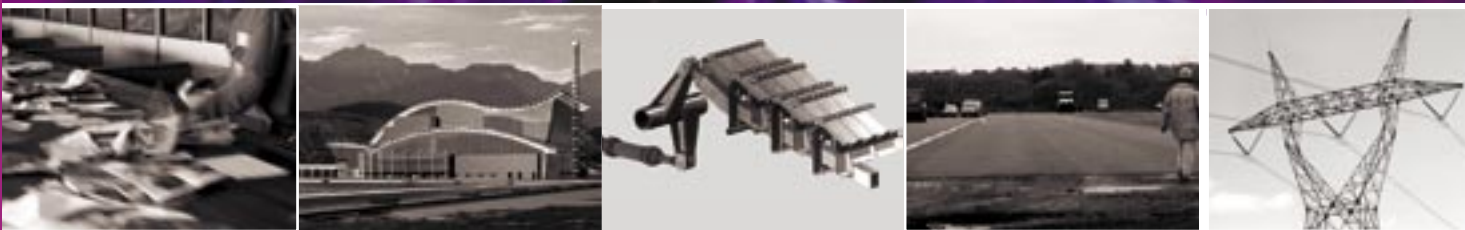


# Energy from Waste:

A good practice guide



The Chartered Institution  
of Wastes Management

## **Energy from Waste: A good practice guide**

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of Wastes Management**

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# Foreword

The challenge of delivering effective and sustainable waste management is an issue which faces all stakeholders including central and local Government, the public and professional waste managers.

Since the publication of Waste Strategy 2000, a wide range of mechanisms have been introduced to help stimulate municipal waste management practices to reflect both the waste hierarchy and the Best Practicable Environmental Option. The importance of improving awareness of the various waste management options is crucial to the evolution of a more sustainable approach to waste management, involving public participation, greater levels of recycling and composting, and the development of the necessary infrastructure to recover value from the residual waste stream.

Energy from Waste has an important role to play in dealing with the residual municipal waste stream and I welcome the publication of this good practice guide as a valuable tool for waste professionals with regard to these options. Embracing both the established technologies and those new to municipal waste management, and drawing on good practice from the UK and overseas, I am sure that this guide will provide an important contribution to the advancement of the debate on waste and resource management.



Elliot Morley MP  
Minister of State for Environment & Agri-environment

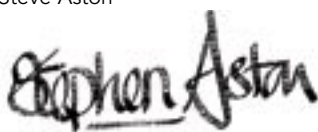
## President's Foreword

Energy from Waste has a wide range of advocates and detractors for an equally wide range of reasons. However, the balance of argument is frequently lost in the presentation of emotive and subjective information, often without scientific basis. Therefore, this publication has been developed to provide independent guidance for decision makers at all levels of government, industry and the community.

The report explores the flexibility and robustness of the technology in terms of its role in an integrated waste management strategy. In addition, it confronts the concerns in relation to emissions and other environmental impacts, its compatibility with recycling, and its relationship with the planning system.

In the UK we are beginning to think and act beyond reliance on continual improvement of the systems we use to manage our wastes. We are moving towards a strategy that considers more sustainable use of materials and resources. This demands a rational approach, which accounts for the materials and energy lost and gained as well as the emissions prevented and controlled. No single option will provide the solution. However, a single-minded approach is necessary; an approach that focuses on repeatedly benefiting from a materials' natural attributes before finally realising the energy value.

Steve Aston



President, CIWM

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## Disclaimer

This good practice guide is intended to provide information to all those considering an Energy from Waste technology as part of an integrated waste management strategy. It has never been the intention that this document should be used for legal or public appeal cases.

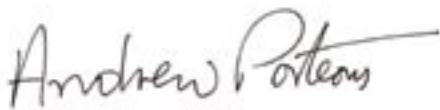
# Chairman's Introduction

Energy from Waste (EfW) is the application of sound proven combustion engineering principles to a variety of technologies which reduce and sanitise the residual municipal waste fraction, after recycling and composting has taken place, in order to recover energy. This guide embraces 'as received' waste combustion (systems capable of dealing with raw, processed or sorted fractions of municipal solid waste), fluidised-bed combustion systems and processed waste energy recovery options such as refuse-derived fuel (RDF), gasification and pyrolysis. Anaerobic digestion of waste is the subject of a separate CIWM guide and is also addressed within the CIWM biological treatment of waste publication. Utilisation of landfill gas is also not incorporated within the scope of this publication.

The aim of the guide is to introduce waste managers, decision makers, planners and a wider audience, to the EfW technologies that are available, the operational principles, the main plant components, operational requirements, and mandatory and operational emission levels. The post-combustion/gasification residues are also considered: how they may be recycled, in the case of ash, and how the gas cleaning residues may be effectively managed in an environmentally sound fashion.

The acquisition of planning permission, utilisation of the thermal energy for district heating and the integration of EfW with other options for waste management are also featured, together with case studies of current practice.

The team of engineering and waste management professionals, who wrote, advised and constructively criticised, and without whom this guide could not have been produced, are listed overleaf. My grateful thanks to all.



Professor Andrew Porteous  
Department of Environmental and Mechanical Engineering,  
The Open University

# 1. UK Policy on Energy from Waste

## Introduction

The UK National Waste Strategies provide the policy framework within which Energy from Waste (EfW) has to operate. Fundamentally, these include adherence to the principles of the waste hierarchy, the Best Practicable Environmental Option and other factors such as the proximity principle and regional self sufficiency. Table 1.1 illustrates some of the relevant elements of the different waste strategies which provide a framework for developing the practice of wastes management in the UK over the short to medium term. The strategies identify a need for increasing landfill diversion (driven by the Landfill Directive targets on biodegradable municipal waste) and focus particularly on increasing recycling and composting levels. In England and Wales there are statutory recycling targets for local authorities to meet.

Whilst EfW is one solution to the landfill diversion targets, there is no clearly identified impetus from Government with regard to this option, and the mechanisms in place for other waste management techniques specifically do not apply to EfW. For example, recycling of materials after processing by any thermal treatment technique does not currently count towards recycling targets. Also, the Renewables Obligation (creating a tradable system of renewable energy certificates) does not apply to 'traditional' EfW, although it does apply to the energy generated in some 'advanced' thermal processes. Thus, the key driver

towards a waste management strategy incorporating EfW is the Landfill Directive, implemented through the respective Landfill Regulations and the Waste and Emissions Trading Bill.

## Landfill Tax

There are a number of other drivers and policy instruments impacting on the UK development of EfW. A significant driver is the Landfill Tax. This mechanism was introduced in 1996 and aims to promote diversion from landfill, which has traditionally been a lower cost option, by adding a tax increment onto the gate fee at landfill sites. This tax component (for 'active' wastes, i.e., not for 'inert' wastes) has been set on an escalator, increasing at a rate of £1 per tonne each year until 2004/5 when it will be £15 per tonne. The Chancellor of the Exchequer has announced an increase in the level of this escalator to at least £3 per tonne each financial year after 2004/5 until it reaches a level of £35 per tonne (Table 1.2).

## Incineration Tax

A tax on incineration of EfW has been suggested in the past, with the likely aim of taxing the EfW option to a lesser degree than landfill to promote maximisation of materials recovery before energy recovery. The Strategy Unit report to Government 'Waste Not, Want Not' recommended that this option should be

Table 1.1 Comparison of elements of the UK national waste strategies

	England	Wales	Scotland	Northern Ireland
Title of strategy	Waste Strategy 2000 (for England and Wales – Wales element superseded by Wise about Waste)	Wise about Waste	National Waste Strategy: Scotland, National Waste Plan and 11 Regional Waste Strategies	Waste Management Strategy for Northern Ireland
Date published	May 2000	June 2002	December 1999	April 2000
Recycling and composting targets	Statutory Targets of 17% Recycling and Composting of household waste by 2003/4 and 25% by 2005/6 Other goals of recycling and composting 30% of household waste by 2010 and 33% by 2015	By 2003/4, at least 15% recycling / composting of MSW (with a minimum of 5% of both) By 2006/7, at least 25% recycling / composting of MSW (with a minimum of 10% of both) By 2009/10 and beyond, at least 40% recycling / composting of MSW (with a minimum of 15% of both)	By 2006, 25% recycling and composting, other targets based on Waste Strategy Areas and their waste plans (using guidance on plan preparation and BPEO, Scotland Waste Plan and 11 regional waste plans published in March 2003).	25% Recycling and Composting by 2010
Waste recovery targets	Recover value from 40% of municipal waste by 2005, 45% by 2010 and 67% by 2015.	No major measures	Reduce municipal waste arisings by 1% per annum.	Recover value from 25% of household waste by 2005, 40% by 2010.
Landfill diversion targets (excluding landfill directive)	By 2005, to reduce the amount of commercial and industrial waste sent to landfill to 85% of that landfilled in 1998	By 2005, to reduce the amount of commercial and industrial waste sent to landfill to 85% of that landfilled in 1998, and to 80% by 2010	Targets based on Area Waste Plans	By 2005, to reduce the amount of commercial and industrial waste sent to landfill to 85% of that in 1998
Waste hierarchy	1 Reduction 2 Reuse 3 Recycling, composting and energy recovery 4 Disposal to landfill / incineration without energy recovery	1 Prevention 2 Minimisation / reduction 3 Reuse 4 Recover materials 5 Recover energy 6 Dispose	1 Reduction 2 Reuse 3 Recycling, Composting and Energy Recovery 4 Disposal to Landfill	1 Reduction 2 Reuse 3 Recycling and composting 4 Recover energy 5 Disposal

Table 1.2 The Landfill Tax Escalator

Year	Level of Landfill Tax (£ t <sup>-1</sup> )
2005/6	18
2006/7	21
2007/8	24
2008/9	27
2009/10	30
2010/11	33
2011/12	35

kept under consideration, but did not recommend implementing a tax at the time of writing their report (November 2002). The Government in their response to the Strategy Unit report stated that it had commissioned a study into the Health and Environmental effects of waste management options and that this work, alongside stakeholder consultation would inform the strategy as regards the use of economic instruments. The Chancellor of the Exchequer has also announced that the Government is considering this option (Budget 2003). Some countries operate an Incineration tax rated on the efficiency of the plant in terms of electricity production and district heating, further details of European examples are included in Chapter 2.

## Legislation for Specific Waste Streams and Energy from Waste

In order to tackle specific waste streams, a series of European Directives have been implemented or are shortly to be implemented in the UK. Some of these have implications for EfW. For example, the Producer Responsibility regulations for Packaging (as implemented in the UK) require the demonstration of recycling and recovery of a specified percentage of the packaging waste stream and EfW plant can sell Packaging Recovery Notes (or PRNs) to the obligated parties covered by this legislation about the packaging processed by the facility.

Both the End of Life Vehicles Directive and the Waste Electrical and Electronic Equipment Directive (which are also Producer Responsibility initiatives) include targets for 'recovery' as well as recycling and this can include EfW. Clearly there are implications here for the definition of 'recovery' (see 'Recovery or Disposal' in Chapter 4) and whether EfW facilities would be eligible under the European definitions with regard to these targets.

## Summary

It is apparent that EfW is an element in the Government's waste strategy and there are a number of policy instruments which impact upon the development of EfW in the UK. These vary across the devolved administrations and with each of the national waste strategies. However, it is accepted by many in the waste management profession that an increase in EfW capacity will be required in the UK in order to achieve the requirements of the Landfill Directive and requirements of the Government's waste strategy.



Tyseley Energy from Waste plant, Birmingham

## 2. Energy from Waste in a European context

### Developments in Member States

Many countries, whether members of the EU or not, have in general adopted and implemented EC policy on waste. Thus, the key directives on incineration, landfill and packaging all form part of the legislative drivers for waste management. Other measures include the setting of targets for recycling, recovery (usually including recycling and energy recovery) and landfill diversion; the targets are either aspirational or have been introduced as statutory requirements. The general emphasis for waste management is to increase diversion from landfill and maximise all forms of recycling and recovery. Various policy measures, including economic instruments, have been introduced or proposed, e.g., tax on disposal to landfill, support for recycling markets, etc. Generally, the prospects for energy recovery in Europe can be categorised into two main groupings:

#### Consolidating

These are countries that have significant EfW capacity already in place and have potential for further expansion of that capacity, e.g., Germany, Netherlands and Sweden, which already treat between 25 and 41% of municipal waste by EfW (also Table 3.1), but are likely to see only a small expansion in capacity over the short term.

#### Expanding

Countries with relatively low existing EfW capacity include Norway, Finland and the UK – and these countries are likely to see significant growth in capacity over the next 5 to 10 years. The opportunities in Norway and Finland are likely to be based around small-scale (less than 100 000 tpa) facilities and co-firing of waste-derived fuels within existing biomass facilities. The southern European countries (Spain, Italy, Portugal) will also need to increase energy recovery though, for various reasons including cost, the pace of development may be less than that experienced in the northern European countries.

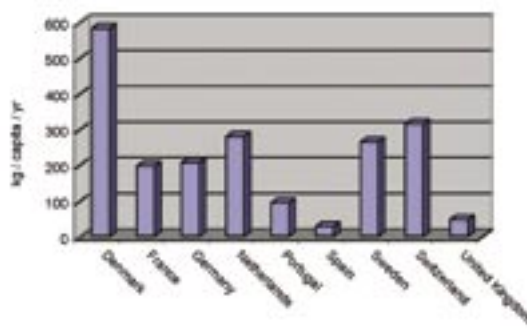


Figure 2.1 The current state of management of the municipal solid waste stream in some European countries by Energy from Waste. (Adapted from ISWA, 2002)

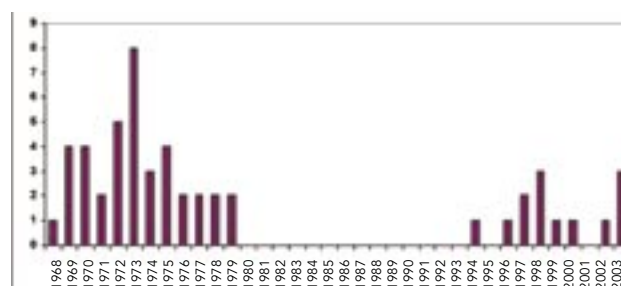


Figure 2.2 New plant commissioned in the UK 1968-2003. (Adapted from J Holmes, 1999.)

It is apparent from Figure 2.1 that the UK has a low usage of EfW relative to the majority of other European Countries. This is a reflection of the economic, legislative and policy drivers in the UK: between 1980 and 1993, there were no new EfW plant in the UK (see Figure 2.2).

### Legislative and regulatory regimes for EfW in EU states

#### Netherlands

In the Netherlands, the Government tax rating that applies to EfW plant is graded with reference to the efficiency of the energy production and use in the facility. Consequently, the tax incentive is to maximise the value recovered from the waste. Efficiencies in excess of 80% are achievable because of the use of District Heating (see Chapter 13) in conjunction with electricity generation. There was also a tax introduced in 1995 for the incineration of waste, at the same time as a landfill tax, however, for incineration this tax is currently set at zero (Table 2.1).

#### Norway

In Norway, all the EfW plants incorporate District Heating systems as well as electricity generation. Not to utilise this heat element of the plant is considered a waste of a potential resource. Furthermore, there is a ban on landfilling unsorted household waste, meaning that 50% of Norway's household waste is source separated and a significant proportion is treated for energy recovery.

#### Sweden

In Sweden to prevent the loss of this energy resource, there is a ban on the landfilling of combustible wastes, this in conjunction with a significant landfill tax represents a driver for encouraging energy recovery.

Table 2.1 Examples of waste management taxes in European Countries.  
(Source: OECD, Strategy Unit and Enviros 2002.)

Member State	Incineration / EfW tax	Charge (€t <sup>-1</sup> )	Landfill tax	Charge (€t <sup>-1</sup> )
Denmark	Duty on waste delivered for burning	44 (no CHP) 38 (with CHP)	Waste delivered to landfill	50
Flanders (Belgium)	Tax on incineration (with/without energy recovery)	6.2–20	Waste delivered to landfill	52–55 (depending on usage of landfill gas)
France	None	-	Waste delivered to landfill	9.14
Netherlands	Incineration Tax	(set at zero)	Differential rates of landfill tax	75 (for combustible non-hazardous waste) 12.5 (for non-combustible non-hazardous waste)
Norway	Basic and additional charge range for waste delivered to an incineration plant	9.93–29.80	Waste delivered to landfill	39.75
Sweden	None	-	General waste delivered for landfill	31

As the environmental issues concerning waste management have evolved, and the concept of a waste hierarchy has developed, it has become clear that an increasingly important reason to incorporate an EfW component within an integrated waste strategy is for the recovery of energy from the residual waste stream. Several EU Member States have encouraged the maximisation of the energy recovery element of the process through a number of legislative and policy measures. The following case studies show the different approaches adopted by Member States with regard to developing a waste strategy incorporating EfW (for more information on the UK regulatory and legislative framework, see Chapter 4).

### Taxes on Waste

The development of 'Incineration Taxes' in a number of Member States, with the proposal also mooted in the UK (Budget 2002), has given the opportunity of promoting effective energy recovery practice. Thus, taxation is a factor in encouraging more sustainable waste management. Table 2.1 shows examples of countries which have adopted incineration and landfill taxes.



Aerial photograph showing the St Ouen Energy from Waste facility in Paris

### EU Developments

Not only has the individual Member State's policy developed over recent years with regard to EfW, but also the European Community Directives (Table 2.2) have had a major impact on the operation and technical requirements of EfW plant across the EU.

There have been a series of EC Directives governing the operation and emissions from EfW plant culminating in the Waste Incineration Directive 2000. This Directive imposes stringent emissions and other environmental controls on EfW plant, and became law in the UK in 2002.\*

Table 2.2 Key EC source legislation with specific regard to the operation of EfW facilities.

