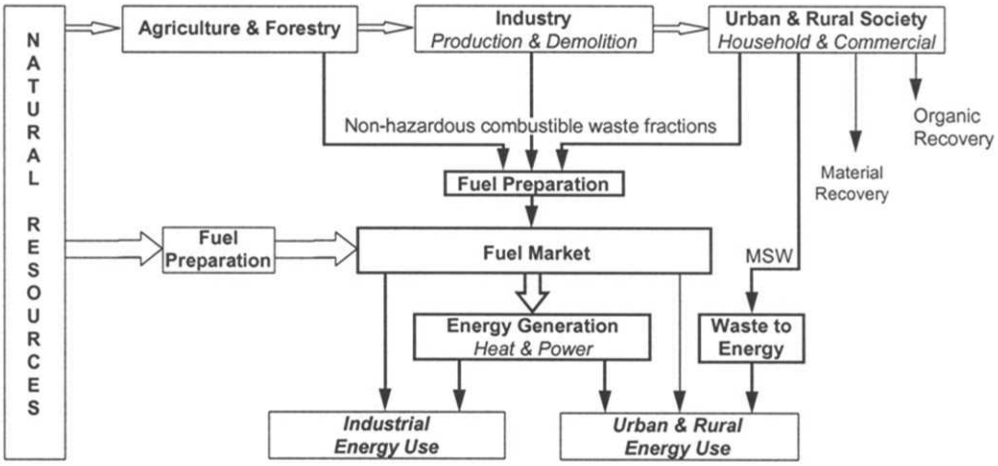

Figure 1.2 Fuel and Energy Recovery of Combustible Waste.

Fuel recovery is a complementary recovery option which deserves thorough evaluation and demonstration. In an LCA evaluation, Recovered Fuel shall be considered a fuel substitute gaining the full environmental credit for avoided extraction and refining of the primary resource yielding the substituted fuel.

Fuel and energy recovery from dry combustible MSW, and other selected source separated waste streams can play an important part in an economically and environmentally sound recovery of wastes, which yields maximum diversion of waste from disposal.

Several techno-economic studies have been performed in connection with MSW arisings and different recovery routes, including incineration with energy recovery. There are, however, no comparable, consistent waste statistics available and there is no average European waste arisings figure. Waste management procedures differ largely by region, available infrastructure and existing local industry.

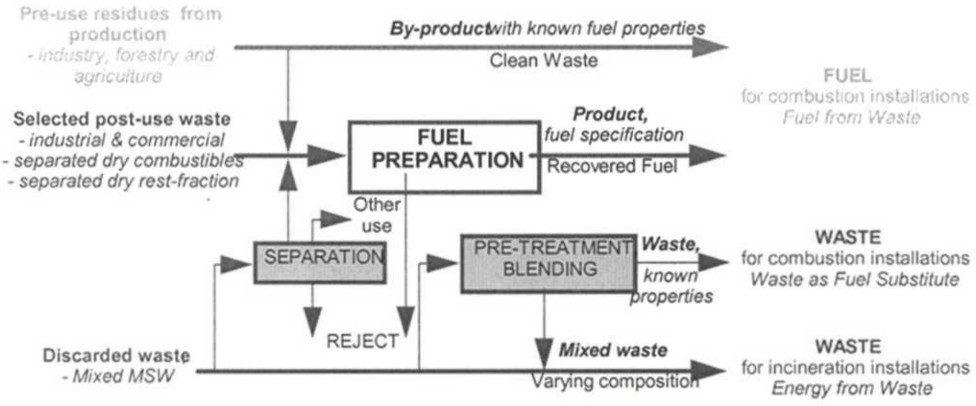

Figure 1.3 *Utilisation of waste as fuel and energy.*

The general scheme for fuel and energy recovery from waste is presented in Figure 1.3. Recovered fuel is produced from selected pre- and post-use non-hazardous combustible waste in a dedicated process according to well-defined specifications.

1.3 Methodology

The conclusions and recommendations of this study are developed along two lines.

- Information about fuel recovery gathered from selected cases where recovered fuel is actually produced and used. These case studies are used to demonstrate the applied technologies and their results, the potential energy gain and the resulting savings in fossil fuel consumption, the savings in waste disposal cost and the environmental aspects involved.
- From documents on waste recovery and the experiences of the case studies, criteria are derived for fuel recovery from non-hazardous combustible waste which can be applied, without having a waste status, as a solid fuel product to be used under normal regulations as every normal solid fuel.

Two types of cases are identified. Integrated cases in which fuel recovery is incorporated in municipal waste processing and disposal, and the recovered fuel is derived from the municipal waste by separated collection or mechanical separation followed by further processing and cases of fuel recovery from specific waste streams. A wide diversity of cases was selected covering many different options for fuel recovery and use which can also show the influence of regional aspects.

The potential volume of recovered fuel in Europe, the resulting sustainable energy and fossil fuel savings and the avoided waste disposal costs are estimated to show the possible impact of this option on European waste and energy management.

The final draft of this report is presented and discussed during a workshop, organised in Brussels on 26 November 1998. The main issues adressed at the workshop are summarised in Appendix B.

2. Requirements for fuels in combustion installations

2.1 Introduction

The basic use of recovered fuel is as an alternative fuel for co-combustion in existing installations. If the plant has been designed for the fuel or if it is technically suited for this kind of fuel, recovered fuel can be the main fuel. In this chapter, some major properties are discussed that influence the operator's choice when he selects a fuel for his combustion installation. An in-depth discussion is presented about the relationship between composition, heating value, combustion temperature, efficiency and resulting suitability of a fuel for a combustion plant. This discussion shows that the heating value in itself is not sufficient to define the basic suitability of a fuel, but that the actual composition and the plant configuration are of decisive influence. For a better understanding of the following paragraphs, a short description of the combustion efficiency of a combustion process is given. Specific aspects related to the combustion technology are discussed in Appendix A.

2.2 Combustion and combustion efficiency

Since recovered fuels should be combusted with high efficiency, the combustion efficiency generally obtained in these systems is stated. Combustion efficiency is a measure of the completeness of oxidation, i.e. the degree to which a fuel is converted in its final combustion products, i.e. CO_2 and H_2O (S, N are not considered). Generally, the combustion efficiency is calculated from the unburned carbon in the ashes and the CO content in the flue gas[1]. (The loss in combustion efficiency in energy installations because of CO is approximately 0.3% at 1000 mg/m_0^3 and 0.02% at 50 mg/m_0^3 CO in the flue gas)

The combustion efficiency only indicates how efficient the system converts the chemical energy in the fuel into heat; it does not say anything about the efficiency of the subsequent use of the heat (which is expressed as boiler efficiency) (see Fig-

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[1] The combustion efficiency is defined as the ratio between the heat produced by the fuel and the fuel input; in formula:

$\eta_c = (m_f * HHV- m_a * HHV_C-m_{CO} * HHV_{CO})/(m_f * HHV)$, in which

m_f = mass flow of the fuel

m_a = mass flow of the ash(es)

HHV = Higher Heating Value of the fuel

HV_C = Heating Value of carbon in the ashes

m_{CO} = mass flow of CO in the flue gas

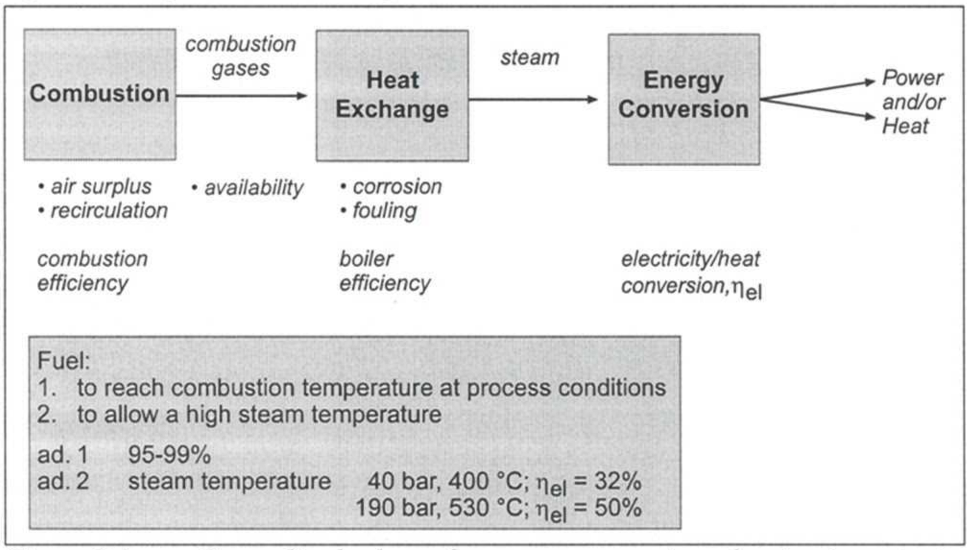
HV_{CO} = Heating Value of CO

ure 2.1). It may be clear, however, that if the combustion efficiency is already low, most probably boiler efficiency will also be low. [1]

Combustion efficiency of solid fuels is governed by three interdependent parameters (3T): temperature, mixing (turbulence) and time; the higher the temperature and the better the mixing, the shorter the time can be to reach the same combustion efficiency.

The combustion process of solid fuels proceeds in three phases:
1. drying;
2. devolatilisation, ignition and gas phase burning;
3. char burn out.

To achieve a high combustion efficiency, all three phases should be allowed sufficient time. In other words, the combustion system has to be designed for a specific fuel or at least for a narrow range of fuels because the drying time, gas burn out time and char burn out time can be very different. Especially the latter can be considerably reduced by reduction of the particle size.



Fuel:
1. to reach combustion temperature at process conditions
2. to allow a high steam temperature

ad. 1 95-99%
ad. 2 steam temperature 40 bar, 400 °C; $\eta_{el} = 32\%$
190 bar, 530 °C; $\eta_{el} = 50\%$

Figure 2.1 Generalised scheme for energy conversion, showing important parameters for overall efficiency
The overall efficiency of e.g. power production from a fuel is determined by is determined by:
- the combustion efficiency;
- the boiler efficiency;
- efficiency of power production from steam (η_{el}).
The steam pressure is an important factor determining the efficiency of power production by a steam cycle. This steam pressure is low in case of corrosive combustion gases such as in waste incinerators, therefor the composition of the flue gases is also important for the overall efficiency.

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[1] Definitions of boiler efficiencies can be found in e.g. DIN 1942 (commissioning test for boilers) and comparable standards.

2.3 Suitability of fuels for combustion installations

Combustion installations are designed for the efficient conversion of a range of fuels into some form of end-use energy: power, steam, hot water or chemical energy. Fuel combustion produces hot flue gases at a selected design-temperature level. Subsequently, the thermal energy in the gases is utilised in, for instance, boiler systems for steam or hot water production, possibly combined with electricity generation, or it is directly transferred to raw materials as is the case in cement kilns. The combination determines the overall plant efficiency of the combustion plant. The combustion plants considered in this study are designed for district heating, power or cement production. Combustion plants operate at a typical temperature level ranging from 800 °C for fluid bed furnaces for district heating or power production, to 1500 °C for pulverised coal power plants and 1800 to 2000 °C for cement furnaces. They are described in Appendix A.

The combustion system is composed of a furnace for the actual efficient combustion to produce thermal energy at selected temperature level and a subsequent system for the efficient conversion of this thermal energy in the desired energy output in the form of e.g. power, steam, hot water, or chemical energy (Figure 2.1). Basically, the suitability of a fuel for a combustion system depends on its ability to produce the required quantity of thermal energy at the desired temperature level under the process conditions in the furnace. The fuel properties determining this ability are the energy content (expressed by the Lower Heating Value or Net Calorific Value, Q_{net}) of the fuel and its chemical composition. The composition determines the amount of combustion air needed and as a result the amount of flue gas produced. To some extent, deviations from the desired temperature level can be accepted, or corrected by altering the quantity of excess combustion air, by recirculating (part of) the flue gases or by preheating the combustion air. The relationship between a fuel and its combustion temperature is further demonstrated below.

Other important fuel properties that determine whether a specific fuel can be applied in a combustion plant arise from its chemical composition and physical properties. Fouling, slagging and corrosion of the boiler are related to the presence of certain components in the total fuel mix such as alkali metals, chlorine and sulphur. These components may therefore have great influence on the availability of the plant; they also affect the ash characteristics, e.g. sintering and melting behaviour. Ash composition can be an important factor in the economics of the combustion plant. Polluting elements, such as heavy metals, can negatively influence options for ash use resulting in high costs for ash disposal. The quality of these residues should not be reduced below the standards (environmental/technical/health) for their use.
The physical form in which the fuel occurs is of importance because the feeding system must be capable of handling the fuel without problems and particles must be small enough for complete burn-out in the relevant combustion technology. Pellets, fluff, briquettes and bales are the most commonly applied physical forms for recovered fuel.

Furthermore, for the combustion process the volatiles are an important fuel parameter with regard to flame stability and burn out of the fuel. Generally, recovered fuels consist of wood, paper and plastics which are high in volatiles compared to coal.

2.4 Heating value and combustion temperature

The heating value of a substance is often used as the decisive parameter that determines whether this substance can be considered to be a fuel. The German Kreislaufwirtschaftsgesetz, for example, demands a minimum Lower Heating Value of 11MJ/kg, before co-combustion is considered as Energy Recovery. However, this is only one aspect of the issue. The actual composition and the design of the combustion system are of equal importance as is shown by the calculation examples below that demonstrate that also low calorific materials can be applied as fuel in a proper installation

The heating value of a substance is largely determined by the composition of the organic fraction and of its water and ash content. The Michel formula allows an estimation of the Lower Heating Value (or Net Calorific Value, Q_{net}) for organic substances of known chemical composition and variable ash and moisture contents (concentrations expressed as wt% of total):

$$Q_{net} = 34.03*C + 102.44*H + 19.10*S + 6.30*N - 9.80*O - 2.44*H_2O \ (MJ/kg)$$

Cellulose and polyethylene are considered to be two typical extreme examples for the composition of the organic fraction with respect to the contents of C, H and O and the corresponding heating value. The chemical compositions used to derive the heating values are $(C_6H_{10}O_5)_n$ for cellulose and $(CH_2)_n$ for polyethylene, respectively.

Figure 2.2 shows the range of calculated Net Calorific Values, Q_{net}, for model fuels consisting of mixtures of pure cellulose with lowest, to pure polyethylene with highest heating value including ranges of ash (0 to 20 wt%) and moisture (5 to 40 wt%) contents. The model fuels are denoted A, B, C, D and E in Figure 2.1. Recovered Fuel is assumed to be a blend of materials and it is anticipated that all relevant Recovered Fuels would fit within the indicated boundaries A-B-C-D-E-A.

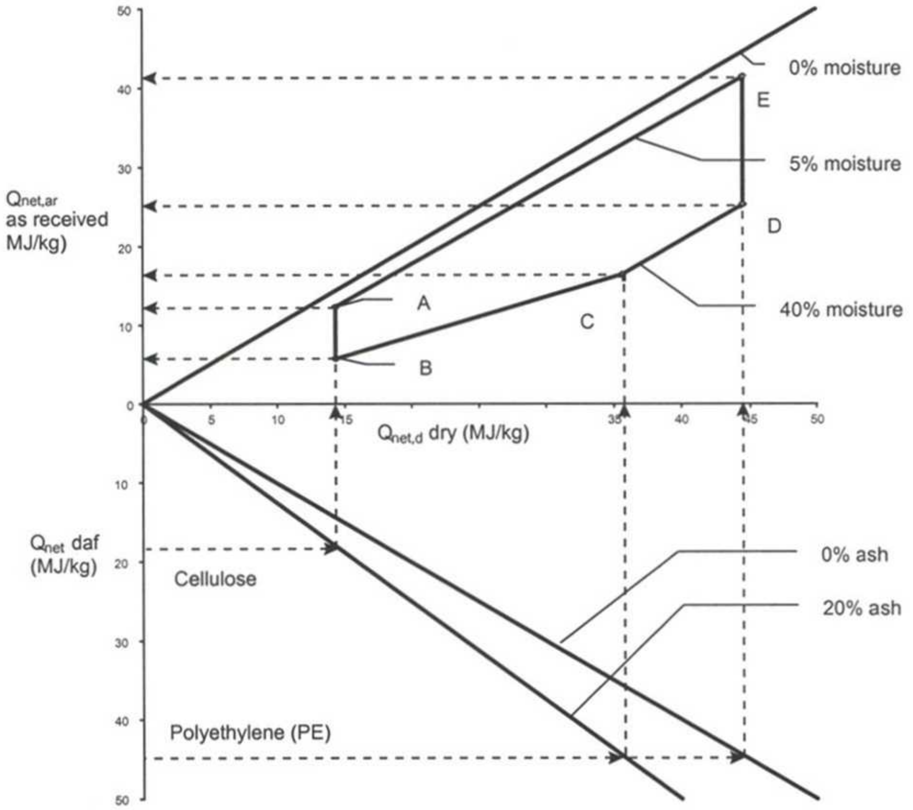

Figure 2.2 Diagram for calculation of Net Calorific Value of ash and moisture containing organic material.

Given a Q_{net} for a (*dry and ash free*) organic material, the $Q_{net,d}$ (*dry*) can be determined for an ash-containing material by following the horizontal arrows in the bottom half of Figure 2.2. From the $Q_{net,d}$ the $Q_{net,ar}$ (*wet as received*) can be determined by following the vertical arrows. The results of the calculation of the heating value for model fuels A, B, C, D and E are presented in Table 2.1.

Table 2.1 Calculated heating values for different model fuels.

Model fuel	A	B	C	D	E
Composition	cellulose	cellulose	PE	PE	PE
Ash (wt%)	20	20	20	0	0
Moisture (wt%)	5	40	40	40	5
Q_{net} (MJ/kg)	12.3	5.7	16.5	25.3	41.5

The calculated combustion temperatures presented in Table 2.2 show a strong relation to the composition of the fuel. The table shows the results of the calculation of the combustion temperatures for the model fuels described above under conditions encountered in two typical combustion systems. The indicated process parameters are example values selected to show the principle. The reference temperature is given as a typical design combustion temperature for the system. In order to be a suitable fuel in a combustion process, it is postulated that the autothermal combustion temperature of the recovered fuel under process conditions (air inlet temperature, oxygen content of the flue gas, and heat loss in the combustion chamber) should be at least as high as the reference temperature. If it is higher the temperature can be corrected by increasing the quantity of excess air.

Table 2.2 Calculation of solid fuel replacement capability.

Typical Combustion System	**Small and Medium Size Units Generation of Heat and Power Grate and Fluidised Bed Coal and Biomass**					**Large Size Units Generation of Power only Pulverised Fuel Combustion Coal**				
T_0 (air inlet), °C	150					300				
T_{ref} (design), °C	850					1400				
Excess O_2, %	6					3				
Heat loss, %	10					5				
Model fuel	A	B	C	D	E	A	B	C	D	E
$Q_{net, ar}$, MJ/kg	12.3	5.7	16.5	25.3	41.5	12.3	5.7	16.5	25.3	41.5
T_{comb}, °C	1500	1100	1400	1490	1610	2050	1310	1720	1850	2040
$T_{comb} > T_{ref}$	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

Table 3.2 shows that all model fuels, with the exception of B in pulverised fuel firing, could serve as a single fuel. Even model fuel B can be co-fired up to 20% with coal, providing a positive effect of reducing emissions of thermal NO_x. This is caused by the somewhat reduced combustion temperature compared to coal alone and is proven. It is reported for co-combustion of sludge in the APAS Clean Coal Technology Programme (92-94) of the European Commission.
The cement kiln is a special case of pulverised firing. Because of the higher preheating temperature (800 °C), all model fuels can be used as a single fuel here. Therefore, with respect to heating value, all recovered fuels in the model range can be categorised 'fuel' for combustion installations.

The relationship between composition and achievable combustion temperature is clearly seen from a comparison of the calculation results for material A and D in Grate and FB firing and for A and E in Pulverised firing. The calculated combustion temperature for A is not lower than for D or E in spite of the much higher heating value of D and especially of E. This is caused by the difference in composition of the organic fraction and the corresponding amount of combustion air required. Cellulose e.g. already contains 42% oxygen itself; consequently, less combustion air is needed than for e.g. polyethylene. The higher energy content of polyethylene is distributed in a larger flue gas volume than cellulose and the flue gas temperature is the same for the examined cases in the two combustion systems.

2.5 Other parameters influencing overall efficiency

As stated before, the achievable combustion temperature is an important parameter but not the only one that determines the suitability of a fuel for a combusting installation. Energy content, combustion behaviour, fouling, corrosion and environmental properties are all to be considered by an operator of a combustion installation when he selects a recovered fuel. To protect his installation, to fulfil legal environmental requirements, and to achieve his aim to produce energy, he will demand full information about the fuel composition and properties, with a guarantee that they will be maintained between agreed, acceptable limits.
Additionally, most operators will ask for a fuel that can be reliably delivered during long periods. (Basically, it is also in the interests of waste management; they will aim at long term options for the use of their fuel product.)
As a consequence, it is very important that producers of recovered fuel are able to control their raw materials and their production process. Strict quality control, combined with process or product certification, will contribute to the acceptance of recovered fuels by operators of combustion plants.

2.6 Quality assurance system for recovered fuels

In discussions on recovered fuel, the continuity of recovered fuel production and quality is a point of concern. Production according to specifications of the customer is an important demand when making a fuel product. Therefore special attention should be paid to the strict maintenance of product quality standards.Producer and user should be well aware of occurring and acceptable variations and have a clear agreement on the limits for variations and on how to deal with these variations.

In Finland a Quality Assurance Manual for Recovered Fuels [1] has been published by the Finnish Bioenergy Association (FINBIO), defining the procedure by which the quality and the energy amount of recovered fuels can be determined in an appropriate way. The basic situation considered is the use of recovered fuel as a substitute fuel in co-combustion. The Manual defines recovered fuels as fuels produced from dry, combustible waste fractions sorted at source in industry, businesses or municipalities. The Manual presents a detailed elaboration of sampling and analytical methods to establish the fuel composition, methods to measure and calculate the delivered energy. The Manual states the following general “principles of use”:
- The Manual defines the terminology of recovered fuels and proposes quality classes. The use of this classification system (see below) is recommended to increase the knowledge of the parties involved, to contribute to the comparison of recovered fuels with other solid fuels and thus to the general acceptability.
- With regard to the technical implementation, the installations for handling and combusting the recovered fuel, including the flue gas cleaning system, should

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[1] FINBIO: Quality assurance manual for recovered fuels, 1998.

be suitable for the combined use of the recovered and the main fuel. The use of recovered fuel should not cause significant changes in the operation and maintenance of the plant, nor in the utilisation of the ash. Emissions should not increase significantly. Test runs with fuel batches prior to delivery can be used for verification.

- The staff of the plant shall be familiar with the quality and the amount of the recovered fuel as well as with the special aspects related to its use.
- To establish the commercial terms of the operation a delivery agreement with the expressed price and terms of delivery is necessary. Retrofit investments may be required; test runs can provide information on this point.
- Possible risks should be considered. These risks include variations in fuel quality, non-homogeneous mixing of fuels, impurities and large lumps. Quality control during fuel production helps minimise the risks. Other possible risks are corrosion because of the chlorine content of the recovered fuel and slagging and fouling influenced by higher contents of sodium, potassium and aluminium.
- Good industrial hygiene is important to prevent health risks. These health risks can arise from e.g. microbial contamination of the fuel.

According to the Manual, a producer/deliverer should also have a documented procedure to ensure, control and verify that the product quality complies with the agreed specification. Furthermore, he should have documented control over raw materials and procedures. Furthermore, based upon procedures for the acceptance of raw materials, he will refuse materials offered of insufficient quality. Upon request, producers and users should submit information to supervising authorities about their raw materials, products and produced energy, residual materials and applied technology. The objective of keeping records is to control the operation and gather statistical information about utilised waste materials

The manual also contains a proposal for the classification of recovered fuel that can contribute to the standardisation and general acceptance of recovered fuels. The classification system is presented below in Table 2.3. Table 2.4 presents the materials composition of the recovered fuels corresponding with fuel classes.
The Manual does not explicitly discuss the option of certification of the production process for recovered fuel nor does it deal with the quality assurance for waste collection systems.

Table 2.3 Quality classes for recovered fuels RF10, RF15 and RF20.

Item	Property	Limit value focus	Unit	Precision	Quality classes and their limit values			Determination frequency minimum
					RF 10	RF 15	RF 20	
1	Net calorific value as received, $Q_{net,ar}$	Delivery batch minimum	MJ/kg	0.1	10.0	15.0	20.0	1 x delivery-batch
2	Moisture, as received, M_{ar}	Delivery batch, maximum	w-%	0.1	40.0	30.0	30.0	1 x delivery-batch
3	Ash content in dry matter, A_d	Combined sample, maximum	w-%	0.1	15.0	15.0	10.0	1 x /month
4	Sulphur content in dry matter, S_d	Combined sample, maximum	w-%	0.01	0.30	0.40	0.50	1 x /month
5	Chlorine content in dry matter, Cl_d	Combined sample, maximum	w-%	0.1	0.5	0.6	0.7	1x /month
6.1	Particle size	Load aim below 95 w-%	mm	10	60	60	60	When required
			mm	10	80	80	80	
6.2	Large items	Load, maximum 1 w-%	mm	10	300	300	300	When required
7	Bulk density, D_{ar},							
	fluff	Load	kg/m³	10	100-300	100-300	50-500	When required
	pellet	Load	kg/m³	10	300-500	300-500	300-500	When required

Table 2.4 Material bases of the quality classes.

Class/Raw material	Wood wastes	Paper, cardboard etc.	Plastics
	wt %	wt %	wt %
RF 10	40 - 100	40 - 90	< 10
RF 15	40 - 90	40 - 70	10 - 20
RF 20	30 - 80	30 - 60	> 20

2.7 Proposed modification for the classification of Recovered Fuel

The following tentative categories of Recovered Fuel, which are based on fuel composition and corresponding heating value as well as on additional information on physical form, moisture and ash content and maximum contents of sulphur and chlorine, are proposed here (Table 2.3). The proposal is based on data extracted from the case studies as well as on theoretical considerations. E.g. the proposed chlorine-content is based on the understanding that fuel mixes are allowed to contain no more than 0.2% chlorine to prevent corrosion (see Appendix B.4). An important difference with the Finnish proposal is the bandwidth that is allowed for the

LHV values; these include the use of low calorific biomass fuels as well as high calorific plastic derived fuels. The possible use of these fuels is demonstrated by the calculated results in Table 2.2.

Table 2.5 Preliminary ideas on categorising Recovered Fuel.

Recovered Fuel	Class I		Class II		Class III	
Dominant material	Wood and paper		Wood/paper/plastic		Plastics	
Ash, %-w (dry)	< 20		< 15		< 10	
$Q_{gross, d}$, MJ/kg	Determine		Determine		Determine	
Physical form	Fluff	Pellet	Fluff	Pellet	Fluff	Pellet
Moisture, %-w (wet)	< 40	< 15	< 30	< 10	< 20	< 2
Bulk density, kg/m³	100-300	300-500	100-300	300-500	50-100	300-500
Net Calorific Value $Q_{net, ar}$, MJ/kg (wet)	> 5	> 10	> 15	> 20	> 25	> 30
Delivered energy E_{ar}, MWh/ton (wet)	> 1.4	> 2.8	> 4.2	> 5.6	> 6.9	> 8.3
Sulphur, g/MJ (dry)	< 0.3		< 0.3		< 0.3	
Chlorine. g/MJ (dry)	< 0.3		< 0.3		< 0.3	
Chlorine, %-w (dry)	< 0.5		< 0.8		< 1	
Sodium, potassium	Determine		Determine		Determine	

Critical properties are indicated by shading.

It should be understood that these categories are of an informative character. Permitting the use of new fuels, recovered or natural, requires detailed consideration of its impact on the combustion process, the equipment, the emissions and the ash quality.

3. Case studies

3.1 Introduction

In this project, 14 cases on fuel recovery were studied. The cases are divided into 'Integrated cases' and 'Specific waste stream cases'. In the integrated cases, fuel recovery is part of the municipal solid waste management system of a certain area. The input of the specific waste stream cases typically consists of industrial wastes, mainly paper, plastic and wood. Some characteristics which shows differences between the integrated cases and the specific waste stream cases are given in Table 3.1.

Table 3.1 Characteristics of cases.

	Integrated	**Specific waste streams**
input	combustible fractions of MSW	industrial pre-use residues or post-use wastes
composition	mixed; mainly consisting of paper, plastics, textiles etc.	well known, homogeneous fractions; mainly wood, non-recyclable paper and plastic
number of sources	high; typically all households in a certain area	low
amount of waste per source	low	high; up to thousands of tonnes/year
position	integrated in MSW-management	individual responsibility of company

The goal of the case studies is:

- to evaluate the economic, technical and environmental aspects of fuel recovery (compared to material and energy recovery) of commercial operations in different regions of the EU;
- to review applied principles and to make recommendations for further EU actions targeted at enterprises producing and/or using recovered fuel as an indigenous alternative fuel.

3.2 Selection of cases

For the selection of the cases the following criteria were applied:

- the cases should be spread all over the EU;
- differently collected fractions from MSW and different types of specific waste streams should be used;
- different types of combustion installations and different use of the recovered energy should be studied.

With these criteria in mind, the consortium selected 14 cases, whose basic features are presented in Table 3.2.

Table 3.2 Basic features of studied cases.

Case name - People served	- Source and type of waste - Fuel preparation technology - Type of combustion installation	- Recovered fuel, tonnes/year - Form of fuel - Used for	- RF input, %-th. - Combustion tech. - Used primary fuel
Integrated cases			
Halmstad (S) - 84.000 [1]	- MSW and industrial waste - Shredding, magnetic separation for RDF - 70.000 t/a MSW mass-burn incineration	- 20.000 RDF - Fluff (used in winter time only) - 220 GWh district heating	- 30% - Grate - MSW
Florence (I) - 500.000	- MSW - Shredding, separation, densification - 15 MW gasifier	- 10.000 (design capacity 50.000) - Pellet - Electricity, fuel gas for cement kiln	- 100% - CFB Gasification
Borlänge (S) - 102.500 [2]	- Dry HHW - Baled for storage - Converted oil-fired heating plant	- 22.000 - As such - 22.5 MW district heating	- 100% - Grate
Pamplona (E) - 280.000	- Intended production of RF in clean MRF - Under evaluation - Under evaluation	- Potentially 30.000 (only HHW)	
Erwitte (D) - 180.000	- Industrial and dry HHW - Shredding, magnetic separation - Co-combustion in rotary kiln	- 100.000 (20% HHW) - Fluff - Cement production (dry process)	- Up to 60% - PF - Coal, oil
Jakobstad (FIN) - 120.000 [3]	- Industrial, commercial and dry HHW - Shredding, separation, blending, pelletising - Co-combustion in 138 MW CHP	- 30.000 (40% HHW) - Pellet - Electricity, steam, district heating	- Up to 20% - BFB - Bark and coal
Wijster (NL) - 2.500.000	- Dry HHW (grey bin) - Separation of light fraction in clean MRF - Under evaluation	- Potentially 170.000 - Under development - Under consideration	
Specific wastes			
Nijmegen (NL)	- Demolition wood - Crushing, magn. sep. pulverising - Co-combustion in power plant	- 60.000 - Powder - Electricity (condensing cycle)	- 5% - PF - Imported coal
Obourg (B)	- Bulky waste - Shredding, baling - Co-combustion in rotary kiln	- 15.000 - Small bales for mid kiln feeding - Cement production (wet process)	- 3% [4] - Bales at mid-kiln - Coal, wastes
Kauttua (FIN)	- Separately collected non-recyclable paper - Shredding and magn. sep. - Co-combustion in 60 MW CHP	- 15.000 - Fluff - Electricity, steam, district heating	- 15% - CFB - Coal, peat, wood
Örebro (S)	- Plastic/paper pre-use waste - Milling and densification - Co-combustion in boiler plant	- 6.000 - Briquette - Low pressure process steam	- Up to 60% - GF - Biomass
Lomma (S)	- Industrial residues and commercial waste - Shredding and magn. sep. - Mono-combustion in 18 MW CHP	- 14.000 - Fluff - Electricity and district heating	- 100% - CFB
Slough (UK)	- Industrial and commercial waste - Shredding, magn. sep., densification - Co-combustion in 130 MW CHP	- 25000 - "Densified Cube" - Electricity and district heating	- Up to 40% - CFB| - Coal
Wietersdorf (A)	- Separately collected plastic packaging - Sorting, shredding, milling - Co-combustion in rotary kiln	- 10.000 - Fluff - Cement production (dry process)	- Up to 30% - PF - Coal, oil, gas

[1] Only Halmstad area, excluding Laholm, Hylte, Falkenberg and Varberg

[2] Borlänge + Falun

[3] Jakobstad (20.000) + surroundings and the Vaasa region

[4] Refers only to mid-kiln feed of waste derived fuel

As can be seen from Figure 3.1 the cases are spread all over Europe with 6 cases in Scandinavia, 5 cases in Western Europe and 3 cases in Central and Southern Europe.

Figure 3.1 Location of cases.

The incoming wastes show a wide variety, from clean pre-use industrial scraps to mixed MSW:

– dry combustibles (two-bin collection)	Borlänge, Jakobstad;
– dry rest fraction (two-bin collection)	Erwitte, Wijster;
– mixed MSW (one-bin collection)	Florence, Halmstad;
– pre-use industrial scrap	Slough, Örebro;
– post-use industrial wastes	Lomma, Kauttua, Slough, Jakobstad;
– plastic packaging	Wietersdorf
– demolition wood	Nijmegen;
– bulky waste	Obourg

It should be noted that several fuel preparation plants and combustion installations take in more than one type of waste. For instance, the Ewapower fuel preparation plant in Jakobstad takes in dry combustibles from the households of Jakobstad, RDF separated from the household waste in Vaasa (some 100 km south of Jakobstad) and post-use as well as pre-use industrial waste from the Jakobstad region.