(Source: EUR Lex Database)

EC source legislation	Number
Directive on the Incineration of Waste	2000/76/EC
Directive on Integrated Pollution Prevention and Control	96/61/EC
Directive on the Landfilling of Waste	1999/31/EC
Decision on harmonising measurement of Dioxins and Furans relating to 1994 Hazardous Waste Incineration Directive	97/283/EC
Council Directive on the Incineration of Hazardous Waste (1994)	94/67/EC

\* For details of EC legislation see: [http://europa.eu.int/eur-lex/en/lif/reg/en\\_register\\_15103030.html](http://europa.eu.int/eur-lex/en/lif/reg/en_register_15103030.html)

### 3. Energy from Waste in an integrated strategy

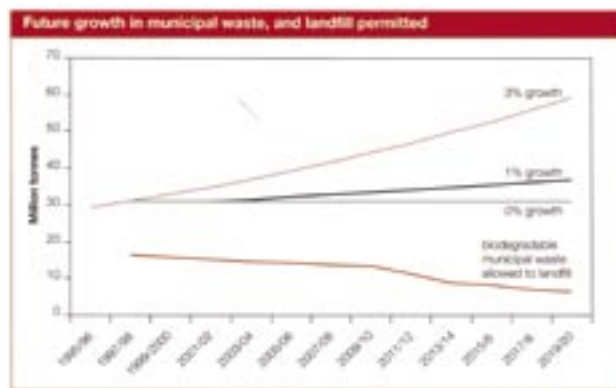
Major changes are required to United Kingdom wastes management practices to enable compliance with existing and proposed European Community Directives. The manner by which these are then transposed into UK law will be a significant driver for change. In order to address the scale of change envisaged, it will be necessary to devise regional and local strategies that deliver new infrastructure and management arrangements and examine all viable techniques and technologies available to achieve the Best Practicable Environmental Option. The potential for flexibility between the various options will also represent a significant challenge as the strategies are expected to meet the challenges of the short and long-term wastes management issues.

Waste management in the United Kingdom continues to be dominated by landfill, an established practice, through reasons of suitable geology, site availability and low disposal costs. Both UK and EU policy encourages a diversification of waste management approaches to facilitate the introduction of sustainable waste management practices. In practical terms, the drive towards sustainable waste management is manifested in the waste management hierarchy, which puts the prevention of waste arising in the first place as the prime aim, followed by: reuse, materials recycling and composting, energy recovery from wastes and final disposal in descending order of priority.

It is clear from policies set in place that in order to meet the targets of the Landfill Directive and the UK national waste strategies, particularly in the light of increasing waste production (Figure 3.1) there is an urgent requirement for a significant increase in the levels of recycling, composting and recovery.

#### Energy from waste and recycling

The argument that energy recovery is not compatible with high levels of recycling and composting is confounded by the experiences of other countries (Table 3.1). The available waste streams and markets for materials recovered from them are able to accommodate high levels of recycling/composting alongside energy recovery. Furthermore, the perception that thermal treatment of the post recycling waste stream will be compromised by the resultant 'low calorific value' of the residual waste available for the process and, hence, the validity of this as an option, is also contradicted, by research into calorific values of different waste streams.



Waste Strategy 2000

Figure 3.1 Waste growth and landfill diversion requirements.

Table 3.2 Definitions of municipal waste

Country	Definition of municipal waste for the purposes of data collection
United Kingdom	'Waste collected by or on behalf of the local authority' (predominantly household, some commercial)
Denmark	'Hazardous and non-hazardous waste covering households, industrial and commercial sectors'
France	'All domestic waste and commercial waste similar to domestic and parks and gardens waste'
Netherlands	'Hazardous and non-hazardous household waste and similar commercial and industrial waste, including construction and demolition waste and parks and gardens waste'
Sweden	'Waste from households and comparable waste from other activities'
EU Landfill Directive	'Waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households.' (includes relevant wastes from households and commercial premises)

The information in Table 3.1 should be interpreted with caution as each country uses a different definition of municipal waste, thus causing bias in the data. To illustrate this point, Table 3.2 includes examples of definitions of municipal waste which are used as a basis for data collection.

Table 3.1 Municipal waste management in European countries

Country	Year	Composting (%)	Energy from Waste (%)	Recycling (%)	Landfill (%)
Belgium	1998	15	21	37	27
Denmark	1999	14	50	25	11
France	1998	6	27	8	58
Netherlands	1999	23	41	24	12
Spain	1999	11	9	16	64
Sweden	1998	8	35	25	33
Switzerland	1996	10	47	31	14
United Kingdom	2000	3	8	9	81

In addition to differing combinations of waste management options occurring across Europe, the trends in each country also vary, with some countries expanding the capacity of EfW while others are decreasing it. Figure 3.2 illustrates the changing waste strategies over a three-year period in Spain, the UK, France and the Netherlands.

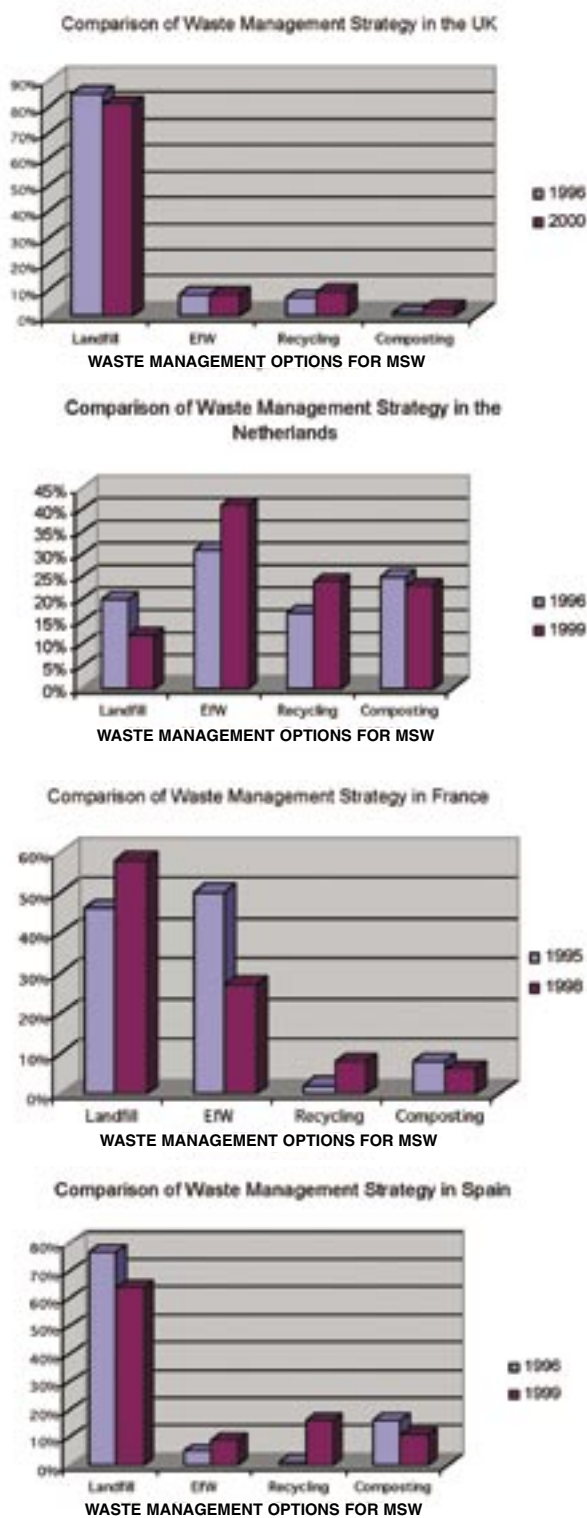


Figure 3.2 Variations in usage of different waste management techniques in EU countries over time.

## Best Practicable Environmental Option

Local authorities in producing their Municipal Waste Management Strategies (MWMS) are required to address how they will meet the requirements of the Landfill Directive and National Waste Strategy targets, and these must include an evaluation of all the available options. A central requirement of UK policy for wastes management is the selection of Best Practicable Environmental Option (BPEO) for dealing with wastes. BPEO will change depending on environmental, geographic, geological, social, economic, technological and waste management criteria. Currently, a wide variety of approaches are being adopted by local authorities in their MWMS, from recycling and composting-based strategies to those with a greater reliance upon EfW. These reflect the local circumstances which impact upon the choice of techniques to be utilised to enable the BPEO to be adopted for their localities. Best Practicable Environmental Option is discussed in more detail in Chapter 5.

## Life Cycle Analysis

A number of studies have been undertaken into the Life Cycle Analysis (LCA) of the various waste management options. A LCA on behalf of the Environment Agency is behind the development of their software-based life cycle assessment tool WISARD (Waste Integrated Systems Assessment for Recovery and Disposal) which is designed to take account of environmental impacts of different scenarios involving the full range of potential solutions, thus, allowing the selection of the most appropriate Waste Management regime. WISARD does not take into account any social or economic implications but can be utilised as an aid to the process to enable authorities to determine the BPEO. Like any model, it is only as good as the fundamental data provided.

## Source separation of household waste and EfW

The requirement to source separate household waste into a variety of material components to facilitate the achievement of recycling and composting targets, is likely to increase over the short to medium term. The nature of the remaining waste stream entering existing and proposed EfW facilities is likely to change with time and will also be influenced by any front end/kerbside collection schemes adopted by the collection authorities. New facilities are designed as an element of an integrated system, specifically to deal with the residual wastes arisings of an area following initial separation of the waste stream for materials recovery. For further information on waste compositional variations and its impact on the calorific value of the waste stream see Chapter 6.

## Scale of plant

The main criteria in the development of any municipal waste management strategy is the selection, feasibility of introduction, and operation of appropriately-sized facilities to deliver the BPEO for the area covered by the plan over a realistic time span (15-25 years). This requires the assessment of all practicable options and seeks to select the optimum mix to deliver their legal obligations with a sustainable solution. A common criticism of EfW plant is that the high level of waste throughput coupled with long-term contracts 'crowd out' recycling and composting initiatives. However, if the planning process is informed by the principle of seeking the BPEO, then all implemented techniques, whether for recycling, composting or thermal treatment will be designed to achieve the optimum balance between them. Any implemented solution must ensure that a degree of flexibility

Table 3.3 Examples of various sizes of plant and gate fees for EfW and other technologies.  
(Source: Cabinet Office 2002)

Facility Type	Size (kt/a)	Capital cost range (£m)	Gate fee range (£/t)
Energy from Waste plant	50	15-20	55
Energy from Waste plant	100	25-35	45
Energy from Waste plant	200	40-60	40
Energy from Waste plant	400	75-100	30
Materials Recovery Facility	25	2.5	20-35
Materials Recovery Facility	50	3.5-3.8	25-40
Landfill	200	4	8-30
Gasification and Pyrolysis	50	10-60	45-60
Gasification and Pyrolysis	100	10-60	45-60
In-vessel composting	20	3-10	18-35
Windrow composting	20	0.85	25-40
Windrow composting	50	0.5-1.2	15-18
Mechanical Biological Treatment (MBT)	50	8-9	15-50

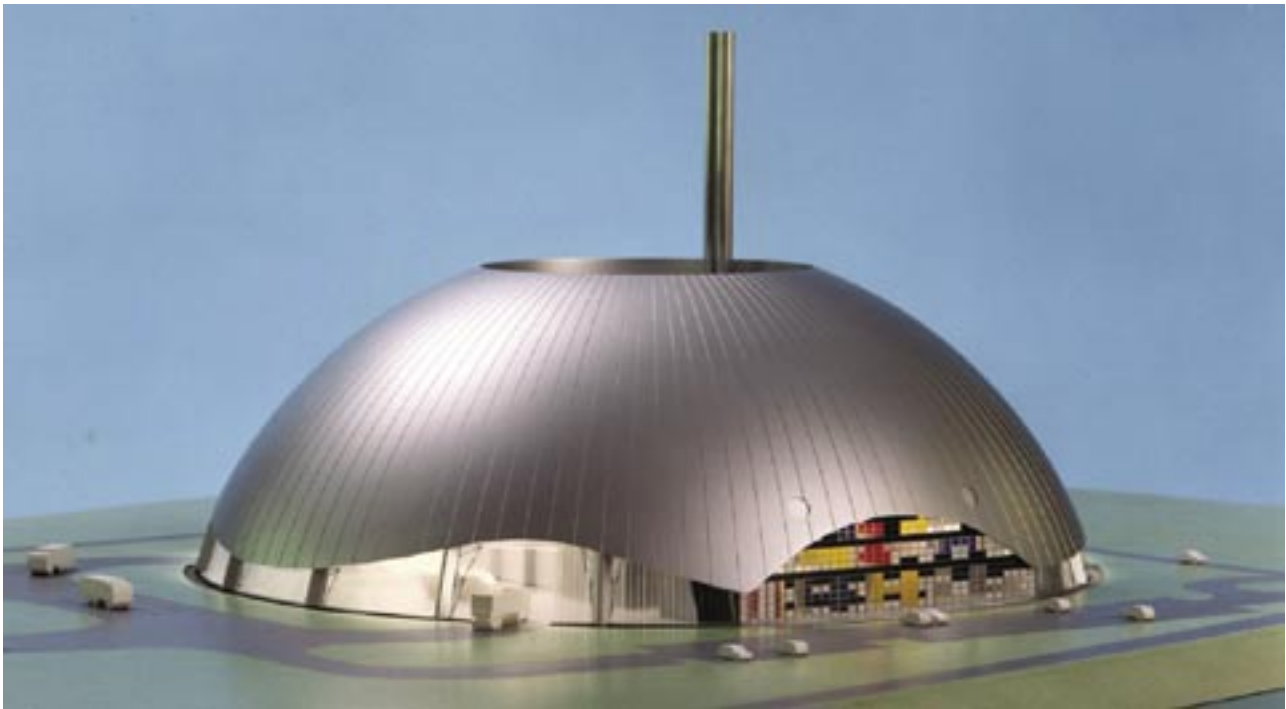
exists within the system to cater for the unforeseen circumstance or equipment repair and maintenance, for example the loss of recycling market or the development of a new recycling market for a material.

The statutory recycling and composting targets for England, (and their non-statutory equivalents in Scotland, Wales and Northern Ireland) together with the required landfill diversion targets from

the Landfill Directive provide a starting point for calculating the size of appropriate plant. Due consideration must however also be given to the possibility of waste minimisation initiatives and performance in excess of statutory targets for recycling and composting in assessing the scale of any proposed waste treatment facilities. Economies of scale clearly apply to EfW facilities (Table 3.3).

Table 3.4 The new generation of Energy from Waste facilities in the UK

EfW Plant	Start up	Capacity of MSW (kt/a)	Technology	Electricity generation (kWhe) Heat utilisation
SELCHP	1994	420	Grate	35
Tyseley	1996	350	Grate	28
Stoke	1997	200	Grate	13
Cleveland	1998	245	Grate	20
Lerwick	1998	26	Grate	district heat only
Wolverhampton	1998	110	Grate	8
Dudley	1998	90	Grate	6
Dundee	1999	120	Fluidised bed	8
Kirklees	2002	136	Grate	11 future district heating
Neath, Swansea	2003	135	RDF	8.2 future district heating
Chineham	2003	90	Grate	8
Grimsby (under construction, due for commissioning in March 2004)	2003	56	Oscillating kiln	3 3MW Industrial CHP
Sheffield (commissioning due in 2005)	2005	150	Grate	8 district heating
Havant (commissioning due in 2005)	2005	165	Grate	14
Allington (commissioning due in 2005)	2005	500	Fluidised bed	29
Marchwood (Under Construction, due to be commissioned in 2005)	2005	165	Grate	14



Innovative design of the Marchwood EfW Facility, Hampshire

More recent EfW plant, (Table 3.4) have been built to a wide range of scales of facility (including smaller scale local solutions and larger scale sub-regional facilities), which are designed as part of an integrated solution recognising the role to be played by recycling/composting techniques and waste minimisation initiatives. This variation in sizes of EfW plant demonstrates that whilst economies of scale do impact on gate fees, smaller scale MSW EfW does have a role to play in achieving the BPEO and therefore contributing to sustainable waste management practice across the United Kingdom.



56 000t EfW facility in Grimsby

Waste management practitioners have to reconcile a number of potentially conflicting principles within the policy guidelines, for example, the proximity principle versus regionalisation. Other factors also influence the rate at which change can be achieved: especially the difficulties in obtaining planning permission, the achievement of PPC and the influence that public concern can have on these decisions.

The technology of EfW plant (as described in subsequent chapters) has been demonstrated to be flexible, proven and robust enough to operate on varied feedstocks to different scales and can therefore be designed to be of appropriate size as a component of an integrated solution.

### **Integrated waste management facilities**

The recycling, composting and recovery targets within the UK waste management strategies, coupled with the requirement to divert waste from landfills not only require a diversification of waste management approaches, they also lend themselves to the establishment of facilities and sites that accommodate more than one waste management option. The practicality of this approach in terms of infrastructure, planning and logistics has been appreciated for some time and, indeed, it has been accepted practice for many years to separate ferrous recyclables through magnetic separation at EfW plant, similarly composting operations have been undertaken at landfill sites. In response to the developing policy and legislation, integrated thermal treatment processes that are designed with significant front-end processing to maximise the removal of recyclables and/or compostables are being offered to the United Kingdom market. There have also been recent developments, e.g., Neath, Port Talbot Case Study (see chapter 9), that incorporate a number of major waste management operations on a single site thus integrating options and infrastructure, which clearly has advantages in terms of the environment and efficiency of operation.



Shenzhen EfW facility design

### **Integrating Energy from Waste into the community and the environment**

There are many examples of good practice overseas and in the UK regarding the integration of EfW plant into the community. These show that plants can be designed to accommodate the needs of a particular town or community and can then provide lower cost district heating to that same community (as well as electricity) thus 'closing the loop' and utilising the residual waste emanating from a locality in a positive and beneficial manner. Additionally, facilities are now being designed in a variety of imaginative ways to make a positive contribution to the environment. In Vienna, one of its EfW plants is an architectural feature of the city. In many other European cities, EfW is integrated into the district heating infrastructure. For example, Paris has three large EfW facilities with extensive district heating systems on the Peripherique, which supply around one third of central Paris' heat requirement (see chapter 12).



Innovative architecture used at the Spittelau EfW facility in Vienna

## Case Study: Kirklees Integrated Waste Management Facility

Kirklees Metropolitan Council is situated in West Yorkshire and is one of the largest Unitary Authorities in the UK with a population of 390 000 living in some 168 000 premises and with 15 000 businesses. The arisings of municipal solid waste (MSW) approach 240 000 tonnes per year.

The waste management strategy developed by the Council was based on a number of fundamental principles, namely:

- Long-term view
- Sustainability
- Proximity
- Flexibility
- Value for money.

In developing the strategy the Council also decided that the preferred business structure be based on the principles of Public Private Partnership (PPP). The procurement process complied with the needs of the EC Procurement Directive and the UK 1990 Environmental Protection Act.

The successful bidder, SITA UK Ltd, established a joint-venture company with the Council in 1998.

The obligations of SITA and the Council, under the 25-year contract, were vested in SITA Kirklees Ltd, the joint-venture company.

The infrastructure developments undertaken by SITA Kirklees Ltd included:

- Material recycling facility (MRF)
- Household waste recycling centres
- Energy from Waste facility (EfW)
- Composting facilities
- Waste transfer station.

A municipal waste incineration plant was built in Huddersfield in 1975. The plant had 'mass burn' incinerators, each rated at 6 tonnes per hour. Under the industrial circumstances prevailing at the time of the design, the plant did not incorporate energy recovery or abatement components. After some 20 years of service and the advent of a new regulatory regime, the decision for closure was realised in 1996.

The new EfW facility occupies the same site as the former plant and utilises, with some modifications, the original pit and chimney. The combustion technology selected for the new unit is of an advanced high-performance moving-grate type, which was considered to be the only commercially-proven concept for the thermal treatment of municipal solid wastes.

The design of the new EfW facility is a single stream with a capacity of 136 000 tonnes of MSW per year, which is approximately 50% of the MSW arisings that are expected to be dealt with in 2006. Setting the capacity at this level will ensure sufficient waste is available to target waste minimization and further recycling/composting initiatives. The EfW facility was designed to comply with the requirements of its permit conditions which anticipated the stringent conditions of the EC Incineration of Wastes Directive 2000/76/EC.

The process generates two residue streams, incinerator bottom ash (IBA) and flue gas treatment residue. IBA is stored in an on-site bunker before being transported for use as intermediate landfill cover or, after processing, for recycling outlets as secondary aggregate. The flue gas treatment system is of the 'semi-dry' variety, comprising a spray dryer absorber vessel and a fabric filter. A water-based slurry incorporating lime and activated carbon is injected into the flue gas at the entrance of the spray dryer absorber vessel to facilitate the neutralisation of acid gases and adsorption of dioxins/furans (PCDD/F) and heavy metals including mercury. Urea is injected into the flue gas



Kirklees Integrated Energy from Waste plant

in the post-combustion chamber in order to limit the emission of  $\text{NO}_x$  ( $\text{NO} + \text{NO}_2$  expressed as  $\text{NO}_x$ ) to a daily average of less than  $200 \text{ mg Nm}^{-3}$ . Solids entrained in the flue gas, namely, flyash, products of reaction and excess reagents are removed by the fabric filter. The residue material from the flue gas treatment system is collected in a silo and transported by tanker, as a 'Special Waste' to an offsite treatment plant and ultimately landfilled.

The facility generates up to 11 MWe and exports electricity to the National Grid under a Non Fossil Fuel Obligation contract. A district heating scheme for nearby housing/industry is being developed. The timeframe for the demolition of the original incineration plant and the construction of the EfW facility spanned 30 months. MSW was first fired in December 2001 and hand-over of the facility took place in April 2002.

During the preparation of the planning application, leaflets were distributed to 117 000 properties informing them of the proposals. Exhibitions were mounted in libraries of Huddersfield and Dewsbury and a mobile exhibition visited 15 sites during the application consideration stage. A total of eight written objections to the application were received.

# 4. Legislation and regulation of Energy from Waste

## Legislation

### IPC, IPPC and LAPC

Waste incineration falls under the provisions of the Environmental Protection Act 1990 and has been regulated under two distinct regimes dependent on the size of the facility: small-scale facilities are under the Local Authority Air Pollution Control (LAPC) regime whereas larger facilities are in transition from the Integrated Pollution Control regime (IPC) derived from the 1990 Act. The facilities covered by the latter IPC regime are now under the new Pollution Prevention and Control (PPC) regime derived from the European IPPC Directive (96/61/EC) and implemented in the UK by the Pollution Prevention and Control (PPC) series of Regulations for England, Wales and Scotland published during 2000. The PPC regime includes the principle of Best Available Technique (BAT) to be applied to process operation and equipment. At the time of writing, the EC are developing Best Available Technique reference notes (BREF) to provide guidance on what constitutes BAT for different processes and industries. The BREFs on waste incineration and waste treatment have not yet been finalised but drafts have been published for consultation and further information on their development is available at <http://eippcb.jrc.es/pages/FActivities.htm>.

In the intervening period before the European guidance is issued, the Environment Agency and SEPA are continuing to use their existing guidance and new cross-cutting guidance principles. The PPC regime includes new principles such as the minimisation of waste in processes, energy efficiency and good environmental management. In order to receive a permit to operate, operators must satisfy the relevant regulatory authority that they can work in accordance with the principles of the PPC regime and the Waste Incineration Directive (WID) implemented in the UK in December 2002.

### Waste Incineration Directive

The Waste Incineration Directive (2000/76/EC) was implemented in England and Wales through the Waste Incineration (England and Wales) Regulations 2002 (<http://www.hms.gov.uk/si/si2002/20022980.htm>), and incorporates the principles of the Waste Incineration Directive. Under the Regulations, all new plants (including alternative thermal treatment processes such as pyrolysis and gasification) must comply with the WID requirements for operation and emission standards, and existing plant must comply with the requirements by the 28th December 2005 at the latest. The Directive covers incineration of hazardous and non-hazardous waste and includes all forms of waste thermal treatment. The Directive has more stringent emissions limits and monitoring requirements than those previously required in the UK including new principles of recovery of heat as far as is practicable from the process and the requirement that residues should be minimised in their amount and harmfulness and recycled where appropriate.

### Hazardous (special) waste

Residues arising from certain flue gas treatment systems (Chapter 11) will be hazardous in nature. This means that they will fall under the additional controls imposed by the Special Waste Regulations 1996, shortly to be superseded by the Hazardous Waste Regulations 2004. Before hazardous wastes are moved, additional documentation, known as 'consignment notes', must be completed and the relevant regulatory authority must

be pre-notified of movements. The waste must be taken, in an appropriate form, to a specially licensed facility capable of receiving such wastes, e.g., a hazardous waste landfill. Other waste management legislation applies to the operation of facilities and movements of wastes, such as that incorporated in the Duty of Care and usage of registered waste carriers.

### Recovery or disposal

Over the past year there have been a number of significant developments at an EU level with regard to the definition of EfW (or 'incineration with energy recovery') being a recovery or a disposal operation. As several other European Directives include targets for recovery, the definition could have far-reaching consequences. In September 2002, the European Court of Justice Advocate General (after *Commission vs. Germany on shipment of waste, C-228/00*) stated that the use of mixed waste in cement kilns must be classed as a recovery operation, based on the concept of using waste as a fuel and replacing energy from other sources. The operation would still occur in the absence of available waste. Additionally, the ruling stated that the burning of municipal waste in incinerators, even with the recovery of energy, cannot be classified as 'recovery' and is a disposal operation, which would cease if there is no available waste. This interpretation was confirmed by the European Court of Justice in February 2003 in a separate case where waste sent from Luxembourg to a municipal EfW plant in France was disposal and not recovery.

In May 2003, the European Commission agreed with the 'Luxembourg' ruling in response to a written question from a Member of the European Parliament. The Commission response referred to the principal objective of a EfW plant being to dispose of waste and therefore 'by applying the concept of the primary objective of the operation, (the court has) excluded dedicated incineration in municipal incinerators' from the EU Waste Framework Directive list of recovery operations. The Packaging Directive (see below), the Waste Electrical and Electronic Equipment Directive (2002/96/EC) and the End of Life Vehicles Directive (2000/53/EC) draw their definitions of recovery from the Waste Framework Directive (75/442/EEC). Therefore, there may be significant implications of this definition both for the achievement of the recovery targets within these Directives and any incentives (e.g., Packaging Recovery Notes) for EfW schemes to be derived from the implementation of these Directives.

### Packaging Waste Regulations

Under the Producer Responsibility (Packaging Waste) series of Regulations covering England and Wales, and Scotland (Northern Ireland is covered by the Producer Responsibility [packaging waste] [Northern Ireland] Regulations 1999), those involved in the manufacture and supply of packaging to the consumer are obligated to recycle and recover specified percentages of the materials that they are responsible for, as they become waste. In order to do this they must obtain Packaging Recovery Notes (PRNs) to demonstrate that they (or more commonly a third party) has recovered or recycled a given quantity of packaging waste. The EfW and some emerging technologies are currently under the definition of recovery used in the UK and so can register with the Environment Agency, SEPA or DOE (NI) EHS (in Northern Ireland) to issue PRNs which will have a market value. There are, however, potential implications of recent rulings in the EU on this subject (as noted above).

## Renewables Obligation

The Renewables Obligation was introduced in 2002 and is a replacement mechanism for the Non-Fossil Fuel Obligation (NFFO). It creates a market in tradable renewable energy certificates for which each supplier of electricity must demonstrate compliance with increasing Government targets for renewable electricity generation. These certificates, Renewable Obligation Certificates (ROCs) demonstrate that electricity was generated from a renewable source. Suppliers must either obtain ROCs sufficient for their obligated target amount from a renewable energy source or may purchase ROCs through a tradable scheme or may pay a 'buyout price' of 3p/kWh for the difference between the statutory obligation and the quantity of ROCs. 'Conventional' EfW is not eligible for the Renewables Obligation as it now stands, however, pyrolysis and gasification technologies are eligible depending on the waste stream processed. For further details on the Renewables Obligation and the Non-Fossil Fuel Obligation see [http://www.dti.gov.uk/energy/renewables/policy\\_obligation/](http://www.dti.gov.uk/energy/renewables/policy_obligation/).

## Regulation

The regulation of EfW plant and other thermal treatment processes (operating at a commercial scale) for waste management is carried out by the Environment Agency (EA) in England, the Scottish Environment Protection Agency (SEPA) in Scotland, Environment Agency Wales in Wales and the Department of the Environment's Environment and Heritage Service in Northern Ireland. There are contact details on these authorities in Appendix E, and such is the pace of change in wastes management regulation, legislation and guidance that readers with an EfW related query would be well advised to contact their regulator or relevant professional body and trade association for the latest position.

## Guidance

The Environment Agency, SEPA and the Department of the Environment's (Northern Ireland) Environment and Heritage Service have all issued guidance on regulation, good practice and legislative requirements for waste management processes. The principle document (still applied from the IPC regime) for EfW is the EA Technical Guidance Note S3.501. This will be superseded by the BREF guidance (a rough draft of this is currently available on the IPPC website at <http://eippcb.jrc.es/pages/FActivities.htm>) and requirements of the Waste Incineration Directive. The Guidance for PPC includes the IPPC Part A(1) Guide for Applicants and General Sector Guidance and Sector Specific Notes. There are also some 'horizontal' guidance notes (those that apply across all IPPC sectors) issued by the Environment Agency for:

- H1 Environmental Assessment and Appraisal of BAT
- H2 Energy Efficiency
- H3 Noise
- H4 Odour.

Other guidance of relevance on waste minimisation topics is available from Envirowise and Energy Efficiency from the Energy Technology Support Unit (ETSU).

## Health and Safety at Work legislation

The Health and Safety at Work Act 1974 is the primary health and safety legislation which is regulated in the UK by the Health and Safety Executive. It applies to all types of waste including a Duty of Care in taking appropriate care for its marking and identification, and containment in suitable containers. Employers should, as far as is reasonably practicable, ensure the health and safety of their employees and of other people affected by their actions in connection with their use, handling, storage and transport of waste. Employees also have responsibilities under the 1974 Act to look after themselves and other people who may be affected by their acts or negligence. Persons who provide or control premises or vehicles used as a place of work have duties to those people using these with regard to their health, safety and welfare. Designers, importers and manufacturers of articles, substances or vehicles and any person designing articles for use at work, must ensure that all are safe when properly used. They must also ensure that any testing or examination is carried out when necessary to ensure that such substances, articles and vehicles can be safely operated and used and that adequate information is provided.

There are a series of related pieces of health and safety legislation which should be consulted for applicability to any given waste management system. The key principles of risk assessment, training, target setting and modern health and safety management are set out in Health and Safety Executive guidance. A good introduction to this area is HSG 65 Managing Successful Health and Safety Systems (HSE, 2000) and for further details on these areas contact the Health and Safety Executive in the first instance and relevant professional and trade bodies such as the CIWM or ESA.

There are additional controls on working time, fire precautions and noise levels, and for the latest available information consult the Health and Safety Executive over potential obligations and good practice guides (see Appendix E). A document published in 2002 by the Waste Industry Safety and Health Forum and the HSE entitled 'Waste Industry Safety and Health – Reducing the Risks' is available free from the HSE and CIWM and is considered good practice in this area.

# 5. The planning context

## Introduction

Gaining planning permission for an EfW plant is a rigorous procedure. This chapter sets out the plan-led nature of the process, centred around the Development Plan, and summarises planning application and Environmental Impact Assessment (EIA) procedures. Issues raised by EfW as part of an integrated waste management strategy for household and municipal waste are discussed. Much of it is applicable to commercial, industrial or other wastes, its scope reflecting the concentration of the public debate thus far on what is in fact only a small part of the total waste stream.

Planning Policy Guidance Note 10: Planning and Waste Management (PPG10) introduced a new approach to planning for waste management. The issues for EfW plants from the requirement for Best Practicable Environmental Option (BPEO), in particular, are discussed in some detail. The guidance note is currently being redrafted as a Planning Policy Statement, expected to be published by the Government in 2004. In Wales, Technical Advice Note 21 Waste is the equivalent to PPG 10. This sets out a requirement for the production of regional waste plans, it also contains guidance on the waste hierarchy, proximity principle, Best Practicable Environmental Option, sustainable waste management option, life cycle assessment, eco design and health impact assessment. The guidance requires the regional waste plan outputs to be incorporated into unitary development plans. In Northern Ireland, the equivalent to PPG10 is Planning Policy Statement (PPS) 11.

There is a commitment, as part of the planning reform programme to re-cast existing policy guidance (PPGs) as Planning Policy Statements (PPS). The review will address these issues and will aim to give a clearer steer on the interpretation of government policy in relation to the land use planning system. A number of issues are likely to be included:

- 1 Explanation of legislative changes to Regional and Waste Planning Authority plan-making procedures to be brought about by the Planning and Compulsory Purchase Act.
- 2 Explanation of the overlap between waste planning and waste licensing, and of the planning requirements of the Landfill Regulations 2000.
- 3 Clarification of Government policy on the waste hierarchy, the position of landfill, incineration and new technologies.
- 4 Guidance on how to consider BPEO in the planning rather than in the process control context.
- 5 The proximity principle and the link to regional self-sufficiency.
- 6 Setting planning proposals in the context of a coherent waste management strategy.

The planning and compensation bill has introduced some quite profound changes to the development plan system including matters such as period for appeals (reducing from 6 to 3 months), period of planning permission (reducing from 5 to 3 years standard condition) and major infrastructure procedures for appeals.

The constraints of space are such that this review focuses primarily on the English and Welsh system. The Scottish system, in which national guidance on waste planning is contained in NPPG10 and PAN63, has many similarities with the English and Welsh system but also many differences. The Area Waste Plan approach has much to commend it, as does the thorough BPEO methodology set out in the SEPA/SNIFFER document. Scotland and Northern Ireland also have separate and in some ways different EIA Regulations.

Different legislation exists on self-governing islands (Jersey, Guernsey and the Isle of Man) but there are many parallels with the mainland and, from experience in Guernsey, these legislatures have learned from some of the problems experienced in the UK.

## The English and Welsh planning system

The key feature of the system is that it is plan led. Planning applications must be determined in accordance with the Development Plan, unless 'material considerations' justify a 'departure' from its policies.



Artists impression of the Lakeside Energy from Waste Facility, Slough

Decisions on planning policies and planning applications are made by elected members of local councils. Although advised by officers, actual power on planning matters lies with these elected lay councillors. Although decisions can be taken out of their hands, by the appeal or Call In procedures, a planning permission granted locally will always be achieved more quickly and with less pain than one determined elsewhere following a public inquiry. This, and the fact that as elected local people, councillors listen to the views of local residents, should underlie the manner in which Waste Disposal Authorities (WDAs) and developers deal with waste planning matters.

## The Development Plan

The 'Development Plan' is a generic term covering all Structure Plans, Local Plans and Unitary Development Plans prepared by Local Planning Authorities. In 'two tier' council areas, it comprises the County Structure Plan along with the Local Plan of the local district, and Minerals and Waste Local Plans prepared by the County. Most Unitary Authorities (UAs) produce Unitary Development Plans (UDPs), although some prepare Structure Plans and Waste Local Plans jointly with neighbours. Alternatively, UA district Local Plans contain waste policies.

## Different approaches

Development plan waste policies may be:

- Site specific or
- Criteria based.

Alternatively,

- Area of search or
- Site safeguard.

Policies are hybrid approaches between site-specific and criteria-based policies.

**Site-specific** policies indicate the locations of predicted pieces of development. The ideal scenario for any developer is to have its site allocated in the Development Plan. While this is the standard way of proceeding with residential or office developments, waste developments tend to be less predictable. Thus, site-specific policies for EfW plants are rare in adopted development plans.

**Criteria-based** policies work on the basis that the industry can promote waste developments wherever it wishes subject to satisfying various pre-conditions. Criteria usually include:

- Protection of landscape, natural or historic heritage
- Control of pollution
- Accessibility to road, rail, and water transport
- Formerly developed land
- Previous waste or industrial use.

**Area of search** policies indicate general locations for waste developments. They tend also to contain criteria indicating the characteristics of acceptable developments.

**Site safeguard** policies accept that in any area there may be a number of sites suitable for waste developments, some sites being more suitable for certain types of development (e.g., EfW, composting, MRF) but that the detailed acceptability of a site will be determined largely by the specific characteristics of a development project. Thus, a number of sites are safeguarded, subject to criteria.

## Development Plan preparation and review

The Development Plan, once adopted by the Council, has status in law. Its preparation and review takes considerable time and involves widespread consultation, including (for UDPs and Local Plans) a local public inquiry (LPI).

The main stages of plan production and review are:

- Issue reports and papers discussing the main subjects to be covered, subject to public consultation
- The first deposit stage, in which, taking account of the comments made on the issues consultation, a set of policies and land use allocations are proposed
- Public consultation on the first deposit
- Sometimes, an amended second deposit, reflecting the outcome of public consultation, itself subject to further consultation
- Proposed modifications by the council to its proposals (again subject to consultation)
- A public local inquiry, chaired by an independent inspector, to hear unresolved objections to the plan

- Receipt of the inspector's report which will include recommendations for how the plan may be changed
- Final modifications to the plan
- Adoption.