Depending on the source, these wastes are shredded, separated, blended and pelletised.
An example of a combustion installation taking in more than one type of fuel is the CHP plant in Slough, where cubes produced in the nearby Fibre Fuel plant are combusted together with traditional RDF pellets, replacing coal.

Table 3.3 Type of combustion installation and use of energy in the cases.

	GF	BFB	CFB	PF	Gasification	CK
District heat	Halmstad, Borlänge					
Process steam	Örebro					
CHP		Jakobstad	Slough, Kauttua, Lomma			
Power only				Nijmegen	Florence	
Cement production					Florence	Obourg, Erwitte, Wietersdorf

Not only by coincidence is the use of energy different throughout Europe. District heat and CHP is concentrated in Scandinavia, (of course favoured by the cold winters). Many cement kilns are located in West or Central Europe.

Looking at the use of the recovered energy, we see that the Florence-case is an interesting case. In Florence, or better Greve, a small town 30 km south of Florence where the gasifier using the RDF pellets from Florence is located, they have two options. The first option is to produce electricity in a gas fired boiler plant for the national grid. The second option is to deliver gas to the cement kiln located 200 m from the gasifier. In this case, the gasifier would be a fuel preparation plant, and the actual combustion installation would be the cement kiln.

3.3 Integrated cases

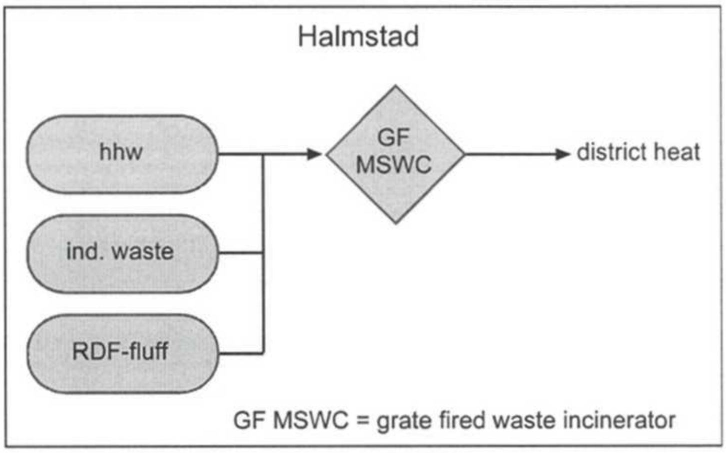
7 integrated cases were selected: Halmstad (S), Pamplona (E), Florence (I), Borlänge (S), Jakobstad (FIN), Wijster (NL) and Erwitte (D).

Halmstad (S)

Halmstad (84.000 inhabitants) is located on the west coast of Sweden, halfway between Malmö and Goteborg. The community-owned waste incinerator is an integrated part of the city's heating system, the incinerator delivers some 220 GWh_{th}/year to the district heating system.

Annually some 30,000 ton MSW and 20,000 ton industrial waste are incinerated. Additionally 20,000 ton RDF fluff, coming from the RDF plant in Falkenberg

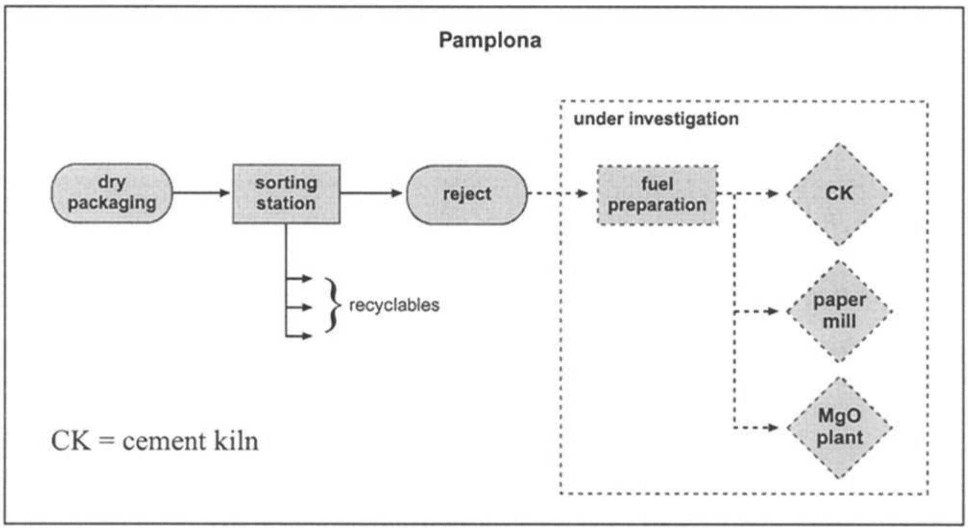
(40 km north of Halmstad) are incinerated. The RDF is mainly incinerated in the winter, during summer it is stockpiled in the open air, covered under wood chips.



The incinerator is grate-fired. The flue gas cleaning system consist of SNCR, ESP, a wet scrubber and a flue gas condenser. Except for PCDD/F, all emissions to air are within the limit values of 89/369/EEC and those set by the local authorities. This is valid for the combustion with and without the RDF-fluff. The problems with PCDD/F may arise from the high temperature in the ESP.
The experiences with RDF fluff as a fuel are positive. It is more homogeneous than the mixed MSW. However, the storage can lead to problems. This concerns specifically odour problems when opening the stockpile.

Pamplona (E)

Pamplona is a city of 280,000 inhabitants, located in the north of Spain. Pamplona is the capital of Navarra, one of the seventeen autonomous regions in Spain. The government of Navarra is very interested in new waste management systems. For Pamplona, this has already led to the introduction of a two bin collection system: recyclables going to a MRF, the rest still going to landfill (there are no waste incinerators in the region). One of the alternatives that is under investigation is the use of the rejects from the MRF for recovered fuel.



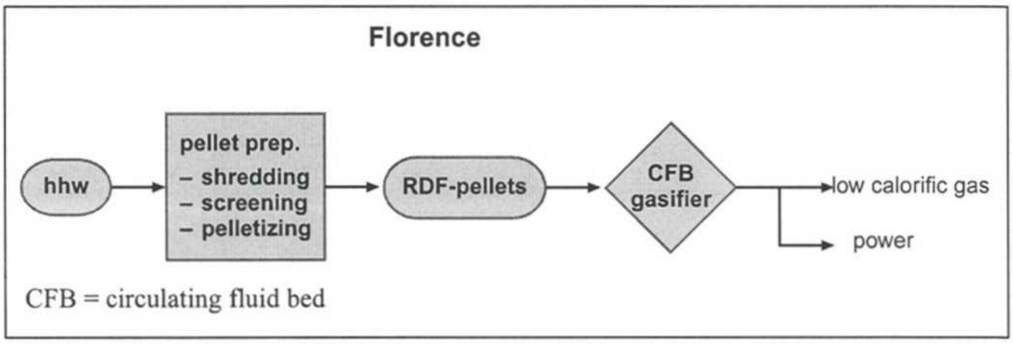
The majority of the population live in high-rise apartment buildings, with up to 12,000 people per km^2. Blue bins for the recycling fraction and green bins for the wet restfraction are located throughout the city and at major points in the more rural towns. In the high-density urban areas collection of the blue and green bins (800-1,000 litre) takes place six times a week, and two to three times a week in the more rural area. All collected waste is transported to the Góngora waste treatment facility, some 12 km outside of Pamplona.

At Góngora the recyclables collected in the blue bins (some 27000 ton in 1996) are sorted in a clean MRF. Besides the recyclable streams, like plastic bottles, the process produces a reject. This reject is a possible source of material for fuel preparation.

Although there is no recovered fuel yet, there are already some potential users of recovered fuel available. These include a cement kiln (coal, petrocoke, fuel oil: 100,000 ton/a), a paper mill (bark 36,000 ton/a; black liquor 111,000 ton/a) and a magnesium oxide plant (35,000 ton/a petrocoke; 5 * 10^6 m^3 natural gas).

Florence (I)

In Florence and the surrounding Fiorentine area some 500,000 people live. Most of the household waste and waste from shops and small industries is collected integrally six times per week. Part of this waste is treated in an RDF plant in Florence, producing RDF pellets which are used at the gasifier near Greve, some 30 km south of Florence.



The RDF plant consists of a drumscreen (30/80/150 mm) + a hammer mill for fraction > 150 mm, magnetic + ballistic separation, shredders, dryers and pelletisers. The plant was designed to take in 500 ton/day of mixed MSW, resulting in approx. 200 tons of RDF pellets. In reality, the output of pellets is some 50 - 60 ton/day, the daily need for 1 gasifier.

In Greve, two 15 MW CFB gasifiers (TPS-Ansaldo) are installed in front of a combustion + post-combustion section. Flue gas cleaning consists of lime injection + bag filters. The input is 60 ton/d of pellets per gasifier; no other fuels are used.

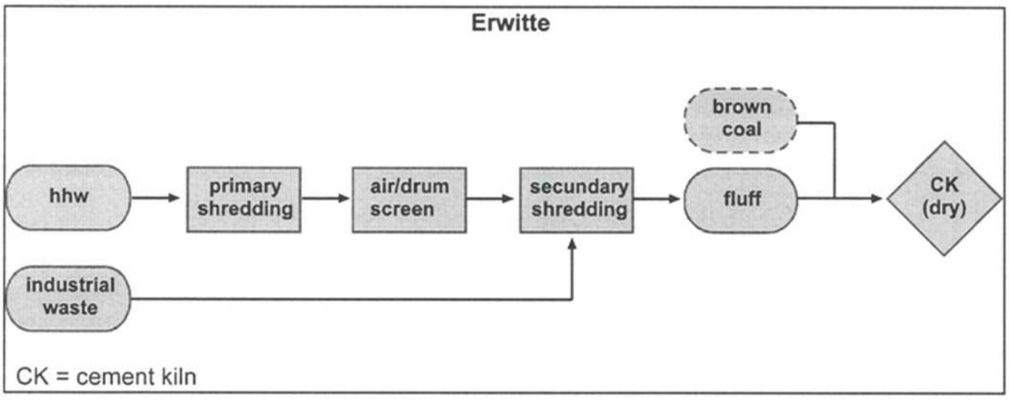
There are two options for the output: First, the produced gas can be combusted to generate some 18 ton/h steam (342 °C, 40 bar), from which a maximum of 2.5 MW_e can be generated for the national grid. Secondly, the gas (19,000 kJ/Nm^3) can be delivered to the nearby cement kiln. Because of the current Italian regulations, which state that electricity produced from waste is green electricity, the generation of electricity is at the moment the most attractive option.

Although constructed in the early nineties, the gasifier has the character of a demonstration plant, suffering great technical problems. Because of these technical problems the long-term availability of the installation is seldom above 40%. The problems include:

- slagging problems in the combustion section and after the post-combustion chambers;
- melting of the bed after shut-down, blocking the bottom section of gasifiers;
- fouling of the tubes, reducing the energy output to approx. 1.5 MW_e;
- copper and aluminium blocking fluidisation.

Erwitte (D)

At the Wittekind cement plant in Erwitte some 15,000-20,000 ton/a of dry rest fraction from households and approx. 80,000 ton/a of industrial scraps are used as recovered fuel. Therefore, a fuel preparation plant is built by MBM Anlagenbau at the site of the cement kiln. The final product is a paper/plastic fluff, with an average LHV of 18 MJ/kg and a Cl content < 0.3%.

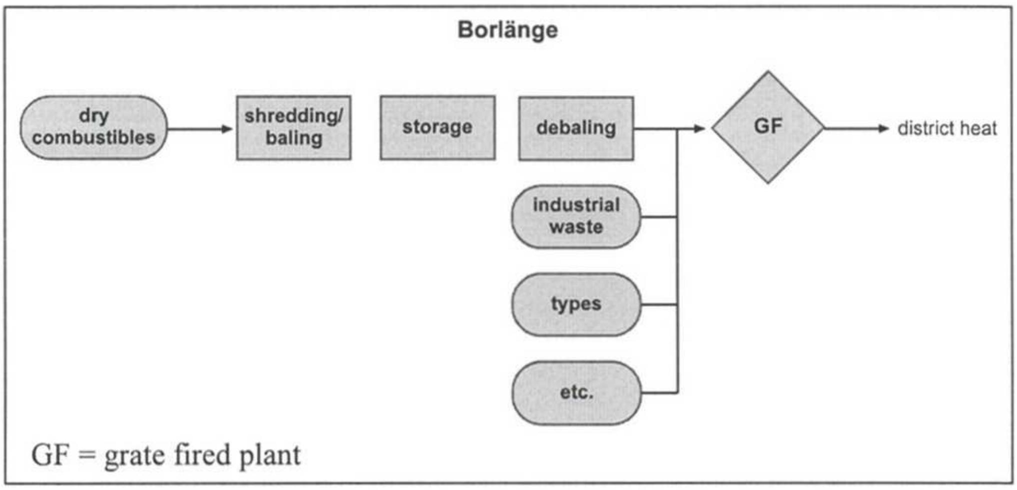


In the Erwitte area wastes from households are collected alternately: one week compostibles, second week the dry rest waste. The restwaste (app. 45,000 ton/a from 180,000 inhabitants) is transferred to the fuel preparation plant, where it is mechanically separated and shredded in three steps. Some 45% is separated out as fuel, the remaining 55% are brought to the nearby landfill.
The industrial wastes, mainly paper and plastics, are coming directly from the manufacturers. Clean scraps are only shredded in two steps, with app. 99% of the input as fluff product.
The industrial fluff is blended with the fluff prepared from the restwaste from households. The final product is a paper/plastic fluff, with an average LHV of 18 MJ/kg and a Cl content < 0.3%.

Wittekind produces cement in a dry process. At the moment they have over ten years experience with the use of recovered fuels. The amount of RF gradually increased from 1.5 ton/h to 12-14 ton/h, now replacing up to 60% of brown coal. The emissions to air are within limit values, which are a mixture between TA-Luft and 17.BIMSCH. One of the positive effects of the RF is a reduction of the NO_x emissions.

Borlänge (S)

Borlänge is a city 200 km north-west of Stockholm. In Borlänge separately collected dry combustibles from household waste are incinerated together with industrial wastes in a grate-fired district heating plant. The output of the plant is approx. 22.5 MW of district heat.



GF = grate fired plant

The most interesting aspect of the Borlänge case is that the fuel preparation only consists of baling for storage during summertime. After opening, the contents of the bales are directly fed to the incinerator; for the quality of the fuel, Borlänge Energi completely relies on the sorting of the people at home.

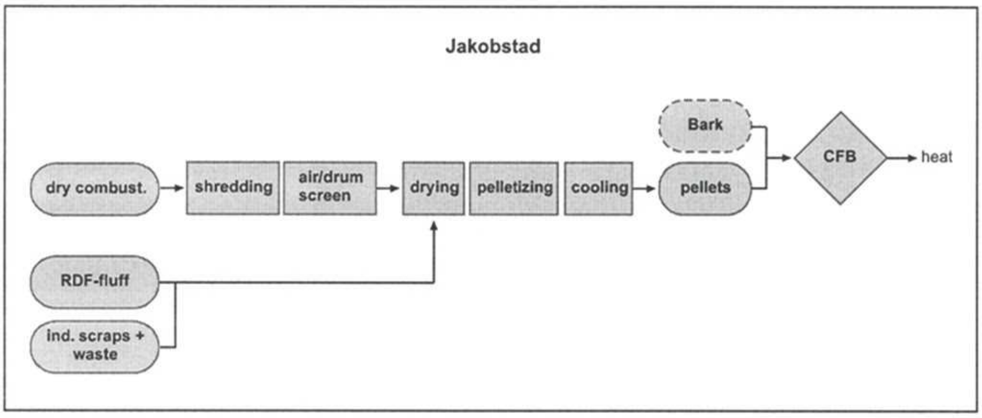
The bales are incinerated during the heating season (approximately 4500 h/year) in the Bäckelund hot water plant. The Bäckeland plant was build in 1969 as an oil fired plant, but was extended with a solid fuel boiler in 1981 to diminish the dependency on oil as a fuel. The flue gasses are cleaned with an electrostatic precipitator and by flue gas condensing.

Jakobstad (FIN)

The Ewapower pelletising plant is located in Jakobstad, a small city (approximately 20,000 inhabitants) on the west coast of Finland. The household waste collection of Jakobstad and surroundings is based on two fractions, dry combustibles and wet rest, that are collected in differently coloured bags in one bin. After collection the bags are optically sorted by colour. In this way it is possible to separately collect a dry combustibles fraction, without the need for a two bin collection system.

After optical sorting the dry combustibles are transported by belt as one of the input streams to the nearby Ewapower pelletizing plant. The incoming dry combustible waste streams are quite divers:

dry household waste from Jakobstad	3,000 ton/a;
commercial. & industrial waste from Jakobstad	5,000 ton/a;
RDF from Vaasa	12,000 ton/a;
commercial. & industrial waste from Vaasa	9,000 ton/a;
other suppliers	8,000 ton/a.

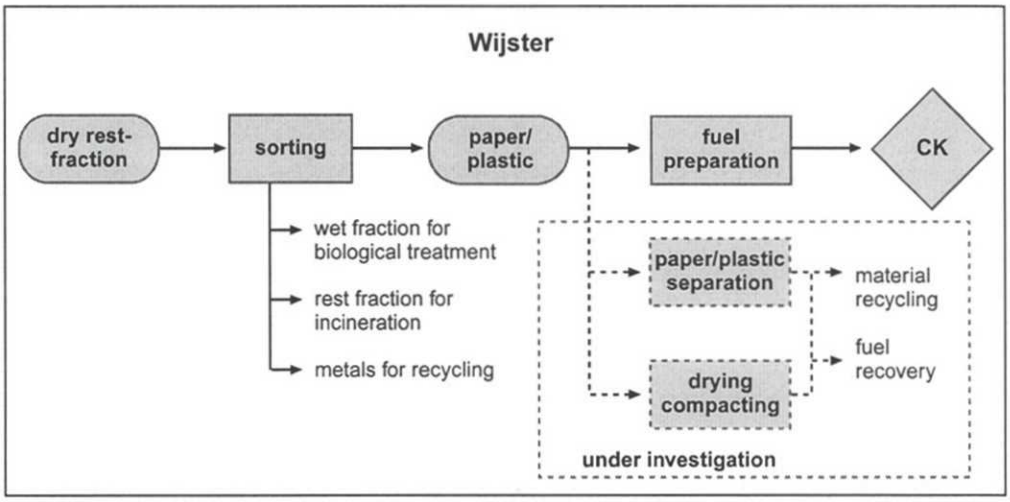


Depending on the type of waste the input is shredded, separated, blended and pelletised, so as to obtain a product with homogeneous specifications. Separation consists of primary shredding, magnetic separation and air/drum screening. The output consists of some 30,000 ton/a of pellets with an LHV of 22 MJ/kg, a moisture content of 3%, ash at 7.5% and Cl at 0.5-0.6%.

The pellets are used in a 138 MW BFB of the nearby UPM-Kymmene pulp and paper mill. The pellets replace up to 20% of coal, used with bark as the main fuel, in the production of 160 ton/h steam (500 °C, 82 bar). In general, the experiences with the use of the pellets are good. The emissions are comparable with the use of only bark, and the low moisture content of the pellets is positive; it compensates for the high moisture content of the bark. A problem is that at the moment the use of pellets is restricted by the feeding system, designed to feed pellets only to one corner of the bed.

Wijster (NL)

Wijster, a small town in the north-eastern part of the Netherlands, is the location of an integrated waste processing plant: the GAVI. The GAVI combines a mechanical separation plant with incineration with energy recovery. In the GAVI, the dry rest fraction of the household waste of approximately 2,500,000 people is treated with similar commercial waste. This equals a total amount of more than 700,000 ton/a; eventually, the total capacity will be increased to 840,000 ton/a.



The mechanical separation plant separates the incoming waste by screens, air classifiers and magnets in four fractions:

- wet organic fraction < 40 mm, for biogas production;
- metals for material recovery;
- light paper/plastic for material or fuel recovery;
- rest for incineration with energy recovery.

For this study, the separation of the light paper/plastic-fraction is of special interest. This fraction is separated with an air classifier from the rest, which goes to the integrated incinerator. At the moment this option is installed in one of the three processing lines, separating some 35,000 tonnes/a of paper/plastic. After optimisation of the process and incorporation in all three lines this amount will increase to approximately 140,000 tonnes. Another 30,000 tonnes/a will be produced at the Vagron-plant in Groningen. This amount will be treated together with the material from Wijster.

Several options for the treatment of this fraction are under investigation, including:

- separation by a wet process for material recovery of a paper and a plastic fraction (pilot tests by the end of this year);
- separation by a wet process, the paper going to material recovery, the plastics to fuel recovery. Substitution of coal in PF is mentioned;
- drying and compacting for fuel recovery.

At this moment the mixed fraction is baled and are transported to Erwitte (D), where a fluff fuel for the cement kiln is produced from it.

Compared to incineration alone, the VAM-concept has several advantages, such as smaller investment costs for the incinerator and higher flexibility of the total waste management system.

On the other hand however VAM faces the problem that not all problems regarding the biological treatment of the wet organic fraction are solved at this moment. As landfilling of this fraction is banned in the Netherlands, other treatment methods must be found, if the problems are not solved.

3.4 Specific waste streams

7 cases with specific waste streams were selected: Kauttua (FIN), Lomma (S), Örebro (S), Slough (UK), Obourg (B), Nijmegen (NL) and Wietersdorf (A)

Kauttua (FIN)

Kauttua is situated in south-west Finland. The Kauttua plant is a 65 MW combined heat and power plant. It is a CFB (Pyroflow) producing 90 ton/h steam (84 bar, 500 °C). The flue gas cleaning consists of an ESP.

The Kauttua plant is a typical multi-fuel plant, as is shown by the following fuel input figures for 1997:

Table 3.4 Fuel input to Kauttua-plant in 1997.

Fuel	%	GWh	ton
coal	34	92	12351
peat	19	53	19505
oil	1	2	157
wood waste	29	80	36723
paper waste	8	20	5876
other waste	9	26	6565
total	100	273	81177

Part of the input to the Kauttua plant comes from the paper sorting plant of Paperinkeräys Oy [1] at Urjala. Here separately collected paper from households and industry is sorted in different qualities for material recycling. The non-recyclable rejects of the sorting process (mainly non-recyclable part, but also some broken wooden pallets) are no longer taken to landfill, but are used for fuel recovery at Kauttua.

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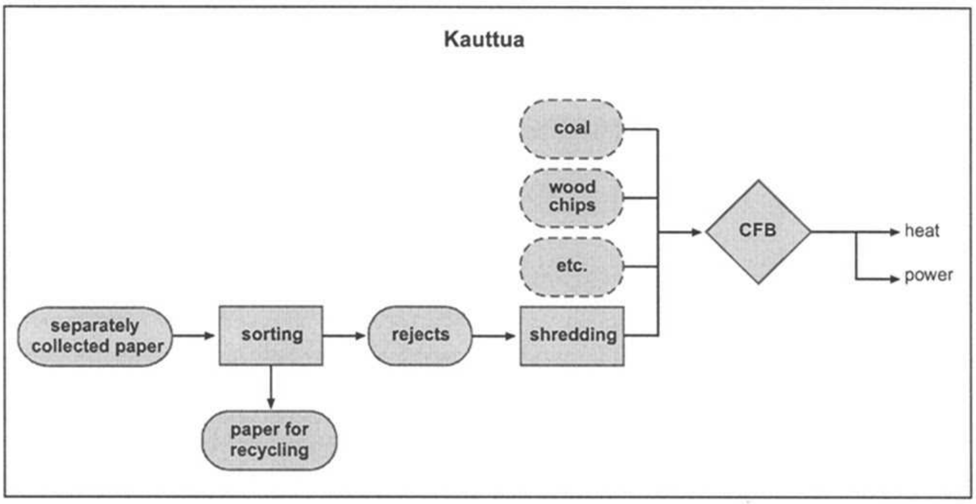
[1] Paperinkeräys Oy is a company owned by 6 major forest industry companies dealing with recovered paper.



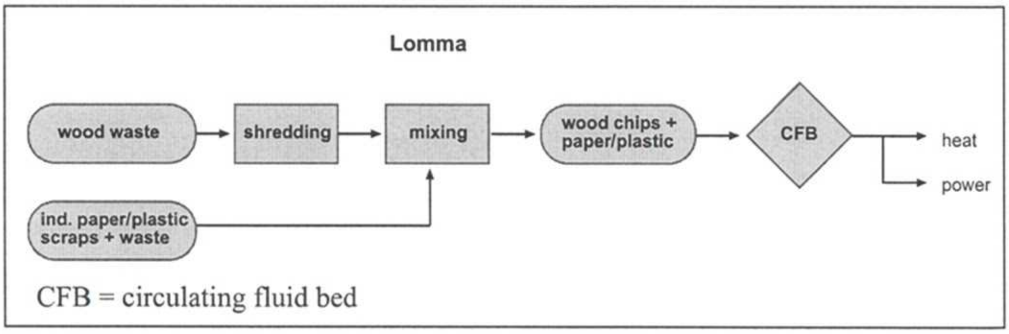
The Kauttua plant is a plant with much experience in the use of recovered fuels, including:

- short-term tests with different RF in 1993/94;
- long-term tests with RDF and PDF 1994;
- use of 11-17% recovered fuels during normal operation in 1996 and 1997.

The results of the tests in 1993 and 1994 were, in general, positive. The fact that recovered fuels are used on a regular basis for the last two years proves that recovered fuels can be used to substitute primary fuels such as coal and peat. The change in the feeding system this winter shows that for substitution adapting the installation to the specifications of the fuel is necessary.

Lomma (S)

Lomma is a small town in the neighbourhood of Malmö in the south of Sweden. The district heat for Lomma is provided by the 18 MW CFB installation of Lomma Energi. During the heating season, the installation produces steam at 510 °C, 61 bar, which is used to generate 11.7 MW of heat and 4.5 MW of electricity. The flue gas cleaning consists of cyclones, textile filter, injection of $Ca(OH)_2$ + activated carbon.



CFB = circulating fluid bed

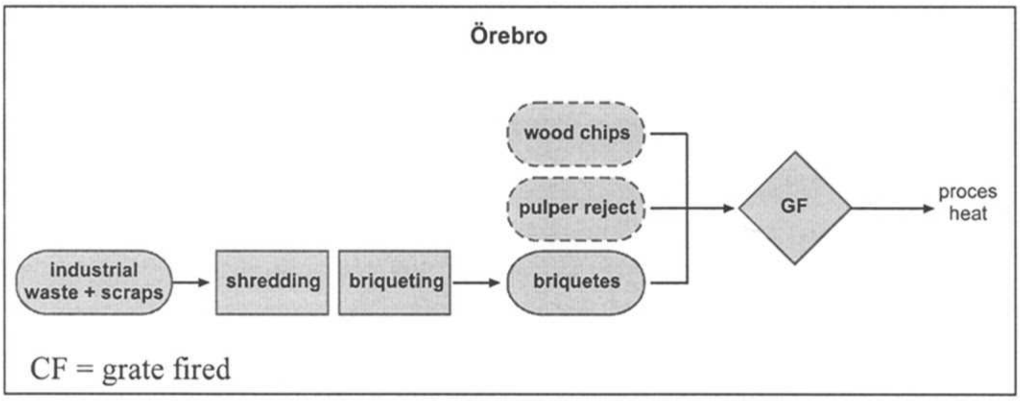
At the Lomma plant, only recovered fuel is used. The fuel is prepared on site. Approximately 12,000-14,000 ton/a of commercial and industrial waste is preselected and shredded. The input consists of 85% waste wood and 15% paper/plastics. The final shredded product has an LHV of 16 MJ/kg, 18-20% moisture, 5% ash and Cl < 0.1%.

The installation is operating excellently; the plant is partially run unmanned. The only major fuel problems so far concerned the uncontrolled accumulation of aluminium in the cyclone. Every now and then blocks of aluminium fall down, thus blocking the feeding of the boiler. This problem was solved by changing the combustion parameters.

Örebro (S)

Örebro Kartongbruk AB, a Swedish cardboard producer, produces some 40,000 tonnes of plasterboard liner at their Örebro plant. Inputs to the process are a.o. 53,000 tonnes of recycled paper, 96.000 tonnes of steam and 50,000 MWh of electricity. A major part of the energy demand of the plant is generated by the three boilers of Örebro Kartongbruk AB. The energy is partly generated from briquettes produced at the Örebro-plant. The briquettes are made on site from clean industrial paper/plastic scraps, e.g. cuttings and off-spec-production. This waste is shredded and then 'glued' together to form briquettes.

One of the boilers of Örebro Kartongbruk AB is an 8 MW grate-fired boiler. In this boiler some 20,000-25,000 m^3/a wood chips are combusted, together with 6,000 ton/a briquettes to generate some 42 GWh of process heat.


Örebro

CF = grate fired

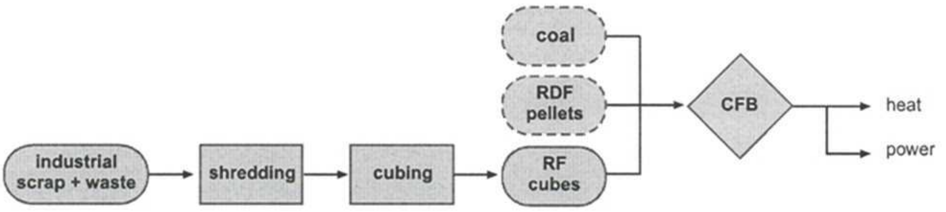
Until recently some 2,000 ton/a reject from the pulper were also used in the boiler. At the moment this is no longer possible because of a new type of waste paper, resulting in more reject with a worse quality.

Slough (UK)

UK Waste and Slough Heat & Power jointly started the Fibre Fuel pelletising plant to produce fuel for the CHP plant of Slough. The fuel preparation process consists of shredding, binding with paper sludge and cubing of unrecyclable paper, board, plastic packaging material and paper sludge. This results in cubes (pellets) with an

LHV of 18-19 MJ/kg and a Cl content of 0.1-0.2%. After further process development during the last two years, the plant is now running at approx. 2,000 ton/month.

Slough



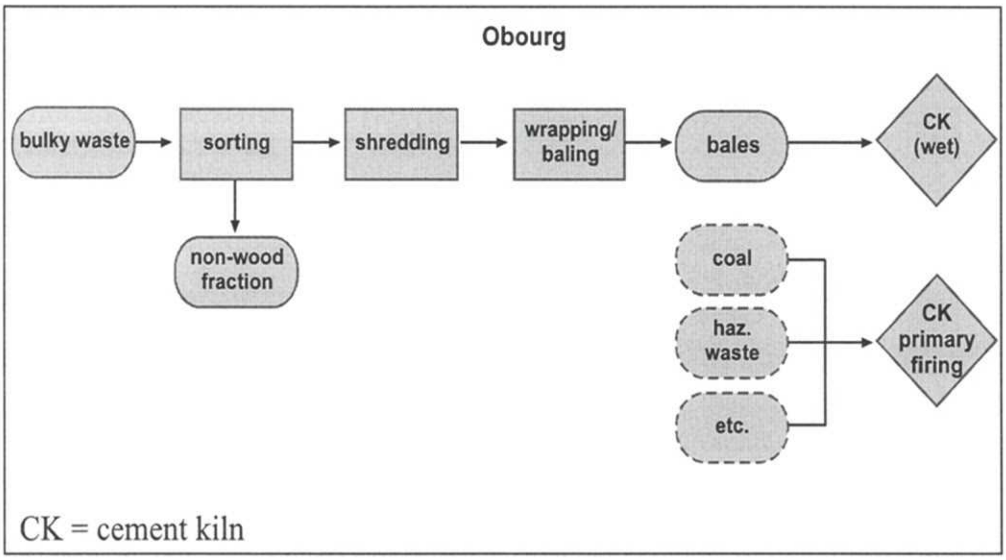
CFB = circulating fluid bed

The fibre fuel is used in two CFB boilers of the nearby CHP plant of Slough Heat & Power, producing 188 ton/h of steam (509 °C, 87 bar). The primary fuel is coal. The emissions with the use of up to 40% of recovered fuel are generally comparable with the emissions of only coal. SO_x emissions are reduced from 700 mg/Nm^3 to 400 mg/Nm^3, HCl emissions increase from 70 mg/Nm^3 to 170 mg/Nm^3, both reflecting the difference in composition between coal and fibre fuel.

Obourg (B)

Ciments d'Obourg is a cement plant located in Obourg, a small village near Mons in the south of Belgium. The two kilns of Ciments d'Obourg produce 3,000 tons of clinker per day each, resulting in a cement production of 2.5 Mton/a.

Since 10 years, more than 1 Mton of hazardous waste have been used at Ciments d'Obourg as alternative fuel and raw material. The activity is now extended to non-hazardous waste such as municipal waste, industrial wastes, sewage sludges and plastics. These wastes are all used in the primary flame. Of particular importance for this study is the use of recovered fuels in the 'mid-kiln process'. In this process, bales of combustibles (approx. 75 × 75 × 25 cm, weighing 85 kg) are fed, halfway (mid-kiln) the 200 m long rotary kiln. The new supplier for the bales, i.e. the local waste management organisation ISPH produces bales from bulky waste the sorting plant consists of a shredder, magnets, a drumscreen and baling equipment. One of the reasons to choose for bulky waste as a fuel was that the gate fee for landfilling is charged per volume. In this way, a high volume of waste is diverted from landfill, while the energy content of the wood-rich bulky waste is utilised in the nearby cement kiln.