This process typically takes two to three years. As local plans need to be reviewed every five years, plan preparation in most Councils is a continuous process.

A Waste Planning Authority should seek to ensure that appropriate policies for the types of waste development which may be needed during the plan period are included in the plan. Depending on how the WDA intends to deliver waste development (e.g., a contract or partnership arrangement with a private sector waste management company), local waste management companies may also work very closely with the WPA in determining the form and content of the Development Plan policies on waste.

Third parties in the form of local residents, Non-Governmental Organisations (NGOs) and other pressure groups can be expected to try and influence the outcome of plan preparation. Land owners and other developers may also put forward alternative solutions and sites.

## Waste management policies

Working alongside Regional Planning bodies, Regional Technical Advisory Bodies should establish Strategic Waste Management Assessments. Waste Disposal Authorities should produce Municipal Waste Management strategies for local implementation of these strategies.

Ideally, these 'operational' policies for waste management should be in place before their land use planning context is considered in the Development Plan.

## Bases for objection to Development Plans

Objectors to Development Plans can challenge the whole basis of the waste policies of the plan. They may claim that the WDA and WPA have not considered properly or fully alternative waste management strategies such as 'zero waste'. Despite the land use planning focus of the Development Plan, such arguments often dominate Local Plan Inquiries.

## Role of WDAs and waste management industry

The WDA and waste industry should be involved in the emerging Development Plan at the earliest possible stage. This may be before the initial work on the issues is reported. If this approach is not taken, the industry (and even sometimes the WDA) may find itself in the position of objecting to the policies of the emerging Development Plan. It is far preferable to appear on the WPA's side at the Public Local Inquiry.

## Planning applications and planning permission

Planning permission is needed for any form of 'development' such as construction, engineering operations (e.g., earthworks) or changes in the use of land or buildings. In the case of waste projects, it falls to the WPA (usually either the County Council or the UA) to grant or refuse planning permission. This power can

be taken away by 'Call In' of the application by the Secretary of State for Transport, Local Government and the Regions or, in Wales, by the Minister for the Environment, Planning and the Countryside. 'Call In' is more likely to occur for projects which are 'departures' from the Development Plan. The Secretary of State/Minister may also choose to determine appeals against refusal of planning permission, otherwise determined by a Planning Inspector.

Planning permission may be full or 'outline'. A full planning permission is one in which all details e.g., site layout, building design and materials, access, landscaping, drainage, are included. If any element is 'reserved' for future consideration, the application and resulting permission is, technically, 'outline'. However, there is a big difference between permissions in which one relatively unimportant detail is left for later consideration and 'bare outline' applications or permissions which comprise just a site plan.

The detailed information required with a planning application is affected by the fact that EfW plants will almost certainly be subject to Environmental Impact Assessment (EIA). Logic (and case law) dictates that a fair amount should be known about a project if its environmental effects are to be fully examined through EIA. For example, one of the most significant issues with EfW plants is their sheer size. If size cannot be determined, then it is impossible to properly carry out the visual assessment required by the EIA regulations.

It is highly beneficial for the design of an EfW plant to have been undertaken to a fairly advanced stage before an application for planning permission is made. For the WPA to be able to make a decision, it is important that all the key details (size, site layout, architecture, materials) are available.

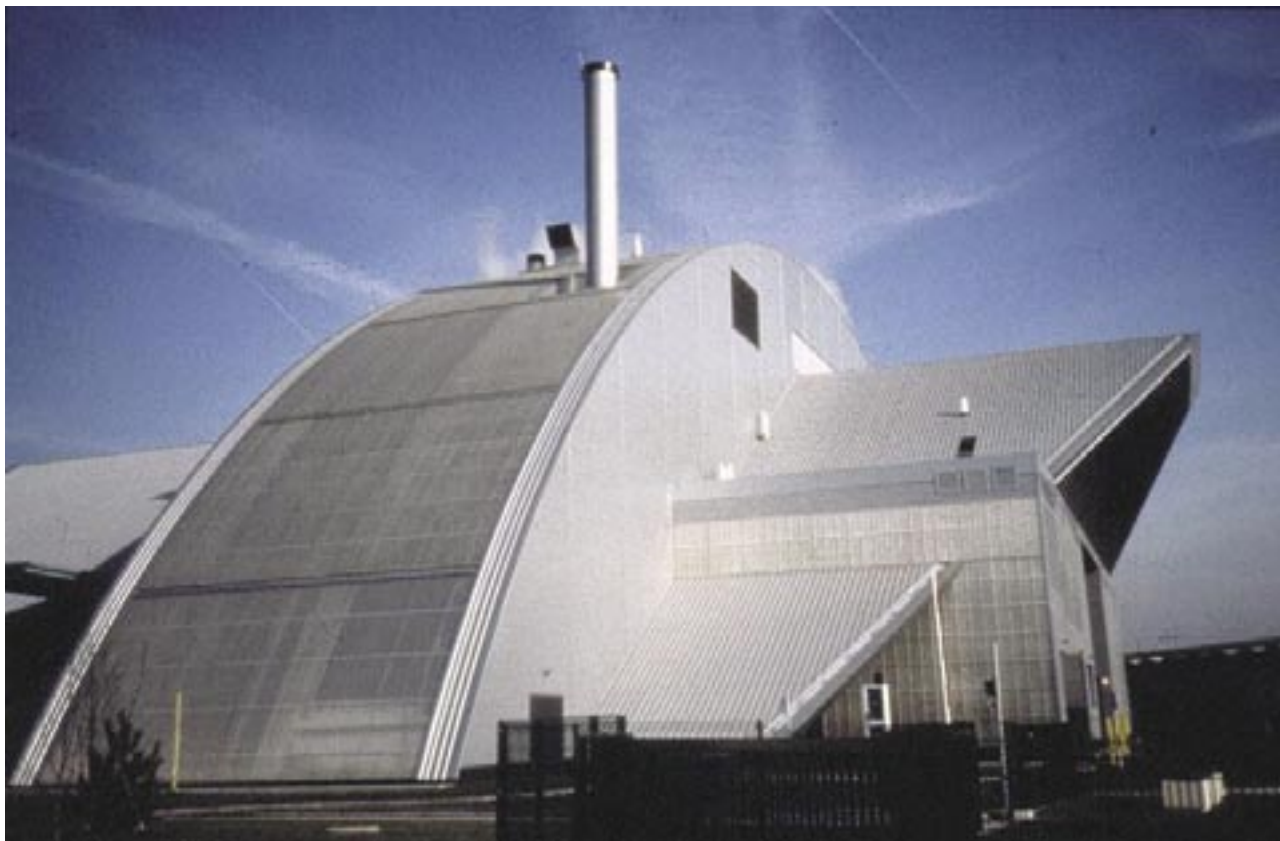
Often changes to the details of design occur after planning permission is granted. If these are minor, they can usually be dealt with through modifications to the planning permission. The developer should be certain that the scope for post-permission changes is small or face having to make a second planning application.

A system of 'permitted development' exists for various relatively minor forms of development. Certain types of relatively minor waste development may qualify but, in practice, the waste industry enjoys little relief from the need for conventional, 'express' planning application processes.

#### Conditions and legal agreements

Most planning permissions are issued subject to conditions limiting the manner in which the site may be developed or operated. Typically, they might address noise control, construction working hours, drainage arrangements, storage of potentially polluting substances, landscaping, or requirements for land contamination studies.

Sometimes a development may be considered to be acceptable in land use planning terms only if works are undertaken off site and, therefore, beyond the scope of a condition. Similarly if the developer needs to agree to, for example, monitoring of emissions, this may exceed the level of control possible through conditions. In these cases, a legal obligation is commonly used. Legal obligations are usually through Section 106 of the Town and Country Planning Act. They may be bilateral agreements (signed by the planning authority and the developer) or unilateral undertakings by the developer.



EfW Facility at Cergy Pontoise minimises visual impact of the chimney.

Where a section 106 agreement or undertaking is needed, planning permission cannot be released until the legal paperwork is signed.

## Environmental Impact Assessment (EIA)

EIA is almost always necessary for EfW developments. The Environmental Impact Assessment (England and Wales) Regulations 1999 set out the approach and methodology to be followed. In practical terms, the main differences compared to a normal planning application are that:

- A much greater level of detail is needed about the development, including a report (contained in an environmental statement) of the results of a systematic examination of the potential environmental effects of the development, taking account of any mitigating factors designed to reduce these effects
- A larger number of organisations need to be consulted about the project and the project must be notified to the regional government office
- The planning authority is allowed 16 weeks in which to determine the application, instead of the normal eight weeks.

Environmental Statements are subject to a considerable degree of scrutiny. There are many occasions in which a planning authority has refused to consider an application because the Environmental Statement is deficient. Therefore, developers and WDAs must understand that time and resources need to be expended on preparing the Environmental Statement. Often the process requires decisions on detailed aspects of project design or operation to be taken at what may feel like an uncomfortably early stage. Sometimes environmental studies can be undertaken only at certain times of the year.

The actual assessment of the effects of the project is undertaken by the WPA on the basis of the information and analysis supplied to it by the developer in the Environmental Statement and other information or comments received through consultation.

Applicants should therefore ensure that assumptions built into any EIA are fully justified and balanced. The environmental statement must be accompanied by a non-technical summary of the proposal and assessment.

It must be accepted by all parties that the WPA may not be technically capable of considering some of the complex environmental issues raised through EIA. Close working with consultees (such as the Environment Agency and the Local Health Authority) may help overcome this problem. However, it is quite usual for a Waste Planning Authority to employ specialist consultants to advise it.

The EIA Regulations include procedures for establishing the need for EIA ('screening'), the scope (or coverage) of the assessment ('scoping'), and for the consultation and publicity arrangements. It is in the interests of all concerned that these procedures are followed transparently. Planning permissions for EfW plants are very likely to be subject to legal challenges and failure to follow procedures properly is one of the main reasons why these challenges are successful.

An aspect of EIA important to EfW plant is that, where alternatives have been considered, they must be explained fully. There is a considerable degree of overlap with BPEO requirements, which also, in effect, require consideration of alternative sites.

## Pollution Prevention Control (PPC)

Much of the information needed to undertake the EIA will be common to the PPC licensing process. It is sensible to run planning and licensing procedures in parallel.

On technical matters, the scope of the planning process should, in theory, be limited to matters where there is a clear land use planning interest. For example, if air pollution is materially affecting the use of land, then it is rightly a consideration in the planning application. In practice it is often hard to make a clear distinction between 'pollution control' and 'land use planning' - objectors would claim that even a fully WID compliant EfW plant might affect local people's perceptions of the quality of their environment and, thus, affect the use of land locally. Perception of effects has been used as a reason for refusal of planning permission.

Planning policy guidance on planning and pollution control (PPG23) and, in Wales, the Technical Advice Note (TAN) 21 Waste, makes clear that the two processes should be distinct. There is no reason why a plant should not gain planning permission before a PPC permit is issued or vice versa. However, it is helpful that the PPC should be gained at the same time as or before planning permission. A draft concordat between the Environment Agency, Local Government Association and CBI suggests this approach.

## Planning Policy Guidance note 10: Planning and Waste Management

PPG10, issued in 1999, was the first PPG to specifically address waste management. It is due to be revised and re-issued as previously described. TAN 21, the equivalent document in Wales, was published in 2001. They replace some of the contents of the older PPG23 ('Planning and Pollution Control' and set out the factors WPAs should consider in Development Plan policies for waste and in handling planning applications. They also contain guidance for potential developers of waste management facilities. The documents establish that the government's policy on waste planning should be founded on four guiding principles:

- Best Practicable Environmental Option
- The Waste Hierarchy
- The Proximity Principle And
- Regional Self-sufficiency.

The local and national waste strategies in place at the time should form a general background to all waste management planning decisions. Thus, the degree to which projects assist in meeting the recycling and recovery targets contained within WS2000 (Wise About Waste 2002, in Wales) is an important consideration in the determination of planning applications. The main area of uncertainty with PPG10 is the concept of BPEO, although, in TAN 21, there is a specific annex covering this methodology.

## Best Practicable Environmental Option (BPEO)

Reference to BPEO occurs throughout WS2000 and PPG10 (TAN 21 and Wise About Waste in Wales) yet there is scant definition of what it means in practice or guidance on how to undertake an assessment. The BPEO will be almost infinitely variable through time and space and, thus, what works in one area at one time will not necessarily be transferable somewhere else. There is, however, guidance within the ODPM document Strategic Planning for Sustainable Waste Management – guidance on option development and appraisal (ODPM 2002).

The most commonly used definition of BPEO is that of the Royal Commission on Environmental Pollution's 12th report, dated 1988, which is:

***'The outcome of a systematic consultative and decision-making procedure which emphasises the protection of the environment across land, air and water. The BPEO establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole, at an acceptable cost, in the long term as well as the short term.'***

The key words here are 'systematic', 'consultative' and 'objectives'. A systematic approach may be one based on multi-variant analysis comparison of a number of generic waste strategies. A tool such as WISARD may be appropriate. This has the advantage of being 'industry standard' i.e., it is approved by the Environment Agency, but it is not intended as a planning tool.

Alternatively, individual bespoke approaches may be derived or it may be more appropriate for a number of standard approaches to be followed in order that their conclusions might be cross-checked. As well as being 'systematic', it is important that methodologies be robust and defensible and that they have clearly stated objectives e.g., meeting the Landfill Directive diversion targets.

The consultative aspect of BPEO analysis raises issues of bias. On the one hand it might seem illogical to ask the views of the lay public on an essentially technical and quite complicated issue. It is also likely that those who respond to consultation may be those who feel strongly about a matter and such views may not be representative of overall public opinion. Notwithstanding this, it is obviously important for any public infrastructure proposal to interact with the local community.

Consultation with technically qualified independent organisations, for example, the considered response of the local health authority to a waste management strategy including EfW should help build balance and credibility into the consultation process.

Aside from achieving a satisfactory definition of and methodology for BPEO assessment, the main problem with its use in waste planning at the moment is timing. The need to find new ways of managing waste does not diminish because in a particular area a BPEO analysis has not been undertaken, however delay and expense caused by promoting a strategy not based on BPEO may actually mean that pausing to carry out a BPEO analysis is quicker in the long term.

On recent projects there has been an inevitable degree of 'post hoc analysis' about BPEO studies. However, the BPEO will not necessarily differ markedly from the actual strategy being followed, particularly when a contract has been let following a lengthy and detailed bidding process, the outcome might be expected to be BPEO, provided the objectives of the tendering process were something like 'provide a service which meets DEFRA recycling targets and Landfill Directive diversion targets in a cost effective and technically secure manner'.

There is a trend, to be welcomed, for WDAs and WPAs to jointly undertake BPEO studies in advance of contract or planning procedures. When these strategies and projects get to the critical stages of Development Plan preparation or planning applications, the earlier investment in a BPEO approach which is systematic, consultative and, possibly most important of all, independent will pay off.

## Characteristics of an EfW project with planning permission

Most of the recent successful EfW projects pre-dated the PPG10/WS2000 requirement for BPEO and the more ambitious recycling plans included in WS2000. However, the following observations may be drawn from them.

### Size

The perceived wisdom used to be that EfW was not viable for plants less than 200 000 tpa. Recently consented plants include Grimsby (56 000 tpa) and Chineham (90 000 tpa). What contributed to make these plants acceptable was that they could be seen to be local solutions to local problems, conforming with the proximity principle.

### CHP

The Grimsby project shows what can be done by selling heat and power directly to an industrial user. Its environmental credentials helped in gaining planning permission. The higher thermal efficiency and, thus, greenhouse gas savings of CHP schemes will undoubtedly assist BPEO cases for future projects.

### Integrated waste solutions

Planning debates quickly focus on the level of recycling proposed alongside the EfW plant and on the 'crowding out' arguments. It is often accepted wisdom for many objectors that high levels of recycling are a proxy for BPEO. Recent successful projects have all been part of Integrated Waste Management systems. It is vitally important to demonstrate that EfWs will not hold back achievement of higher levels of recycling.

### Public consultation and partnerships

The Project Integra schemes in Hampshire illustrate the benefits of extended and detailed public consultation allied closely to the Minerals and Waste Local Plan and, subsequently, to planning applications. Although not equivalent to the type of BPEO approach now advocated by PPG10 and WS2000, the Inspector at the Portsmouth public inquiry found that the systematic approach to identifying sites and technologies and consultative nature of Project Integra could be considered sufficiently BPEO-like to make the scheme acceptable.

## WDA and WPA functions

PPG10 contains much guidance on the relative functions of the WDA and the WPA. There is less emphasis on this aspect in TAN 21 in Wales, probably due to the fact that all the authorities in Wales are Unitary Authorities. Successful schemes have largely been those where the planners and waste disposal officers of the authorities concerned worked together over a sustained period to identify and develop a strategy, and have it included in a Development Plan.

In tendering for a contract, the tenderers are most likely ultimately to be successful with planning applications if they proactively involve both the WDA and WPA in formulating their proposals. However, once a planning application process is under way, WDAs and WPAs must be very careful to ensure absolute transparency on the way that the project is handled. Projects do not gain planning permission because they are required to deliver a strategy or contract devised by the local authority in exercise of any of its other functions. If it appears this way, the route is open to a successful legal challenge.

## Human Rights Act

So far the effects of the Human Rights Act has not been fully tested. A Judicial Review of the Marchwood EfW scheme in Hampshire failed because the judge dismissed the complainant's case, which was that the public inquiry into the Minerals and Waste local plan had not been a fair and just hearing before an impartial decision maker.

However, this is a complex area of policy and law. The British Government is currently appealing to have a European Court human rights case finding against it in the case of noise from Heathrow Airport overturned. The outcome of this will be watched carefully by potential future applicants for Judicial Review.

## Final comments

Waste management is a public issue and because it relies on large projects which need planning permission, it can be the focus of heated debates. Many environmental non-governmental organisations (NGOs) see waste as the one area which links all other areas of economic activity and resource use.

Planning is a public process. It can be political at any level: local, national, party, single issue, etc. To be successful, planning projects should be subject to public consultation and reactive to the results.

Preparation for the inevitable public debate during preparation of the Development Plan and at the planning application stage can assist enormously in gaining a positive outcome. The BPEO approach, which should be followed early on with joint working between WDA, WPA and the waste industry and with appropriate consultation, provides perhaps the best hope of an intelligent debate leading to a sensible solution.

# 6. Waste characterisation, composition and combustion characteristics

## Introduction

This chapter outlines the key waste characteristics and related combustion emissions which should be considered as an integral part of an EfW feasibility assessment.

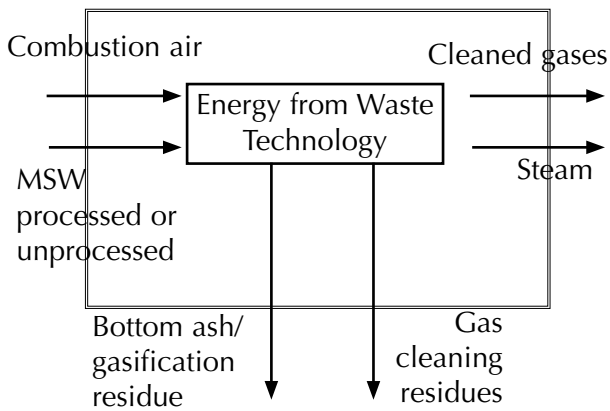


Figure 6.1 Simplified Energy from Waste box diagram.

## Municipal Solid Waste

Municipal Solid Waste totals around  $30 \times 10^6$  tpa in the UK and is the principal subject of this chapter. It is assumed that any recycling/composting has been maximised as far as is practicable before it arrives as a fuel at the EfW plant (as shown in Figure 6.1).

Municipal wastes have an intrinsic energy content, expressed by their 'calorific value', which is strongly dependent on the waste source and composition. 'Calorific value' (CV) is an important indicator in determining how much energy can be generated and recovered from an incineration process. Note that plastics can be up to 15% by weight in densely populated urban areas. This can raise the calorific value by up to  $1 \text{ MJ kg}^{-1}$  (typical Calorific Value of MSW  $10.6 \text{ MJ kg}^{-1}$ ). It can be seen in Table 6.1 that plastic production requires much less energy per kilogram than other packaging materials.

Table 6.1 Energy involved in production of packaging materials (Scott 1999, RSC ISBN 085404 5783).

Material	Energy ( $\text{kW kg}^{-1}$ )
Aluminium	74.1
Steel	13.9
Glass	7.9
Paper	7.1
Plastics	3.1

A typical compositional analysis of MSW arisings is given in Figure 6.2 and the corresponding ultimate analysis is given in Table 6.2.

It is clear, that with energy recovery via EfW, there is an effective solution for residual waste plastics left in the municipal waste stream. As recycling is economically restrictive for some plastics, it is fortuitous that energy may be effectively recovered from them.

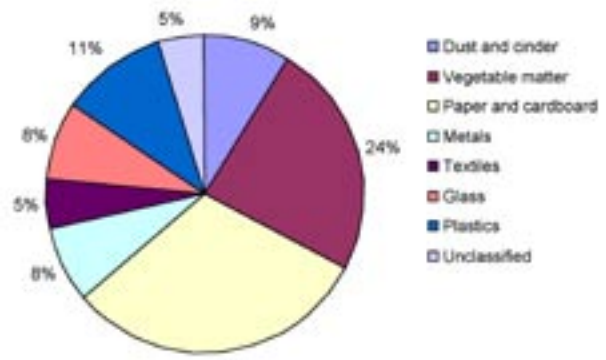


Figure 6.2 Material analysis of sample of MSW.

Table 6.2 Ultimate analysis of 'as received' waste.

Material	% by weight
Carbon	24
Hydrogen	3.2
Oxygen	15.9
Nitrogen	0.7
Sulphur	0.1
Water	31.2
Chlorine	0.7
Ash and Inerts	24.2
Nett Calorific Value as fired	$10.6 \text{ MJ kg}^{-1}$
Moisture	31.2 w/w
Combustibles	44.6 w/w
Inerts	24.2 w/w

It has been observed that whilst recycling/composting operations may diminish waste quantities, they have a limited effect on CV (sometimes it is increased). Figure 6.3 illustrates this aspect for a wide range of recycling scenarios. [DTI, Energy from Waste, Best Practice Guide, Data Courtesy of Hants County Council].

An EfW plant is designed to cope with a wide range of CVs from any post-recycling/composting operation as illustrated in Figure 6.4. The possible operational calorific value range is from 60 – 125 per cent of the design value. This means that EfW plant installed now, have every likelihood of cleanly and efficiently combusting input wastes throughout their (typically 25-year) working lifetimes, potentially dealing with a variety of waste compositions throughout that period, as materials and waste management practices develop over time.

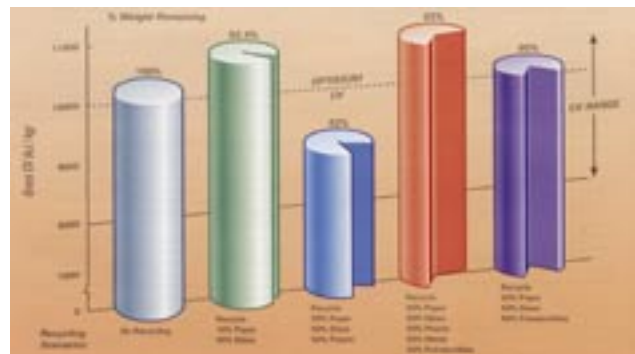


Figure 6.3 The effect of recycling on the Gross Calorific Value of Household Waste. (DTI/Hants CC)

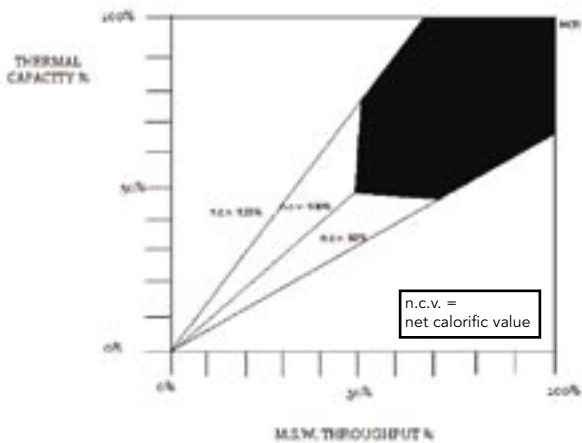


Figure 6.4 Conventional grate system standardised combustion performance diagram.

### Waste combustion

Using the waste analysis in Figure 6.2, Table 6.3 gives the mass balance per kg of input MSW combusted with 100% excess air (excess air is required to ensure high combustion efficiencies).

Table 6.3 Input/output mass balance for 1 kg of MSW.

Material	Mass (kg)
<b>Inputs</b>	
MSW	1.0
Dry air	6.4
Total inputs	7.4
<b>Outputs</b>	
CO <sub>2</sub>	0.881
H <sub>2</sub> O	0.288
O <sub>2</sub>	0.738
N <sub>2</sub>	4.9
HCl	0.007
Ash residue	0.242
Water vapour (from MSW)	0.312
Total outputs (rounded off)	7.4

The percentage composition of the exiting flue gases from the combustion process is given in Table 6.4.

Table 6.4 Percentage composition (by weight) of flue gases at the combustion exit.

Material	%
CO <sub>2</sub> contribution	12.3
Neutral H <sub>2</sub> O contribution	8.37
Neutral O <sub>2</sub> contribution	10.3
Neutral N <sub>2</sub> contribution	68.4
Residual pollutants	0.015
Total (rounded)	100.00

It is to be noted that ~85% of the CO<sub>2</sub> is bio-derived, and hence the nett CO<sub>2</sub> per kWh generated is as calculated in Table 6.5 on the basis of 500 kWh per tonne of input waste (EfW plant can generate in excess of this figure).

Table 6.5 Comparative (typical) CO<sub>2</sub> emissions from industrial boilers and power generation plant.

Coal-fired	410 g/kWh thermal (ca 950 g CO <sub>2</sub> /kWh electricity)
Gas-fired	226 g/kWh thermal (ca 525 g CO <sub>2</sub> /kWh electricity)
Combined-cycle gas turbine (CCGT)	c. 400 g CO <sub>2</sub> /kWh electricity
CO <sub>2</sub> saving achieved by EfW electrical power generation is:	
coal	(950-264) <sup>†</sup> = 686 g/kWh electricity
gas	(525-264) <sup>†</sup> = 261 g/kWh electricity
CCGT	(400-264) <sup>†</sup> = 136 g/kWh electricity [c. 90% reduction in particulates compared with coal-fired power generation is also achieved].

As residual MSW consigned to EfW does not end up in landfill disposal, there is an avoided methane credit equivalent to 1.2 tonnes CO<sub>2</sub> avoided from landfilling per tonne of input waste. This gives an additional avoided greenhouse gas credit / kWh.

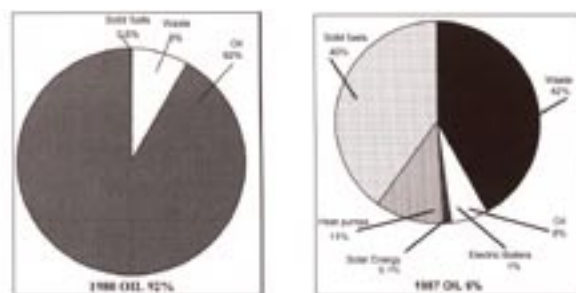
If the CHP route is chosen (see Chapter 12), by virtue of its enhanced overall efficiency there are further reduced greenhouse gas emissions (MSW CHP Schemes reduce fossil carbon emissions by 76% compared with conventional means). The major resource savings possible are exemplified by Uppsala's district (Sweden) heating fuel oil consumption for 1980 and 1987 respectively as per Figures 6.5 and 6.6.

### Summary

Municipal solid waste combustion to the very highest standard is possible with today's combustion and emission control technologies. MSW is a biofuel in its own right, and helps conserve energy sources and can provide heat and/or power at reduced CO<sub>2</sub> emission levels compared with conventional fossil-fuel technologies. The potential resources saved through EfW combustion processes are given in Table 6.6.

Table 6.6 Energy equivalence of 1 tonne of MSW.

1 t of MSW is equivalent to	2.5 t of steam (400°C, 40 bar)
1 t of MSW is equivalent to	30 t of hot water (at 180-130°C)
1 t of MSW is equivalent to	200 kg of oil
1 t of MSW is equivalent to	500 kWh electricity



Figures 6.5 and 6.6 Uppsala District Heating Mix, before and after EfW installed.

<sup>†</sup>264 is a calculation for bio-derived CO<sub>2</sub> for an EfW plant.  
Source: Porteous, A. – *Incineration of residual municipal solid waste for both energy recovery and environmentally sound waste disposal – a consideration of selected major non-economic determinants*

# 7. The 'as received' waste combustion process

## Introduction

This chapter deals with waste combustion technologies based on established grate and furnace systems which form the vast majority of existing and new EfW facilities for municipal wastes management in the UK and overseas. Other terms which have been used to describe this technology are: 'Moving Grate', 'Energy from Waste' and 'Mass-burn incineration with energy recovery'.

## Historical note

In the United Kingdom, both the Horsefall Destructor Company of Leeds and Heenan and Froude of Worcester were active in incineration in the latter half of the 19th century, with their cell-type furnace systems. By the beginning of the 20th century electricity was being generated in plants by recovering the energy released from the incineration of refuse. The first electrical EfW plant in the UK appears to have been built in Oldham in 1895, whilst in Europe Zurich operated a facility in 1904, and, in the USA, the Delaney Street facility provided lighting for parts of New York from 1905. Early plants in this time scale were all known as batch facilities. Many such incinerators were built throughout Europe and the United States of which a surprising number had energy recovery.



Heenan advert from the 1912 edition of 'The Cleansing Superintendent', a forerunner of *Wastes Management Journal*.

## Recent history

The major advance in waste incineration during the 20th century was the development of moving grates, which allow refuse to be fed continuously into a furnace, initially either by gravity or mechanical means. Once again, this technique may have been a British invention although this is open to contention. For example, the Heenan and Froude Co. were building moving-grate continuous 'mass-burn' incinerators in the early 1920s. The moving-grate system was then, and is today, the heart of the so called mass-burn system, where waste is processed at the plant 'as received'. In modern waste management, this is post-source separation for the recovery of recyclable materials before the recovery of energy from the residual waste stream. Such systems, particularly incorporating integrated grate and furnace systems, have now been developed to a high degree of sophistication, providing very high levels of reliability, efficiency and consistent release of energy.

The development of the moving-grate system certainly caused a major increase in the use of EfW systems in Europe, particularly in countries like Switzerland where there was very little landfill potential. Today, there are around 1000 grate and furnace-based incineration or EfW plants in operation worldwide.

The grate and furnace technologies of today are ideally suited to the combustion not only of black bag waste but also the residual waste stream following extensive source separation for recycle recovery. Technologies have not only been continuously developed to respond to the changing nature of waste, but also to enable the technology to respond fully to increasingly stringent legislation. A primary objective for designers and engineers of EfW plant is to incorporate designs and systems that provide environmentally sound sustainable incineration technology reducing and preventing air, ground and water pollution.

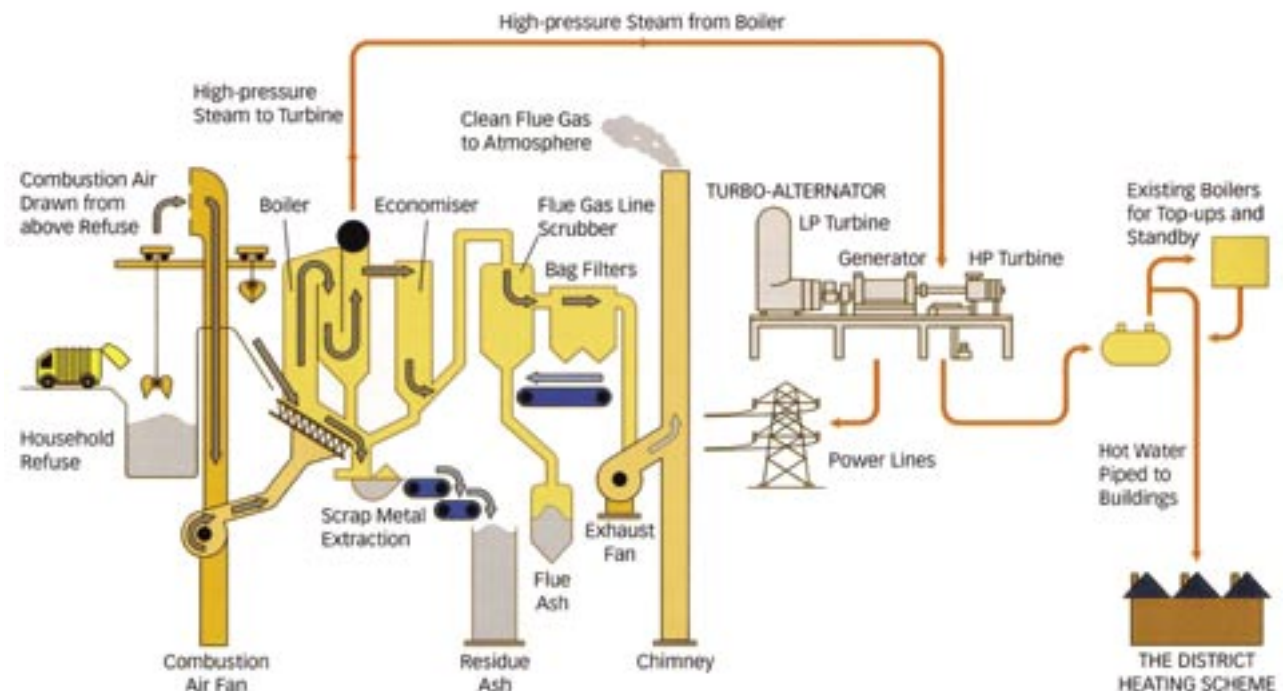


Figure 7.1 Flow Diagram of an Energy from Waste plant (incorporating a District Heating component)

## Combustion

During combustion, the organic component of the refuse is oxidised to CO<sub>2</sub> and water whilst the solid residues are transformed into a mineralised form (ash). The volume of the refuse is reduced by around 90% and the weight by around 75%.

Typically, when operating at the design point at nominal load, combustion of the waste is completed on about two thirds of the stoker length with the remaining end section of the grate and its under-grate air control ensuring completion of combustion and complete burn out and progressive cooling of the ash residue.

### Combustion firing diagram

The purpose of a combustion firing diagram is principally to define the main operating zones and parameters of the furnace boiler assembly. In the typical diagram for a 12 tph furnace provided, the plant is based on a lower heating value (LHV) ranging from 7.11 to 12.14 MJ kg<sup>-1</sup> with a minimum mass capacity equal to 60% of the nominal mass capacity and a continuous maximum capacity of 105%. See Figure 6.4 for a standardised combustion performance diagram.

### Combustion air

Any combustion process needs oxygen. In order to control the entire combustion process, (i.e. during the process changes from drying, through gasification, combustion and finally burn-out), it is important to operate with a carefully controlled distribution of air in the various process zones.

Combustion air normally consists of primary and secondary air (although some suppliers may incorporate a tertiary air stream). An excess amount of air is provided in relation to the specific flow necessary for combustion: the percentage of excess air is designed to ensure that the temperature in the furnace remains higher than the minimum value of 850°C required by EU and UK regulations.

Air supply ensuring optimum grate performance. Variations in wastes composition /calorific value and plant throughput require a controllable air supply system both in terms of the volume and velocity of supply as well as its distribution, as during operation it may be necessary to vary the extent and location of the drying and primary air combustion zones in relation to the waste composition and loading.

The combustion air is normally provided by a single forced draft fan (supplying both the primary and secondary air) for each combustion stream. The fan draws the air from above the waste pit, thus removing any odours and dust from the reception area.

### Primary and secondary air

The primary air, which ensures direct combustion within the bed mass, is supplied from below the grate and distributed to the entire grate area through various air zones, each equipped with a separate control. Pre-heating of the primary air via a steam air heater assists efficient combustion of wet and low calorific value wastes.

Typically, depending on the type of grate, a number of adjustable air zones (between 4 and 6) are incorporated under the grate bed such that the primary combustion air may be supplied to the waste layer through small openings normally

located in the front side of the grate bars. These small air gaps form a very high resistance to ensure uniform air distribution across the surface of each grate zone. Small particles known as 'riddlings' may drop through the bars.

The total air supply area from these openings is quite small being about no more than about 1.5 to 2.0% of the total grate area with typical air velocities of around 10 to 15 m s<sup>-1</sup>.