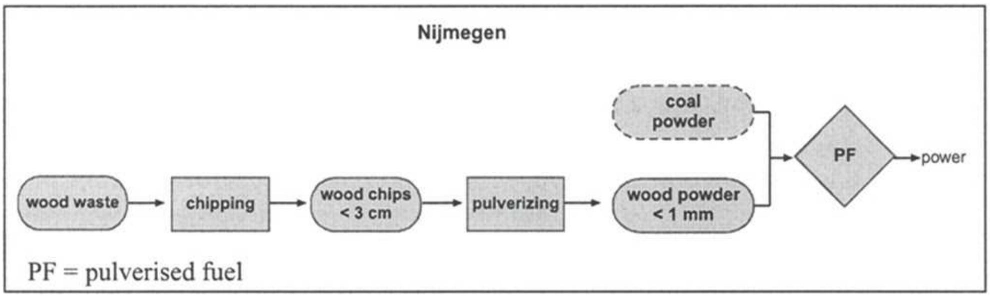


CK = cement kiln

Over the last decade Ciments d'Obourg succeeded in reducing the emissions to the air while increasing the amount of waste. In test trials it was also proved that the mid kiln feeding of non-hazardous waste does not result in increased emissions.

Nijmegen (NL)

EPON is a Dutch energy production company. At their Gelderland power station (635 MW_e) at Nijmegen, waste wood is used after processing as a secondary fuel in a coal-fired power station. On average, 5% of the combustion energy is supplied by wood. The amount of electricity generated based on pulverised wood will be 20 MW_e, which will replace 45,000 tons of coal per year. Annually 60,000 tons of waste wood will be used as fuel, reducing the CO_2 emission by 110,000 tons.



PF = pulverised fuel

Waste wood and demolition wood are collected at three locations in the Netherlands. The wood is sorted and processed to raw wood chips and then transported to EPON in containers. Two hammer pulverisers (each with a capacity of 10 ton/h) reduce the material from its original size (approx. 3 cm) to particles of 1-8 mm. After that, the material is transported to the four pulverisers of the installation where it is further reduced in size and dried with pre-heated air. The end product is collected in a dust collector. Each pulverising system works independently and produces 2.5 ton/h of end product with a density of 200-240 kg/m^3. In a static classifier, approx.

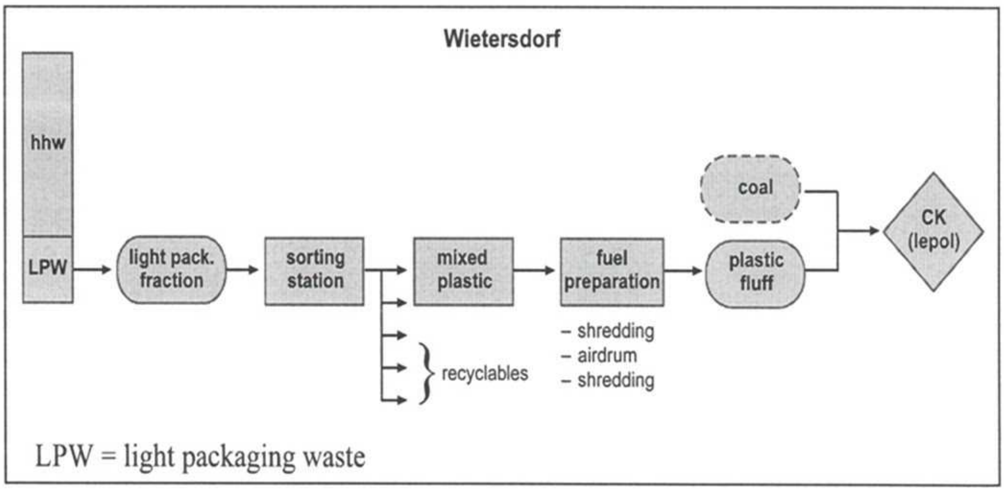
15-25% of particles smaller than 800 μm is removed from the end product. A sieve removes the oversized particles, which are returned to the pulverisers. The product from the sieve, together with the product from the classifier, is transported to a storage silo. From there it is transported to four individual wood burners (total capacity 54 MW_{th}) which are mounted in the side walls of the boiler.

The energy required for pulverising and drying the wood is approx. 10% of the total energy production. The total investment amounts to approx. 15 MECU.

Wietersdorf (A)

In Austria, the cement industry represents the largest single outlet for plastic packaging collected to comply with Austrian packaging law. Throughout Austria light packaging, like plastic packaging are separately collected and transported to sorting stations, where streams for material recycling are sorted out. For the plastics these are e.g. plastic bottles. One of the side streams of the sorting process is a mixed plastic waste (MPW) fraction, which after processing can be used as a fuel in cement kilns. At the moment three cement kilns use mixed plastic waste as a fuel. The total capacity was estimated at 20,000 tons in 1996.

One of the fuel production sites (owned by Baufeld) is next to the cement plant of W+P in Wietersdorf. Baufeld and W+P have improved the MPW feed preparation and fuel dosing system since the early 1990s. The fuel preparation consists of primary shredding with a hammermill, separation of a 'light fuel' with an air/drum and secondary shredding. The system is now able to operate at an MPW input of 1.6 ton/h, averaged over a month.
The quality management of Baufeld relies on checks of the incoming MPW as well as on the design of the plant. Earlier negative experiences resulting in equipment shut down (primarily from the mills) caused this strict quality management.



LPW = light packaging waste

The cement kiln at Wietersdorf is of a Lepol-type. Emissions at W+P are controlled with a two field ESP. The MPW addition has significantly reduced the levels of SO_x

as well as of NO_x.
The process of W+P (Lepol type) is able to take high amounts of chlorine. Increasing the amounts of MPW raised the chlorine level. As W+P has no other alternative fuel the chlorine level in the feed is determined by the MPW amount; the coal has a rather low Cl content of 0.06%.

4. Evaluation of fuel recovery cases

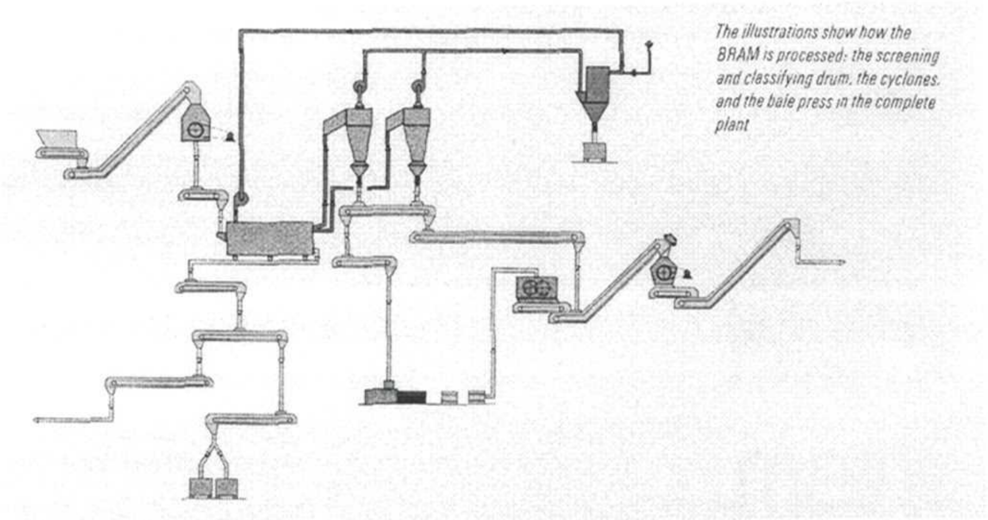
In this chapter the technical, economic and environmental effects of the fuel recovery concept as they are found in the different cases are discussed, considering the different local circumstances. The recovered fuel should fulfil certain technical, economic and environmental criteria. In the overall picture the recovered fuels should generally perform as well as the substituted fuel. (The influence of fuel composition on the combustion process is discussed in chapter 2 and in Appendix B).

The cases show a wide variety in incoming waste streams, fuel preparation and combustion installations. To demonstrate the potential of the fuel recovery concept it is useful to show the possibilities in all these different cases. The fuel recovery concept is strongly dependent on local circumstances. A solution that works well within one part of Europe will not necessarily work well in another part. Local circumstances can be the demand for a certain type of energy (e.g. district heating), the local availability of a specific waste stream, alternative waste management options, the nearby presence of potential users of the recovered fuel (e.g. industrial boilers or cement kilns), etc.

4.1 Technical evaluation

The technical evaluation focuses on topics such as fuel preparation, fuel handling at the combustion installation, behaviour in the combustion installation, availability of the combustion installation, etc.

Fuel preparation technologies vary considerably depending on source and type of waste and on the requirements of the customer/combustion installation. The main function of the fuel preparation is to upgrade selected materials to a specified fuel. In the different cases we can distinguish two major fuel types: shredded or fluff-like material and densified fuels such as pellets, cubes and briquettes. Up to the densification, the processes for these two types are quite similar. In general, they consist of shredders, magnets and screening devices. Figure 4.1 shows as an example the flow sheet of the sorting plant in Erwitte built by MBM-Anlagenbau, which produces fluff for the nearby cement kiln.



The illustrations show how the BRAM is processed: the screening and classifying drum, the cyclones, and the bale press in the complete plant

Figure 4.1 Flow sheet of the sorting plant in Erwitte [MBM Anlagenbau].

For nearby grate-fired or fluidised bed installations, the use of a fluff material with a rather high moisture content is feasible, but if the fuel has to be transported and stored it needs drying and densification in order to improve total economy. Eventually the fuel has to be provided in a free flowing form suitable for existing handling equipment. Densified recovered fuels can have Lower Heating Values (LHV) up to approx. 30 MJ/kg depending on composition. The contribution of different waste sources to the heating value of recovered fuels in some selected cases is presented in Figure 4.2.

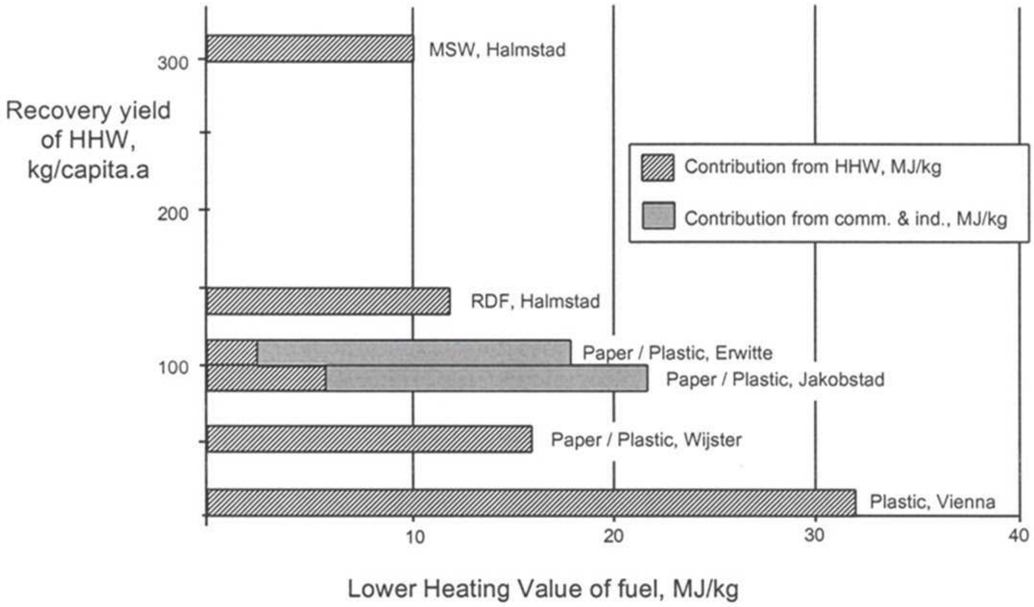


Figure 4.2 Heating values of recovered fuels, contribution to LHV from different waste sources and total rates of recovery for HHW in selected cases.

A general observation with respect to fuel preparation is that the technology to produce recovered fuel is available. However, most projects have start-up problems, often resulting in redesigning the fuel preparation plant. Often, these technical problems concern the fine-tuning of the installation to the incoming waste streams and the specifications of the desired end product, which may vary considerably from case to case.

Fuel handling at the combustion installation involves storage, transport to the boiler and the feeding to the boiler. In storage, the densified products show advantages over the fluff-like fuels.
It is interesting to see that in cases where shredded material or fluff is used, e.g. in Kauttua, Lomma and Erwitte, the fuel is prepared on site with a maximum storage time of a few days. If longer storage is needed, e.g. for the winter time, other solutions are used such as baled the material or covered stock piling.
For internal transport, several solutions are available, e.g. belt and screw conveyers. Because of the different behaviour of the recovered fuel compared to primary fuels such as coal and peat, separate feeding units are used in many cases. These in itself can cause new limitations, as was shown in Jakobstad, where originally the recovered fuel was fed only at one corner of a BFB, leading to hot spots in the bed if the load of recovered fuel was too high.
In short we can say that, as for the fuel preparation, the technical solutions for the fuel handling are available, but that fine-tuning is necessary.

In general, the experiences with the combustion of the recovered fuels are positive. Compared to mixed waste, recovered fuels are more homogeneous. This is also stated at the waste incinerator in Halmstad, where RDF is co-incinerated during the heating season. In Jakobstad a positive effect was noted from the lower moisture content of the RF-pellet compared to the primary fuel bark.
On the other hand, there are also problems possible. In Lomma, the presence of aluminium led to clogging problems in the cyclone, but changing the combustion parameters solved this problem. Another example is the gasifier in Greve, where the RDF pellets from Florence are used. One of the problems of this demonstration plant was the clogging of the fluidisation airpipes at the bottom of the gasifier after typically one thousand operation hours. This clogging was caused by aluminium and copper, probably from nails in fruit boxes frequently used in the Florence area. Possible solutions are a separation of non-ferrous metals in the fuel preparation and/or another design of the airpipes. As said before, these are, however, specific 'case problems', which are not typical for the use of recovered fuels, but only show that the possibilities and the technical problems and solutions differ from case to case.

Furthermore, the cases show that typical problems one could expect (such as fouling and corrosion) do not have to occur if the specifications on the recovered fuel are compatible with the primary fuel. One must, however, be aware of the problems that certain contaminations can cause.

4.2 Economic evaluation of the integrated cases

In general, three parties are involved: the waste owner, the company preparing the recovered fuel and the user of the fuel. The waste owner compares the total of collection costs and gate fee of the fuel preparation plant (positive or negative) with the costs of alternative solutions. The user of the recovered fuel compares the price of the recovered fuel with those of the primary and/or alternatives fuels. For the fuel preparation plant the difference between these two determines if the fuel preparation plant can make a profit. The economic consequences of the fuel recovery concept are elucidated for the following cases: Wijster, Halmstad, Jakobstad and Wietersdorf.

In Figure 4.3 the cost comparisons are presented graphically.

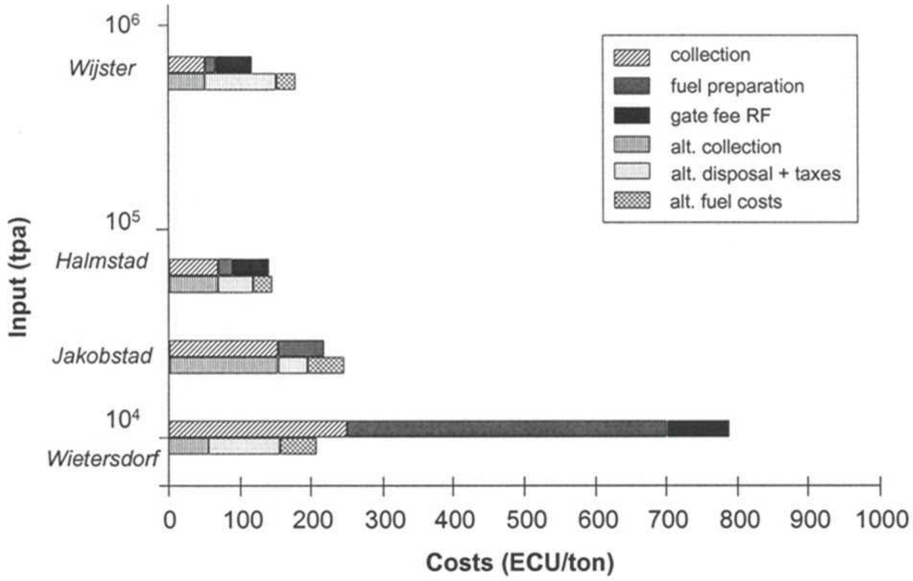


Figure 4.3 Comparison of fuel recovery vs. alternative disposal costs for selected cases.

In the Wijster case we compare the separation of the light paper/plastic fraction followed by co-combustion at the cement kiln in Erwitte with the situation where this fraction is left in the feed for incineration with energy recovery at the GAVI. The light paper/plastic fraction is separated in the GAVI, so the fuel recovery concept has no influence on the collection system. The costs for the normal two-bin collection system are approx. 50 ECU/ton in the Netherlands.
The separation costs in the GAVI are estimated at 15 ECU/ton. The exact transport costs and gate fee for the Erwitte plant are not given, but estimated at 50 ECU/ton. So the total costs for the fuel recovery concept are 115 ECU/ton.
The internal incineration fee at the GAVI is approx. 100 ECU/t; so if compared to this fee, the fuel recovery concept is cheaper. The savings in fuel costs in Erwitte

are estimated at 30 ECU/ton. Thus the total costs for the alternative route are approx. 180 ECU/ton, 65 ECU/ton more than with the fuel recovery concept.

In the Halmstad case, we compare the RDF separation route with the landfilling option. Again there is no influence on the collection systems and costs; they are estimated at 80 ECU/ton. The separation of the RDF fluff in Falkenberg and the transport plus the gate fee at the Halmstad incinerator are estimated at 20 ECU/ton and 50 ECU/ton, respectively. The alternative landfilling costs are around 60 ECU/ton, the savings in costs for the primary fuel for district heating are 25 ECU/ton.
The total costs for the fuel recovery concept amount to 150 ECU/ton and for the alternative route 165 ECU/ton: they are in the same order. The advantages of the fuel recovery concept are in the diversion from landfill (in Falkenberg) and the savings in fuel costs (in Halmstad).

In Jakobstad, the collection system is also the same for both routes. Because of local circumstances the collection costs are high: approx. 160 ECU/ton. In the fuel route the dry combustibles are separated by optical sorting and then pelletised; the costs are estimated at 30 ECU/ton and 40 ECU/ton, respectively. Costs for landfilling are around 40 ECU/ton; the saved fuel is in the order of 50 ECU/ton. The total costs for the fuel recovery concept are 230 ECU/ton and for the alternative route 250 ECU/ton: as in Halmstad, they are in the same order. The advantages of the fuel recovery concept are again in the diversion from landfill and the savings in fuel costs.

A last case is Wietersdorf. As a consequence of the Austrian Packaging Law, a light packaging fraction is separately collected. Small quantities per household and the low density lead to high collection costs of 250 ECU/ton. After collection the packaging fraction is sorted into different fractions; from the mixed plastic fraction a fluffy fuel is made. Manual labour and low throughputs lead to high costs, as high as 450 ECU/ton. Besides that, a gate fee of approx. 75 ECU/ton is asked at the cement kiln, making the total costs 775 ECU/ton. Although the product is a high calorific fuel, it is clear that this route is an expensive compared to traditional collection and incineration of household waste (approx. 150 ECU/ton as an average for the EU).

The examples given before show that the fuel recovery route can be an economically attractive route. Depending on local circumstances, the total costs are equal or even lower than alternative options. Local circumstances can be:

- costs for alternative disposal routes. These are influenced by factors such as scale factors, regulations options for selling energy. E.g. Dutch incinerators are large, have expensive flue gas cleaning equipment and limited possibilities to sell heat, whereas Swedish incinerators are smaller, but have better opportunities to sell their heat. In the end, incineration costs are lower in Sweden than in the Netherlands, despite of the smaller scale of the incineration plants.

- taxes on alternative disposal routes. Several countries (e.g. Sweden and Finland) have taxes on landfill, thus increasing the costs of this option in favour of recovery operations.
- regulations and laws. E.g. the Austrian and German Packaging Laws prescribing the recovery of packagings.
- environmental taxes on primary fuels, e.g. on CO_2, SO_x and NO_x. In Sweden, coal for heat production is highly taxed. In the Swedish case, coal costs around 7 ECU/MW_h, while the tax is 26 ECU/MW_h. These taxes favour the use of biomass, but also increase the margin for recovered fuels.

4.3 Environmental evaluation

Recovered fuels can be produced from different sources, such as pre-use industrial residues, post-use industrial waste and selected fractions from commerce and households. Depending on the source, the composition and the amount of contamination of a recovered fuel will differ. The main difference between coal and the recovered fuels are found in the content of sulphur, chlorine and heavy metals. In many cases, if recovered fuels with plastics are considered and compared to coal, the chlorine of the recovered fuels are higher and the sulphur is lower. And generally, the heavy metals content will stay in the range or increase. These changes will affect either the emissions to air or water or the concentrations in the solid residues (including clinker produced for cement.).

Emissions to air

The higher amounts of contaminations do not necessarily lead to higher emissions to the air and the resulting emissions are within limit values, as is shown in the following examples:
- long-term trials with RDF in 1993/94 and the current use of recovered fuels in the CHP plant in Kauttua;
- compliance tests in 1993 and current use of recovered fuels in the CHP plant in Slough;
- experiences reported by UPM-Kymmene in Jakobstad;
- the increasing substitution by recovered fuel over the last ten years in the cement kiln in Erwitte;
- the increasing use of hazardous waste over the last ten years and test trials with the mid-kiln feeding of bales of non-hazardous combustibles at the cement kiln of Ciments d'Obourg.

Some data on selected cases proving that the emissions with and without RF are comparable with each other is presented in Table 4.1.

Table 4.1 Emission values without and with recovered fuel at selected cases.

Emission	89/369/EEC	HALMSTAD (S)		JAKOBSTAD (FIN)		SLOUGH (UK)		OBOURG (B)		NIJMEGEN (NL)	
Component [1]	**Limit value**	**Without**	**With [3]**	**Without**	**With [4]**	**Without**	**With [5]**	**Without**	**With [6]**	**Without**	**With [7]**
Dust	30	3	3	20	30	20	20	10	8		< 20
CO	100	30	50	60	60	80	80				< 50
TOC	20					2	2	8			
SO_x	300	150	90	10	<16	700	400	120			< 400
NO_x	-	160	150	210	190	70	70	340			< 200
HCl	50	20	20	1	5	70	170	2	1		< 10
Hg	0,2	0,002	0,002	0,001	0,001	< 0.01	< 0.01	0.02	0.03		< 0,05
Cd	0,2		0,070	0,001	0,001	< 0,01	< 0,01	< 0,01	< 0,01		< 0,05
PCDD/F [2]	-		2,5	< 0,1	< 0,1	< 0,1	< 0,1				
Comb. technology Main Fuel Flue gas treatment		Mass burn MSW "Hot" ESP, SNCR, wet scrubber, condenser		Bubbling FB Bark ESP		Circulating FB Coal Limestone injection Fabric filter		Rotary kiln Coal and waste ESP		Pulverised Fuel Coal ESP, FGD, SCR	

Notes:

- No limit; ( ) No measurement

[1] mg/m^3 dry gas, 11% O_2,

[2] ng/m^3 ITEQ

[3] 50% RDF-fluff

[4] 8% RF-pellet

[5] 40% RF-cube

[6] 5% RF-bales midkiln

[7] 5% RF-pulverized wood

Emissions to water and solid residues

Pollutants not emitted to air will be transferred to the solid residues or will be discharged into water. The amount and type of solid residues is determined by the combustion system, the flue gas cleaning equipment and the type of fuels used. A short summary of the combustion system and flue gas cleaning equipment encountered in the case studies is presented in table 4.2.

Table 4.2 Combustion system and flue gas cleaning equipment in the several cases

Case	Combustion system	Fluegas cleaning equipment
Halmstad	grate	ESP, wet scrubber, SNCR, condenser
Borlänge	grate	ESP, condenser
Örebro	grate	cyclone
Florence	CFB-gasification	bag filter, lime injection
Jakobstad	BFB	ESP
Kauttua	CFB	ESP
Lomma	CFB	bag filter, $Ca(OH)_2$ + active carbon injection
Slough	CFB	bag filter, limestone injection
Nijmegen	PF	ESP, FGD, SCR
Erwitte, Wijster	cement kiln	ESP
Obourg	cement kiln	ESP
Wietersdorf	cement kiln	ESP

Except for Halmstad and Borlänge all flue gas cleaning systems are dry, resulting in solid residues like fly-ash and bottom-ash. These residues are either landfilled or (re)used, e.g. in clinker production or in construction applications. Most certainly in the cases where the solid residues are (re)used, the effect of the recovered fuel on the solid residues is critical:

- in Nijmegen some 220 tonnes of coal are combusted per hour. Besides the energy produced, this results in 5-10% ash or 100,000-150,000 tonnes of ashes and some 40,000 tonnes of gypsum from the desulphurization per year. It is evident that to be cost effective it is absolutely necessary that the re-use of these products is not hampered by the wood powder that is co-combusted;
- for the three cement kilns in the case studies (Erwitte, Obourg and Wietersdorf) cement production is the primary process. The quality of clinker and cement therefor must remain within product standards when recovered fuels are co-combusted.

In general, an increase in solid residue contamination not necessarily results in increased leaching of elements into the environment during the use of the solid residues or cement products. This is supported by many investigations on solid residues and cements, such as research on cement products carried out for Ciments d'Obourg.[1] In this study, the environmental properties of cement mortars have been studied in their service life as well as in the secondary life (construction debris). A comparison of the leaching behaviour of cement mortars from natural raw materials and special cements produced using alternative fuels and raw materials showed that the leachability of special cements does not exceed the leachability of traditional cements. For crucial elements such as Cr, even lower leachability is observed in spite of a higher total composition.

The emphasis in environmental evaluation has been on the service life of cement products. This stage proves to be of very limited concern. The emphasis should be on the "second" life of cement mortars. If construction debris is reused as aggregate in cement mortar , again leachability is of limited concern. When construction debris are reused as aggregate for road construction, environmental issues can be relevant as oxyanionic species (e.g. chromate, sulphate, molybdate, vanadate) may exceed critical limits. With the possible exception of Cd, metals such as Pb and Zn are unlikely to become critical, even in the second life of cement mortars.

This illustrates that an evaluation of cement mortars on total composition is not a valid method for judging environmental impact. New environmental criteria should be developed based on leachability.

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[1] Ciments d'Obourg: Characterisation of the leaching behaviour of cement mortars to assess long term environmental behaviour during their service life and their recycling stage, 1989, by H.A. van der Sloot ECN, to be published.

4.4 Other issues

The technical, economic and environmental evaluations already have shown that local circumstances have their effects in the different cases. Important issues include the availability of wastes and the existing waste management options, the demand for energy, the availability of installations which can use the recovered fuel and economic aspects such as taxes, gate fees for existing waste routes, etc.

The demographic situation also affects (together with local policy) whether a waste is landfilled or recovered, as material or fuel or as energy from incineration. The feasibility for waste incineration is much less in certain scarcely populated areas than in densely populated areas. The choice between landfill or incineration, however, has a great influence on the overall effects of the fuel recovery option:

- In the case of landfilling, the fuel recovery concept results in the reduction of the use of fossil fuels and in the landfilling of wastes. This under the assumption that the energy demand is the same in both cases and that the recovered fuel replaces an equivalent amount of energy from traditional fuels.
- In a densely populated area where MSW incineration (with energy recovery) is regarded as an alternative for landfilling (until that moment the only actual disposal method), the introduction of fuel recovery could be very attractive as it can save on required installation capacity. Waste treatment could consist of three methods:
  - separate collection of the wet organic fraction for biological treatment,
  - fuel recovery of a selected part of the waste and combustion in existing infrastructure,
  - a dedicated waste incineration plant for the rest fraction.

  Diversion from landfill is maximal, costs for waste incineration are minimised and the energy efficiency is high. This option of fuel recovery from municipal solid waste is studied in the Netherlands as a way to treat the growing waste volume which may not be landfilled anymore because of the landfill ban. In fact, the waste management scheme described above (separate collection of organics, fuel recovery and incineration of the rest fraction) is the system adopted by the VAM in Wijster.

4.5 Model calculations: fuel recovery and municipal waste management

4.5.1 Scenarios

The cases described in the previous chapters differ in many respects which makes mutual comparison difficult. To this end, 5 scenarios are drawn up, covering the most important options for integrating fuel recovery in municipal waste management. The purpose of the model calculations is to illustrate and to compare the economics of the scenarios. Not the absolute but the relative cost level is of importance. It is emphasised that the names of the towns are used but that modifications from the real cases are introduced for better comparison. That is why they are indicated by "....". The actual costs in case reality can differ from the calculated model costs because of local circumstances such as the general price level in a certain region, existing infrastructure, demand for energy, waste volumes, taxes, possible revenues, local industry etc.

The basic characteristics of the scenarios are described in Table 4.3. These scenarios are selected for model calculations resulting in generalised data, enabling their comparison. Two traditional scenarios are considered for reference: collection of household waste in one bin and energy recovery by incineration ("Halmstad" case) or disposal in landfill. All scenarios result in rest fractions that have to be disposed of.

Table 4.3 Basic characteristics of the scenarios.

Scenario	**Traditional Reference**	**Optical sorting**	**3-bin combustibles**	**2-bin mechanical separation**	**3-bin recyclables**
Case	**"Halmstad"/ Landfill**	**"Jakobstad"**	**"Borlänge"**	**"Wijster"**	**"Wietersdorf, (Erwitte)"**
Collection system	1-bin kerbside	2 fractions in 1-bin kerbside + optical sorting	2-bin kerbside + 1 bring	2-bin kerbside	2-bin kerbside + 1 bag
Collected fractions	mixed household waste	dry combustibles wet rest	dry combustibles organic inert/rest	dry rest organic	recyclables organic rest
Treatment	incineration (or landfill)	dry comb. to fuel preparation wet rest biological	dry comb to fuel preparation organic to biological inert/rest to landfill	dry rest to separation plant organic to biological	recyclables to MRF organic to biological rest to incineration

The scenarios are shortly described below.

Traditional MSW scenarios

In this scenario all household waste (including waste from small shops etc.) is kerbside collected in one bin. Treatment consists of landfill or of incineration followed by landfill of the ashes.

This latter scenario is valid for the MSW from *Halmstad*, which is incinerated in the MSW-incinerator of "Halmstad" (together with industrial waste and RDF from Falkenberg).

Optical sorting
In the 'optical sorting' scenario two fractions are collected in one bin in differently coloured bags (e.g. black and white). After collection the bags are optically sorted by colour. This system is used in *Jakobstad*, where dry combustibles are collected in a white bag and the wet rest fraction is collected in black bags.

From the dry combustibles and specific combustible waste from commerce and industry a fuel is prepared. This can be fluff or a pellet (pellet in the case of "Jakobstad"). For the wet rest fraction there are several possibilities, including landfill, incineration or (as in the "Jakobstad"-case) separation and anaerobic treatment of the organic part and fuel preparation from the combustibles. The advantage of this collection system is that two fractions can be collected in one bin. This results in lower container costs, but introduces costs for the optical sorting.

2-bin mechanical separation
The '2-bin mechanical separation' scenario is based on the *Wijster* case. In this scenario two fractions, organics (green bin) and dry rest (grey bin), are kerbside collected in two bin. In the Netherlands the collection typically is alternating: one week the green bin, the next week the grey bin.

The organic fraction is biologically treated by aerobic composting. The dry fraction is mechanically separated. In "Wijster" the dry rest fraction is separated in a fraction < 40 mm for anaerobic biological treatment in a bio-reactor, a paper/plastic fraction > 180 mm, some metals for recycling and a rest fraction for incineration. For this paper/plastic fraction several options are possible, including fuel preparation.

The advantages of this system compared to incineration are a high flexibility, lower investments in MSW-incineration capacity and a clean compost from the separately collected organic fraction. Due to the alternating collection system the increase in collection costs is limited.

3-bin combustibles
This system is based on the situation in *Borlänge* and Norrköping. The organic fraction and the dry combustibles are kerbside collected in two bins. A rest fraction, as well as materials for recycling, are brought to small recycling stations.
Compared to the '2-bin combustibles' scenario, it is now possible to use the organic fraction to produce a clean quality compost from the organic fraction. In *Borlänge*, the fraction dry combustibles is only baled for storage during the summer and district heating in the wintertime; there is no actual fuel, fluff or pellet, production.

3-bin recyclables
In this scenario three fractions are kerbside collected: organics, recyclables (mainly packaging) and a dry rest fraction. The recyclables can be collected in a third bin or in a plastic bag. This scenario is typically the system used in many places in Germany and Austria to comply with the national packaging directive. Compared to the

'2-bin recyclables' scenario it is possible to produce a clean quality compost from the organic fraction.

The recyclables are hand-sorted in a MRF. Often this results in a mixed plastics fraction which can be used for fuel preparation, e.g. the *Wietersdorf* case.
For the dry rest fraction there are several options, such as landfilling, incineration or fuel preparation as in Erwitte. *Wietersdorf* is used as the example.

The Pamplona case is not modelled because it differs in too many aspects from the other cases.