Secondary air is normally introduced at high velocity through inlet nozzles at the nose of the front and rear combustion arches which form the neck of the furnace. This air supply is critical to the turbulent mixing of combustion of the unburned gases (i.e., volatiles) and acting as a temperature regulator. Secondary air is injected into the combustion chamber through carefully located nozzles in order to achieve a turbulent mixing of the combustion gases and complete combustion followed by final burn-out and cooling of the ash. Automatic control of the secondary air ensures that any momentary shortage or surplus of primary air will immediately be compensated for by an increase or decrease in secondary air.

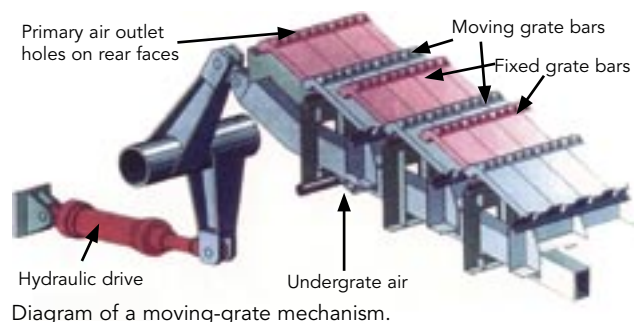
## Grate technology – integrated furnace designs

The heart of an EfW plant is the combustion grate and the furnace. The first task of the combustion system is to ensure the destruction of all the organic elements and pollutants contained in the waste by providing the necessary high-temperature profiles through the system as well as the required burn-out residence times and to minimise the entrained fly ash to prevent the formation of pollutants such as dioxins and furans. Fully engineered integration of grate, furnace and boiler are critical to ensure the plant achieves the required levels of performance.

The principal functions of the moving grate are to transport, mix and maintain an even level of the 'fuel' waste during its combustion and ultimate burn-out by regulating the residence time of the waste on the grate whilst at the same time to arrange for the adequate input of the larger part of the combustion air (primary air) and to optimise its distribution across the fuel bed to suit the various combustion stages.

### Grate designs

Various grate designs are available, the principal types are usually characterised by the method used to transport the waste stream, i.e., they may be described as inclined or horizontal forward and reverse reciprocating grates, roller grates (inclined), or rocking grates. The inclination of the various sloping reciprocating or step type or roller grates may range up to 26 degrees of slope, whilst others use horizontal arrangements.



Grate performance is critical to the entire plant performance, therefore the grate type, design and dimensioning should be carefully selected. The design should in every respect not only be suitable for the specific waste(s) the plant will treat but be able to accept a wide variation and possible changes in both calorific value and waste composition. Furthermore, regardless of the specific properties and varying 'quality' of the waste, the grate should be able to meet all requirements for waste capacity, operational reliability, combustion efficiency, and operation at partial load.

The grate is designed for uniform combustion without any special preparation or shredding of incoming waste materials except for possible size reduction of particularly bulky waste (such as wardrobes). Therefore, in selecting a grate it is important to ensure that the suppliers' design is applicable to the expected waste types and this must be well proven from several long-term operational references. At the same time, the grate and its integral furnace should be robust, reliable and economical in both capital and operating costs.

In summary, to meet the widely varying combustion characteristics of household and commercial refuse, the grate and firing system must be capable of:

- Conveying fuel and ash in a controlled manner from feed chute to grate end
- Efficiently turning and mixing the refuse on the bed to ensure complete burnout
- Controlling primary air admission to match the combustion requirements
- Adapting to the variable properties of the refuse.

### The moving grate

An appropriately designed moving grate forms the bottom of the furnace, where it should provide an efficient and continuously controlled transport with even distribution of the waste on the grate surface through the combustion zone under constant agitation and even distribution of the primary combustion air. Grates are normally sectioned into individually adjustable air supply zones with the combustion air preheated to accommodate variations in the lower calorific value of the waste.



Moving grate

Any grate should be able to effectively mix, and distribute the waste layer creating the largest possible 'fuel' surface, which, with appropriate air control, will ensure efficient drying, ignition, combustion, and final burn out of the slag/ash.

### Sizing criteria

The grate is usually divided longitudinally, into individually adjustable sections. In cases where the grate is very wide, it should also be divided into separate tracks across the width. The number of grate sections is dependent on several factors, including the grate type, the waste composition and CV, the required capacity, and, based on the designers experience – for operation at partial load and maximum load at varying calorific values. The number of longitudinal divisions may vary from one to six sections, depending on the type of grate.

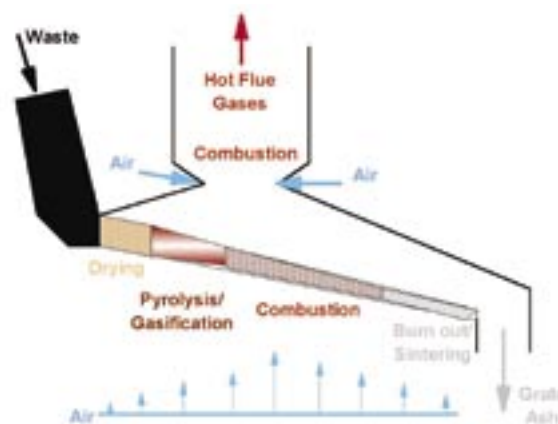
### The furnace

Following the combustion of the waste on the grate the resultant gases of combustion (flue gases) are completely burnt in the upper combustion chamber itself. It is therefore essential that the grate and furnace are designed as a fully integrated unit and not regarded as separate supply items.

The furnace walls are today normally of water-wall design although they may be refractory lined. Typically the vertical walls of the first chamber may be protected by silicon-carbide-based lining whilst the upper half above the refractory level may also be protected by an 'Inconel' or similar material lining.

The majority of water-walled furnaces operate with low excess air levels, thus reducing the furnace volume and the size of the air pollution control equipment.

The design of the furnace and the secondary combustion chamber, the after-burning zone, should provide for a long retention and, hence, reaction time of the flue gases at high temperature. The first radiation pass of the boiler, which forms the secondary combustion chamber, should be designed with a large volume and sufficient height so that all reactions in the flue gas are complete before reaching any unprotected boiler walls. To minimise any risk of slag deposits and ash fouling on the furnace walls, low furnace loading together with a low relative flue gas velocity in the furnace are critical aspects of the design and operation. Typically the flue gas velocity in the furnace should be maintained at a level lower than 3.5 to 4.0 m s<sup>-1</sup>.



Another requirement for optimum furnace performance is the design of the secondary air supply system, it being important to create effective mixing of the flue gases both above the waste layer and at the inlet to the secondary combustion chamber. The secondary air is normally supplied through rows of nozzles in the zones at the inlet to the secondary combustion chamber, although some designs also include some rows of nozzles in the furnace itself depending on the furnace's flue gas flow.

Flue gas recirculation, to partially replace secondary air to the furnace, is now a common feature of modern plant. Start-up and auxiliary burners should also be incorporated in the furnace arrangement.

### Furnace geometry

Based on practical proven performance of their respective plant designs, the different technology suppliers have developed varying arrangements of furnace geometry. In the majority of cases, this geometry is determined by the arrangement of the front and rear furnace arches and the position of the first boiler pass which rises between them.

### Secondary furnaces (Secondary combustion zone)

The Waste Incineration (England and Wales) Regulations 2002 require that the flue gas temperature should be increased, even under the most unfavourable conditions to a minimum of 850°C<sup>†</sup>, measured near the inner wall or at another representative point of the combustion chamber as authorised by the competent authority for at least 2 s. The percentage of oxygen is also measured. These criteria are factors in the destruction of dioxins (see chapter 11).

The secondary combustion zone, which consists of the first part of the radiation pass, starts after the last injection of secondary air or of re-circulated flue gas. Efficient turbulence of the flue gas at the inlet to the secondary combustion zone should exist at any load except at start up and shut down.

### Auxiliary firing systems

The auxiliary firing system enables the combustion gas temperature to be kept above 850°C for 2 s in accordance with the regulations (EU Directive 2000/76/EC). Two burners, (occasionally one) are installed on the lateral faces of the first chamber of the furnace. Normally, the burners are only used during start-up and shut-down operations or when the temperature of the combustion gas falls below 850°C to maintain the combustion chamber temperature.

### Flue gas recirculation

Flue gas recirculation (FGR) has operational, economic and environmental advantages. However, escape of flue gas must be avoided by using all-welded connections, etc. to reduce the potential for corrosion of joints. The recirculated flue gas is recovered from the flue gas beyond the dust filter and then injected through separate nozzles into the furnace at the inlet to the secondary combustion chamber. The primary advantages of flue gas recirculation include:

- A higher thermal efficiency as the excess air and the oxygen content can be significantly reduced (i.e., efficiency can increase by ~ 1-3 per cent)
- Reduction in dioxin generation (again from reduced amount



Process monitoring

- of excess air and the low oxygen content)
- Improvements in the flow and turbulence conditions — particularly at partial load.
- Decreases in the amount of flue gas entering the flue gas cleaning system.

### Firing-control system

The function of the firing-control system is to respond to the changing calorific value of the refuse by adjusting the fuel and air flows so that the pre-set steam capacity is maintained as accurately as possible, without affecting burnout quality. System set points are normally the steaming output and the O<sub>2</sub> content in the furnace, with controlled variables being combustion air flow and the feed rate of refuse to the grate. Improved instrumentation and control systems are in continuous development. The objective is to establish and maintain steady operational parameters, such as steam production, oxygen content of the flue gases, temperature, gas flow and minimum rate of emissions.

### Ash and slag removal system

The burned out ash and slag are collected and transported in a conveyor or similar transport system. Following extraction of recyclable ferrous materials, the ash and slag can be processed for construction materials use (see Chapter 12). Rejected ash and slag etc can be disposed of in a suitable landfill.

<sup>†</sup> This requirement will also be reflected in other devolved administrations legislation as part of the implementation of the WID, see chapter 4.

## Heat recovery steam generators (boilers)

The principal purpose of the heat recovery steam generator (boiler) is to exchange heat between the flue gas and the water/steam circuit. Although boilers may produce hot water or low pressure (LP) steam, the most common practice today is for higher pressure (HP) steam to be produced to drive a turbine generating set and it is then cooled in an air-cooled condenser. The amount of electricity that may be produced from a given steam throughput is dependent on the steam conditions (typically 40 bar pressure and 400°C temperature), which are important criteria in boiler design. This is because waste differs from fossil fuel principally due to the presence of chlorides in the waste stream. These are released as chlorine and/or HCl during combustion) which, combined with sulphur and high flue gas temperatures, may lead to corrosion, even at relatively low temperatures.

### Boiler design criteria

Due to the highly corrosive nature of the flue gases, HP steam boilers must be designed to operate with high availability whilst avoiding potential serious operational problems such as erosion, corrosion, fouling, short continuous operation periods, insufficient availability and extensive repair and maintenance. Refuse-fired boilers invariably have generously dimensioned radiant passes, with low flue-gas velocities to reduce fly ash entrainment. It is usual for the walls of the open vertical passes to be of gas-tight tube-fin-tube welded (membrane wall) construction and incorporated as evaporator surfaces.

On-load cleaning of boiler surfaces is very important and the system(s) used must be suited to the specific boiler location and surface arrangement taking into account velocity, temperatures and geometrical features of the surfaces to be cleaned. The choice of systems that existing plant utilise include: soot blowing; rapping; vibrating; and shot blasting. Boilers should be designed for a minimum of 8000 hours operation per annum without the requirement for manual cleaning.

### The steam circuit

The steam energy is converted to power by a turbine and generator set. The superheated and high-pressure steam from the boiler expands in the steam turbine, converting the energy content of the steam to kinetic energy which is further transformed to electrical energy by the generator. The excess heat of the low-pressure steam is either converted to hot water within the heat exchanger (condenser) and then passed to a process steam user (or district heating network) or cooled away (see Chapter 12).

## Plant guarantees

The following are some of the mechanical guarantees that should be expected:

- Performance to design guarantees i.e., within the furnace operating diagram
- Combustion quality, i.e., minimum 850°C for at least 2 s in the presence of minimum 6% oxygen
- Limits on CO concentration
- Bottom ash quality – i.e., less than 3% unburned carbon by weight
- Flue gas cleaning residues volume and quality
- Flue gas cleaning performance per EC directive and operating permit
- Exported energy
- Quantities of consumables.

## Chimney

The treated flue gas is finally emitted via the chimney. Chimney height normally depends on local topography and prevailing meteorological conditions. For many years the calculation of stack height has been regulated by the Environment Agency, or in the case of Scotland, by SEPA.

## Energy recovery

A typical EfW plant generates electricity from waste with an efficiency of around 22–25% (compared with a coal-fired plant at c. 35%). Taking into account the energy required to operate the plant itself a typical rule of thumb is that c. 500 kWh of electricity can be generated (nett) from one tonne of waste. However, if district heating / CHP systems are incorporated into the design of plant energy generation, efficiencies of >85% are possible (see Chapter 12).

## Kilns – rotary and oscillating

Various designs and types of kiln technology have been used for the combustion of chemical, hazardous, industrial and clinical waste treatment. However, in today's environment, apart from the technology referred to as the 'oscillating kiln' technology, none of the other designs have had any real role in the combustion of MSW although 'rotary kilns' could be used for the incineration of prepared MSW. The oscillating kiln has a variety of established reference plants burning MSW in France and the first installation of this technology in the UK is currently being built at Grimsby (see case study overleaf).

### Rotary kilns

Incineration in a rotary kiln is normally a two-stage continuous process consisting of a kiln and a secondary combustion chamber, followed by a heat exchanger (boiler) and gas cleaning plant. In a typical installation, the incoming waste enters the feed hopper from where a ram-type feeder conveys the raw material to the kiln, which is the primary combustion chamber. The kiln is a cylindrical steel shell normally refractory lined, although there have been examples of kilns with a tubular water-wall-type shell: to date this type has not been used for combustion of MSW. Rotary kilns are normally inclined downwards from the feed end and slowly rotate about their cylindrical axis, this rotation moves the waste through the kiln with a tumbling action to ensure that all waste layers are subjected to heat and combustion air.



Schematic of a rotary kiln Energy from Waste facility.

Kilns operate with a higher excess air ratio than grate and furnace or fluidised-bed units and have therefore a slightly lower energy efficiency. Residence time may be changed by adjusting the kiln's rotational speed however, as the retention time for the flue gases is limited, an 'after burning' (secondary combustion) chamber is required to complete reaction and burnout of the flammable gases at high temperature. Temperatures within the kiln reach c. 900°C, whilst in the secondary combustion chamber temperatures can be between 1100 and 1200°C and a minimum 2 s residence time can be achieved to meet the requirements of legislation (see chapter 4). Waste heat can be recovered via a boiler in the form of hot water or as steam for power generation or as part of a CHP scheme. The flue-gases then flow to a flue gas cleaning system, from where they are discharged to atmosphere via a chimney.

The residues, following completion of combustion, are a sterile ash which may be discharged by the rotary action of the kiln to an ash hopper. Due to the fully refractory-lined surfaces, rotary kilns can operate in a slagging mode whereby high-temperature operation melts the inorganic waste to produce a fused glass-like ash (slag) which is low in organics and has low leachability. Rotary kiln capacities can range from under 0.25 tph up to c. 20 tph. An important consideration in rotary kiln selection is the design and type of seals between the rotating kiln and the end plates to prevent gas leakage.

### The oscillating kiln

There is only one supplier of the oscillating kiln based technology. However, there is considerable long-term operational experience with the technology for MSW treatment, primarily in small-scale plant in France. The oscillating kiln is similar to the rotary kiln in being a two-stage continuous process consisting of a kiln and a secondary combustion chamber, followed by a heat exchanger (boiler) and gas cleaning plant.

The oscillating kiln is also a tube-type furnace, but in contrast to a rotary kiln, it makes an oscillating motion about the central axis of the tube. An important feature of this kiln is that the latter stage conical end of the tube is designed such that the lower surface of the truncated cone is horizontal when the axis of the tube is inclined at an angle of 8.5°. This continual reduction provides for an extended residence time in the burn-out zone.

Both the cylindrical front portion and the conical rear section of the cell are constructed as a welded double shell, lined internally with ceramic castings and externally where the cell interfaces with the post-combustion chamber. The incoming waste enters the feed hopper from where a ram-type feeder conveys a pre-determined constant volume to the upstream end front face of the cell. The slope and oscillating motion of the cell ensure intensive mixing of the waste, at the same time transporting the ash residues to the ash hopper. Primary and secondary air is distributed to air channels located in the annular space around the cell via fixed air ducts.

Pre-heated primary air at c. 40% excess air, enters through nozzles located in the second part of the cylinder and within the cone, under the refuse bed, to support a good combustion reaction. The location of these nozzles determines the limits of the combustion area. There are no air nozzles in the first section, i.e., the drying and gasification zone. Secondary air is supplied via nozzles located in the upper part of the combustion chamber where it mixes in a turbulent manner with the combustion gases. A proportion of secondary air may also be supplied at the end of the cell.

The flue gas exit is positioned at the end of the first third of the cell length in the upper part of the cell. The size and shape of the cell ensure adequate gas retention for completion as far as possible of the combustion reaction, which is then fully completed in the post-combustion chamber. The perpendicular post-combustion chamber encloses the front third of the kiln. At the top, the chamber narrows into a duct creating an overall pressure drop ensuring a minimum two second residence time. Gases then pass to a recovery boiler (i.e. heat exchanger), usually of the vertical type for the smaller units and horizontal type for the large units.

In all cases, at least two radiant passes made of gas-tight membrane walls reduce the temperature to avoid tube fouling (by sticky particles) and ensure there is no potential for high temperature corrosion of tube bundles. The gas then enters a third convection pass, also of membrane wall construction, although in the final stage of the horizontal type boiler this final pass may be cased in steel plate. The boiler may produce saturated or superheated steam depending on application, i.e., the steam produced can be used for:

- District heating
- Steam supply to an industrial user
- Production of electricity by employing either a condensing steam turbine or a back-pressure steam turbine
- Production of electricity and use of low pressure exhaust steam from a back-pressure steam turbine.

## Industrial Combined Heat and Power in conjunction with a Local Authority Recycling and Disposal Contract

On the 7th December 1999, NEWLINCS began a 25 domestic and municipal waste management contract with North East Lincolnshire Council. The scope of the contract is for the recycling, recovery and final disposal of the waste arisings in the borough, which were 85 000 tonnes in 2002. Additionally, there are two Civic Amenity Centres, one that was purpose built for the contract, and the other completely refurbished.