4.5.2 Starting points for model calculations

Waste volumes
The consequences of the selected scenarios are calculated for a typical regional area in Europe. For the model calculations several assumptions were made based on the cases and existing knowledge. Basic assumptions regard e.g. the waste quantity and the unit costs for the treatment methods like landfill, incineration and fuel preparation. The major features are listed below.

Intake area	City, incl. surroundings
Inhabitants	150,000
Households	60,000
Household waste	300 kg/individual = 750 kg/household, resulting in 45,000 ton/a
Commercial and (small-scale) industrial (target fractions)	30,000 ton/a C&I
Large scale industry (target fractions)	25,000 ton/a LSI
TOTAL	100,000 ton/a

For the *collection of household waste,* the following data are assumed:

Single family houses (50% of households)	
Collection productivity	600 households /truck/day (9 t/d.truck)
Collection frequency	one bin: every week two bin: every second week recyclables every four weeks
Multi family houses (50% of households)	
Container density	20 households /container
Collection productivity	100 containers/truck/day (30 t/d.truck)
specific volume waste	100-200 kg/m^3
Collection frequency	when full

Commercial and industrial wastes are assumed to be the result of a collection system, specifically directed at combustible fractions. Therefor, *commercial and (small* *scale) industrial waste (C&I)* and *the combustible wastes from large scale industry* (LSI) are important sources for fuel fluff or fuel pellet production. C&I is collected with a system comparable with collection from multi-family houses. LSI is directly transported in bulk to the recovery plant.

Sorting, recovery and disposal

Mass balances for the unit operations, considered in the model calculations are listed below.

Landfill

Input	all hhw, dry rest, C&I and/or LSI
Costs	process : 50 ECU/ton input

Incineration with energy recovery

Input	all hhw, dry rest or combustibles, C&I and/or LSI
Output	75% incineration gasses 25% ashes
Energy	heat : 3,14 MWh/ton input electricity : 0,556 MWh/ton input
Costs	process : 87.5 ECU/ton input landfilled ashes : 50 ECU/ton ashes or 12.5 ECU/ton input recycled ashes : 0 ECU/ton
Revenues	heat : 10 ECU/MWh electricity : 36 ECU/MWh

Optical sorting

Input	dry combustibles and wet rest collected in one bin
Costs	process : 20 ECU/ton input

Mechanical separation

Input	dry rest and C&I
Output	40% organics < 40 mm for bioreactor, 40% RDF for incineration with energy recovery 20% paper/plastic for fuel preparation
Costs	process : 15 ECU/ton input

Hand sorting

Input	recyclables
Output	50% recyclables for material recycling 50% mixed plastic for fuel preparation
Costs	process : 200 ECU/ton input

Aerobic composting

Input	organics from hhw
Output	40% compost
Costs	process : 50 ECU/ton input

Anaerobic digestion

Input	wet rest from hhw
Output	40% compost; 100 m^3/ton input biogas
Costs	process : 50 ECU/ton input
Revenues	0.05 ECU/m^3 biogas

Bioreactor

Input	organics < 40 mm from mechanical separation
Output	70 m^3/ton input biogas
Costs	process : 60 ECU/ton input
Revenues	0.05 ECU/m^3 biogas

Fluff fuel preparation

Input	100 % of dry combustibles from hhw, 20 % paper/plastic mech. separated from dry rest and C&I, 75% of C&I, and 90% of LSI
Output	80% fluff, 15% reject and 5% water for dry combustibles 90% fluff, 5% reject and 5% water for other inputs
Fuel	size < 50 mm, LHV ~15 MJ/kg, ash 10%
Costs	process: 15 ECU/ton input rejects: 50 ECU/ton
Revenues	25 ECU/ton fluff

Pellet fuel preparation

Input	100 % of dry combustibles from hhw, 20 % paper/plastic mech. separated from dry rest and C&I, 75% of C&I, and 90% of LSI
Output	60% pellet, 25% reject and 15% evaporated moisture for dry combustibles 80% pellet, 5% reject and 15% water for other inputs
Fuel	LHV ~20 MJ/kg, ash 10%
Costs	process: 40 ECU/ton input rejects: 50 ECU/ton reject
Revenues	35 ECU/ton pellet

Plastic fuel preparation

Input	50% of recyclables
Output	90% plastic fuel, 5% reject, 5% water
Fuel	size < 10 mm, LHV ~30 MJ/kg, ash 5%
Revenues	50 ECU/ton plastic fuel
Costs	process: 200 ECU/ton input rejects: 50 ECU/ton reject

The use of the unit cost figures for the waste treatment unit operations as indicated above is based on the assumption that a minimum scale of operation is achieved. It is expected that the Wijster process requires a larger waste volume than in the current model to realise the indicated cost figures, especially for incineration.

The maximum revenue for the fluff fuel with 15 MJ/kg is assumed to be 25 ECU/ton fluff. This value is based on a comparison of the heating values of coal and fuel fluff, approx. 30 and 15 MJ/t respectively, and a coal price of max. 50 ECU/ton. Special investments needed for the recovered fuel combustion and market conditions will normally result in a considerably lower price.

4.5.3 Calculated mass flows and cost figures

The calculated mass flows and cost figures are summarised in the following Tables 4.4 to 4.13.

Table 4.4 Collected wastes, modelled mass flows in kt/a.

Collection input	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
bin-1 HHW	45	45	30	30 + 15	15	26
bin-2 HHW			15		15	15
bin-3 HHW					15	4
Commercial & Industrial	30	30	30	30	30	30
Large scale Industry	25	25	25	25	25	25
TOTAL	100	100	100	100	100	100

Table 4.5 Input to sorting plant, mass flow (kt/a) and waste type.

Type of sorting	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
Manual						4 Light packaging.
Optical				45 Household w.		
Mechanical			60 MSW			

Table 4.6 Input to recovery systems (or direct to landfill), modelled mass flows (kt/a).

Type of recovery	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
Energy recovery		100	24			
Fuel fluff production			35		60	2
Fuel pellet production				65		
Aerobic composting			15		15	15
Anaerobic digestion				25		
Bio-reactor			24			
Material recycling						2
Direct landfill	100		2	10	25	81
TOTAL	100	100	100	100	100	100

Table 4.7 Output of recovery and total input to landfill, modelled mass (kt/a) and energy flows.

Recovered products and disposal.	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
Electricity	-	-	13,4 GWh	-		-
District heat	-	314 GWh	-	-		-
Evaporated. Moisture.	-	-	2 kt/a	10 kt/a	3	-
Fluff fuel	-	-	31kt/a	-	53 kt/a	2 kt/a
Pellet fuel	-	-	-	48 kt/a		-
Biogas fuel	-	-	1,7 Mm^3/a	2,5 Mm^3/a		-
Compost	-	-	8 kt/a	10 kt/a	6 kt/a	6 kt/a
Materials for recycling	-	-	6 kt/a (slag)	-		2 kt/a
Landfill	100 kt/a	25 kt/a	7 kt/a	22 kt/a		81 kt/a

*Table 4.8 Modelled annual collection costs, quantity (kt/a)*unit cost (ECU/t).*

Collected waste	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
bin-1 HHW	45 * 60	45 * 60	30 * 50	45 * 60	15 *90	26 * 55
bin 2 HHW	-	-	15 * 90	-	15 * 100	15 * 90
bin-3 HHW	-	-	-	-	15 * 50	4 * 250
Commercial & Industrial	30 * 40	30 * 40	30 * 40	30 * 40	30 * 40	30 * 40
Large scale Industrial	25 * 10	25 * 10	25 * 10	25 * 10	25 * 10	25 * 10
TOTAL (MECU/a)	4.15	4.15	4.30	4.15	5.05	5.23

*Table 4.9 Modelled annual sorting cost, quantity (kt/a)*unit cost (ECU/t).*

Type of sorting	**1-bin "Landfill"**	**1-bin "Halmstad"**	**2-bin "Wijster"**	**1-bin "Jakobstad"**	**3-bin "Borlänge"**	**3-bin "Wietersdorf"**
Manual						4 * 200
Optical				45 * 20		
Mechanical separation			60 * 15			
TOTAL (MECU/a)			0.90	0.90		0.8

*Table 4.10 Modelled annual cost for recovery and disposal, quantity (kt/a)*unit cost (ECU/t).*

Type of recovery and disposal	**1-bin "Landfill"**	**1-bin "Halmstad"**	**2-bin "Wijster"**	**1-bin "Jakobstad"**	**3-bin "Borlänge"**	**3-bin "Wietersdorf"**
Energy recovery	-	100 * 87,5	24 * 87,5	-	-	-
Fuel fluff	-	-	35 * 15	-	60 * 15	2 * 200
Fuel pellet	-	-	-	65 * 40	-	-
Aerobic composting	-	-	15 * 50	-	15 * 50	15 * 50
Anaerobic digestion	-	-	-	25 * 50	-	-
Bio-reactor	-	-	24 * 60	-	-	-
Landfill	100 * 50	25 * 50	7 * 50	22 * 50	35 * 50	81 * 50
Material recycling	-	-	6 * 0 (slag)	-	-	2 * 0
TOTAL (MECU/a)	5.00	10.00	5.05	4.95	3.39	5.21

Table 4.11 Model prices for calculation of revenues, based on Dutch electricity price and coal price of 6 ECU/MWh.

Type of recovery and disposal	**1-bin "Landfill"**	**1-bin "Halmstad"**	**2-bin "Wijster"**	**1-bin "Jakobstad"**	**3-bin "Borlänge"**	**3-bin "Wietersdorf"**
Electricity	-	-	36 ECU/MWh	-		
District heat	-	10 ECU/MWh	-	-		-
Evaporated moisture	-	-	-	-		-
Fluff fuel	-	-	25 ECU/t	-	25 ECU/t	50 ECU/t
Pellet fuel	-	-	-	35 ECU/t		-
Bio-gas fuel	-	-	0.05 ECU/m^3	0.05 ECU/m^3		-
Compost	-	-	0	0	0	0
Slag	-	-	0	-		-
Landfill	50 ECU/t	50 ECU/t	50 ECU/t	50 ECU/t		50 ECU/t

Table 4.12 Calculated annual revenues according to model (MECU/a).

Type of recovery and disposal	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
Electricity	-	-	0.48	-		-
District heat	-	3.14	-	-		-
Fluff 15 MJ/kg	-	-	0.78	-	1.31	-
Pellet 20 MJ/kg	-	-	-	1.68		-
Fluff 30 MJ/kg	-	-	-	-		0.09
Bio-gas	-	-	0.08	0.13		-
Compost	-	-	0	0	0	0
Slag	-	-	0	-		-
TOTAL	-	3.14	1.34	1.81	1.31	0.09

Table 4.13 Net annual costs in modelled situation (total costs minus revenues, MECU/a) and diversion from landfill (% of total waste flow).

Type of recovery and disposal	1-bin "Landfill"	1-bin "Halmstad"	2-bin "Wijster"	1-bin "Jakobstad"	3-bin "Borlänge"	3-bin "Wietersdorf"
Total cost	9.15	14.15	10.25	10.00	8.44	11.24
Total revenues	-	3,14	1.34	1.81	1.31	0.09
Net cost	**9.15**	**11.01**	**8.91**	**8.19**	**7.13**	**11.15**
Difference to landfill		**+ 1,86**	**- 0.26**	**- 0.96**	**-2.02**	**+ 1.30**
Diversion from landfill		75 %	93 %	78 %	65 %	19 %

For the "Wijster" scenario the mass flows to the incinerator are to small to use the unit cost. This scenarios is attractive but requires larger amounts of waste than in the modelled situation.

The results of the model calculations show that most scenarios with fuel recovery result in lower average waste management cost if compared to incineration, but in a cost increase if compared to landfill. The advantages of fuel recovery (fossil fuel saving CO_2 - and emission reduction) can be effectuated without significant rise of waste management costs, if the energy value of the recovered fuel would be appreciated at prices equivalent to that of coal. Consequently, following these economic calculations, if a region considers a more modern waste management than "all-waste-to-landfill', the full recovery concept in one of its variants is strongly competitive compared to incineration. The selection of the exact fuel recovery option should well take into account the special advantageous local conditions e.g. for the use of the recovered fuel.

The results indicate that the realisation of the theoretically calculated fuel revenues can significantly contribute to the economics of fuel recovery. However, special investments needed for the recovered fuel combustion and market conditions will normally result in a considerably lower price.

5. Recovered fuel as a product

5.1 Introduction

In this chapter, conditions are proposed that have to be fulfilled for the production of a recovered fuel product, that contributes to a sustainable use of energy in our society, at the same time maintaining full protection of public health. The fulfilment of these conditions should give to the recovered fuel the product status and allow it to be treated like other solid fuels. From the case studies it was concluded that a non-waste, product status of recovered fuel will stimulate the acceptance by end-users and waste management authorities.

The proposed conditions are directed to the interests and responsibilities of each of the parties involved: the waste management company and authority, the fuel producer, the user, trade and transportation. Different documents discussing aspects of producing a product from waste in general, of fuel production from waste in particular, and of quality management are reviewed.

5.2 Waste management aspects

The position of a waste management authority with regard to fuel recovery is at least twofold. From its history, waste management aims at control of waste flows to ensure a hygienic and safe disposal of wastes for the protection of public health and the environment. To this end, strict control on waste handling operations is necessary. However, modern waste management also has other major goal, the conservation of resources and a contribution to saving of natural resources.
As a consequence, the European Directive 75/442/EEC on waste, as amended by 91/156/EEC, specifies that:

Member states shall take appropriate measures to encourage:

- firstly, the prevention or reduction of waste production and its harmfulness, (…);
- secondly, the recovery of waste by means of recycling, re-use, reclamation or any other process with the view:
    - to extract secondary raw materials, or,
    - the use of waste as a source of energy.

According to the EU directives, waste treatment, recycling and energy recovery should be promoted. The notion of waste recovery, including recycling, implies that there is a point where a waste ceases to be a waste and becomes a "normal" product or good that no longer is subject of waste legislation and regulation. The marking of this point is investigated in this chapter.

5.3 Waste or non-waste

The discussion whether a material is a waste is a difficult one and not particularly relevant in this study. It is clear that (most of the) considered starting materials for fuel recovery are (non-hazardous) wastes. More interesting within the scope of this study is to discuss at which point in a recovery process a waste ceases to be a waste and looses its waste status. The marking of this point would be an important aid in the formulation of technical conditions for waste recovery processes resulting in recovered fuel products that can make their way on the fuel market.
Existing examples of regulations on this subject can be found in Netherlands regulations, French law and in a proposal of the OECD. These will be summarised here briefly; the OECD discussion paper will be used for the formulation of conditions for recovered fuel production processes.

The first example is encountered in Netherlands law and is not of particular interest for this study. Materials are not considered waste if they are directly applied, in a production process, without any or a small intermediate processing.

5.3.1 The French methodological guide

Another example is found in the methodological guide [1] of the French environmental ministry “Waste or non-waste?”. It specifies the criteria to be respected so that waste, in its raw state or after treatment, may benefit the status of product, not subject to the regulations applying to waste. Though energy recovery operations and/or recovery routes are excluded, the criteria are presented here because they contain useful elements that could be applied for fuel products. The general criteria for “non-waste” are:

- it should have use value;
- its characteristics should be recognised;
- the users should be identified and stable in the medium term;
- its traceability should be ensured from production up to its ultimate state;
- there is a non-discard guarantee throughout the recovery cycle;
- its use should be consistent with a high level of environmental protection;
- the relations between producer and user(s) should be set out and contractualised.

As an example, conditions enabling product classification for materials from recovery facilities are formulated. The full example is shown below.

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[1] Ministère de l’Environnement, Direction de la Prévention des Pollutions et des Risques, Sous-Direction des Produits et des Déchets: Waste or non-waste? Methodological guide, 25 February 1997.

MATERIALS FROM WASTE RECOVERY FACILITIES **Conditions enabling product classification**	
PRODUCER **(waste treatment activity)**	**USER(S)**
Technical specifications/contractual conditions Treatment process Regularity of product characteristics	*Identified/qualified process* Use value of the material is known Acceptability/specifications
Medium-term stability of recovery activity Correspondence between user needs and product-technical specifications	2. *Process stability in medium term*
Contract/quantities Acceptance of materials (quality, quantity, reference systems) Non-discard commitment Responsibility of transport *Flow traceability* Transport in compliance with the general rules concerning transport *Adaptation guarantee in the event of force majeure or contract application difficulty* "Replacement" solutions *Respect of all regulations specific to the environment*	
Identification of market need *Producer responsibility* Contract execution	8. *User responsibility* Contract execution

5.3.2 The OECD proposal

A more condensed formulation to define the transformation from waste to non-waste material is proposed in the OECD Final Draft Guidance Document for Distinguishing Waste from Non-waste [1]. According to this Document, a waste ceases to be a waste when a recovery, or another comparable process, eliminates or sufficiently diminishes the threat posed to the environment by the original material (waste) and yields a material of sufficient beneficial use. In general, the recovery of a material (waste) will have taken place when:

- it requires no further processing by a Table 2.B operation [2]; and,
- the recovered material can and will be used in the same way as a material which has not been defined as a waste, and

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[1] OECD, Environment Policy Committee, Waste Management Policy Group: Final Draft Guidance Document for distinguishing Waste from Non-waste, 23-24 April 1998.

[2] Recovery processes are specified in a table ("Table 2.B") of the waste definition contained in the OECD council decision on the Transfrontier Movements of Hazardous Waste.

- the recovered material meets all relevant health and environmental requirements.

This is the fundamental proposal in the OECD final draft document. In some explanatory remarks, the proposal states that transfer of a waste material to a recovery operation is insufficient to loose the waste status. "When a waste is subjected to a recovery process more than one material can be produced at the end of the process. It is likely that at least one of the materials produced at the end of the process could be a waste. The fact that a material meets a recognised national/international standard/specification when it is derived from an environmentally sound recovery operation may provide evidence that it has ceased to be a waste. However, the existence of a specification is in itself not sufficient." Though in the fundamental proposal the term "specification" is not used, it follows from this remark that meeting a product specification can be an important factor in the determination whether a waste has ceased to be a waste after a recovery operation.

5.4 Point of view of the American Plastics Council

The American Plastics Council (APC) has issued a memorandum [1] on what it calls "Process Engineered Fuel" (PEF), which according to the APC is a manufactured product for the fuel market, derived from paper and plastic, which are themselves derived from materials that are or can be used as commercial fuels. The APC puts forward the following positive properties of PEF products:

- PEF is manufactured specifically for the fuel market. In chemical composition, thermal properties, and physical form it meets the demanding requirements of fuel and energy industries for a quality alternative fuel. It provides a partial replacement for traditional fossil fuels where it is typically co-fired at a substitution rate of 5-30% by weight of the primary fuel. The heating content can be more than 15 MJ/kg because of the presence of plastics in combination with paper. Good Combustion Practice and standard operator training are basically unchanged when using PEF.

- PEF is manufactured in a controlled process. Therefore it can meet quality specifications, has consistent and predictable product properties and has a market value. Emissions and ash quality are also predictable.

- PEF production and use have positive environmental benefits in the areas of resource conservation (waste minimization and increased energy efficiency) and pollution prevention. PEF can reduce sulphur dioxide and nitrogen oxides when co-fired with many coals as primary fuels.

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[1] American Plastics Council, Memorandum on Process Engineered Fuel to the ICCR Solid Waste Definition Subgroup, 24 October 1997.

Plastics in the PEF have a high hydrogen to carbon ratio resulting in lower energy-related specific release of carbon dioxide than coals. Furthermore, the presence of plastics contributes to a higher heat content per unit fuel than can be achieved with biomass alone enabling combustion in high efficiency solid fuel burners, as a partial substitute for non-renewable, fossil fuels.
PEF allows materials to serve two purposes: first, as material product (plastic or paper product) and, second, as an energy source when material recovery is technically or economically impractical.

- a PEF industry and market exists in the United States. The particular source of feedstock differs depending on local infrastructure. Markets exist in utility, industrial and institutional areas. Competition in the energy sector has increased the level of interest in competitively priced alternative fuels such as PEF.

5.5 Environmental aspects of recovered fuel combustion

The most important environmental advantages of the use of recovered fuel are the saving of fossil fuel and the high energy efficiency compared to waste combustion and financial savings in waste incinerator investment costs. The potential of these advantages is indicated in Chapter 6. This section deals with possibly harmful, environmental effects of the change in fuel composition when recovered fuel is introduced in a combustion installation. These possible harmful effects concern the emissions into the air and the quality of the ash for reuse purposes.

For the basic situation, coal substitution by recovered fuel from municipal waste, there is generally for macro-components a change in the mixed fuel from sulphur to chlorine. Sulphur occurs in coal at percent level, chlorine often occurs in recovered fuel, typically at a 0.5 to 1 per cent level. In cases where a power production plants includes flue gas desulphurisation, this quantity will be removed in the desulphurisation process. Next, if gypsum is produced, the chlorine can be washed out of the flue gas gypsum to comply with the gypsum quality standards and led to the water treatment. In other processes, the chlorine will be captured in the by-products. The effect of chlorine on the quality of the ashes deserves more attention to ensure that any use of these ashes is ascertained.
In the ppm range, a change in heavy metals composition can occur. Heavy metals will nomally be caught in the bottom and fly ash residues. Therefore, gaseous emissions are usually not problematic in such a situation and, if this also applies to the quality and thus the utilisation of the residual materials, the recovered fuel has no serious consequences in this respect. Only Hg and Tl can be problematic, as is especially known from cement plants. Normally however, they do not occur in recovered fuel.
In comparing these emissions, it should be taken into account that also indirect positive effects of recovered fuel occur, e.g. a reduction in the emissions of coal mining or oil production. In fact, an approach based on Life Cycle Analysis (LCA)

methods is necessary for a complete and fair comparison. Nevertheless, a significant deterioration in local emissions or in the utilisation options of ashes is not in line with the sustainable use of recovered fuel.

The results of the case studies (see Chapters 3 and 4) confirm that a significant deterioration in the gaseous emissions normally does not occur, even not if high substitution levels are applied. However, some general formulation of what an acceptable situation is, is necessary. The following options, with regard to the emission situation, are brought forward:

- Recovered fuel can be used as a fuel product if the emissions of the combustion process stay within existing limits for the use of regular fuels.
- Recovered fuel can be used as a product under regular fuel regulations if the overall emission situation improves.
- Recovered fuel can be used as a product in a combustion installation operating according to BAT (Best Available Technology) guidelines with the appropriate emission figures for combustion installations.
- Recovered fuel can be used as a product if the composition is better than a standard. This standard could be based on commercial coal compositions taking into consideration the arguments put forward above with respect to heavy metals, sulphur and chlorine.

The case studies show that, to protect their costly plant, plant operators pay much attention to an appropriate fuel quality to safeguard the economic operation of their plant and to prevent corrosion and fouling problems and exceeding the emission limits. The recovered fuel should specifically fit to their installation. In this situation, recovered fuel can be regarded upon as any regular fuel; there is not established a need for additional regulations. As a consequence, it is concluded here that, with regard to the emission situation, recovered fuel should be acceptable if the emissions fulfil existing limits for the installation.

Ash reuse is especially important for large scale coal power plants producing large ash quantities. Small scale plants, especially those burning biomass with little ash, often dispose of their ash in landfills and, as a consequence, ash quality is less critical. Cement kilns immobilise the ash in the cement product and their is ample information that, generally, leaching from cement is within all existing limits.
For large scale power plants it is environmentally unacceptable that ash reuse would be obstructed by the us of recovered fuel. However, this would also affect the economics of these plants. It appeared during the case studies that the ash removal options are of great concern for the operators of the large scale coal power plants. It is thus to be expected that there will be no tendency to use recovered fuel at the cost of the ash quality.

5.6 Conclusions and recommendations for recovered fuel

The fundamental approach of the OECD final draft document and important elements from the document and the French methodological guide are taken over in the approach of this study. The following criteria for recovered fuels are proposed to mark the transfer from waste to recovered fuel product:

- Recovered fuel should meet specifications set by the user and approved by the permitting authority that ensure the proper use in the intended (type of) combustion installation.
  Specifications for fuels in a combustion installation are often very specific for the installation considered. The lay-out of the installation, the temperature level and the gas cleaning equipment installed determine the necessary fuel specifications for efficient combustion, avoidance of excessive corrosion and fouling and fulfilling emission limits. Though according to the OECD document an (inter)national standard or specification is preferred, it is proposed here that such a specification should be set up for each individual installation that has the intention to (co)-combust recovered fuels. The individual approach seems the more essential as many power plants and other combustion plants use their own typical coal or mix of coals.

- The fuel recovery facility should be able to produce the fuel according to the specification from the user(s) and should operate according to clear quality assurance methods. The Finnish Quality Assurance manual is a clear document on this subject that can be used as a model.

- The fate of the recovered fuel should be well documented, to ensure that the fuel is used as intended. This documentation should give the waste management authorities the certainty that its production has resulted in a useful product and that it is actually used for its purpose.

- For transportation and/or storage, the recovered fuel should be hygienic to handle and to store. This imposes conditions either on the quality of the raw material, the recovery operation or the form in which the fuel is produced. Source-separated material will more easily result in a hygienic product than material separated mechanically from mixed household waste. In the latter case, it may be necessary to pay attention to the form in which the fuel is produced, for instance as pellets or as bales wrapped in plastic foil.

- Overall emissions of the combustion process should not significantly increase because of the introduction of recovered fuel and ash use, if any, should not be obstructed. Fossil fuel savings and e.g. reduced emissions from coal mining could possibly be taken into account in a Life Cycle Analysis approach. Furthermore, it is proposed to allow the use of recovered fuel as a fuel product, a non-waste material, in combustion plants if the emissions stay within existing limits for the use of regular fuels.

The recovery operation, handling, storage and combustion of the recovered fuel should be in accordance with environmental regulations. This is not brought forward here as a specific condition for a recovered fuel product as it is considered standard practice. Nor is it mentioned that combustion tests with the recovered fuel in the combustion installation are obligatory; it is the responsibility of the user of the combustion installation to protect his often very capital-intensive plant from corrosion and fouling and to maintain its availability and efficiency. He is also responsible for satisfying the emission limits and the quality of his product.
Product quality includes technical aspects as well as the environmental behaviour, for instance, the leaching behaviour of cement products produced with recovered fuel is part of product quality.

The success and the quality (i.e., good energy efficiency at low emissions and fouling) of fuel recovery depends on the quality of each step in the chain: collection/sorting -production-combustion. All steps should be well under control to assure an overall positive application. The Finnish Quality Assurance Manual is mainly directed to the quality control of the fuel composition.
It is recommended to elaborate a CEN standard for the quality assurance or certification of all processes involved. This would be a valuable contribution to the quality assurance of recovered fuel product and its use.
Figure 5.1 shows schematically the flows of specifications and materials in opposite direction and the mutual contractual arrangements, to ensure the quality of recovered fuel production and delivery.

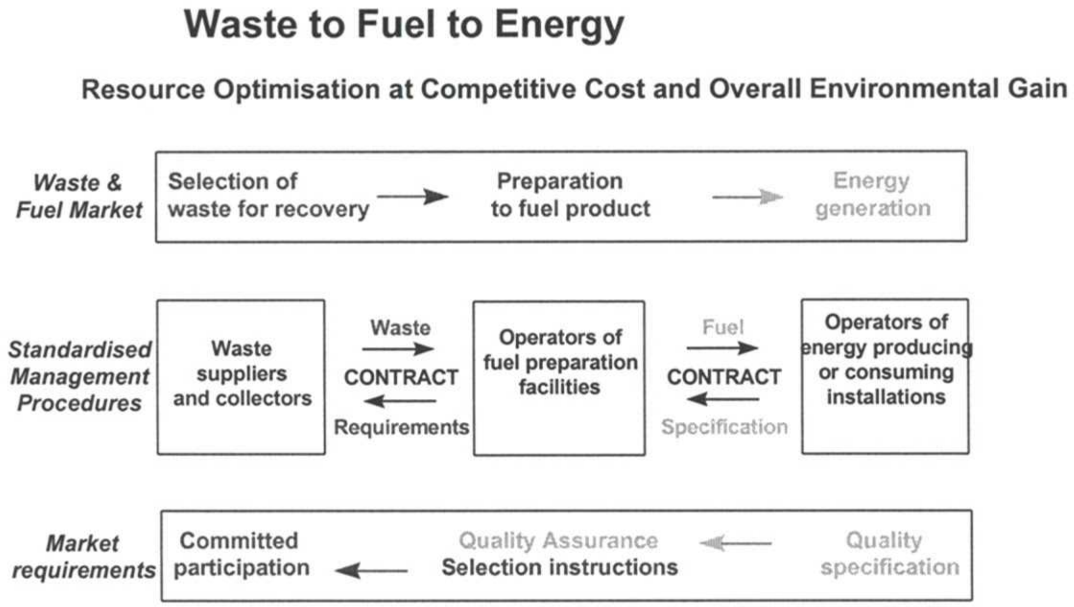

Figure 5.1 Scheme of material and information flows for recovered fuel products, controlled by mutual contractual arrangements

It is recommended to commission a detailed support study of the possibility and the usefulness of establishing rules for fuel compositions that are allowed for fossil fuel substitution. This could be an option to establish very clear rules. It is expected, however, that such a generalisation will be difficulty to achieve. Such a study would have to include a detailed comparison with coals used in the EU.

In Table 5.1 the proposed criteria for a fuel product are summarised. These could be further developed and formalised in a CEN standard for solid recovered fuel, based on a mandate from the Commission.

Table 5.1 Criteria for assessment of the product status of recovered fuel.

Criteria for recovered fuel	• Recovered fuel shall meet public specifications which are set by the user(s) and approved by the permitting authority in order to ensure the proper and safe use in the intended (type of) combustion installation. • The recovered fuel shall be safe and hygienic to handle and to store. This imposes requirements on the quality of the raw material, the recovery operation and/or the form in which the fuel is produced. The fuel recovery facility shall operate according to a documented quality assurance system. • The use of the recovered fuel shall be contractually ensured for the long term. • Overall emissions of the combustion process should stay within existing limits applicable to the use of regular fuels and the use of solid residues shall be maintained.

6. Potential for fuel recovery in the EU

6.1 Introduction

This chapter discusses the potential and related economic features of the implementation of the fuel recovery concept on a large scale in the European Union, especially in regions where waste nowadays is landfilled. Recommendations with regard to research, development and demonstration to stimulate this implementation and to resolve current bottle-necks are suggested. The following aspects are considered:

- The potential contribution to the reduction of fossil fuel consumption and CO_2 emission.
  In a first approach, a MJ recovered fuel can substitute a MJ of solid fuel and can thus contribute to the saving of natural resources. The ultimate, potential saving amounts to the combustible fraction that can be extracted from now deposited combustible waste. Introduction of recovered fuel in areas already provided with a MSW incinerator is possible (and also put into practice) but not included in the potential volume estimates below (6.3). The potential reduction in CO_2 emission is estimated in 6.4.
- The potential contribution to employment in SME in Europe by the introduction fuel recovery as a new industrial activity is estimated in 6.5.
- The contribution to a cost-effective sustainable waste management system. The evaluation of the selected cases by model calculations in Chapter 4.5 shows that there are many alternative approaches for the introduction of recovered fuel. Economic aspects of fuel recovery on a large scale in the EU are indicated in 6.5.
- Current status and further demonstration and development.
  The case studies show that that fuel recovery can be successfully put into practice. However, currently, the potential of the recovered fuel concept is, as estimated in 6.3, is widely unused. Recommendations are given for further demonstration and development (6.6).

6.2 Waste management and fuel recovery: economic aspects

The case studies show that fuel recovery is technically feasible and that its use meets environmental standards for emissions from the (co-)combustion process. Co-combustion of recovered fuels will result the same efficiencies that are reached with commonly used fuels. There is wide variety in concept between the 14 selected cases, that enables fuel recovery to take optimal advantage of local circumstances. To consider the introduction of fuel recovery in regions with an existing infrastructure of waste incineration facilities is possible but only obvious if the existing incineration capacity is insufficient and exceeded by the waste quantity. Therefor, the option of fuel recovery in a region having only landfill is taken as a starting point

for this chapter to investigate the consequences for the implementation of fuel recovery in the EU on a large scale.
Model calculations, Chapter 4.5, are made to compare the recovered fuel option with the alternative options of landfill and incineration. From these calculations it appears, that there is a number of fuel recovery options economically attractive compared to incineration and for which waste management costs are in the same order as for the landfill option. As a consequence, these fuel recovery schemes are very interesting for regions with only landfill of waste, which consider to implement more modern waste management schemes.

For Municipal Solid Waste, separate collection of organics or combustibles combined with mechanical or optical sorting, appears to be the most cost-effective solution for to recover fuel as fluff or as pellets. The model calculations show that the annual costs of these options almost equal those of landfill and are well below costs of the incineration reference case.
Investment costs for fuel recovery e.g. by mechanical separation by rotating sieves, sifting and shredding are estimated at 200 ECU per t/a input capacity. Compared to incineration with a required investment of 1000 ECU per t/a incineration capacity, fuel recovery will considerably reduce the investment cost for sustainable waste management.

In the following sections it is assumed that in the EU fuel recovery by one of the cost-effective options is implemented on a large scale. Estimates will be given of the potential volumes of fuel that can be recovered, the resulting reductions in fossil fuel use and CO_2, the economic consequences and of related employment.

6.3 Potential volume of recovered fuel production

Estimates of waste production in Europe are only tentative. It is estimated [1] that the annual production of municipal waste amounts to 170 Mt in the period 1990-1995. An indication of the potential volume of recovered fuel and the energy quantity it represents can be estimated based on the following assumptions:
- 60% landfill in Europe;
- 40% of waste is combustible with 15 to 20 MJ/kg;
- the volume of industrial waste to be used for fuel recovery is of the same order as the fuel recovered from MSW volume;
- other potential sources (waste wood, agricultural wastes and RF production in regions provided with municipal waste incinerators) are not taken into account.

The amount of combustibles is then estimated at approx. 80 Mt/a, representing a potential of 1.2×10^{12} MJ/a or 30 Mtoe/a (million tons of oil equivalent per year).

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[1] IPTS: The legal definition of waste and its impact on waste management in Europe, 1997.

In 1995 the amount of fuels used for energy generation in EU15 was approx. 1200 Mtoe, 260 Mtoe of which were solid fuels (Out of these, 82 Mtoe were indigenous hard coal, 85 Mtoe imported hard coal, 54 Mtoe brown coal, 3 Mtoe peat and 33 Mtoe biomass and waste [1]).

Consequently, the corresponding potential coal saving by full introduction of fuel recovery corresponds to approximately 3% of the EU annual production.

What is the capacity in existing combustion plants for the co-combustion of this large estimated potential RF production?
The fluid bed capacity for solid fuels in the EU is estimated, based on a limited list of fluid bed plants in operation, to be equivalent with the combustion of more than 50 Mt/a of a solid fuel with 15 MJ/kg. This capacity includes coal, brown coal, biomass and other solids fuels. At 30% substitution, these plants could absorb 20% of the potentially recovered fuel. Furthermore, there is a large potential for waste wood co-combustion in pulverised coal-fired power stations after demonstrated successes of the current initiatives. Newly to erect biomass plants could also be made suitable for RF combustion.
The cement industry in Europe uses approx. 16 Mtoe/a [2]. Assuming 50% substitution is possible, only the cement industry could absorb 25% of the potentially recovered fuel.

The conclusion is that for the time being, there exists sufficient co-combustion capacity for the structural implementation of recovered fuel on a large scale. Currently, this is not the limiting factor for fuel recovery; for the future, new installations will come on stream.

6.4 Fossil fuel saving and CO_2 emission reduction

The potential annual quantity of combustibles was estimated above at approx. 80 Mt/a, representing a potential of 1.2×10^{12} MJ/a or 30 Mtoe/a (million tons of oil equivalent per year).
The corresponding potential coal saving corresponds to approximately 40 Mt/a or approximately 3% of the EU's fossil fuel consumption. The potential CO_2 emission reduction is estimated below at 64 to 100 Mt/a or 2 to 3 % of the current annual emission of the EU.

It can be argued that the carbon, which already served a function in the product phase and which cannot efficiently serve in the same application again substitutes carbon in fuels and reduces the amount of greenhouse gases from landfill. A signifi-

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[1] Solid Fuel Working Group for the European Commission: Clean use of coal and other solid fuels, 1997.

cant fraction of organic wastes in landfills is converted into methane with a higher greenhouse gas potential. Each carbon atom taken out of the ground, used as a product and landfilled sooner or later will be released as CO_2 or methane. In industrial combustion processes the conversion to CO_2 is virtually complete and controlled; no methane and almost no other organics will be released. Following this argument, the combustion of the plastics fraction reduces the greenhouse gas emissions from landfill and does not emit additional greenhouse gasses. In that case, considering that substituting fossil fuels by a product which would otherwise have been dumped in a landfill does not emit additional CO_2, co-combustion of the plastics fraction is also CO_2 neutral on the global CO_2 balance. The validity of this argument of course depends on the actual processes occurring in landfills.
Following this conclusion, fuel recovery even reduces the CO_2 emission of the EU countries by 3%.

The potential contribution to the CO_2 emission reduction can be formally estimated from CO_2 emission data, supplied by a report for the Dutch Ministry for the Environment (VROM), that is based on directives by the International Panel on Climate Change (IPCC) [1]. In addition it is assumed that a mixed paper/plastics fuel recovered from municipal wastes consists of 70% paper and 30% plastics (by weight) in agreement with their occurrence in the waste [2]. The CO_2 emission factor of recovered fuel can be calculated as 40 kg/MJ from the CO_2 emission for plastic waste (2 kg CO_2/kg plastics). This CO_2 emission factor lower than the emission factor for coal (94 kg/MJ). (The emission factor for paper waste or wood waste is zero).The potential quantity of recovered fuel (80 Mt/a) can substitute approx. 40 Mt/a coal and reduce the CO_2 emission with 64 Mt/a, or approx. 2 % of the annual production of the EU. In this view, the plastics fraction does not contribute to the CO_2 emission reduction. However, it has a positive function in recovered fuel by increasing the heating value of e.g. the paper fraction of approx. 10 to 15 MJ/kg or even higher. This creates more options for the use of the recovered fuel, including use at a higher energy efficiency.

6.5 Economic aspects: costs and employment

Economic aspects of the large scale introduction of fuel recovery in the EU in regions with at present only landfill of waste, is estimated based on the information collected in the cases and the model calculations. It was estimated that 40 Mt/a recovered fuel could be produced from 110 Mt/a municipal waste, otherwise landfilled and 40 Mt/a from industrial waste, saving in total approximately 40 Mt/a coal.

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[1] TNO, CBS, RIVM, ECN: Method for the calculation of greenhouse gas emissions. Publication series Emission registration **37**, 1997 (in Dutch).

[2] Rijpkema, L.P.M., Zeevalkink, J.A.Specific processing costs of waste materials in a municipal solid waste combustion facility. TNO-MEP report R 96/248, November 1996.

According to 6.2, cost-effective fuel recovery schemes can be implemented cost-neutral compared in regions where all waste is landfilled. Fuel recovery schemes can be adapted to local circumstances to take optimal advantage.
The investment cost for fuel recovery at a scale of 80 Mt/a are roughly estimated at 20 billion ECU; the annual cost at 2 to 3 billion ECU. These costs do not include additional collection costs. The potential value of the recovered fuel with 15 MJ/kg is in the order of 25 Ecu/t, if compared to coal (approx. 50 ECU/t with 30 MJ/kg). Thus the value of the reduction in coal consumption is in the order of 2 billion ECU/a. For the cost-neutral introduction of fuel recovery, it is important that this fuel value is realised in practice, which requires an increase in the acceptance of recovered fuel by end-users.

Incineration of 80 Mt/a MSW in specialised incineration plants would need investment costs in the order of 80 billion ECU. Annual cost would amount to 8 billion ECU.

Employment for the production of the recovered fuel would amount to 20,000 people This estimate is based on the assumption that 10 employees are required for a recovery plant with a production of approx. 40,000 ton/a.

6.6 Development of fuel recovery in the EU

It is concluded that there is a 3% potential in fossil fuel saving by the introduction of the fuel recovery concept, resulting in a 2 to 3% possible reduction in CO_2 emissions. Furthermore, fuel will create employment in SME. If introduced as part of a new modern waste management policy, the costs associated with fuel recovery are largely compensated by the savings in landfilling and/or incineration cost for waste disposal, and fossil fuel cost for the end-user.
Users accept the recovered fuel product when it is competitively priced and produced in accordance with their specifications. The major areas of use are the substitution of solid fuels in grate combustion installations, in fluid beds and in cement kilns. In pulverised coal plants, there are initiatives for the co-combustion on a large scale of wood-derived fuels and dried sludge. However, the potential of recovered fuel is largely unused yet. The application of fuels based on mixed waste paper and plastics is still under development, especially for pulverised coal installations.

Cost calculations reveal that it is important for the economics of fuel recovery projects that a fair fuel price can be realised on the fuel market. To this end, a strategy is necessary that develops the status of recovered fuel and brings it in the same position on the fuel market as commonly used fuels.

To stimulate fuel recovery, more demonstration projects are necessary to further the experience and confidence in fuel recovery and its use. Development and research projects, in general as well as especially directed to the production and use of recovered fuel from municipal waste can open new possibilities for the highly efficient use of recovered fuel, e.g. in pulverised coal plants. Research on ash properties, slagging and fouling related to RF properties should be intensified to decrease uncertainties on the use of recovered fuel.

Additional in-depth studies can support the fuel recovery concept. Studies e.g. based on Life Cycle Analysis methods, should compare the environmental effects of fuel recovery with waste incineration and other options for recovery, and disposed, to investigate the environmental effects of this concept.
A successful policy to stimulate the use of, and therefore the demand for, recovered fuels as a sustainable, competitively priced alternative for fossil fuels could significantly contribute to a decrease in CO_2 emissions in the EU.

7. Summary, conclusions and recommendations

7.1 Summary

7.1.1 Introduction

This report summarises the central findings and conclusions of a joint study, "Fuel and Energy Recovery", which is executed within the THERMIE programme of DG XVII of the European Commission. The general aim of this study is to explore routes for energy utilisation of non-hazardous combustible wastes which can more sensibly be recovered for their energy value than any other purpose. In particular the study investigates different routes of **fuel recovery**, i.e. preparation of a fuel from selected wastes for use as a storable, marketable alternative fuel for the energy sector.

The fuel recovery route combines the economic and environmental goals of the manufacturing industry, the waste management industry and energy-producing industries. It involves modern multifuel combustion technology where recovered fuel can effectively substitute a substantial part of used solid fuels on a one-to-one basis. It is a decentralised complement to traditional, well-proven mass burn incineration technology. It provides new jobs in the waste management sector when implemented on a larger scale.

The fuel recovery option is fully compatible with the Waste Strategy and the Energy Policy of the European Commission. It is best implemented in a concept of Integrated Resource Management and should be an essential element of a sustainable economy. It both ensures a high level of environmental protection and reduces the dependency on fossil fuels.

Waste are considered a sustainable source of energy. Combustible, non-hazardous waste that is presently disposed of in landfills, has a significant potential for fossil fuel substitution in the European Union. When implemented, this would result in a significant reduction of greenhouse-gas emissions.

The study is a technical, economic and environmental evaluation and reviews the potentials and the needs for development of fuel recovery. It is based on case studies for selected regions in Europe. It gives indications for further technical development and strategic studies and proposes criteria for the assessment of the product status of recovered fuel.

7.1.2 Background, objectives and approach

Industry at large is committed to the principles of Sustainable Growth and Development, to a three-step hierarchy for Waste Management and to the striving for reduction of the dependency on fossil fuels. "Prevention" is a key issue in the continuous improvement of performance and recovery processes and products. Unavoidable wastes shall be utilised as efficiently and as far as possible. Recovery of combustible waste materials shall be directed to the route which maximises conservation of resources at minimum societal cost.

Clean and distinct waste fractions, such as secondary or tertiary packaging, may be sensibly recovered for their original material value, but scattered, small contaminated objects of mixed material composition, such as small primary packaging, are often better recovered for their energy value. The Industrial Consortium (see page 2) supporting this study shares the vision that fuel recovery is an eco-efficient, cost-effective option to substantially increase recovery rates with corresponding diversion of waste from disposal. However, only exhaustive Life Cycle Analysis, combined with economic evaluation, for defined systems at specific geographical locations with clearly described demographics and infrastructures, can provide non-biased information on the preferable recovery route (Figure 7.1).

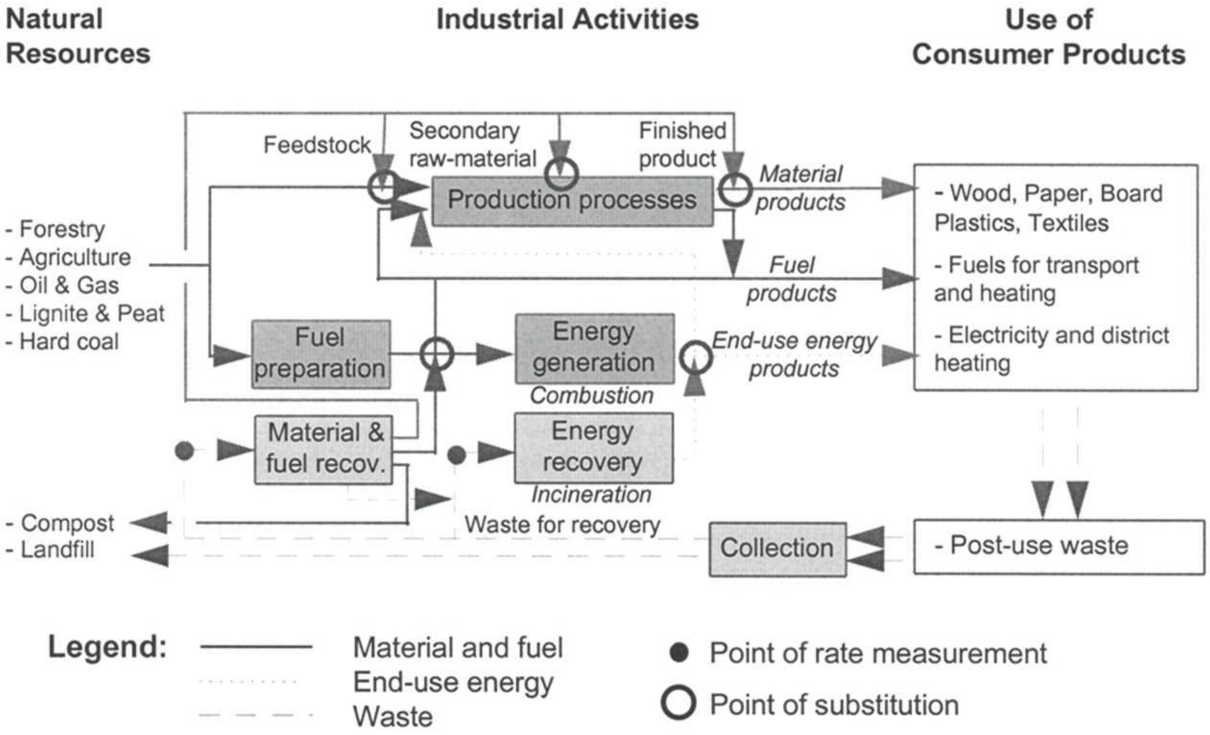

Figure 7.1 Life cycles of organic materials.

In 1995 the amount of fuels used for energy generation in EU15 was approx. 1200 million tons of oil equivalent (Mtoe), 260 Mtoe of which were solid fuels. Out of these, 82 Mtoe were indigenous hard coal, 85 Mtoe imported hard coal, 54 Mtoe brown coal, 3 Mtoe peat and 33 Mtoe biomass and waste. The energy content of combustible wastes presently disposed of in landfill each year is in the order of 30 Mtoe. So even after successful waste prevention and a substantial increase in sensible material recovery there is a large potential for increased energy recovery and fuel recovery of combustible waste for the substitution of fossil fuels.

In the forestry and petrochemical industry there is a long tradition of using side-streams and **pre-use** production residues as fuel. These "clean wastes" (Figure 7.2) are well defined and can usually be used without further pre-treatment. The use of these materials as fuel is not addressed further in this report.

The incineration with energy recovery of mixed municipal solid waste also has a long tradition. Because of the heterogeneity of the waste stream and the possible presence of harmful components, incineration of waste is regulated more strictly than combustion of regular fuels, where the permit is specific to the used fuel.

The fuel recovery route (Figure 7.2) is a complementary option, which can utilise existing infrastructure in the urban society. It includes selection of input and a preparation process. The recovered fuel is a product which meets specifications set by the end-user.

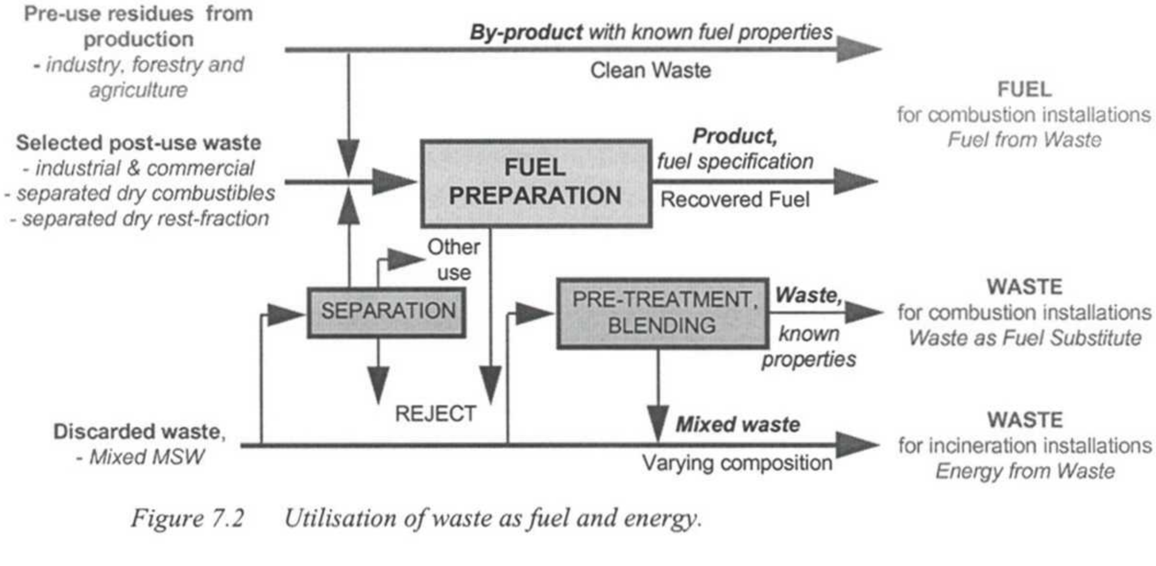

Figure 7.2 Utilisation of waste as fuel and energy.

Recovery is sustainable only if it is economic and the recovered product has a market. The collection scheme of "waste for recovery" has to be compatible with the recovery operation. It has a significant influence on both the total cost and the quality of the recovered product. Material and fuel recovery operations for organic materials complement each other and may be accomplished within the same facility.

Fuel recovery is a complementary option, e.g. for locations where the wet organic part of household waste is separately collected for biological treatment. At locations where the existing incineration installation is fully loaded, fuel recovery can also make economic and environmental sense by extracting the high calorific part of mixed MSW, together with commercial and industrial waste, for fuel production and use for substitution of locally used solid fuels.

7.1.3 The study

The study generally aims at presenting different approaches to use non-hazardous combustible waste as a source of energy. It is executed in the form of Case Studies for fourteen locations in eight Member Sates. Seven of these are "Integrated cases" addressing all waste streams in the studied region, and seven cases address specific waste streams diverted to fuel production for use as fuel. The study particularly aims at evaluating the technical, economic and environmental performance of Fuel Recovery from post-use wastes. The study includes traditional mass burn technologies for incineration of mixed MSW, as well as various multi-fuel combustion technologies for energy generation, including gasification.

The main objective is to analyse how selected combustible waste fractions, which traditionally enter the mixed MSW stream, are utilised as energy and fuel in "integrated cases". In these cases the fate of all waste streams are addressed. This in order to demonstrate the importance of Integrated Resource Management.

Halmstad is a reference case for MSW incineration with energy recovery, where the generated heat is used for the city's district heating system. Additional RDF from the nearby municipality Falkenberg, stored over the summer period, as well as substantial amounts of industrial waste is co-fired in the winter time when there is a larger demand for district heating.

Borlänge, Pamplona, Erwitte, Jakobstad and Wijster are cases applying separate selection schemes for wet organic waste and dry (combustible) waste and different fuel preparation schemes for the energy rich fraction. In Florence, an RDF pellet is presently made from mixed MSW, but a two-bin collection system is to be introduced.

The use of post-use combustible waste fractions from small industrial and commercial enterprises is also addressed together with some separately collected post-consumer "specific wastes".
The basic features of all studied cases are presented in Table 7.1.

Table 7.1 Basic features of studied cases.

Case name - People served	- Source and type of waste - Fuel preparation technology - Type of combustion	- Recovered fuel, ton/year - Form of fuel - Used for	- RF input, %-th. - Combustion tech. - Used primary fuel
Integrated cases			
Halmstad (S) - 84.000 [1]	- MSW and industrial waste - Shredding, magnetic separation for RDF - 70.000 t/a MSW mass-burn incineration	- 50000 MSW + 20.000 RDF - Fluff (used in winter time only) - 220 GWh district heating	- 30% - Grate - MSW
Florence (I) - 500.000	- MSW - Shredding, separation, densification - 15 MW gasifier	- 10.000 (design capacity 50.000) - Pellet - Electricity, fuel gas for cement kiln	- 100% - CFB Gasification
Borlänge (S) - 102.500 [2]	- Dry HHW - Baled for storage - Converted oil-fired heating plant	- 22.000 - As such - 22.5 MW district heating	- 100% - Grate
Pamplona (E) - 280.000 -	- Intended production of RF in clean MRF - Under evaluation - Under evaluation	- Potentially 30.000 (HHW only)	
Erwitte (D) - 180.000	- Industrial and dry HHW - Shredding, magnetic separation - Co-combustion in rotary kiln	- 100.000 (20% HHW) - Fluff - Cement production (dry process)	- Up to 60% - PF - Coal, oil
Jakobstad (FIN) - 120.000 [3]	- Industrial, commercial and dry HHW - Shredding, separation, blending, pelletising - Co-combustion in 138 MW CHP	- 30.000 (40% HHW) - Pellet - Electricity, steam, district heating	- Up to 20% - BFB - Bark and coal
Wijster (NL) - 2.500.000	- Dry HHW (grey bin) - Separation of light fraction in clean MRF - Under evaluation	- Potentially 170.000 - Under development - Under consideration	
Specific wastes			
Nijmegen (NL)	- Demolition wood - Crushing, magn. sep. pulverising - Co-combustion in power plant	- 60.000 - Powder - Electricity (condensing cycle)	- 5% - PF - Imported coal
Obourg (B)	- Bulky waste - Shredding, baling - Co-combustion in rotary kiln	- 15.000 - Small bales for mid kiln feeding - Cement production (wet process)	- 3% [4] - Bales at mid-kiln - Coal, wastes
Kauttua (FIN)	- Industrial wastes and non-recyclable paper - Shredding and magn. sep. - Co-combustion in 60 MW CHP	- 15.000 - Fluff - Electricity, steam, district heating	- 15% - CFB - Coal, peat, wood
Örebro (S)	- Plastic/paper pre-use waste and rejects - Milling and densification - Co-combustion in boiler plant	- 6.000 - Briquette - Low pressure process steam	- Up to 60% - GF - Biomass
Lomma (S)	- Industrial residues and commercial waste - Shredding and magn. sep. - Mono-combustion in 18 MW CHP	- 14.000 - Fluff - Electricity and district heating	- 100% - CFB
Slough (UK)	- Industrial and commercial waste - Shredding, magn. sep., densification - Co-combustion in 130 MW CHP	- 25000 - "Cube" - Electricity and district heating	- Up to 40% - CFB - Coal
Wietersdorf (A)	- Separately collected plastic packaging - Sorting, shredding, milling - Co-combustion in rotary kiln	- 10.000 - Fluff - Cement production (dry process)	- - PF - Coal, oil, gas

[1] Only Halmstad area, excluding Laholm, Hylte, Falkenberg and Varberg

[2] Borlänge + Falun

[3] Jakobstad (20.000) + surroundings and the Vaasa region

[4] Refers only to mid-kiln feeding of waste derived fuel

7.2 Conclusions

7.2.1 General

There is a significant potential in fossil fuel saving by the introduction of the fuel recovery concept. Furthermore, fuel recovery can be the basis for an interesting industrial activity, creating employment in SME. If introduced **as part of** a new modern waste management policy, the costs associated with fuel recovery are largely compensated by the savings in corresponding disposal costs and the cost for otherwise purchased fossil fuel in the society.

Wastes can be considered renewable sources of energy and the use of recovered fuels therefore is CO_2-neutral regardless of composition, in the same way as biomass. In a first approach, a MJ recovered fuel saves a MJ of solid fuel. The ultimate, potential saving then amounts to the combustible fraction that can be extracted from the combustible waste presently disposed. Introduction of recovered fuel in areas already provided with a MSW incinerator can be feasible but is not included in the estimates of the potential for fuel recovery.

Waste (co-) combustion contributes to the saving of fossil fuels and CO_2 emission reduction. Counting only combustible, non-hazardous waste that presently is disposed of in landfill, it is estimated that the recovered fuel production could amount to 80 Mt/a. Potential fossil fuel saving in the European Union can be in the order of 30 million tons of oil equivalent per year. Counted as CO_2, this can result in a reduction of greenhouse-gas emissions 2% to 3% of the current level.

This option for CO_2 reduction is economically attractive as it can be incorporated in cost-effective waste management schemes and produces an accepted, alternative fuel for high-efficiency energy conversion in a concept of Integrated Resource Management. It is estimated that fuel recovery could create employment for 20,000 people in Europe. The investment cost for fuel recovery at a scale of 80 Mt/a are roughly estimated at 20 billion ECU, the annual cost at 3 billion ECU. The value of the potential reduction in coal consumption is in the order of 2 billion ECU/a. The costs for waste collection and delivery to fuel preparation are competitive to available disposal routes. For comparison: the investment required for the construction of modern waste incineration facilities for 80 Mt/a municipal solid waste would exceed 80 billion ECU. Annual cost would be in the order of
8 billion ECU.

The cases show a wide variety of options for fuel recovery. Implementation of fuel recovery in waste management results in cost-effective options that can be adapted to regional conditions. Depending on the regional waste management policy, fuel recovery reduces the waste volume to be disposed of in landfills or it minimises the need for waste incineration capacity. Especially in scarcely populated areas, where waste incineration facilities are uneconomic, and also in more densely populated areas, fuel recovery reduces the required capacity of waste incineration facilities.

The recovered fuel concept is fully compatible with the “proximity” principle. Transportation of the fuel product would not be in contradiction with this principle. However, in most cases, because of the strong linkage between fuel production and use, the fuel is also used locally.

Recovered fuel is an accepted product, because in general it is a competitively priced fuel, produced in accordance with specifications formulated by the user. Main areas of use are the substitution of solid fuels in cement kilns and in fluid bed and grate fired combustion installations and other industrial furnaces. In pulverised coal plants, wood derived fuels and dried sludge is already co-combusted on a large scale, but fuels based on mixed waste paper and plastics are still in the development phase.

7.2.2 Technical

A general observation considering fuel preparation is that the technology to produce recovered fuel is available. However, most plants have had start-up problems, which differ from case to case, often resulting in modifications to the fuel preparation process.

Fuel preparation technologies and resulting product quality vary considerably depending on source and type of waste and on the requirements of the combustion installation. For nearby grate-fired or fluidised bed installations a fluff of rather high moisture content is feasible, but if the fuel has to be transported and stored it needs drying and densification in order to improve total economy.

Recovered fuels generally have higher contents of alkali metals and halogens compared to coal (but equal to many biomass fuels). These may lead to problems of fouling and corrosion in the superheater region of high steam parameter boiler plants. Special, case to case, consideration must be given to chlorine content, which generally should be kept well below 1 wt%, depending on sulphur and alkali content of primary fuel, substitution rate and specific installation requirements.

In general, the experiences with the combustion of the recovered fuels are positive. Compared to mixed waste, recovered fuels are homogeneous. This is also stated at the waste incinerator in Halmstad, where RDF is co-incinerated during the heating season. In Jakobstad, a positive effect of the lower moisture content of the fuel pellet compared to the primary fuel bark was noticed, and in several cases a reduction in NO_x emissions was reported.

7.2.3 Economic

Economics differ depending on scale, local infrastructures and policies and because of different economic incentives (e.g. taxes and levies) in the different countries. Based on information from the cases and approximations by TNO, the cost estimates for several selected cases presented in Figure 7.3 are made. The costs for waste collection, depending on scheme and volume, and delivery to fuel preparation are generally competitive to alternative disposal routes, i.e. tipping fee plus possible disposal tax, **when fuel recovery is well integrated** into the total waste management system of the region. Costs for fuel preparation and for the corresponding fuel substituted are added in the overall picture for a full comparison.

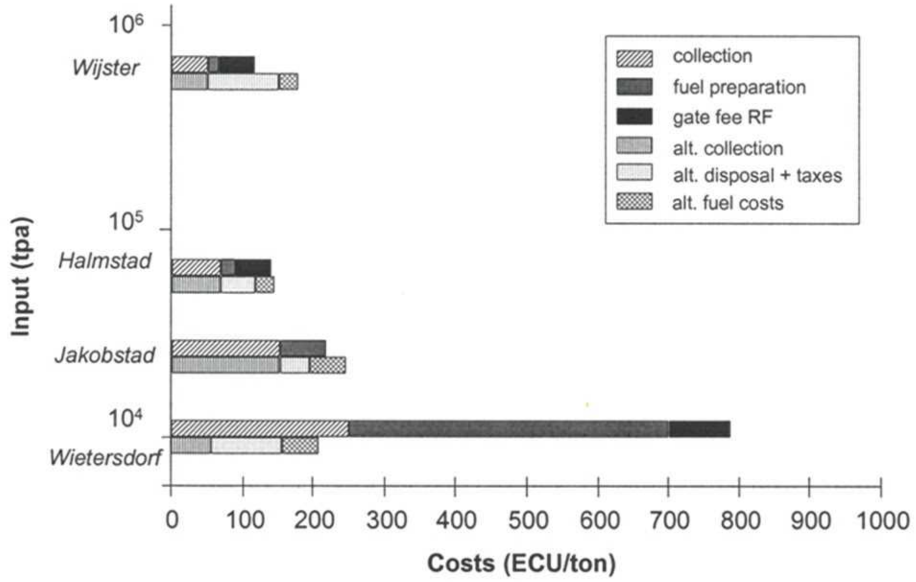

Figure 7.3 Comparison of fuel recovery vs. alternative disposal for selected cases.

Model calculation confirm that is possible to implement the recovered fuel concept at virtually no additional cost compared to landfill, if for the recovered fuel a price equivalent to that of commission coal is obtained.

7.2.4 Environmental

The use of recovered fuel does not necessarily lead to higher emissions to air compared to primary fuel and the resulting emissions are within limit values, as is shown, for instance, in the following examples:

- long-term trials with RDF in 1993/94 and the current use of recovered fuels in the CHP plant in Kauttua;
- compliance tests in 1993 and current use of recovered fuels in the CHP plant in Slough;

- experiences reported by UPM Kymmene in Jakobstad;
- the increasing substitution by recovered fuel over the last ten years in the cement kiln in Erwitte;
- the increasing use of waste over the last ten years and test trials with the mid-kiln feeding of bales of non-hazardous combustibles at the cement kiln of Ciments d'Obourg;
- the use of a plastic fluff fuel in the main flame of the cement kiln in Wietersdorf.

Some data on selected cases proving that the emissions with and without RF are comparable with each other is presented in Table 7.2.

Table 7.2 Emission values without and with recovered fuel for selected cases.

Emission	**89/369/EEC**	**HALMSTAD (S)**		**JAKOBSTAD (FIN)**		**SLOUGH (UK)**		**OBOURG (B)**		**NIJMEGEN (NL)**	
Component $^{1)}$	**Limit value**	**Without**	**With** $^{3)}$	**Without**	**With** $^{4)}$	**Without**	**With** $^{5)}$	**Without**	**With** $^{6)}$	**Without**	**With** $^{7)}$
Dust	30	3	3	20	30	20	20	10	8		< 20
CO	100	30	50	60	60	80	80				< 50
TOC	20					2	2	8			
SO_x	300	150	90	10	<16	700	400	120			< 400
NO_x	-	160	150	210	190	70	70	340			< 200
HCl	50	20	20	1	5	70	170	2	1		< 10
Hg	0,2	0,002	0,002	0,001	0,001	< 0.01	< 0.01	0.02	0.03		< 0,05
Cd	0,2		0,070	0,001	0,001	< 0,01	< 0,01	< 0,01	< 0,01		< 0,05
PCDD/F $^{2)}$	-		2,5	< 0,1	< 0,1	< 0,1	< 0,1				
Comb. technology		Mass burn		Bubbling FB		Circulating FB		Rotary kiln		Pulverised Fuel	
Main Fuel		MSW		Bark		Coal		Coal and waste		Coal	
Flue gas treatment		"Hot" ESP, SNCR, wet scrubber, condenser		ESP		Limestone injection Fabric filter		ESP		ESP, FGD, SCR	

Notes:

- No limit; ( ) No measurement

$^{1)}$ mg/m^3 dry gas, 11% O_2,

$^{2)}$ ng/m^3 ITEQ

$^{3)}$ 50% RDF-fluff

$^{4)}$ 8% RF-pellet

$^{5)}$ 40% RF-cube

$^{6)}$ 5% RF-bales midkiln

$^{7)}$ 5% RF-pulverized wood

The main differences between coal and recovered fuels are found in the contents of sulphur, chlorine and heavy metals. In general, the contents of chlorine and heavy metals are higher in the recovered fuels (but chlorine can be at the same level in straw) and the amount of sulphur is lower compared to coal.

The cases studied show that a) co-combustion of recovered fuel is efficient, b) combustion quality may be improved and c) overall emissions do not increase as a consequence compared to primary fuel alone. There is no environmental need for additional costly flue gas treatment equipment, nor for the continuos monitoring of gaseous or aqueous emissions.

7.3 Recommendations

Two issues need to be solved for the successful implementation of the fuel recovery concept. The general acceptance of recovered fuel and the confidence in its use must be improved. Secondly, the status of recovered fuel product must be secured and, consequently, the use of recovered fuel should be regulated similar to that of regular fuels.

The main proposals for solving these issues are:

- In order to give more confidence in the economic and environmental gains and in the long-term reliability and availability of recovered fuels, further development and demonstration is needed on fuel quality and co-combustion in different technologies. In this respect, special attention should be paid to the co-combustion of recovered fuel from municipal waste in pulverised coal plants because of the technical difficulties.

- Further LCA and economic assessment studies should be conducted for fuel recovery, material recovery and energy recovery for several scenarios and combustible materials. It should be endorsed by all parties including the waste management sector. In LCA studies in the development of products aiming at total recovery of components, the RF route could be included as an option.