The local strategy is to focus on the segregated kerbside collection of different materials, such as green waste, papers, glass and cans. There are also 43 "Bring To" sites, collecting a wide range of recyclable materials.

The contract will be the first in the UK to make use of the Cylcerval oscillating kiln technology, which is a simple and well-proven incineration system that has been in operation for close to 30 years, with over 25 plants in five different countries. Planning consent for a new integrated waste management facility was received in January 2001, with a commercial operation date of March 2004.

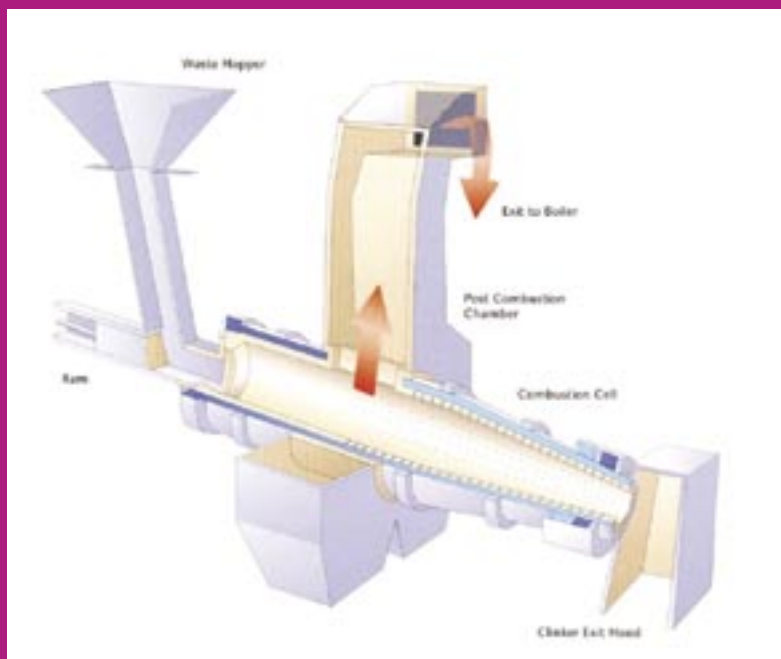
The energy from the 56 000 tonne per year plant will be utilised as combined heat and power to supply an adjacent chemical manufacturing facility; it will effectively replace their current fossil fuel energy centre. The electricity exported from the site will be around 3MW with an additional 3MW will be exported as heat.

The plant uses a semi-dry scrubber for Flue Gas Treatment, with urea injected as a DeNO<sub>x</sub> control. There is an overband magnet for the removal of metal from the bottom ash for recycling and the facility for non-ferrous separation with the installation of an Eddy Current separator.

The facility itself had a capital cost of under £20m.

To date, the recycling rate has increased to over 20% from the starting rate of 6.5% (in 1999). The ultimate recycling target of 33% would, on 2002 waste generation figures, leave just over 56 000 tonnes of residual waste to be sent to the CHP facility (with a rather optimistic assumption of zero waste growth for the remaining contract term).

This minimises the waste sent to landfill to an extremely low proportion of the overall municipal arisings.



# 8. Fluidised-bed combustion

## Introduction

The purpose of any combustion process is to convert the energy in the fuel into heat through oxidation. The quality of combustion depends on the combination of what is often referred to as the three 'ts': time, temperature and turbulence. A fluidised bed is a bed of solid particles with gas flowing through the bed to give an expanded, suspended mass that behaves like a liquid. The fluidised bed therefore exhibits a zero angle of repose; it seeks its own level and assumes the shape of the containing vessel.

A fluidised bed works on the general principle that a bed of particles (usually sand) at rest in a vessel will offer a resistance to a flow of gas injected into the base of the vessel. As the gas flow is increased, the bed expands upwards to offer lower resistance. With increasing flow, the bed continues to expand until the upward force of the gas is sufficient to support the weight of material in the bed, causing considerable turbulence and mixing. The bed therefore becomes 'fluidised'. Further increase in gas flow causes instability in the bed.

For over 50 years fluidised beds have been used successfully in many industries for a wide range of applications. These include chemical processes for the cracking of hydrocarbons, the roasting and calcination of ores in the mining industries, and the combustion of fuels for raising steam and power production. They have also been used for the combustion of a wide range of fuels, including coal, wood and peat as well as wastes such as sludges and MSW for energy recovery.

## The fluidised-bed process

MSW is pre-treated to achieve a fuel with a particle size of less than 150 mm. The fuel is held in the hot fluidised bed for a reasonable time and the thorough mixing of the fuel and the combustion air allows new surfaces of the fuel to be exposed until complete combustion is achieved with low excess air ratios. The temperature within the combustion zone of a fluidised bed can be held relatively constant without hot or cold spots. As a result, the inherent characteristics of a fluidised bed make the technology of special interest to combustion engineers particularly when combustion with low emissions are being sought.

The formation of thermal  $\text{NO}_x$  is a function of combustion temperature. The fluidised bed usually operates within a relatively narrow temperature range. Typically, the temperature in the bed can be as low as 650°C and 850°C in the freeboard. This ensures that the formation of thermal  $\text{NO}_x$  is kept to a minimum. As a result of the low excess air, lower temperatures and the good level of mixing, a fluidised bed can achieve low carbon monoxide (CO) and oxides of nitrogen ( $\text{NO}_x$ ) levels (as shown in Table 10.1).

The high ratio of bed material to fuel creates a high thermal mass allowing a fluidised-bed boiler to operate over a wide and variable range of fuel characteristics. Fluidised beds can be designed to handle fuels with CVs ranging from 7 to 28 MJ  $\text{kg}^{-1}$ . The technology also offers a quick start-up and shutdown performance with controlled emissions. The lack of moving mechanical parts in the combustion zone of a fluidised bed is also considered an advantage.

## Types of fluidised bed

There are several types designs of fluidised bed used for the combustion of fuels each having its own characteristics. The three types that have generally been exploited for the combustion of waste are:

**Bubbling fluidised bed (BFB)** – a bubbling fluidised bed is, as the name implies, a bed where the velocity of the air (through the sand and fuel) is sufficient to maintain all the bed material in a fluidised state. The sand and flue gases separate in the freeboard area with the bed material falling back into the bed and the flue gases carrying forward to the heat recovery sections. The turbulence experienced is similar to that in a boiling kettle of water.

**Revolving fluidised bed (RFB)** – a revolving fluidised bed is one where the bed of sand and fuel is propelled into a revolving motion by using differential air pressures in the various section of the bottom distributor plate and deflector plates placed strategically in the lower portion of the furnace. The revolving characteristics can be used to good effect by using two revolving portions of the bed turning in opposite directions. This increases the mixing in the bed thus maintaining uniform bed temperatures and reduces the carryover of sand into the freeboard area.

**Circulating fluidised bed (CFB)** – a circulating fluidised bed is one where the air flow is increased to a point where a portion of the sand is carried through the freeboard area and out of the combustion zone. The sand is captured in hot cyclones and returned to the bed. A CFB boiler is normally only used on larger capacity units. The increased turbulence created by the increased airflow improves the quality of combustion resulting in lower emissions.

The major parts of a fluidised-bed system can be identified as follows:

- 1 **Fluidisation vessel** - comprising a gas distributor (plate or nozzles) below the bed, a fluidised-bed section and a freeboard section above the bed for disengaging the bed particles from the flue gases.
- 2 **Fuel feeder** - charging MSW fuel into the top of the bed. The fuel feeder may also be used to feed additives into the bed such as new sand and limestone/lime.
- 3 **Solids discharge** - drawing solid material from below the bed. Material is constantly drawn from the bottom of the bed and classified to recover the sand. The smaller particles are returned to the bed with the larger items, including glass, ceramics and metals rejected as bottom ash.

## Major sections of the plant

Fluidised-bed EfW plants usually comprises the following major sections:

- Waste reception
- Waste preparation
- Materials recovery for recycling
- Fuel storage and feeding
- Fluidised-bed boiler
- Steam raising and power generation
- Flue gas cleaning
- Residue handling.

## Fluidised bed case study: TIRMadrid Plant, Madrid, Spain

This facility is owned by TIRMadrid (Tratamiento Integral de Residuos de Madrid s.a.) and is situated in Valdemingómez, near Madrid. TIRMadrid has three shareholders: Urbaser (Urban Services) 66%; Endesa (electric company) 15%; and Union Fenosa (electric company) 19%.

### Drivers

In 1989, Madrid City Council decided to act on waste disposal in the region, as the landfill site was becoming full. The practice at the time was to recycle as much waste as possible and to compost the organic waste. In 1990, Urbaser proposed that city council develop, construct and maintain a waste-to-energy recovery facility. The EC (under the THERMIE program) sponsored the project with US\$1.7 million. In 1992, TIRMadrid was contracted to operate the plant and, in the same year, purchased it for US\$125 million.

### Incineration and Environmental Technology

The TIRMadrid plant accepted 441 000 t MSW in 1999, of which 62 000 t was recovered for sale, 119 000 t was landfilled or composted, and 260 000 t RDF was fed to the three bubbling fluidised beds (BFBs). RDF is transported from each of three hoppers (10–13 t h<sup>-1</sup>) by double screws into two shafts operating as the feeding system into the furnace about 3 m above the bed. The floor of the bed (4 m x 6 m) slopes down from the centre to the side walls, producing circular mixing patterns in the bed. Larger particles are moved over the bed bottom to the side walls, into the ash/sand removal system. Average residence time of waste in the bed is four minutes. In order to slow combustion and to keep the bed temperature at 670°C, recirculated flue gas and water (up to 2 500 kg h<sup>-1</sup>) are injected above the bed. In the freeboard, temperatures of 900°C are reached.

The boilers consist of two vertical radiation sections (water-cooled walls), a horizontal convection section superheater and a vertical economiser. Each boiler has a nominal output of 41 t h<sup>-1</sup> of steam at 420°C and 46 bar. Under design conditions, a total of 29 MWe is generated (at 19.4% overall efficiency).

Gas cleaning for each line begins in the fluidised bed, with injection of fine limestone from above via secondary air outlets. This provides partial SO<sub>2</sub> and HCl removal and reduces fouling and corrosion in the superheater. Flue gases traverse the three boiler sections to a pair of hot gas cyclones to remove fly ash; a semi-dry absorber (calcium hydroxide); a high-performance bag filter with dry injection of lime and activated carbon to remove the remaining fly ash, heavy metals and organic components; and an induced draft fan, which prevents pressure drops in the system and drives the exhaust gases into the stack. Emissions regulations give limits of: SO<sub>2</sub> 300 mg Nm<sup>-3</sup>; CO 100 mg Nm<sup>-3</sup>; HCl 50 mg Nm<sup>-3</sup>; and dioxins 0.1 ng Nm<sup>-3</sup>.

### Capital/Operation and Maintenance (O and M)

The capital cost of the plant was US\$125 million, 80% for the thermal facility and 20% for waste recovery. O and M costs, including ash disposal, are US\$13.5 million annually (US\$30.60 per t MSW).

### Waste reception

Typically, vehicles delivering waste to the site are weighed before unloading onto a flat floor or bunkers within a reception hall. The reception hall should be held under negative air pressure to minimise the egress of dust and odours.

### Waste preparation

Municipal waste requires some sorting and feed preparation, including removal of incombustible materials like large pieces of metal, or blocks of building rubble, before it can be satisfactorily combusted in a fluidised-bed boiler.

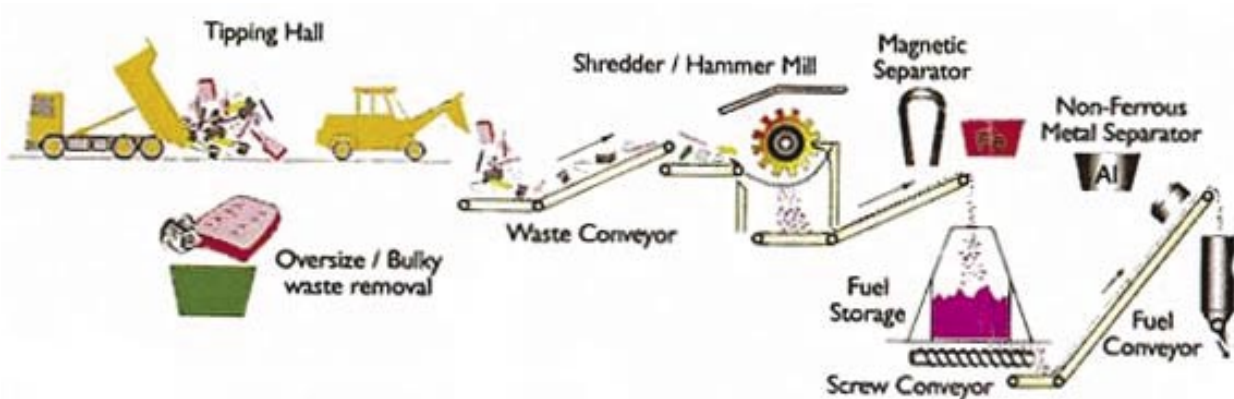


Figure 8.1 Feedstock preparation for fluidised-bed combustion process.

The purpose of the treatment is size reduction and upgrade of fuel quality. Size reduction improves the fluidisation and combustion of the fuel in the sand bed. Waste is moved by front-end loaders or grab cranes to feed hoppers on heavy-duty hammer mills for shredding, typically to less than 150 mm in size.

### Material recovery for recycling

Some fluidised-bed waste preparation facilities also incorporate trommel screens before hand picking to recover plastics, metals and paper products. Size reduction of the waste may improve metal recovery for recycling. Magnets (as with other EfW systems) are used to recover ferrous metals, and non-ferrous metals, including aluminium, are separated using an eddy current gap. Shredded waste, often referred to as a Refuse Derived Fuel (RDF), in the form of a 'flock' is stored before combustion in the fluidised-bed boiler.

### Fuel storage and feeding

A prepared fuel store is usually incorporated as a buffer store. RDF recovered from the fuel store is fed into the boiler using dedicated fuel-feeders equipped with seals or valves to prevent the ingress of air. Feeders are positioned to direct the RDF into the lower freeboard section of the combustion chamber above the fluidised bed. Bed material (sand) and bed additives such as dolomite are fed to the furnace together with the fuel.

### Fluidised-bed boiler

The RDF is burnt in a fluidised bed sized to match the incoming waste stream. One or more boilers are installed depending on the unit size and the availability required. Combustion air is supplied by the forced air fan, which also fluidises the bed. The induced fan keeps the boiler and its associated components under slight negative pressure, ensuring that air 'leaks' into the boiler rather than escaping due to the air pressure from fluidising the bed. The lower section of the fluidised-bed vessel is usually covered in refractory material to protect the exposed metal areas from erosion. Bed temperature can be controlled by flue gas recirculation and extreme temperature peaks by the injection of water. Start-up is achieved using gas- or oil-fired burners mounted in the combustion zone. Once the operating temperature is reached, waste fuel can be introduced. Additional burners will be mounted above the freeboard to maintain the correct combustion temperature under poor or wet fuel conditions. The relatively low volumes of fuel in the bed and the high volume of hot bed material retained in the combustion zone, allows the plant to shut down (for several hours a day if required) and start again rapidly. This can be achieved with minimal disturbance to emissions and no significant use of heating oil or gas.

### Steam raising and power generation

Steam is generated in a water-tube boiler and is used to drive a condensing steam turbine/alternator. Some fluidised-bed boilers have water tubes enclosing the fluidised bed. The power generated is used to supply the EfW plant with the balance exported (parasitic load). The turbine condenser is usually air-cooled but low-pressure steam can be exported if suitable heating loads are available. In a CFB boiler, it is possible to incorporate a steam superheater in the 'dead leg' where the sand is returned to the boiler having been recovered by the cyclone system. This improves the steam conditions and the thermal efficiency of the plant. The chlorides that potentially cause high temperature corrosion when combusting refuse derived fuels under these enhanced steam conditions pass out of the boiler with the rest of the flue gases.

### Residue handling

There are normally three different ash residue fractions produced in a fluidised-bed boiler:

**Bottom ash** - incombustible material builds up in the bed over a period of time due to the ceramics, metals and other inert materials present in the MSW fuel. Bottom ash is continuously extracted from the bottom of the bed. Reusable sand is separated from the larger particles using a classifier and returned to the bed. The coarse material is cooled and can be used as a secondary aggregate following conditioning. The bottom ash is characterised by the low carbon content, typically less than 0.5%.

**Cyclone ash** - coarse dust recovered from the boiler passes and the cyclone is added to the bottom ash. This is an ash stream that is characteristic of the fluidised-bed system only.

**Fly ash** - the fine dust not collected by cyclones are captured in the flue gas treatment plant.

For more information on residue management, see Chapter 11.

## 9. Processed waste technologies

The pre-processing of MSW to provide a suitable feedstock for thermal treatment is achieved by the technologies of refuse derived fuel (RDF) plant, pyrolysis and gasification. The level of pre-processing required depends upon the type and robustness of the system employed and is commonly incorporated into the 'front-end' of the facility. All these technologies fall within the scope of the Waste Incineration Directive and they tend to be smaller scale than moving-grate EfW (with the exception of co-incineration). However, they have significant potential in modern waste management as part of an integrated system incorporating other technologies such as mechanical biological treatment (MBT) or other residual waste treatment processes. The output of some MBT systems may be fed into pyrolysis and gasification systems or used to provide a feedstock for RDF plant.

### Refuse Derived Fuel

The Government has defined refuse derived fuel as 'turning the combustible portion of waste, such as paper and plastics, into a fuel which can be stored and transported, or directly used on site to produce heat and/or power'.

RDF preparation requires sorting of the household waste to remove recyclable materials and wet putrescible materials. The combustible residue being shredded and either burnt directly as a 'coarse floc' – so-called RDF, or compressed into pellets (densified RDF or dRDF). RDF pellets may then be sold (dependent on markets) as a distributed fuel to industrial users with suitable boilers fitted with appropriate gas cleaning to satisfy regulations and their operating licences. It should be noted, however, that the development of UK markets for dRDF did not live up to expectations at the time the technology was developed in the 1970s and 1980s and there is no indication that the situation has improved in today's industry sectors.



Pelletised refuse derived fuel

Furthermore, pelletisation is energy intensive and, hence, can be costly. Conversely, and as has been noted previously, the drivers for waste management have now changed, and the level of interest in RDF systems as part of an integrated waste management solution has increased in recent times.