- Further work is needed on the development of specifications for recovered fuel quality with respect to combustion chemistry and to the fate of alkali metals, sulphur and chlorine in combustion, and to their influence on the problems of possible fouling and corrosion in high efficiency power production. The influence from co-combustion on the usability of by-products i.e. bottom and fly ashes and flue gas desulphurisation residues should be investigated. Leaching behaviour of the ashes will be part of this investigation.

- The recovered fuel product should be dealt with and used like a regular fuel provided it is produced in a permitted facility operating and producing fuel in accordance with specifications of the end-user. Proposed criteria for the product status of recovered fuels are summarised in Table 7.3. These could be further developed and formalised in a CEN standard for solid recovered fuel, based on a mandate from the Commission.

Table 7.3 Criteria for assessment of the product status of recovered fuel.

Criteria for recovered fuel	• Recovered fuel shall meet public specifications which are set by the user(s) and approved by the permitting authority in order to ensure the proper and safe use in the intended (type of) combustion installation. • The recovered fuel shall be safe and hygienic to handle and to store. This imposes requirements on the quality of the raw material, the recovery operation and/or the form in which the fuel is produced. The fuel recovery facility shall operate according to a documented quality assurance system. • The use of the recovered fuel shall be contractually ensured for the long term. • Overall emissions of the combustion process should stay within existing limits applicable to the use of regular fuels and the use of solid residues shall not be obstructed.

Note:
This proposal is in line with proposals from e.g. the French Ministry of Environment and from the OECD Waste Policy working group and the Quality Assurance Manual for Recovered Fuels, published by the Finnish Bioenergy Association.

The recovery operation, handling, storage and combustion of the recovered fuel should be in accordance with environmental regulations. This is not brought forward here as a specific condition for a recovered fuel product as it is considered standard practice. Nor is it mentioned that combustion tests with the recovered fuel in the combustion installation are obligatory; it is the responsibility of the user of the combustion installation to protect his often very capital-intensive plant from corrosion and fouling and to maintain its availability and efficiency. He is also responsible for the emission limits to be met and for the quality of his product. Product quality includes technical aspects as well as environmental behaviour, for instance, the leaching behaviour of cement products produced with recovered fuel is part of product quality.

Appendix A Use of and requirements for RF related to combustion plants

A.1 Introduction

As already mentioned, the LHV is not the only factor determining whether an RF is suited as a substitute fuel. The composition of the RF and the actual plant configuration are also of importance. There are thus two main factors to consider with regard to the use of RF in combustion installations:

- is the installation dedicated to the RF or is the RF co-fired with other fuels and, if so, which type of fuels?
- what type of combustion installations is used: chain stoker, spreader stoker, PF (pulverised fuel), FB (fluid bed), etc.

In the following it is assumed that the RF will be co-fired with other fuels, because in that case the RF has to fulfil more requirements than when a dedicated combustion installation is used. In the latter case, the installation can be specifically designed for the RF, leading to less severe quality requirements for the RF.
It is assumed that the RF will be co-combusted with other solid fuels. The two main fuels of interest are biomass and coal. It is also assumed that the RF consists of paper and plastic, ranging from pure paper and plastics to blends, because this is the fuel that is the most difficult one to handle compared to RF from dried sludges and wood residues and wastes

In the following chapters the use of RF in four types of installations is discussed:

- PF (pulverised fuel) systems;
- grate systems;
- FB (fluid bed) systems;
- cement kiln/rotary kiln systems.

When we discuss the requirements set on RF for co-firing, we should distinguish between the combustion process, emissions and flue gas cleaning and the use of the generated heat.

A.2 PF (pulverised fuel) system

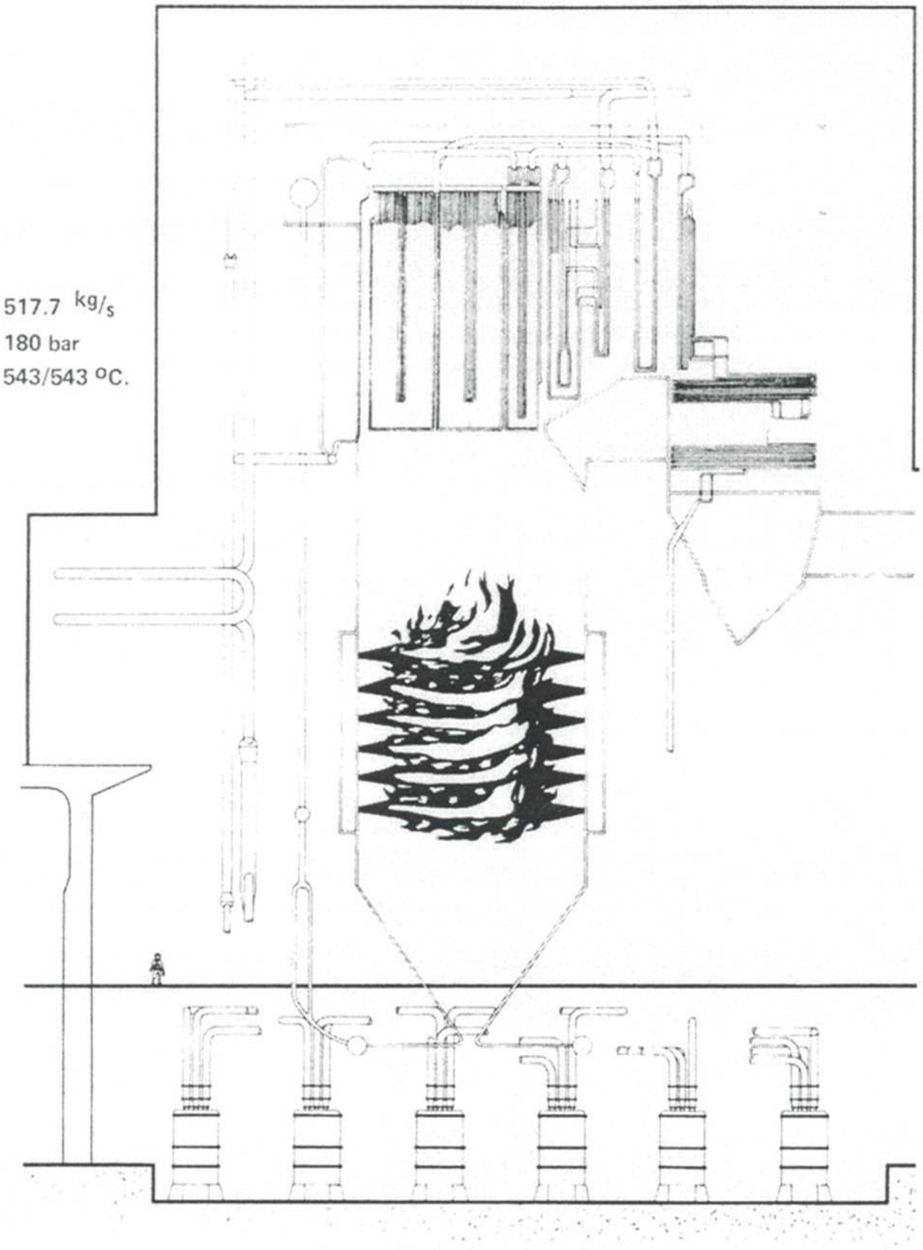

Figure A.1 Schematic diagram of PF combustion system.

PF-firing is the most widely used system in power generation from coal. In a typical PF system, four burners are placed at the corners or at the walls of the combustion chamber. The very finely ground coal (approximately 70 μm) is blown tangentially into the combustion chamber which leads to a swirl with a high mixing intensity and high temperatures (1600 °C). Residence time of the coal particles in the combustion zone is approximately 2 seconds, which explains the need for very fine particles to reach the required char burn out. In modern installations, the energy efficiency can amount to approx. 40%.

If RF were to be co-fired in this system, it must also be ground to a very fine particle size (depending on volatile content); not necessarily as fine as the coal, because it can be fired through a separate port, but still to sizes only reachable by extensive milling. Because of the high plastic content in RF from municipal waste, the milling must be carried out using special equipment to produce a fluff of < 10 mm. The costs for this type of milling are high which makes the option of co-firing this RF type with PF, at least at present, unattractive. For other recovered fuels e.g. from wood waste or dried sludges, co-combustion is easier to realise. As by far the largest potential for co-firing is in PF installations, development of large-scale preparation technology to make the RF suitable for PF co-firing is worthwhile.

Pulverised fuel firing systems are highly efficient at the cost of flexibility with regard to the input. To meet the high technical standard of this plant type, the recovered fuel should meet strict minimum standards. Therefor, the fuel product should be available for a long(er) period in a nearly constant and uniform quality. Long term certainty is also essential as introduction of recovered fuel generally requires high investment cost.

PF plants are often operating on a large scale, and produce large ash quantities (fly ash and bottom ash), which are to a high degree used as construction materials. From an environmental and from an economic point of view, it is essential that recovered fuels do not block this use. The higher chlorine and alkali content of recovered fuel from municipal waste, can cause problems in this respect, if they increase the leaching from the ashes.

Many PF plants throughout Europe are equipped with only dedusting for flue gas treatment, which also puts limitations to the composition of the fuels. If desulphurization equipment is present, these limitations are less sever, but the use of the gypsum should be attended to then.

A.3 Grate systems

The major elements of a grate combustion installation are:
- the bunker and waste/fuel supply;
- the grate; devolatilisation and combustion of the remaining char takes place here;
- the furnace; the zone for (post)-combustion of the volatiles;
- the boiler; steam is generated here and fed to the steam turbine for generation of electricity;

- flue gas cleaning; this causes the emissions of air-pollutant components to remain under the standards;
- ash removal; here a distinction must be made between bottom ash and flue gas cleaning residue, including fly ash.

Moving grate stokers are normally used for small to medium size installations (30 to 150 MW_{th}); they find application in the industry for steam production and in district heating/co-generation plants. In these systems, the fuel is combusted on a chain with holes through which the combustion air is supplied. The feeding systems in use at these installations are screw feeders, spreaders and pneumatic conveyers, and combinations of these. Figure B.2 shows an example of such a system. The fuel is fed to the revolving paddle which spreads it into the combustion chamber. Typical features of this type of combustor are: a limitation in capacity and generally a relatively low combustion efficiency, sometimes as low as 95%. This is caused by the fact that small unburned particles fall through the grate and are removed with the ash, and by the poor mixing of the fuel on the grate.

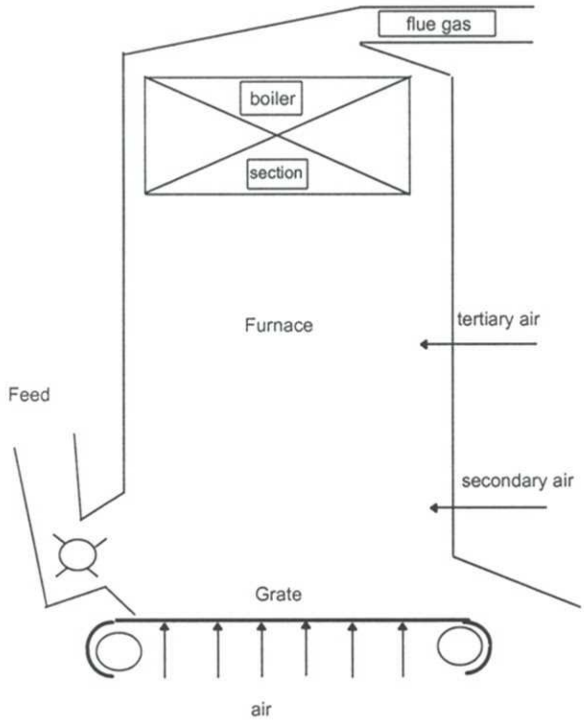

Figure A.2 Schematic diagram of a grate system.

In these systems, substituting part of the fuel by RF should not pose great problems. An important requirement is that an even distribution of the fuel over the grate is achieved in order to prevent hot spots, which may lead to slagging and fouling of walls, or even burn through and damage the grate. When firing coal, this requirement leads to restrictions in the use of the type of coals and its size: usually, high volatile bituminous coals with less than 15% ash and a particle size distribution of 0-25 mm with less than 25% of 0-2 mm are used for spreader stokers and often an even narrower range for pneumatic transport. As far as known, there are few coal-fired grate systems that co-fire waste-derived fuel.

As stated above, the mixing of the fuel is essential. The same applies to the incineration of MSW. This has led to new designs for the grate. This type of grate (described hereafter) is now also used for biomass combustion.

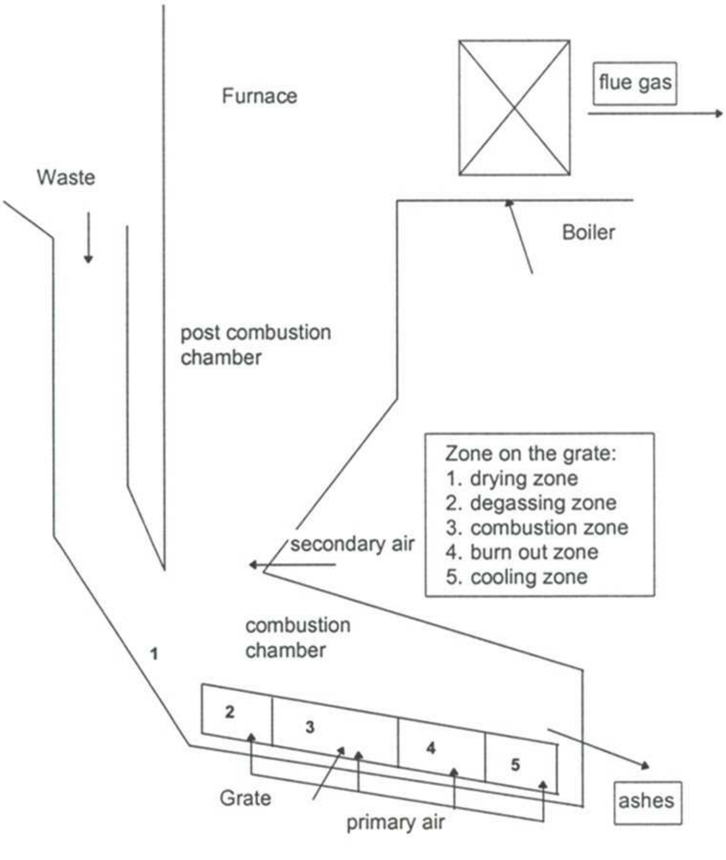

Figure A.3 Schematic diagram of a mass burn combustion system.

Although the term Mass Burn literally means ‘burning waste in large quantities’, in the world of MSW (Municipal Solid Waste) combustion it generally refers to the combustion of the MSW as such, i.e. without pre-treatment. The only pre-treatment used can be the size reduction of very bulky waste such as furniture, etc. As combustion without any pre-treatment is only possible in grate systems, the term Mass Burn generally refers to this type of combustion system.

The mass burn grate system has been considerably improved compared to the system mentioned before. As can be seen in Figure B.3 the grate has been inclined and is divided in sections; the combustion air to these sections can be separately controlled. The grate moves forward and backward thus poking the material to ensure complete combustion. Considerable effort has been put into the improvement of the mass burn combustion, not only with regard to the grate but also to the control system. Sophisticated equipment like IR (Infra Red) cameras combined with computers is in use to locate the main fire on the grate and keep it fixed by adjusting the feeding system and/or the speed of the grate. These improvements have led to a much better combustion efficiency. The boiler efficiency (and consequently the electrical efficiency) has remained more or less the same. Because of the corrosive nature of the flue gases, which in turn is caused by the composition of the waste and especially by the chlorine content, the steam parameters are usually limited to ~420 °C and ~40 bar, leading to an electrical efficiency of ~22%.

The co-combustion of RF on a grate with other solid fuels should not pose great problems, as long as the load remains in the operating area as depicted in Figure B.4. Care should be taken that the fuel blend is well mixed before it is fed to the grate to prevent hot spots. Much attention should be given to the feeding system itself. Spreader stokers e.g. will not work properly with fluff material; ram or screw feeders must be used. To prevent early entrainment of the light parts of the RF into the furnace section, the air velocity should be limited; the pressure drop across the grate should be at least 3 times as high as across the fuel layer to ensure an even distribution of the combustion air. The combustion efficiency of grate systems is generally lower than in FB or cement kiln.

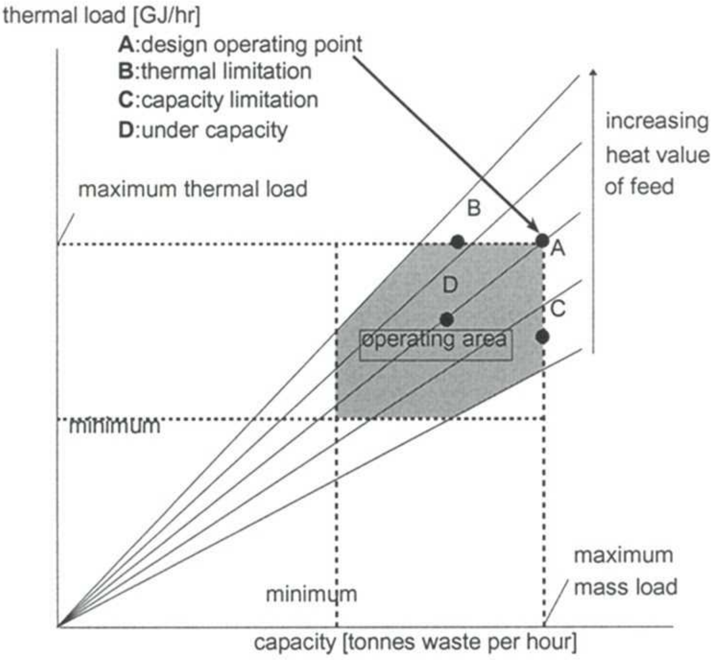

Figure A.4 Combustion diagram for mass burn.

Co-firing of RF in a mass burn system is, of course, possible without problems as long as not so much normal waste is substituted by RF that the LCV becomes too high (see Figure B.4). (Water-cooled grates or addition of extra air are means to overcome this problem, but lead to heat losses and thus to even lower efficiency). It would be senseless to make a high quality RF and then mix it with low quality material and burn it with low efficiency in a mass burn installation.

The flue gas cleaning needed after a grate system is also largely dependent on the composition of the fuel and, of course, the governing emission standards. A dust filter will, of course, always be installed. If coal is used as the primary fuel, SO_2 removal might be necessary depending on the emission standards. NO_x will originate mainly from the nitrogen in the fuel. It can be reduced by primary measures, i.e. using secondary and tertiary air. Secondary measures in the form of SNCR or SCR might be necessary.

The heat is used for steam generation. The efficiency of the heat recovery is largely dependent on the composition of the solid fuel. If the amount of corrosive or fouling agents in the fuel is low, high steam parameters can be used, thus, a high boiler efficiency is obtained.

A.4 FB (Fluidized Bed) systems

In a FB, the fuel is burned in a bed of inert material (such as sand) resting on a 'grid plate' through which the air needed for fluidisation of the bed and for the combustion is supplied (Figure B.6).

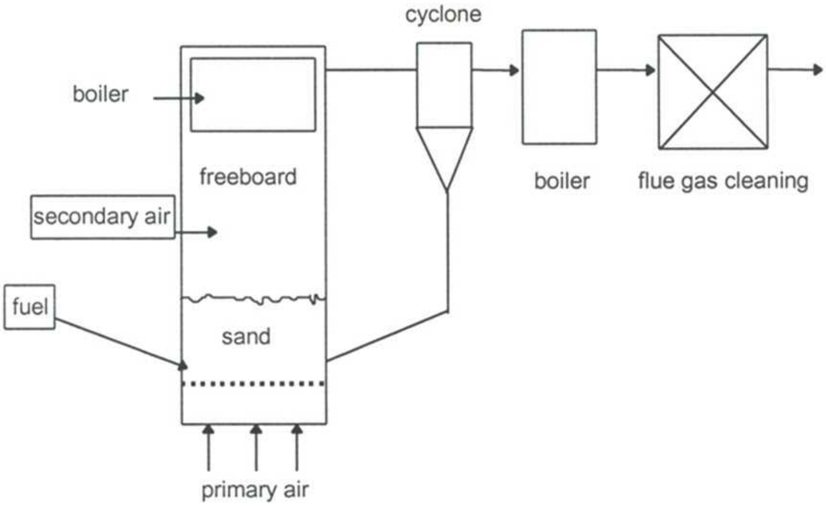

Figure A.5 Schematic diagram of FB combustor.

The combustion air fluidises the sand so that it acts as a boiling liquid. The fuel, introduced into the bed by means of gravity, a screw, or pneumatically is mixed with the bed material immediately. There are two main types of FBs: the Bubbling Fluid Bed (BFB) and the Circulating Fluid Bed (CFB). In the latter case, the air velocity is so high that there is no longer a dense bed; all material is entrained with the air, separated from the flue gas in a cyclone and returned from there to the "bed" section. Typical features of FBs are that the fuel particle size must be within a certain range (< 50 mm) and that sorbents (generally limestone) can be added to the bed to bind pollutants such as SO_2, avoiding the use of special flue gas cleaning equipment. Many fluid bed combustors are in use throughout the world for the combustion of coal and/or waste and low-grade biomass fuels, both in small- and in large-scale applications (10-700 MW_{th}). This type of combustor is very flexible with respect to fuel type because the bedmaterial acts as a thermal flywheel and the amount of fuel in the bed is below 5%. As long as the feeding system succeeds in transporting the fuel into the FB there normally are no problems. Combustion efficiency of FB installations is normally well above 98%. This type of combustor is very well suited for the co-combustion of coal and RF. Around the world a large number of FBs are in operation for the combustion of MSW (e.g. 170 in Japan, 8 in Sweden, 3 in USA), coal and biomass.

To burn RF in a BFB (bubbling fluid bed) little pre-treatment will be necessary. Materials that could produce lead to problems such as metals and glass are not supposed to be present in RF. The same holds true for large pieces of incombustibles (like stones) that could lead to de-fluidisation of the bed. The pre-treatment required will be a size reduction to approximately 300 mm, and preferably 50 mm. Underbed or inbed feed systems should be used; overbed feeding of fluff material might lead to entrainment of light parts into the freeboard. This in turn might cause fouling and corrosion of the superheater tubes. Another problem that might occur in an FB system is sintering of the bed because of high alkaline and/or chlorine contents in the fuel. This can normally be prevented by limiting the bed temperature to < 850 °C or adding sorbents.
If a CFB is used pre-treatment should be more severe, i.e. large pieces must not be present and the size of the feed must be within pre-defined ranges (< 50 mm) to prevent problems with the fluidisation. A well known point of interest in CFB is the possibility of erosion both of pipes and walls, because of the high fluidisation velocity.
Combustion efficiency in both FB systems is high (> 98%); the total boiler efficiency (taking into account all losses) can be > 93%.

FB combustors using coal as fuel are normally used to generate steam. In BFB combustion the major part of the steam is generated through pipes in the bed and in the freeboard. In CFB there are only pipes in the freeboard. Steam conditions can be 520 °C and 100 bar leading to an overall electrical efficiency of > 40%. These temperatures, however, can only be tolerated if the maximum chlorine level in the solid fuel is 0.2%. Higher levels lead to such an increase in corrosion rates of the in-bed tubes and superheaters tubes (in addition to erosion of the tubes) that either the steam conditions must be lowered (leading to loss in electrical efficiency) or downtime must be accepted to exchange or repair the tubes. Alkalis in the fuel may lead to corrosive deposits on the tubes increasing the effect of the chlorine attack.

Limestone can be added to the bed to bind SO_2. This limestone will also bind (part of) the chlorine although the bed temperature is not optimal; this, however, has sometimes led to an increase in corrosion instead of a decrease.

It thus follows that substituting part of the coal by RF should not lead to chlorine concentrations higher than 0.2% in the fuel blend, in other words the chlorine content of the RF should be as low as possible.

FBs are equipped with a cyclone and a dust filter. No other gas cleaning is normally necessary to reach the required emission levels. SO_2 emissions can be effectively controlled by adding limestone; also Cl^- is, to a large extent, captured by the limestone. NO_x emission is low because the combustion temperature is low (no thermal NO_x formation). It is not expected that adding RF to the coal will lead to drastic changes in the emissions.

A.5 Cement kiln/rotary kiln systems

Cement production can be divided into heating of raw materials to form clinker and, next, grinding of the clinker and mixing with gypsum, fly ashes and other materials to produce cement.

Essential components for the clinker are CaO, SiO_2, Al_2O_3 and Fe_2O_3. Gypsum is added to the clinker after cooling. Blended and ground raw materials (such as limestone, clay, sand and iron ore) are fed into the cement kiln and burnt under controlled high-temperature conditions. Typically, the cement kiln is a long rotating cylinder. The raw materials are fed at the elevated end and, through the rotations of the kiln, move slowly down towards the firing end where heat is applied using coal, gas or oil (a simplified scheme is presented in Figure B.6). A solids temperature of approximately 1450 °C is necessary to produce a melt, required for clinker formation. In fact, Figure B.6 is a strong simplification of a modern cement process in which the kiln is preceeded by a number of cyclones in which the raw materials are preheated and the calcination step can occur. In these installations there are additional options to feed the recovered fuel in an optimal way.

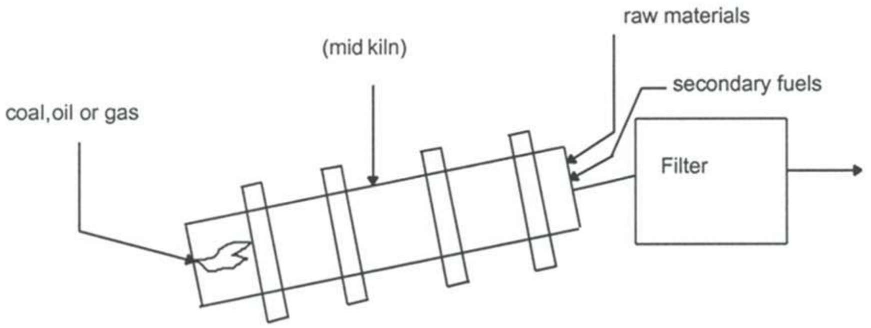

Figure A.6 Schematic diagram of a cement kiln.

Because of the high temperature and long residence time a high combustion efficiency is achieved, well above 99%. Because of (heat) losses the overall energy efficiency will be around 80%.

As in the FB case, little pre-treatment of the RF is necessary. RF can be fed as fluff by injection with air at the main flame or as pellets; bales or large pieces can be fed via a mid kiln feeding system or with the raw material intake. The cement industry has ample experience with co-combustion of RF materials and all kinds of waste materials: tyres, spent oils, sludges. Generally, chlorine contents in the RF of approximately 0.5% should give no problems but each plant has its own requirements.

Generally, cement kilns are equipped with an electrostatic precipitator (ESP) for flue gas cleaning. Important is that fly ash can be recycled to the kiln. Because of

the alkaline environment there is a good removal of metals, sulphur and chlorine from the flue gases. High NO_x concentrations are the result of the high combustion temperatures required in the process. Lower calorific fuels such as RF can result in lower NO_x emissions.
Volatile metals T, Hg and Cd should be restricted in the feed because they can accumulate in the kiln/cyclone system.

Appendix B

Workshop on
Fuel and Energy Recovery
THERMIE, DIS-1375-97-FI

November 26, 1998
Holiday Inn Brussels Airport

Proceedings

Edited by
Martin Frankenhaeuser / Borealis

List of contents:

1. Programme
2. Summary
3. Presentations
4. List of registered participants

Programme for Workshop on "Fuel and Energy Recovery"

THERMIE 'B', DIS-1375-97-FI
Thursday, 26 November, 1998
Holiday Inn Brussels Airport

Time	Topic	Speaker	Organisation
9.30	**Registration**		
10.00	**Session 1, General**	M. Frankenhaeuser	DIS-1375-97-FI
	• Basic Principles		
	- Opening	P. de Sampaio Nunes	E.C. DG XVII
	- Energy policy; Definition of Fuel	S. Furfari	E.C. DG XVII
	- Waste Strategy; Waste Incineration	L. Krämer	E.C. DG XI
	- Introduction, Objective, Received comments, Terminology	M. Frankenhaeuser	Borealis
11.10	**Coffee**		
11.30	**Session 2, Overview and proposals**	K. Maniatis	E.C. DG XVII
	• Fuel Characteristics, Fuel Recovery and Energy Recovery vs Landfill, efficiency and CO_2		
	- Calorific Gain	B. Maijgren	CEN TC261/SC4/WG4
	- Recovered fuel & potential for EU	J. Zeevalkink	TNO
	- The role of standardisation	G. De Jongh	CEN
12.45	**Lunch**		
13.45	**Session 3, Cases Studies**	J-M. Bemtgen	E.C. DG XVII
	• Technical, economical and environmental performance		
	- Summary of Case Studies	G. Krajenbrink	TNO
	- Halmstad (S)	P-O. Andersson	Renhållningsbolaget
	- Jakobstad (FIN)	H. Nygård	Ekorosk
	- Wijster (NL)	H. Schaap	VAM
	- Erwitte (D)	H-D. Maury	MBM
15.20	**Coffee**		
15.40	**Session 4, Discussion**	G. Molina Igartua	E.C. DG XVII
	• Waste to Fuel to Energy		
	• Recovered Fuel - Waste or product?	Panel [1] + Audience	
	- Q & A		
17.15	**A way forward, Closing remarks**	J-M. Bemtgen	E.C. DG XVII
17.30	- End of Workshop		

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[1] **O. Linher** / DG III; **L. Krämer** / DG XI; **M. van der Poel** / Eurelectric;
K. Nilsson / International Solid Waste Association;
B. Lemmes / Organic Reclamation & Composting Association;
K. Strange / World Resource Foundation

Summary

Main issues addressed at the "Fuel and Energy Recovery" Workshop on November 26, 1998 in Brussels regarding the distributed **draft report, presentations** and **discussions**:

- **Energy Policy and CO_2**
  Science and technology teaches us that improving efficiency reduces emissions and that substituting fossil fuel by biomass and waste, as well as by other renewable energy sources, is a means to achieve the Kyoto engagements for CO_2 reduction. A potential 2 to 3 % reduction of CO_2 emissions by utilising presently landfilled non-hazardous combustible waste for fuel and energy recovery could be achieved in the European Community. This is a significant share of the target.

- **Waste Strategy and Waste Management Hierarchy**
  Prevention by source reduction, re-use and recovery, followed by safe final disposal are well acknowledged principles for waste management. The study addresses unavoidable combustible wastes arising after successful prevention and current sustainable recycling.

- **Integrated Resource Management**
  All economic recovery options which reduce consumption of raw materials (including fuels) and reduce overall emissions should be promoted. This specific study reports on developments in the field of Fuel and Energy Recovery.

- **Terminology and definitions present a problem**
  It is generally agreed that definitions of e.g. "waste", "waste treatment" (recovery and disposal), "recovery operation" and the resulting "non-waste product" need to be improved. A differentiation between pre-use and post-use wastes was discussed. The waste status remains until the recovery operation has been completed. Some key terms related to production and recovery operations are positioned in the chart below.

Material origin	Raw material	Semi-finished product	Finished product	*Product destiny*
Natural resource	Renewable Fossil		- Material products **- Fuel products** **- End-use energy**	*Market*
Production residues = Scrap = Pre-use waste	Mono-material ***- "Clean waste" with known fuel properties*** Multi-material	***- "Alternative fuel"***	- Material products ***- "Recovered fuel"*** **- End-use energy**	*Market*
Post-use waste	Selected *- Industrial* *- Commercial* *- Household* Mixed	***- "Alternative fuel"***	- Sec. raw material - Material products ***- "Recovered fuel"*** **- End-use energy**	*Market*
"Waste status"	*Untreated waste*	*Pre-treated waste*	*Treated waste* **= Product**	

Key terms regarding Fuel and Energy in production and recovery operations.

- **Basic principles for recovery (including recycling)**
  Recovery basically means converting waste into useful material or end-use energy product. Energy recovery through direct incineration is a R1 operation (*"use principally as a fuel"*) according to the European Waste Directive. R2-10 operations result in material products. R3 is *"recycling/reclamation of organic substances"* (for the original purpose or for other purposes). This should be applicable for *fuel recovery*, i.e. processing non-hazardous combustible waste into products for the fuel market. In several Member States such fuel production processes are recognised and used for defined pre-use wastes.

- **Co-incineration and co-combustion vs. dedicated incineration**
  Co-incineration means burning pre-treated selected waste (*alternative fuel* in the chart above) as a substitute for part of regular fuel in plants dedicated to the production of material or end-use energy products. Co-combustion means burning a mixture of fuels.
  The Case Studies show that fuel recovery, at no or low additional cost compared to landfill, can utilise existing infrastructure for local energy production with overall beneficial environmental impact. Fuel recovery is complementary to organic recovery of the wet organic waste fraction, and also to dedicated incineration with energy recovery. The latter is demonstrated in the VAM/Wijster case in the Netherlands, where fuel recovery, energy recovery and organic recovery are integrated within the same plant.

Co-incineration is seen as a threat to dedicated incineration. On the other hand, it is seen as an economic option to achieve a significant diversion of combustible waste from landfill in small to medium sized municipalities and scarcely populated regions, where dedicated incineration at present (and developing) regulation is economically unrealistic.

- **Overall efficiency and overall emissions vs. purpose of process**
  No agreement was reached on whether environmental regulation should reflect the purpose of the process. It was generally recognised that an overall improvement of efficiency and reduction of emissions can be reached by co-incineration. On one hand it is argued that all combustion processes should strictly have the same environmental regulations, regardless of the purpose of the process. Another view is that since efficiency and emissions depend on the fuel input as well as on the process itself, a controlled input of selected and well defined fuels would make more extensive and costly end-of-pipe cleaning and continuos emissions monitoring environmentally unnecessary.

- **Product standards - needed both for compost and fuel markets**
  In order to stimulate recovery, including recycling, it is essential to develop product specifications and/or standards for fuel in the same manner as for compost. Once standards for the market are agreed upon, the initiative to develop the necessary processes to produce accepted products for the market should be left to industry.

- **More work is needed**
  It was generally agreed that more work and discussion is needed in order to develop a common position on co-incineration and co-combustion, especially on subjects which were not in the scope of the study or where deeper insight is required, such as on:

    - the effect of co-incineration on solid and liquid residues from energy conversion processes;
    - Life Cycle Assessment and economic analysis for the substitution of fossil fuel at co-incineration or co-combustion, compared to dedicated incineration of mixed municipal solid waste and energy production from fossil fuel in separate plants;
    - development of guidelines on and assessment of “recovered fuel”, eventually in the form of a European Standard.

Opening of Seminar

P. de Sampaio Nunes, European Commission

Director DG XVII-D: Energy Technology Programme

Ladies and Gentlemen,

It is an honour for me to open this workshop, entitled "Fuel and Energy Recovery".

This workshop is organised within the frame of a study, performed by key industrial partners in order to assist DG XVII:

1. To better define the future strategies on the role of waste-to-energy as an innovative means to reduce CO_2 emissions
2. To help us to select the most promising technologies which deserve further development within FP5.

Some participants may be surprised to see the importance that the Energy Technology Programme of the European Commission attaches to this subject. Thus let me please shortly outline the EU energy policy and strategy.

The Directorate General for Energy was created in the seventies, just after the first oil shock, with the mandate to address the key problem of security of supply and import dependence. In the eighties the environmental dimension was added on top of security of supply on the EU energy policy. Our role was to solve the conflicting requirements between pollution reduction and delivering cheap and efficient energy. In the nineties, a further dimension was added through the Rio conference and the Kyoto engagement. CO_2 reduction is in line with the requirements of security of supply, as the best way to reduce CO_2 emissions is to reduce the input of carbon in industrial production.

I would like to recall that by far the largest proportion of our energy (electricity and heat) is produced by the combustion of carbon into CO_2 (more than 80% worldwide and 79% in the EU). The remaining part is composed of nuclear, hydro, wind, PV, solar thermal etc. 14% of the crude oil extracted from our earth is not burned but converted into plastics and other materials (EU15, 1996). This illustrates the importance of combustion in our society.

The European industry made significant progress in combustion technology. Efficiency has doubled over the last decades, whereas the emission of pollutants has decreased even much more. Further significant progress is expected within the next decade. However, this progress is not sufficient to achieve the Kyoto targets, as it is partially offset by an expected increase in energy demand. Also the use of renewables will not be able to carry the difficult burden alone. Further efforts must be made in order to reduce the consumption of fossil fuels.

Here we link the EU energy policy and strategy with the workshop. The aim of the study is to assess the possibilities and the potential of using wastes as fuels in advanced heat and power generation. Some of you will ask the question on how wastes may reduce CO_2. For answering this question we must go back to the basics of recycling.

Why do we want to recycle? The aim of recycling is to re-use the material, component or element of a given product and that the same quantity of raw material is not extracted from our natural resources. Recycling of steel preserves the resources of iron ore. Recycling of plastic preserves the resources of crude oil. If the plastic is not recycled, we need to use new crude oil. New crude oil means new carbon into the system and thus additional CO_2 emissions into the atmosphere. Recycling of plastics means re-using the carbon a second time for a product without its carbon being converted to CO_2 and being lost into the atmosphere. Recycling of plastics means substitution of fossil fuels and is thus in line with sustainable development of reducing the use of natural resources. It is also in line with the best way to reduce CO_2: to reduce the consumption of carbon.

Recycling is thus an important concept in the energy policy, which aims at conserving fossil fuels. This contributes to sustainable growth, security of supply and natural resource conservation and finally to contribute to the achievement of the Kyoto targets.

The second important question is to determine whether recycling may be applied to energy generation. This question must be answered positively from a science and technology point of view. Energy is a product. So is electricity. This has been decided on the world trade level: electricity is regulated GATT as it is a product (GATS regulates energy transmission, distribution and storage, as they are not a product, but a service). Thus energy and material are basically on equal foot for recycling.

Thus we come to the debate of material recycling versus fuel recycling or material and fuel recycling. Opponents and proponents have a large number of examples for supporting their case. With the integration of industrial production and power production we also see the emerging of cases with complex interactions of mass and energy flows which may not be separated without negatively influencing the environment. The EU's energy RTD programmes have supported many technologies for material recycling and energy recycling and their integration. THERMIE supports new technologies, which use energy more rationally. The waste management and material recycling chain is very energy intensive. New technology may significantly reduce this energy consumption and is thus supported increasingly by

THERMIE. Recycling of wastes into energy is equally important and receives strong support. Wet organic wastes are quite often not suited for combustion and thus THERMIE supports advanced composting and digestion processes. In Community legislation the term “fuel recycling” is not used. In order to be consistent with the Community legislation we hereafter use the term ‘energy recovery”.

The determination of whether material recycling or energy recovery of a given waste is the favoured solution for sustainable growth has to be determined by Life Cycle Assessments. This matter is complex and a purely technological discussion cannot give a global coherent picture. I propose that we discuss the technical details and the implication on the legal framework and its impact on the EU’s energy and environment policies in an integrated way. We have thus asked many environmental experts to comment on this subject. I thank them for their constructive inputs and the time that they have devoted to this important subject. I hope that this workshop will conclude in the same constructive spirit.

Energy policy; Definition of Fuel

P. de Sampaio Nunes

European Commission

Directorate General for Energy (DG XVII)

Director for Energy Technology

Presented sheets:

Energy Policy of the EU

- Reduce consumption of energy
- Security of supply
- Sustainable development
- Increase industrial competitiveness
- Reduce environmental impact
- Reduce pollutants
- Reduce CO_2 emissions (Kyoto engagement)

EU Policy of the Energy Technology

- Satisfying the conflicting requirements between
  - Supplying cheap energy in sufficient quantity
  - Using less resources
  - Reducing emissions (all end-of-pipe cleaning up processes consume energy)
  - Reducing greenhouse gas emissions

- These conflicting requirements can only be solved by new technology

Approach of the Energy Technology

- More sophisticated energy supply
  - advanced power generation technology
  - fuel switch to cleaner or less carbon intensive fuels
  - renewable energy sources

- More rational end use of energy
  - in transport
  - in buildings
  - in industry

The Greenhouse effect

- 80% of the energy = generated through combustion of carbon into CO_2 (fossil fuel based)
  - 81% worldwide, 79% EU15 (1996)
  - remaining part = nuclear + hydro + wind + PV + solar thermal, etc.

- EU policy: reduce CO_2 emissions (Kyoto engagement)

- Each carbon extracted from the earth (fossil fuel) sooner or later ends up in the atmosphere as CO_2 (or as another more harmful greenhouse gas)

- The best way to reduce CO_2 emissions is to reduce the extraction of fossil fuels
  - this preserves resources
  - this increases security of supply

Ways to reduce CO_2 emissions

- Increase efficiency of power plants

- Substitute fossil fuels by CO_2 neutral fuels
  e.g. coal or oil by biomass, wastes or other fuels

- Substitute fossil fuels by less CO_2 intensive fuels
  e.g. coal by natural gas

- Increase Nuclear
  strong political problem of public acceptance in most Member States

- Integrate power and heat production

- Use energy more rationally in industry

- Use energy more rationally in buildings

- Use energy more rationally in transport

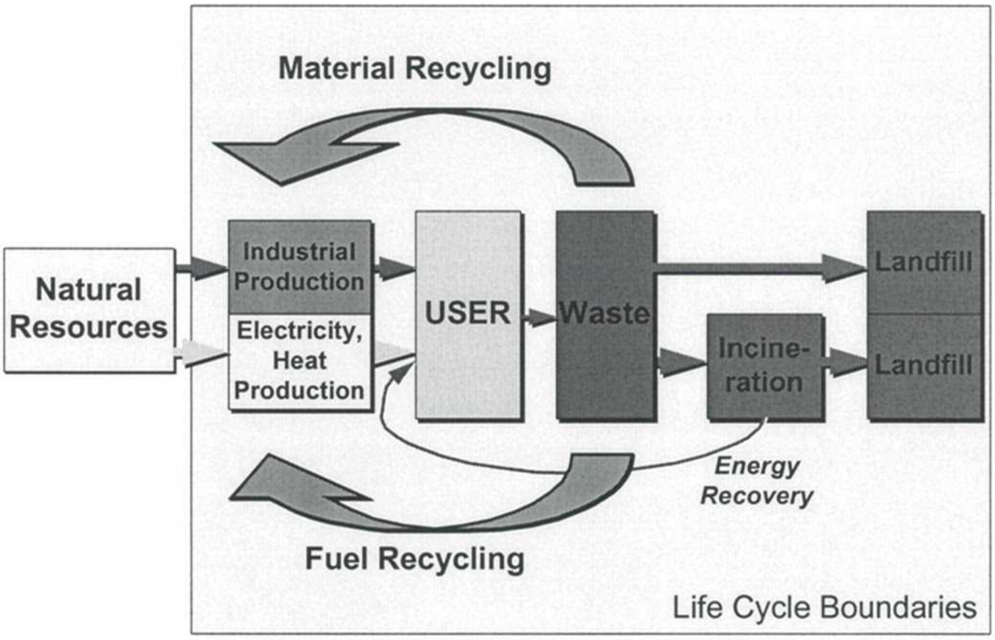
Are wastes CO_2 neutral?

- The aim of recycling is to re-use the same material again (instead of using new resources)

- Recycling of (carbon containing) wastes re-uses the same carbon again for the same or a different product

- Recycling permits to leave an equivalent quantity of carbon in the earth
- Thus recycling is CO_2 neutral
- Difference whether the waste derived product is a material or energy?
  - Is waste to material CO_2 neutral?
  - If yes, then waste to energy is also CO_2 neutral

Waste Recycling



Potential of Wastes to Reduce CO_2

- ~86% of crude oil is used for energy
- ~14% is used for production of materials
  ~ half is material recycled
  ~ half is landfilled or incinerated (thus this carbon is lost for recycling)
  - This carbon contained in wastes could substitute coal or oil in power plants (fuel recycling),
  - electricity production could reduce its CO_2 emissions by the same amount

- Not all wastes are suited for fuel recycling; fuels have strict quality criteria

- Some 5-10% of coal could be substituted by fossil derived wastes or biomass

Fossil Fuels, Biomass, Wastes and other Fuels

- Overlap of technical borders of fossil fuels, biomass, municipal, agricultural and industrial residues and wastes, etc.: they all contain carbon and are combustible

- Main difference is the origin of carbon:
  - organic carbon of recent origin (photosynthesis cycle of a few years)
  - fossil fuel derived (thousands to millions of years for formation)

- Natural carbon cycle is some 100 - 300 years
  (absorption/ desorption of CO_2 in oceans, carbonate formation and dissolution, etc)

- Biomass and organic wastes have shorter cycles and are thus CO_2 neutral (the CO_2 emitted during combustion may be subtracted as recycled through photosynthesis)

Waste-to-Energy

- Waste incineration:
  - inhomogeneous wastes lead to
  - unstable combustion and emission peaks
  - technology adapted to these problems:
    expensive, low efficiency, difficult public acceptance

- Recovery of wastes to fuels, and used in advanced power generation
  - fuels are homogenised, blended and well characterised products which are converted into energy (a high added value product)
  - waste sorting, fuel preparation and characterisation is mandatory
  - stable combustion and predictable emissions in power plants
  - flue gas treatment is optimised for relevant emissions

- Such technology development is supported by the EU in the Non-Nuclear Energy programme (JOULE-THERMIE)

Projects supported by THERMIE: Recycling of wastes to material

- Promising results obtained or in progress with:
  - wood
  - agricultural residues
  - paper
  - organic material to compost
  - plastics
  - tires

- metals (ferrous and aluminium)
- slag and fly ash to cement, etc.

Projects supported by THERMIE: Recovery of wastes to energy

- Promising results obtained or in progress with:
  - Sewage sludge and paper sludge in power plants (pulverised fuel fired gasification processes, fluidised bed) : lower emissions than for coal alone
  - agricultural residues, straw, litter, etc.
  - forestry residues
  - wood cuttings, saw dust, demolition wood, etc.
  - textile residues (natural and synthetic fibres)
  - pet coke and refinery residues (incl. LPG)
  - plastic cuttings from plastic film production
  - tires
  - MSW (thermo-chemical, anaerobic digestion), etc.

Results for Waste-to-Energy

- Strongest effect on NOx reduction:
  NOx values lower than for coal or for secondary fuel alone through
  synergy effects in the flame

- Other emissions usually lower: usually non-linear effects observed
  not to be explained by dilution
  exception for sulphur, which behaves linearly

- Efficiency usually not changed
- Solid residues (slag, fly ash, etc.) no problem encountered
- Waste recycling in power plants: Globally strong positive effect for the environment

Life Cycle Assessment

- Life cycle assessment (LCA) is the necessary tool to choose the best local, regional and global waste management solutions

- LCA must include
  industrial production processes
  the complete power sector (not only the streams for industry)
  waste management sector (collection, sorting, preparation)
  transport sector
  mass and energy balance and exergy losses
  all emissions to land, water and air

Conclusions

- First priority: prevention
- Worst option: landfill
- In-between: choose the solution that best preserves natural resources and reduces emissions
- Fuel and material recycling are equivalent
  - at the same amount of fossil fuels preserving
  - and at the same level of emission reduction
- More room also for composting, bio-digestion, etc.
- Without LCA no "a priori" choice
- There is not one single winning solution:
  - they complement each other

Future Activities in DG XVII on Wastes within Energy Technology

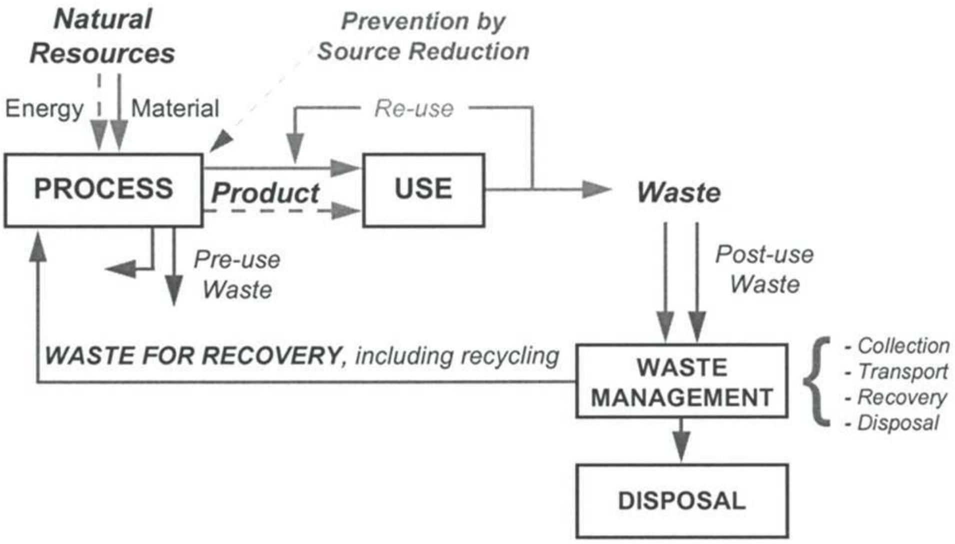
- Within 5th Framework Programme: support technologies which are cost effective and use energy more rationally in:
  - material recycling with less energy input (most selection, sorting and recycling processes are energy intensive)
  - energy recycling with less material input (higher efficiency needs less wastes)
  - biological and bio-chemical processes (composting, bio-digestion, etc.)
  - data gathering and generation for comparative analysis, benchmarking, etc.
    - as input for LCAs and
    - as input for EU policies on energy, environment, industry, etc.

Introduction, Objectives, Received comments and terminology

Martin Frankenhaeuser

Borealis

Simplified scheme for Integrated Resource and Waste Management



Sustainable Recovery

- Saves natural resources
- Reduces overall emissions
- Produces useful products (including energy) or secondary raw materials
- Is economically competitive

Objectives of the Study

- To report on technical, economical and environmental aspects of Energy Recovery in general and Fuel Recovery in particular
- To indicate the needs for further development and demonstration on preparation and use of alternative fuels in general and recovered fuels in particular
- To propose a way forward for cost effective and environmentally sound Fuel Recovery as a means to reduce the dependency on fossil fuels for efficient energy generation and thereby help reach the Kyoto commitments for a reduction of greenhouse gas emissions

Scope of the Study

The Study is executed as a multi-client project for the THERMIE-programme of the European Commission. It reports on technical, economical and environmental aspects of current activities in the Union. It especially aims at recovery of pre- and post-use non-hazardous combustible waste in the form of:

- Energy Recovery through direct incineration of waste or co-incineration of pre-treated alternative fuel
- Preparation of a storable Recovered Fuel for substitution of fossil fuel for production of energy or material products

Received Comments

The draft report has received comments which are grouped in three categories:

- Terminology (to be discussed here)
- CO_2 discussion (in session 2)
- General comments (in session 4)

Revised proposal for terminology

- Legal definitions
- Proposed interpretations
- Proposed new definitions

Goals of the Workshop

- To present and discuss results of the study with relevant stakeholders
- To discuss conclusions and recommendations of the study
- To explore whether a consensus could be reached to position fuel recovery as a complementary recovery route for combustible materials which are not suited for other recovery
- To explore whether stakeholders would recommend to develop procedures whereby the production and use of specified Recovered Fuels could be assessed and regulated as other fuels for combustion installations, e.g. in the form of a voluntary agreement or as an European Standard

Calorific Gain

Barbro Maijgren

CEN TC 261/SC 4/WG 4

Essential Requirements **for Packaging to be Recoverable in the form of Energy**
Packaging Directive [94/62/EC]

Essential Requirement for Energy Recovery

The Packaging (*fuel*) shall be combustible and give a net contribution of energy:

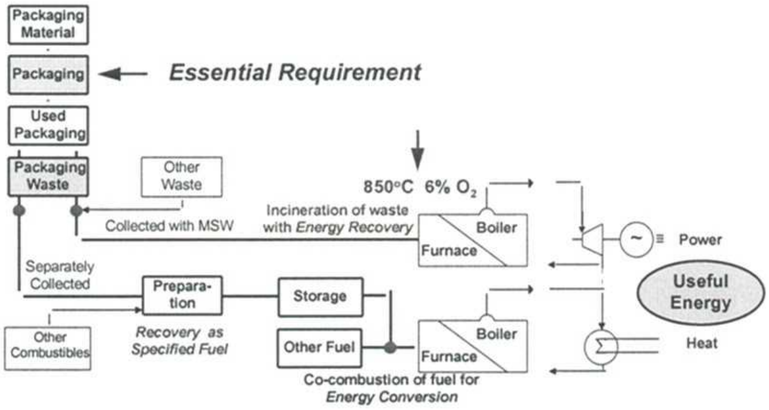
Calorific Gain $\mathbf{Q_{net} - H_a > 0}$

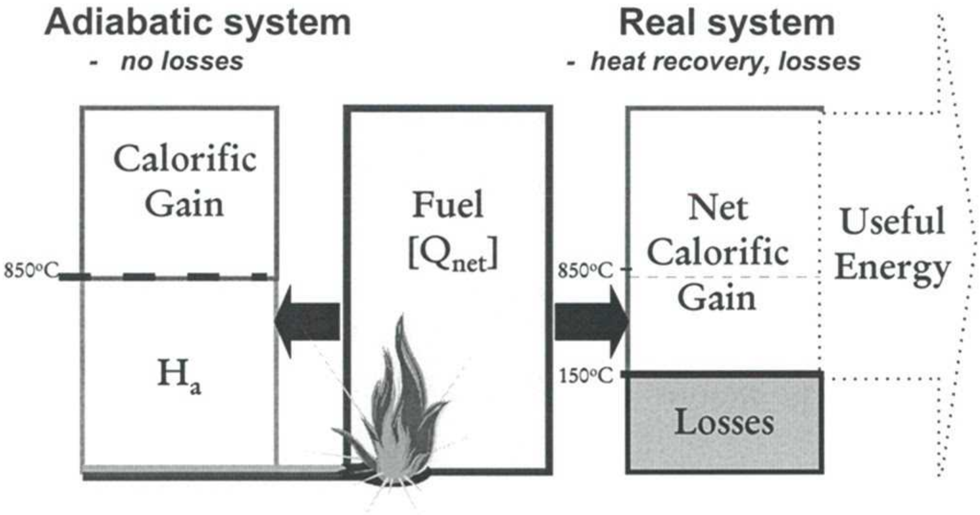
Q_{net} = net calorific value
H_a = energy required to adiabatically heat combustion products, residues and excess air to the actual combustion temperature

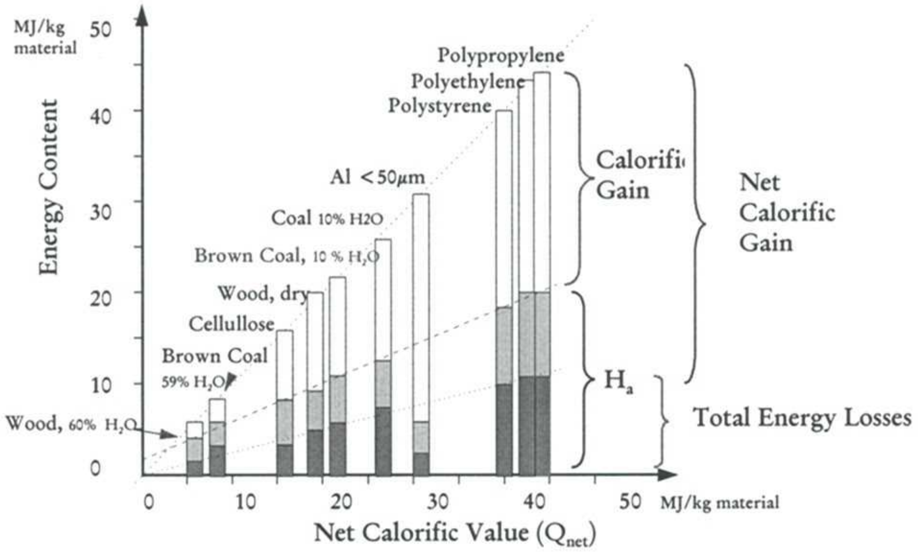
H_a depends on material composition and combustion conditions

- waste incinerator: 850°C, 6% O_2

Two routes: **ENERGY RECOVERY AND RECOVERY AS FUEL**




Adiabatic system
- no losses
Real system
- heat recovery, losses
Calorific Gain
850°C
H_a
Fuel [Q_net]
850°C
150°C
Net Calorific Gain
Useful Energy
Losses


MJ/kg material
Energy Content
50
40
30
20
10
0
Polypropylene
Polyethylene
Polystyrene
Al < 50µm
Coal 10% H2O
Brown Coal, 10 % H₂O
Wood, dry
Cellullose
Brown Coal 59% H₂O
Wood, 60% H₂O
Calorific Gain
Net Calorific Gain
H_a
Total Energy Losses
0
10
20
30
40
50
MJ/kg material
Net Calorific Value (Q_net)

Recovered fuel and potential for EU

Jan Zeevalkink

TNO Institute of Environmental Sciences, Energy Research and Process Innovation

Topics

Fuel Recovery

- What is a fuel?
  - heating value
  - efficiency
  - user demands

- Potential of recovered fuel
  - volume
  - advantages

- Recovered fuel: a product
  - criteria

RF: potential production volume in EU

- Municipal waste: 170 Mt/a
- Landfill (60%): 100 Mt/a
- 40% RF: 40 Mt/a
- Industrial wastes: 40 Mt/a
- Total: 80 Mt/a

Fossil fuel saving

RF potential: 80 Mt/a, 15 MJ/kg: 30 Mtoe/a

			Potential substition by RF
Total fuel EU	1200	Mtoe/a	3 %
Solid fuel	260	Mtoe/a	8 %
Hard coal	170	Mtoe/a	15 %
Imported hard coal	85	Mtoe/a	30 %

Potential of RF: Summary

- Saves 30 Mtoe/a = 10% of solid fuel consumption EU
- Creates employment for 20,000 persons
- Reduces CO_2 emission up to 100 Mt/a: 3%
- No extra cost compared to landfill

Recovered fuel: a product!
Criteria for recovered fuel

- Recovered fuel shall meet public specifications which are set by the user(s) and approved by the permitting authority in order to ensure the proper and safe use in the intended (type of) combustion installation

- The recovered fuel shall be safe and hygienic to handle and to store. This imposes requirements on the quality of the raw material, the recovery operation and/or the form in which the fuel is produced. The fuel recovery facility shall operate according to a documented quality assurance system

- The use of the recovered fuel shall be contractually ensured for the long term

- Overall emissions of the combustion process should stay within existing limits applicable to the use of regular fuels and the use of solid residues shall not be obstructed

Further recommendations for RF implementation

- Demonstration
- Research (fouling, corrosion, ash)
- LCA and economic assessment
- Develop product criteria and upgrade to CEN standard

Recovered Fuel: a Product!

- Cost neutral CO_2 reduction
- Fossil fuel saving
- Cost effective waste and resource management
- CEN standard, based on EC mandate

The Role of Standardisation

Guido De Jongh

CEN

CEN is made up of

A “system” to carry out formal processes shared between:

- 19 National Members [from EU, EFTA, CEEC(1)] and the representative expertise they assemble from each country
- 6 associates
- The CEN Central Secretariat

Partners:

- Common work with CENELEC and ETSI
- 300 trade and professional bodies in liaison with technical committees
- Organisations providing first drafts:
  - aerospace industries (AECMA, ECSS)
  - European Committee for Iron and Steel Standardisation (ECISS)

Key Values

- Consensus in drafting
- Voluntarily application
- Transparency of work programme
- Independence of committees from any single interest group
- Publicly available drafts and standards

How it works

Industrial and social needs

Requests
↓
Decision - Technical Board
↓

Use Existing Document (e.g. ISO) ↓ or Transferring to ISO (Vienna Agreement) ↓ or Set up new Technical Committee ↓

Public Enquiry
↓
Formal vote
↓
National implementation
Use and feedback - revision

Status of Documents

- European Standard - EN ("harmonised standards" cited in the Official Journal)
- European Prestandard - ENV
- CEN workshop Agreement - CWA
- CEN Report - CR

Statistics (November 1998)

- 4600 standards
- About 9000 projects in hand
- 274 technical committees

Technical barriers to trade - background
Treaty of Rome (1957), Articles 30-36

Prohibits "... measures having equivalent effect [to quantitative restrictions] ... and disguised restrictions."

allows for "directives for the approximation of such [legal] provisions".

(technical annexes)

The "New Approach" Council Resolution (1985)

- Legislative harmonisation - Article 100 - limited to "essential requirements" in the general interest
- Drafting of technical specifications entrusted to competent organisations
- Standards remain voluntary BUT there is a "presumption of conformity" to the essential requirements of directive(s) conferred on products made to harmonised standards

Summary of cases

G.W. Krajenbrink

TNO Institute of Environmental Sciences, Energy Research and Process Innovation

Goals of case studies

- Evaluate economical, technical and environmental aspects of fuel recovery (compared to material and energy recovery) by case studies of commercial operations in different regions of the EU
- Review applied principles and draw recommendations for further EU actions targeted to enterprises producing and/or using recovered fuel

Location of cases

Characteristics of cases

	Integrated	Specific waste streams
input	combustible fractions of MSW	industrial pre-use residues or post-use wastes
composition	mixed; mainly consisting of paper, plastics, textiles etc.	well known, homogeneous fractions; mainly wood, non-recyclable paper and plastic
number of sources	high; typically all households in a certain area	low
amount of waste per source	low	high; up to thousands of tonnes/year
position	integrated in MSW-management	individual responsibility of company

Integrated cases

Case name - People served	- Source and type of waste - Fuel preparation technology - Type of combustion installation	- Recovered fuel, tonnes/year - Form of fuel - Used for	- RF input, %-th. - Combustion tech. - Used primary fuel
Halmstad (S) - 84.000 [1]	- MSW and industrial waste - Shredding, magnetic separation for RDF - 70.000 t/a MSW mass-burn incineration	- 20.000 RDF - Fluff (used in winter time only) - 220 GWh district heating	- 30% - Grate - MSW
Florence (I) - 500.000	- MSW - Shredding, separation, densification - 15 MW gasifier	- 10.000 (design capacity 50.000) - Pellet - Electricity, fuel gas for cement kiln	- 100% - CFB Gasification
Borlänge (S) - 102.500 [2]	- Dry HHW - Baled for storage - Converted oil-fired heating plant	- 22.000 - As such - 22.5 MW district heating	- 100% - Grate
Pamplona (E) - 280.000	- Intended production of RF in clean MRF - Under evaluation - Under evaluation	- Potentially 30.000 (only HHW)	
Erwitte (D) - 180.000	- Industrial and dry HHW - Shredding, magnetic separation - Co-combustion in rotary kiln	- 100.000 (20% HHW) - Fluff - Cement production (dry process)	- Up to 60% - PF - Coal, oil
Jakobstad (FIN) - 120.000 [3]	- Industrial, commercial and dry HHW - Shredding, separation, blending, pelletising - Co-combustion in 138 MW CHP	- 30.000 (40% HHW) - Pellet - Electricity, steam, district heating	- Up to 20% - BFB - Bark and coal
Wijster (NL) - 2.500.000	- Dry HHW (grey bin) - Separation of light fraction in clean MRF - Under evaluation	- Potentially 170.000 - Under development - Under consideration	

F. **Modelled net annual cost for 100.000 t/a waste**[1]

Total cost minus total revenues, MECU/a

	1-bin **"Landfill"**	**1-bin** **"Halmstad"**	**2-bin** **"Wijster"**	**1-bin** 2 fractions **"Jakobstad"**	**3-bin** **"Wietersdorf"**
Total cost	9,15	14,15	10,25	10,00	11,24
Tot. revenue	-	3,14[2]	1,34[3]	1,81[4]	0,09
Net cost	**9,15**	**11,01**	**8,91**	**8,19**	**11,15**
Difference to landfill		**+ 1,86**	**- 0,26**	**- 0,96**	**+ 2,00**
Diversion from landfill		75 %	93 %	78 %	19 %

Note 1: 45 kt/a household + 30 kt/a commercial & small industry + 25 kt/a from large industry.

Note 2: All district heating; all year around demand. **Note 3**: 1/3 from electricity.

Note 4: All fuel; possible only if there is a pull in an open fuel market.

General conclusions for Fuel recovery

- Technically feasible
- Environmental sound
- Economically attractive

Case Studies - Halmstad (Sweden)

P-O. Andersson

Renhållningsbolaget

Ladies and Gentlemen!

In this speech I would like to give a short presentation of our company and of Halmstad. I would also like to make some minor comments to the report "Fuel and Energy Recovery".

Halmstad is situated on the west coast of Sweden between the two cities of Malmö and Gothenburg. Halmstad is one of the 15 largest cities in Sweden. There are 84 000 inhabitants living in 39 000 households. The municipality of Halmstad covers an area of 1020 km^2. Approximately 60 % of the people live in the urban area. 50 % of the people live in flats and 50 % in single family houses.

Halmstads Renhållnings AB, founded in 1974, is responsible for waste management, collection, transport, recovery and disposal of waste.

The company collects household, commercial and hazardous waste. A lot of recyclable wastes such as glass, newspapers, corrugated board, plastic and metal cans are collected separately after source separation.

The company has 80 collection places with containers for that purpose. We also have 7 recycling centres where people can leave their bulky waste, such as old furniture, refrigerators, garden waste and a lot of other things.

Wastes which are not recycled are used in the company waste to energy plant to produce heat for the city central district heating system. Slag and other unburnable materials are disposed at our own landfills.

The total quantity of MSW, i.e. household waste and waste from enterprises in Halmstad, is approximately 40 000 t/a. The total amount of source separated waste is 22 000 tons.

HRAB also supplies heat to the municipality of Halmstad.

The total energy consumption for the district heating system in Halmstad is approximately 360 GWh per year. HRAB produces 200 GWh, approximately 56 % of the total consumption. To produce this amount of heat, the company needs more fuel and has to add this fuel from the nearby situated cities.

We use 70 000 tons per year. 20 000 tons are RDF which is delivered from Falkenberg, a town 40 km from Halmstad.

In the summer, the demand for heating is less than in the winter. We, therefore, store both RDF and industrial waste from the middle of April until the beginning of October. The RDF from this season is stored in plastic bales and industrial and commercial waste in the open on the ground.

Before we used to stock pile RDF in the open air, covered with wood chips. This storing is not allowed anymore due to some problems with smell from the stockpile when the pile is open. Sometimes the odour is noticed by inhabitants living in single houses at a distance of 600 m from the plant.

We are not sure that the smell is going to be less when we open the plastic bales. The opening of the bales takes place outdoors because we do not have any closed building for unloading.

The RDF is produced in a plant in Falkenberg. The plant is 15 years old and produces RDF from household waste. It separates plastic and other dry material from the organic wet fraction by shredding, tumbling, sorting and magnetic separation.

A compost is made from the organic fraction which is mainly used on golf courses as a fertiliser.

From 25 000 tons of household waste, 3000 tons compost and 20 000 tons of RDF are produced. 8 000 tons are stored from summer to winter outside the Kristinehed plant.

The Kristinehed plant has two lines for incineration. Each line has a grate and furnace connected to a boiler where heat is collected by water circulated in closed tubes. We do not produce any steam for electricity.

The flue gas cleaning system consists of an ESP and a wet system. The gases are sprayed with water in scrubbers to absorb the acid and more heat is recovered in a condenser cooled by water from the district heating system. In the last step, the moisture in the flue gas is exchanged to the primary air for the furnace. The water is cleaned in the plant and let out into the nearby river.

The total energy efficiency of the plant is 100 %, and the availability is 98 % with 7 700 running hours per year. The plant is 26 years old and we are just planning to build a new line with a 15 t/h capacity.

To fulfil the new requirements proposed in the EU directives, we have to install an extra filter to reduce SO_2 and dioxin. The investment cost for this installation is estimated at 25 million Swedish crowns; the cost per ton is estimated at 120 SEK/ton.

Why incinerate RDF?

First of all, the plant in Falkenberg was built to produce compost from MSW. In the beginning, RDF was planned to be used in a combustion plant at Falkenberg. The plant was never built. Furthermore, there was no need for compost. During the 80's, Sweden built 20 plants for producing compost and RDF. Today there are only two left.

It has been proven throughout the years that it is very difficult to burn RDF from MSW in ordinary combustion plants. The chlorine value is too high which causes well-known problems in the superheater.

The content of lead is too high in the compost and does not fulfil the requirements for agricultural use. Our experience is that RDF is difficult to store, odour problems occur and plastic and paper is carried by wind to the surroundings of the plant. RDF fluff as fuel is good. In a small plant such as ours, it is easy to burn. RDF has a low metal content and gravel and glass are separated from the fluff.

In a big incineration plant, we do not think that the advantages are so big. Actually, in our new plant, we are planning to burn just source separated household waste. We don't see any need for separated RDF. In Sweden most people source separate their wastes. People take an active part in the recycling schemes. The cost of 500 SEK/ton to produce RDF does not justify the benefits of RDF. The gate fee at an incineration plant in Sweden is typically 300-500 SEK/ton.

Some remarks on the report:

I think that the most important statement in the report is that "waste can be considered a renewable source of energy and can be in an order of 30 million tons of oil equivalent per year. Converted into CO_2 this can result in a reduction of greenhouse gas emission of up to 3 % of the current level".

To achieve this there must be an important need for incineration capacity where waste can be used to produce energy.

We do not agree that fuel recovered from mixed household waste could reduce the required capacity of waste incineration because it is absolutely necessary to have the same emission limits both for RDF and MSW.

We think it is impossible to control and to fulfil emission criteria when the target is moved from the outlet stream to the inlet stream of the combustion process. It is not difficult to measure gas, water and ashes but very hard to measure a heterogeneous material from waste even if you call it recovered fuel.

Case Studies - Halmstad (Sweden)

P-O. Andersson

Renhållningsbolaget

Halmstad municipality, Sweden

- Number of inhabitants 1996 - 83 549 (75 789 population center & 7 760 countryside)
- Number of households 1996 - 39 489 (20 132 detached houses & 19 357 apartments)
- 3 000 summer cottages
- Area of municipality 1020 sq km
- Longest transport distance 30 km
- 80 recycling stations in Halmstad

Development of household waste, kg/person

Year	1975	1980	1985	1990	1996	2000
Waste to energy	337	361	376	401	277	236
Source separation	23	15	44	94	261	272
Total	360	376	420	495	538	509

District heating production in Halmstad 1996

Waste to energy	199	GWh
Natural gas	90	GWh
Electrically heated burners	5	GWh
Hot water from process industry	36	GWh
Wood	8	GWh

Total amount of waste 1996

Household waste	Halmstad	23 000	ton
	Laholm	6000	ton
	Varberg	21 000	ton
Industrial waste	Halmstad	14 000	ton
	Other municipality	5 000	ton
Other waste		4 000	ton
Total		73 000	ton

Case Studies- Ekorosk, Jakobstad (FIN)

Henry Nygård

What is EWAPOWER?

- Fuel preparation facility (pelletizing)
- Part of an Integrated Waste Management Concept including
    - source separation
    - material recycling
    - biological treatment
    - hazardous waste collection

What does EWAPOWER do?

Refines source separated non-recyclable packaging material into 30.000 t/a fuel pellets, replacing 180.000 MWh/a worth of imported coal.

Why Fuel Refining?

- No acceptance for incineration of non-recyclables
- Existing, local demand
- Offering a High Quality Classified Product
- Storage, Transport and Handling

Quality Control

Customer	*Hauler*	*Reception*	*Processing*	*Utilisation*
Small customers Large customers	Entrepreneurs	Operational personnel	Advanced mechanical treatment	CHP combined with wood bark
Contract relationship	Contract relationship	Visual, manual control	Magnetic separation Pneumatic separation Drying Sieving	Systemized sampling and analysing by UPM, VTT
	Licensed operation	Removal of non-complying material		

Overall Advantages

- Substituting fossil fuel
- Raw material available locally
- Reduced need of long distance transportation
- Utilization of disregarded resources
- Resource optimization
- Environmental impact optimization

VAM

Gives New Life to Waste

Wijster (NL)

ir. Henk Schaap

VAM:

Founded in 1929 by the Dutch central Government

Turnover:	350 million guilders
Employees:	400
Handling	1.8 million tons of wastes
Contract position:	1.2 million tons for next 15 - 20 years

GAVI-VAM -project

Combination of techniques
- mechanical separation of light fraction
- recovery of different materials
- incineration of RDF
- generation of energy
- cleaning of flue gases

Capacity
- maximum intake 840.000 tonnes
- incineration capacity 400.000 tonnes RDF

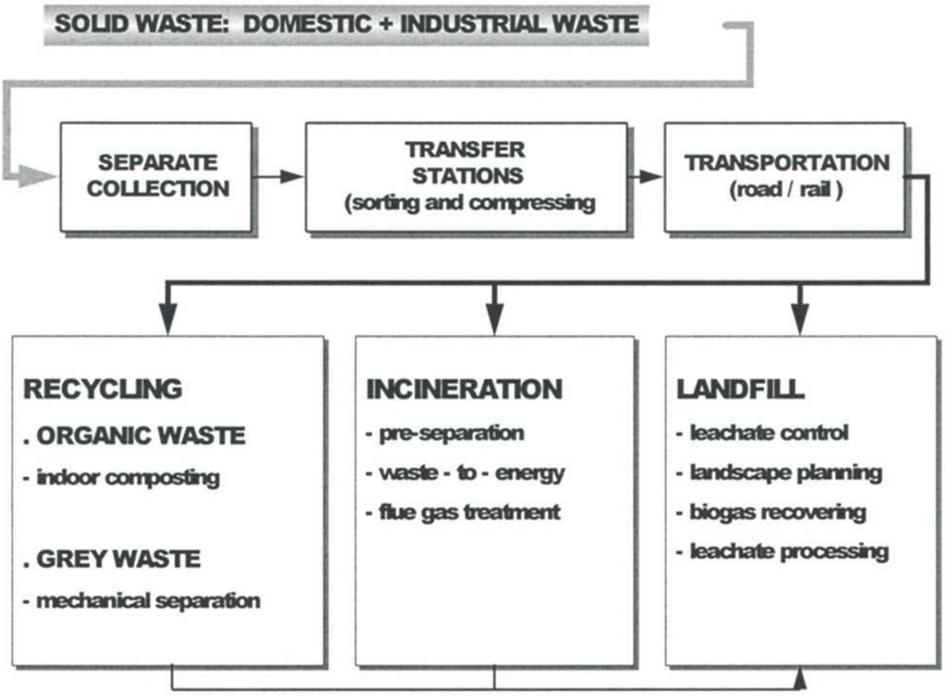
Investments
- 940 million guilders

In operation since April 1996

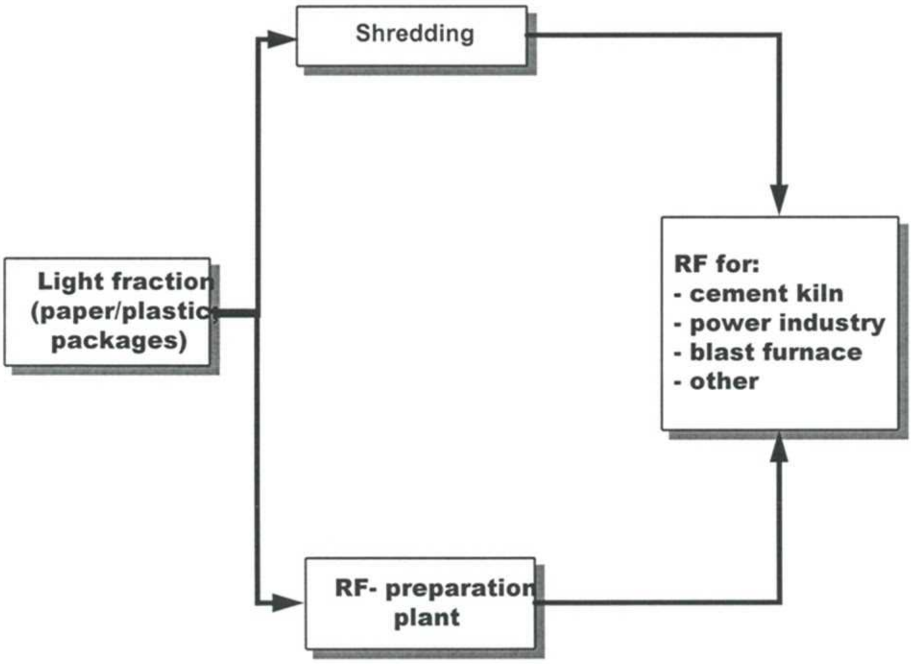
Separation of light fraction:

Alternative options:
- Mixture sold as RF
- Upgrading to special fuels
- Post separation in paper pulp and plastics

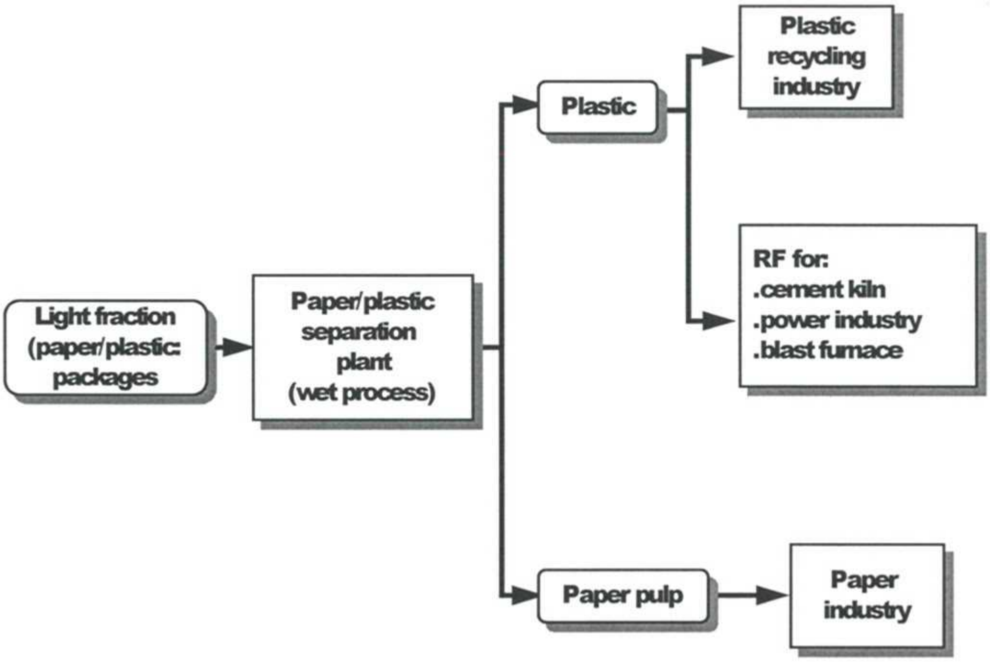
Basic approach of VAM GAVI plant:



Mechanical separation and upgrading of light fraction for RF production:



Separation of light paper/plastics fraction for recovery:



Case Studies: Erwitte (D)

H-D. Maury

MBM Industrieanlagen GmbH & Co., Ahlen, Germany

General view of MBM:

- Our main activities are in the field of the cement, lime and gypsum industries with the highlights of thermal process with cyclone preheaters, bypass and precalcining plants. Crushing, grinding, classifying, transport and the other necessary process machinery belong also to our range of supply.
- **Directly connected to the clinker burning process we are active in the field of secondary fuels. We deliver plants for RDF, produce secondary fuels from industrial wastes by our own and deliver them to cement plants. We also build the necessary equipment for handling them for storage up to the injection into the kiln.**
- The third main activity is decontamination of contaminated soils; for this process we also use the well-known cyclone preheater system.

Production of RDF and use of this secondary fuel in cement rotary kilns

In the early 80's, as a result of rising energy prices and site shortages for waste disposal, a West-German cement manufacturer in Westfalia, Portland Zementwerk Wittekind, began to study and develop methods for using the combustible parts of general household waste as an alternative fuel for clinker processing. The actual development of this process includes the introduction of a waste classifying system, crushing equipment and from this, the production of an alternative fuel suitable for blowing into the rotary kiln. Problems over certain aspects of this waste fuel burning were initially met, particularly in respect of chlorines and PCC synthetic materials which caused preheater blockages and corresponding plant shutdowns. This problem worsened with the decision to modify the preheater from a four to six stage system. To help overcome such difficulties and to allow the plant to burn larger quantities of rubbish, MBM Industrieanlagen specialists became increasingly involved at this plant and were then given the order to develop a new chlorine bypass installation so that shut-downs are now minimised and the usage of alternative waste fuels maximised.

Fuel production

Fig. 1 (figure not included in this document) shows a general view of the processing plant. Domestic and industrial refuse is delivered in municipal collection lorries and placed in intermediate storage.

Wheeled front-end loaders transfer bulk refuse to the apron feeder hopper and an under-ground extractor transports the refuse to the prehomogenizing system. The material is coarsely broken up in a disintegrator which allows optimum separation in the screening and classifying drum. The fine refuse <50 mm, in which the minerals collect, is removed in the first stage of this sorting drum and taken to the adjacent deposit on a conveyor belt. Because the bulky combustible fraction has been removed, this residual material occupies only 30% of the deposit volume which would have been needed for the untreated household refuse.

In the second stage the air-entrainable fraction, the light-weight material is sucked off and then separated from classifying air in cyclones. A bag filter removes the fine dust from the classifying air which is then recycled. The plant operates with a closed-circuit air system.

There are two possible routes for further treatment of the separated light-weight material:
If the RDF processing plant is directly linked to the cement works the light - weight material is finely comminuted in a special cutting mill. Before it is injected into the kiln the now fully processed RDF is homogenized in a buffer hopper and converted into suitable state for metered feeding.

The second route is to compress the raw fuel into bales after it leaves the cyclones. In the form of bales the densely compacted fuel is largely protected from oxidation and can be stored for several months without loss of quality. When needed the bales are broken up in a ripping machine, separated and comminuted in a fine disintegrator to the edge length required for injection into the kiln. This stockpiling makes the kiln operation independent of the refuse delivery and processing.

Composition of household refuse

For the planning of an RDF processing plant it is necessary to know the composition of the expected feed material for the plant. Extensive studies have been conducted in different areas, several results are to be seen in Table 1:

TABLE 1: Composition of household and industrial garbage

Fraktion	BRD	Westfalen	Israel	Polen
	1985	in Gew.-%		
Zellstoff, Windeln	2,8	2,7		*) in 6,7
Papier	12,0	13,2		19,0
Materialverbund	1,1	0,9	19,4	6,0
Verpackungsverbund	1,9	2,1		*) in 3
Pappe	4,0	3,6		*) in 2
Hartplastik			6,0	
	5,4	6,4		8,0
Weichplastik			9,1	
Mineralien und	12,1	14,1	)	6,0
pflanzliche Stoffe	45,9	43,1	) 51,3	41,0
Textilien	2,0	2,8	3,9	7,0
Metall	3,2	3,4		1,0
Glas	9,2	4,0	7,3	12,0
Holz	-	3,7	3,0	
Problemabfälle	0,4	-	-	*) in 8
Summe	100,0	100,0	100,0	100,0

The figures show that there are no substantial differences in the composition of the garbage. Only in the plastics there are considerable differences between Israel and the other areas. The reason is different large applications of paper and plastic packaging materials in Israel and Europe.

With or without separate collecting of paper or plastics in reference to the whole amount of garbage the values show the mixture as typically in every industrial state.

The emission characteristics of RDF

In an earlier publication we have indicated that the elemental composition in the RDF corres-ponds to that of the fuels normally used in cement production. From this it can be deducted that that the use of RDF should not be expected to result in any changes in emission of heavy metals. On the other hand the NO_x emission is 30% lower than for pure coal firing.

It is to be expected that the emissions during cement production must be substantially lower than in refuse-burning plants. In cement production the very large quantity of absorbent material represented by the raw meal used as raw material, corresponds to the flue gas cleaning with appropriate absorbent material generally used in combustion processes. Lower emission levels are, therefore, to be expected than with other combustion processes. The mean heavy metal contents listed in Table 2 were measured in the clean gas during the emission measurements.

TABLE 2: *Emission values when using fuel out of waste*

Probenbezeichnung		**Klasse ***	**Betriebszustand mit Ausschleusung:** E-Filter 07. u. 08.10.88 µg/m³	Bypass 31.01.89 µg/m³	**TA-Luft** µg/m³
Arsen	As	II	1,33	<0,7	1000
Cadmium	Cd	I	1,4	1,3	200
Thallium	Tl	I	2,1	<0,3	200
Quecksilber	Hg	I	24,0	86,0	200
Blei	Pb	III	32,0	22,0	5000
Chrom	Cr	III	2,3 **	1,3 **	5000
Nickel	Ni	II	2,4 **	2,6 **	1000

* *Klasseneinteilung gemäss TA-Luft vom 27.02.86, Abschnitt 3.1.4*
** *ohne Gasphase*

Two operating conditions were investigated:

a) Removal of a partial mass flow of environmentally relevant elements at the electrostatic precipitator.
b) Removal of a partial mass flow of environmentally relevant elements through the bypass system.

The results of the measurements in Table 2 show that for both modes of operation the results found are very much lower than the values specified in the German Clean Air Regulations, without any special secondary treatment of the exhaust gas . As expected, there were no detectable hydrocarbons in the exhaust gases as the combustion took place at more than 2000°C.

Table 3 shows the emission values when firing the kiln with pure coal compared with the emissions using a mixture of 30% coal and 70% secondary fuel.

TABLE 3: *Emission with firing of pure coal and mixture of coal with RDF*

Messung		1	5	
BRAM-Einsatz	t/h	0	12	
	%	0	70	
Staub		mg/m^3	65	39
NO_2	mg/m^3	837	583	
SO_2	mg/m^3	131	18-35	
Cl^-	mg/m^3	5,5	1,1	
Klasse I Cd, Hg, Tl	mg/m^3	0,037	0,031	
Klasse II As, Co, Ni Se, Te	mg/m^3	2,56	0,0031	
Klasse III Sb, Pb, Cr, Cu, Mn, V, Sn	mg/m^3	0,0107	0,0058	
PAH	µg/m^3	n.b.	0,0004	
PCB	µg/m^3	n.b.	n.n.	
PCDD/F	ng/m^3	n.b.	0,001-0,002	

Emissionen bei reiner Kohlefeuerung und bei Mischfeuerung von 30% Kohle und 70% BRAM

Residues for utilisation

In addition to refuse-derived fuel various other residues, including those from the plastics, textiles and paper industries which only have to be comminuted to an injectable particle size, are available to the cement industry for utilisation as secondary fuels.

Sometimes this comminution is expensive and requires specially adapted comminution machinery, but as a rule primary size reduction and fine grinding is sufficient. The residues are each of one type only, generally with a high calorific value, and must be mixed in the processing plant so that the cement works can be assured of a consistent quality.

The paper, plastics and carpet residues are supplied to the cement works either comminuted and in bulk or – if a fairly long transport distance has to be covered and the volume has to be as small as possible because of the transport costs – as pellets. However, if the material is delivered as pellets the works has to carry out final comminution with a cutter mill.

During the past year MBM has built a processing plant at Ahlen for secondary fuels which supplies the various cement works with comminuted injectable, or pelletized, secondary fuels. At present 120 000 tonnes of fuel are supplied annually, but further orders are being negotiated so there are plans to increase the capacity of the processing plant.

In Poland MBM moreover has built one RDF plant of most modern design. This plant was opened at the beginning of 1998 on a landfill site of the town of Opole. The fuel, produced from household refuse, is intended for firing the rotary kiln of the Odra cement works.

MBM now becomes one of the leading companies in the field of secondary fuels and the company is in a position to support a cement works operator with know-how from the time when he first considers the idea of utilising secondary fuel. MBM carries out environmental compatibility studies, provides extensive assistance in licensing procedures and takes care of all necessary technical documentation. Binding quotations are given on the possible use of secondary fuels based on analysis of the available raw materials and the primary fuels used, taking into account the technical capabilities of the existing kiln and cooler equipment. For example, MBM has elaborated the complete study for testing the recovery of replacement fuels for the cement industry from domestic and industrial refuse for Tel Aviv, Israel.

Recovered Fuel - Waste or product?

Otto Linher

DG III

Ladies and Gentlemen

Having listened to different presentations today, I feel that it is necessary to make some distinctions between technical, scientific and legislative issues. The subjects around technical progress towards an increased efficiency and environmental friendliness of energy recovery from wastes certainly find our unanimous support. You will forgive me that, in my presentation, I will concentrate on the field that is my business, namely the conception of legislation.

Following the earlier discussions, I think it is necessary to put some subjects into the correct light. The promotion of energy recovery from incineration of wastes is an established policy of the Commission. Where feasible, it is even obligatory under the new Commission Proposal for the Incineration of Wastes. On the questions whether incineration with energy recovery should be promoted over landfills, there exist, however, vastly diverging opinions. It is, therefore, likely that the decision between landfilling and incineration will in the foreseeable future remain a domain of Member States.

During the workshop, the question was frequently raised whether "recovered fuels" are wastes or products. Whatever one thinks about how this issue should be solved, it is necessary to see that Community legislation is entirely clear in this respect. In order to re-become a product, a waste necessarily must undergo a recovery process. In this context, the Waste Framework Directive contains an exhaustive list of recognised recovery options in Annex IIB. The only operation dealing with energy recovery is R1 "Use principally as fuel or other means to generate energy". It is clear from this formulation that not the *production of the fuel* but only the *use as a fuel* finishes the recovery of the waste and that the product of this operation is energy.

Any move to recognise "recovered fuel" as products must, therefore, pass via a change of Community legislation. Should this be the intention, industry should clearly identify the problems encountered in practice by the fact that it is submitted to waste legislation by contrast to product legislation. Such problems could be additional costs for emission abatement that are disproportional to the environmental benefits achieved. It would, however, also be necessary to demonstrate the possibility to control that only the fuels are used that do not cause emissions beyond the levels for which the authorisation has been given.

Further questions that arise are: Should the same wastes be submitted to strict emission controls if they are mixed and is it enough to separate these wastes to allow higher emissions? If fuels are "clean", why is there a problem with the current limits of waste legislation?

The Commission is certainly willing to examine a well-founded proposal from the industry. The use of terminology is an option to change public perception but does not necessarily change the hard facts of Community legislation. In any case, care should be taken not to create confusion through the use of new terms.

Recovered Fuel - Waste or product?

M. van der Poel

Eurelectric

Eurelectric is the association of the European Union Electricity Supply Industry representing it in public affairs, in particular in relation to the institutions of the European Union, in order to promote its interests at the political level.

Eurelectric welcomes the initiative to get a better perception of the issue of recovery of fuel and the way it can be used. The Electricity Supply Industry has already experience with co-combustion. And among others things in relation with sustainability, this subject is important, now and for the next future.

sub-1 **Optimalisation of policy for removal of waste to energy-efficiency.**

- This means that it is necessary that when recovered fuel is seperated from waste, recovered fuel will be recognized by the authorities as a product
- In this way regulation of the use of recovered fuel has to be comparable with regular fuels. In some countries now a fee has to be paid for co-combustion of recoverd fuel because it is classified as waste
- To stimulate the proper use of recovered fuel, and in that context also the acceptance of the authorities and public, it has to be underlined that a good definition of recovered fuel and quality standards have to be developed

sub-2 **Policy on emissionlevels for burning waste and biomass as an additional fuel.**

- It can be find that on local level the limiting values are not always the same for co-combustion installations. That is why policy is neccessary. The existing limits applicable to the use of regular fuels should be the guideline.

sub-3 **Operational and technical boundery conditions for co-combustion installations such as powerstations**

- Coal fired power stations are equipments of a very high technical standard and not intended to burn waste. That is why recovered fuel for the Electricity Supply Industry has to meet minimum standards.
- Recovered fuel shall meet specifications which are set by the user and approved by the permitting authority in order to ensure the proper use in the intended combustion installation
- Recovered fuel shall also be safe and hygiënic to handle and to store. Requirements in this framework are necessary.

Sub-4 **Quality change of residues (fly ash / bottom ash / and FGD gypsum) and the consquences for use of these residues**

- In the Electricity Supply Industry a high rate of the ashes (fly ash and bottom ash) and also FGD-gypsum from coal-fired power stations are used as construction materials. For that reason not all "recovered fuel" can be used for co-combustion in coal-fired power stations. This, among other things, because of the environmental aspects (leaching), technical requirements and behavior in construction materials and also aspects of health and nasty smell when using ashes in products just as cement and concrete.
- When the users of secondary raw material have any choice, there is the risk that they are conservative and don't choose for the ashes from co-combustion or that they only want to buy these ashes for lower prices

sub-5 **Commercial and/or environmental drive for initiative for co-combustion**

- Recoverd fuel can be economicaly attractive because of the low or negative cost price
- However availability and continuity of supply and stable prices of additional fuel have to be assured
- The use of primary fuel can be decreased when recovered fuel that otherwise should be disposed off or burned in an incinerator can be used for co-combustion in a power plant. Depending on the kind and quality of the recovered fuel it can also be stated that a reduction of the total emission of CO_2 can be reached.

sub-6 **Acceptance from public and authorities (image)**

- An assessment of the impact of co-combustion of recovered fuel on the public living around the power plant is important in relation to get a licence.
- But also the impact of combustion of recovered fuel on the public in general (public image of the company)
- It means acceptation by national and local authorities.

Looking to the six points mentioned here, the conclusion is that there are good chances but also problems to be solved. For that reason Eurelectric welcomes again the initiative to get a better perception of the issue of recovery of fuel and the way it can be used.

Workshop on "Fuel and Energy Recovery"

Based on the TNO-Report "TNO-MEP-DR 98/220, November 1998

Kjell Nilsson

Chairman of ISWA Working Group on Thermal Treatment (WGTT)

Comments to the TNO-Report

The basic points of view from the ISWA WGTT are as follows:

- **The strict requirements on waste as fuel must be the same independent of where and when waste or waste-derived fuels are used**. That is valid for not only emissions but also control systems and operation procedures.
- Only very few types of waste, as tires and specific, homogenous industrial wastes, make it possible to predict the influence on gas emissions and residues. Therefore, presorting of waste for co-incineration is no guarantee for the avoidance of environmental problems.
- **There are risks in using waste fuels for co-incineration:**
    - Waste management will be dependant upon market conditions of industry production (e.g. cement). If that market fails, the disposal of waste fuels will probably be the responsibility of the municipality.
    - The waste may have an unknown, negative impact on the products (cement).
    - Stockpiling of waste at industrial plants may cause damages (fire risk).
- **The comparisons with landfilling is non-relevant since landfilling is not an alternative.**
- **The economic calculations and evaluations are not reliable**. Here is a need of total revision based on realistic case models.

Recovered Fuel and compost:

Complementary solutions, similar problems

Bert Lemmes

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ORCA –	Organic Reclamation & Composting Association: promotes 1. The eco-efficient use of biological treatment to recover organic resources, 2. Applications of compost, and 3. The use of biodegradable products to enhance sustainable development.
IBPMA –	International Biodegradable Products Manufacturers Association: is a worldwide network, promoting the use of biodegradable products, in applications that enhance quality of performance and functionality or provide added value, environmental or social benefits.
MERLIN –	Multi-Purpose Eco-Efficiency Research Lemmes International: is a company with a network consisting of the world's leading specialists on the environment and IWM, recovery-technologies such as biological treatment, recycling and incineration with energy-recovery.

To find a representative of biological treatment at a seminar for recovered fuel and combustion technology, might seem contradictory at first sight. But only at first sight. Indeed all the things that make good compost, spoil a good recovered fuel, so it is necessary getting them in the appropriate fraction and the appropriate treatment. The high calorific combustible fraction of the waste on the other hand, is mostly composed of elements that are not readily compostable, that would be sieved out during the process and end up in the overflow or 'nuisance' fraction. But apart from this complementarity composting and combustion of RF share an important fundamental problem.

We have both been forced to try and approach the solutions of our problems from the 'waste'-side. We both have been trying to the impossible the get the definition of waste and waste-streams adapted to make an industrial recovery process viable and eco-efficient. But trying to get waste re-defined as resources or to get certain fractions of waste re-named, re-labelled to allow a more appropriate treatment, has been only partly efficient.

But one approach, the most obvious one, has not been exploited sufficiently so far. Let's imagine a scenario where the European authorities were only to define, standardise and certify the "END-PRODUCT": in our case 'compost', in your case 'recovered fuel'.

It is indeed impossible or irrelevant to try and define a waste stream that can be recovered through biological treatment without simultaneously defining the treatment technology. Indeed, the fraction of waste that can be recovered and converted into good quality compost becomes wider and includes more different sub-streams, when the level of technology is raised. Ex., A static, open windrow system can only deal with a limited fraction of organic waste (mostly green waste) whereas a sophisticated anaerobic digestion system can easily deal with the total organic fraction of MSW (including the non-recyclable paper fraction, hygienic tissues and many more).

But is it the task of the commission to define the technology the can or will be used in waste recovery? Hardly. This would be equal to blocking all technological progress and to force the municipalities to use a certain technology. If and when you cannot say anything about the technology to be implemented, how are you going to define the waste-stream to be treated? How are you going to make a positive or negative list of items that belong or do not belong in one or the other fraction?

The solution is not that difficult! Ex., When talking about the making of beer, nobody will impose on the brewer what ingredients to use or what technology to implement to make his specific brand of beer. No legislation restricts itself to defining quality parameters of 'beer' and leaves the rest to free market mechanisms.

Where is the difference with 'compost'? Where is the difference with 'RF'? They are both valuable products that should be defined, standardised and certified as such. And those valuable products will have their market and will command their price. After that, the free market mechanisms will incite the industrialists in combination with the local authorities to set up "production plants for compost" or "production plants for RF" using appropriate technology and using an appropriate feedstock to achieve their targets. As far as biological treatment is concerned this could mean that the biological treatment industry would be involved in setting up more or less sophisticated source separation schemes with the local authorities, and even co-financing them, as they are providing the correct basic material for its production process in order to achieve a quality compost.

And just as we advocate a harmonisation of the rules and regulations that define the use of fertilisers (organic or not), manures, sludges and composts in the same agricultural context, we think it to be necessary to study the same option for 'fuels', whether recovered, fossil or other.

It is only through the acceptance of our products as a valuable contribution to sustainable development that we will be able to generate a permanently developing, innovative industry that produces these products in an eco-efficient way.

Concluding Remarks

Jean-Marie Bemtgen

European Commission

Directorate General for Energy (DG XVII)

This workshop "**Fuel and Energy Recovery**" has triggered off a constructive discussion between engineers, environmentalists, economists and lawyers on a most difficult and important subject: namely how to best use wastes as resources. The subject is of growing importance as it is recognised that wastes are a resource in their own way and that within a sustainable development they contribute to conserve a significant part of valuable natural resources, be they materials or fuels.

The EU's waste strategy says that material recycling is preferred to energy recovery if environmentally sound. What means "*if environmentally sound?*" The participants of this workshop agree on the overall aim (i.e. to protect the environment, the citizen and the competitiveness of EU's industry) but their opinions diverge on which processes are environmentally sound. This is mainly due to the lacking of a rigorous methodology for life cycle assessment (LCA).

It also became obvious that the commonly used wording "*it is generally accepted that ...*" often lacks scientific and technical grounds. It is agreed that more technical data and a robust LCA methodology are needed both for energy recovery and for material recycling. More advanced technology with increased efficiency of material recycling and of energy recovery need to be developed. These subjects are strongly energy related, as the main aim is to reduce fuel consumption and emissions of greenhouse gases and of pollutants. These subjects should thus be included in the future energy key actions of the fifth framework programme.

Deficiencies in legal definitions on "*waste*", "*fuel*" and "*material*" became apparent. Whereas wastes are defined quite extensively, "*fuel*" is defined in the Large Combustion Plant (LCP) directive by two lines only. The participants insisted that this deficiency needs to be corrected in the next revision of this directive.

It is generally agreed that a more intensive co-operation between engineers, environmentalists, economists and lawyers is needed as the complexity of industrial integration and recovery operations is increasing.

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ORGANISATIONS FOR THE PROMOTION OF ENERGY TECHNOLOGY

Within each Member State there are a number of organisations recognized by the European Commission as an Organisation for the Promotion of Energy Technology (OPET). It is the role of these organisations to help to coordinate specific promotional activities within Member States. These include staging of promotional events such as conferences, seminars, workshops or exhibitions as well as production of publications associated with the THERMIE programme.

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