### RDF case study: Neath Port Talbot Modern MRF / RDF based EfW technology

The most recent integrated waste management project in the UK incorporating RDF has been designed to produce a semi-densified RDF pellet. The facility combines a waste processing (separation and recycling) plant comprised of two lines, one for mixed and the other for separated waste, a composting plant and an integral EfW module.

The waste reception (tipping hall) area incorporating dust/odour and fire control systems is of flat floor construction onto which delivery vehicles discharge the wastes which is fed to the process line conveyor by appropriate mechanical means.

A primary (mixed waste) processing line comprises plate feeder and hopper; a refuse bag splitting device; a conveyor belt weigher; and a large rotary screen (with its associated conveyors) which mechanically sorts waste into a number of specific size ranges.

Typically four size fractions of waste are separated by this screen:

- a) 6 mm fine rejects
- b) 6-80 mm fine screenings
- c) +80-140 mm coarse screenings
- d) +140 mm oversize

The fine rejects stream contains finer particulate such as dust, glass particles etc. that need to be removed before the compost and dRDF streams. The fine screenings contain a large portion of the organic material in the waste. The coarse size screenings pass to a manual picking section where the recovery of selected recyclables takes place within fully enclosed air-conditioned cabins, followed by automatic recovery of ferrous and non-ferrous metal and baling/ densification systems. There is an automatic baling system for the recyclable materials and a dRDF preparation system incorporating a primary pulveriser.

After pulverisation material is transferred to the fuel densification (RDF) plant comprising: secondary screen, air classifier, cyclone and associated conveyors, and mechanical separation systems for producing compost plant feed and glass cullet. The +140 mm oversize materials including larger items such as cardboard, paper, dense plastic and textiles is also conveyed to the picking stations where suitable paper, card and various grades of plastic can be "picked off" as recyclates.

The residual material is then passed under a magnetic separator for the removal of ferrous metal items before being fed to the primary pulverisation process where it is reduced to a size suitable for RDF production. The material prepared in the primary process lines for the production of dRDF is transferred to the dRDF production process then to a suitable storage area, from where it is fed utilising a bucket loader into the combustor. The combustor design chosen for this facility is based on a conventional combustion grate specifically designed to handle waste products from domestic and commercial sources.

The installation consists of twin refractory-lined combustors fired by conventional hydraulically operated inclined rocking grates with gas-oil-fired start-up burners. Gases are ducted into two separate waste heat boilers, each stream having a superheater located between the first and second pass, before passing to an economiser section and gas cleaning system based on a fabric filter unit, followed by an induced draught fan and a single twin-flue 35 m high chimney.

The superheated steam passes to a multi-stage condensing turbine generator with steam conditions at the turbine stop valve of 250 psig and 250°C. The base of each combustor unit is refractory lined to a height of 4.5 m, whilst above this refractory section is a 5 m high water-cooled section connected directly to the waste heat boiler.

Gases exit from the top of the combustor via a refractory lined duct directly into the all-welded horizontal two-pass fire-tube waste-heat boiler designed to the requirements of BS 2790, 1989. There are three grates per combustor each of which has its own separate primary air plenum, each plenum having three compartments for optimising air distribution.

Gas recirculation is injected through three side openings down each side of the combustor through the same ports as the secondary air. With reduced primary air levels and re-circulation of c. 20% of the flue gases, very low NO<sub>x</sub> levels should result. This design arrangement also ensures a minimum gas retention time of not less than 2 s at a temperature above 850°C. A heavy duty screw conveyor at the base of the combustor moves the bottom ash to a wet ash conditioning unit.

To meet the environmental control requirements under the PPC Regulations, the flue gas treatment plant comprises hydrated lime and powdered activated carbon injection systems together with a fabric bag filter capable of operating at a continuous temperature of 180°C. Automatic on-line cleaning of the fabric bags is also incorporated. The plant also includes an air-cooled condenser housed in an acoustic barrier compound; together with a boiler feedwater treatment and dosing system.

## Co-incineration

The combustion of selected elements of the waste stream as substitute fuels in certain processes, (such as in cement kilns) is known as co-incineration. This also complies with the recent European interpretation of 'Recovery' (see chapter 4). There are a number of niche applications for co-incineration in the UK, and a recent example including a co-incineration element is being developed in Leicester. There have been a number of examples of applications by cement manufacturers for the use of waste tyres as substitute fuels for high temperature cement manufacture and this is likely to be a growth area due to the ban on landfilling of tyres which has already come into effect for whole tyres, as the result of the Landfill Directive. Some secondary liquid fuels and RDF may also be used for the purposes of co-incineration. Table 9.1 shows examples of co-incineration of alternative fuels in cement kilns in 2001, with the anticipated increase in variety and tonnage of waste-derived fuel usage estimated for the near future.

Table 9.1 UK cement industry use of alternative fuels\*.

Fuel	2001 – actual use (t)	Estimates of potential use in next 3-5 years (t)
Waste-derived liquid fuels	110 000	200 000
Tyres	40 000	290 000
Packaging and packaging waste	0	500 000
Waste oils	0	90 000 to 345 000
Meat and bone meal, (MBM)	0	140 000
Processed sewage pellets, (PSP)	0	40 000
Total	150 000	1 260 000 excluding waste oils 1 515 000 including waste oils

\*Source: British Cement Association, reproduced from House of Commons, Environment, Food and Rural Affairs Committee: 'Hazardous Waste', Eighth Report of Session 2001-02.

## Pyrolysis and gasification technologies

### Introduction

Conventional combustion systems (see chapter 7) dominate the EfW technology market – they are a well developed and established technology for treating municipal solid waste (MSW). These conventional systems operate by combusting waste in a large furnace in the presence of excess air. Newer, so called 'advanced thermal treatment' technologies based on pyrolysis and gasification are starting to be demonstrated at commercial scale. These technologies have a long history of application to fossil fuels and certain homogeneous waste fuels but their application to MSW is relatively new and there is no full-scale operational plant experience in the UK at present.

## Generic description of the technology

Gasification is a process by which a solid or liquid feedstock is converted to a gaseous product by partial oxidation under the application of heat. For organic-based feedstocks, such as most wastes, the resultant gas is typically a mixture of carbon monoxide, carbon dioxide, hydrogen, methane, water, nitrogen and small amounts of higher hydrocarbons. The gas has a calorific value (CV) typically in the range 4 to 10 MJ Nm<sup>-3</sup> when the oxidant is air, as is normally the case. Where the oxidant is oxygen (or oxygen-enriched air) the resulting gas is often referred to as synthesis gas and has a CV typically in the range 10 to 15 MJ Nm<sup>-3</sup>. The gas will contain traces of tars and particulate matter as contaminants and will need to be cleaned before use. The gasification process is not new: coal gasification has been used since the early 1800s to produce town gas and the first four-stroke engine was run on producer gas in 1876. The application to wastes, and in particular to MSW or products derived from MSW, is, however, relatively new and still in the early (commercial) demonstration stage.

Pyrolysis describes the process by which the feedstock is thermally degraded in the absence of an oxidising agent (air or oxygen). Thus, pyrolysis plants typically have a chamber or reactor that is sealed to prevent air ingress. In practice, complete elimination of air is difficult to achieve and some oxidation is likely to occur. The pyrolysis process produces gas, liquid and char, the relative proportions of which depend on the operational temperature, exposure time and type of feedstock. Long exposure (hours) with low temperatures (400–500°C) will maximise the production of char (charcoal is produced in this way). Short exposure (<1s) with high temperatures (500–1000°C), referred to as 'flash' pyrolysis, will give a higher proportion of gas or liquid. If a liquid fuel (pyrolysis oil) is desired, rapid quenching of the gaseous product is necessary. The liquid fuel can be stored and transported easily allowing greater opportunities for beneficial use.

Gasification and pyrolysis processes will produce two types of solid:

- Ash – derived from inert solid material already present in the waste, e.g., glass and stones
- Carbon char

The latter may have a variety of industrial uses or it could be used as a fuel product. Otherwise, it would be a residue requiring disposal. The char has a significant heat value and can be subjected to gasification – the resulting fuel gas can be mixed with that produced from the initial pyrolysis process.

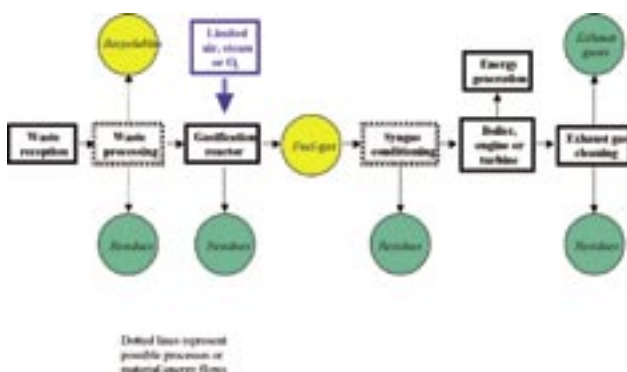


Figure 9.1 Gasification.

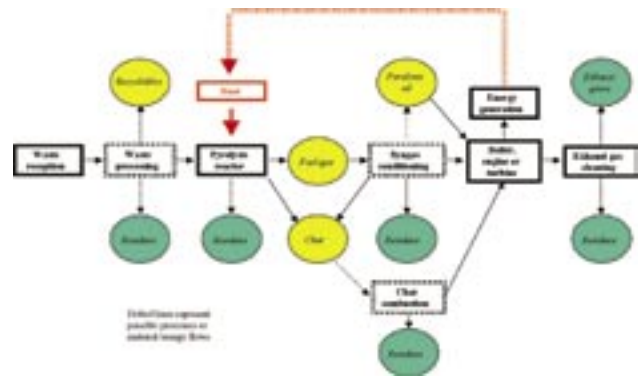


Figure 9.2 Pyrolysis.

## Characteristics and utilisation of intermediate fuels

The intermediate fuels produced by these thermal processes can be in gaseous and/or liquid form. Where a fuel gas is produced, its composition and calorific value (CV) will be dependent on the waste composition and type of process. Table 9.2 shows the typical major components for fuel gas derived from MSW.

Table 9.2 Typical composition of fuel-gas from processed MSW (% volume – dry gas)\*

	Fluidised bed gasification (air-blown)	Pyrolysis
CO	10	34
CO <sub>2</sub>	16	19
H <sub>2</sub>	7	33
CH <sub>4</sub>	5	6
C <sub>x</sub> H <sub>y</sub>	4	3
N <sub>2</sub>	54	5
Gross CV (MJ m <sup>-3</sup> )	5–7.5	11

\*Source: NERL 1996; IEA/EU 1997.

In addition to these major components, the fuel gas will also contain trace contaminants such as particulates, acid gases and heavy metals; these have the potential to cause operational problems in any downstream energy conversion process.

Liquid fuels (the fuel product of pyrolysis processes) typically comprises of 15–25% water with the remainder (organic) fraction comprising acetic and other acids, sugars and minor quantities of aldehydes, ketones and alcohols.

The conversion of fuel gas or liquid fuel to energy can be undertaken using conventional boilers or through a gas engine. The advantages claimed for this type of conversion, over more conventional combustion systems include the following:

- The comparatively smaller volumes of fuel gas are easier and relatively inexpensively cleaned of contaminants, unless using a conventional boiler and
- The potential for utilising higher temperature cycles and hence gaining higher conversion efficiencies.

The simplest, and most common, arrangement is to close-couple the gasifier, or pyrolysis reactor, to a burner with only minimal dust removal. The advantage is that the sensible heat of the gas is used fully and the equipment is relatively cheap. The disadvantage is that non-combustible contaminants, such as sulphur, nitrogen and halogen compounds, will pass through into the burner and into the exhaust gas where traditional end of pipe solutions will need to be applied. There is also the potential for fouling of the heat transfer surfaces and corrosion of boiler tubing.

Internal combustion engines will tend to be used at electrical outputs below 5 MWe. In particular, they are likely to be popular below 250 kW where mass production units can be used. The approach is likely to be modular, with the total capacity made up from several standardised units, following the same path as landfill gas. Where a high efficiency is necessary, gas turbines are likely to dominate over 15 MW capacity but are unlikely to be used below 5 MWe. An exception to this could come from the current interest in micro-turbines at under 250 kWe output.

### Process emissions and pollution control

Pyrolysis/gasification systems for processed MSW are still at a relatively early stage of development. Not surprisingly, therefore, the data set of commercial operation on emissions is limited and of variable quality. In many cases, the published data is the result of a single test in a pilot or demonstration plant and/or undertaken under conditions that are unrepresentative, e.g., of variations in feedstock.

Gaseous emissions will result from the combustion of fuel gas and/or liquid fuels. To meet the emission limits set in the Waste Incineration Directive, these emissions will need to be treated. The abatement technologies will be similar to those applied to conventional waste combustion i.e., selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) for NO<sub>x</sub> reduction, fabric filters for particulates, carbon injection and filtering for dioxins and semi-dry or wet scrubbing for acid gases.

Figures 9.1 and 9.2 indicate the potential for solid and liquid residues from several stages of the process. Ash residues are generally less than those produced from conventional systems but a contributing factor for this may be the pre-sorting that occurs before pyrolysis/gasification. Further, many of the processes involve a high-temperature stage, which tends to vitrify the ash. Carbon (char) and sulphur (removed from producer gas) are potentially recoverable for secondary use. Solid residues from the primary reactor may contain a higher proportion of heavy metal content of the waste input compared with conventional combustion and may also have a higher organic loading. The primary reactor and fuel gas cleaning processes may also give rise to liquid residues with potentially high organic loading.

### Process (energy) conversion efficiency

Many of the plant components for gasification/pyrolysis systems will be similar to those found for conventional combustion systems. The main difference will relate to the physical size e.g., as gas volumes are lower. For a given quantity of waste, one can expect to see smaller plant sizes – smaller fans, pumps, pollution abatement equipment etc. with a consequent lower energy use. Additionally, the production of a fuel gas or liquid fuel opens up the possibility of achieving higher power conversion efficiencies than conventional waste-fired systems, which are limited to steam-cycle generation.

However, in determining what exactly is the conversion efficiency one must take account of all of the process stages involved in the conversion of the waste feedstock. Gasification/pyrolysis systems may have additional plant requirements not normally associated with conventional systems e.g., pre-treatment facility to produce a homogeneous feedstock, oxygen generation plant etc. Residue treatment (ash melting and/or vitrification) will also consume energy.

Reported energy outputs for gasification pyrolysis systems are in the range 300 to 750 kWh t<sup>-1</sup> of processed feedstock (i.e., sorted and/or unsorted MSW). This compares to a typical output of 550 kWh t<sup>-1</sup> of MSW for conventional combustion systems using unsorted waste. Higher efficiencies should not be expected unless and until proven by several years' continuous operation and making due allowance for the higher calorific value of processed feedstock.

# 10. Flue gas treatment options

There are several commercially proven thermal treatment technologies used for processing municipal solid waste (MSW). Currently, the grate and furnace technology which is fuelled with 'as received' MSW, is the dominant technology. For this reason and space constraints, the contents of this chapter will concentrate on the flue gas treatment (FGT) options and issues related to the grate and furnace incineration of MSW.

Facilities used for treating MSW by means of thermal techniques are regulated and subject to the objectives and principles of EC environmental policy. Both new and existing incineration facilities are subject to the operational conditions and technical requirements embodied in EC Directives, Incineration of Waste, Integrated Pollution Prevention and Control (IPPC) and Landfilling of Waste.

The planning and IPPC authorisation processes require particulars of the plant and equipment to be employed including details of the FGT system that is to be used to control emission to atmosphere of pollutants formed by the combustion process.

Notable provisions that may influence FGT system architecture are listed in the following:

## Waste Incineration Directive (WID) extracts

- |             |  |
|-------------|--|
| Art. 4-2(c) | 'the residues will be minimised in their amount and harmfulness and recycled where appropriate'  |
| Art. 4-2(d) | 'the disposal of the residues which cannot be prevented, reduce or recycled will be carried out in conformity with national and Community legislation'                     |
| Art. 7-1    | 'Incineration plants shall be designed, built, equipped and operated in such a way that the emission limit values set out in Annex V are not exceeded in the exhaust gas'. |

## Integrated Pollution Prevention and Control (IPPC) Directive extracts

- |           |  |
|-----------|--|
| Art. 2-11 | 'best available techniques shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole: In determining the best available technique, special consideration should be given to the items listed in Annex IV' |
| Art. 3    | 'Member States shall take the necessary measures to provide that the competent authorities ensure that installations are operated in such a way that:<br>(c) waste produced is avoided in accordance with Council Directive 75/442/EEC of 15th July 1975 on waste; where waste is produced, it is recovered or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment'   |
| Art. 9-1  | 'Member States shall ensure that the permit includes all measures necessary for compliance with the requirements of Articles 3 and 10 for the granting of permits in order to achieve a high level of protection for the environment as a whole by means of protection of the air, water and land'   |
| Art. 9-4  | 'Without prejudice to Article 10, the emission limit values and the equivalent parameters and technical measures referred to in paragraph 3 shall be based on best available techniques, without prescribing the use of any technique or specific technology'  |
| Art. 10   | 'Where an environmental quality standard require stricter conditions than those achievable by the use of the best available techniques, additional measures shall in particular be required in the permit, without prejudice to other measures which might be taken to comply with environmental quality standards'  |
| Art. 11   | 'Member States shall ensure that the competent authority follows or is informed of developments in best available techniques'.   |

Table 10.1 Pollutant concentration at economiser outlet, typical values\*

Fly ash (dust)	mg Nm <sup>-3</sup>	3000–6000
Acidic gases HCl SO <sub>2</sub> HF NO + NO <sub>2</sub> as NO <sub>2</sub>	mg Nm <sup>-3</sup>	600–1800 peaks +3000 200–800 peaks +1500 10–30 250–500 peaks +800
Heavy metals	mg Nm <sup>-3</sup>	40–60
Volatile organic compounds	mg Nm <sup>-3</sup>	40–100
Dioxins/furans (PCDD/F)	ng.TEQ Nm <sup>-3</sup>	1–10

\* The above values are corrected to 273 K, 101.3 kPa and 11% O<sub>2</sub>, dry gas basis.

## Characteristics of MSW incinerator flue gases

Combustion of one tonne of MSW in a modern grate-type furnace will generate 5200–6000 Nm<sub>3</sub> h<sup>-1</sup> of flue gases with fluctuating composition and thermal properties. The flue gases contain a range of substances, classified as pollutants, which exhibit rapid variation in concentration due to the inherent heterogeneous nature of municipal solid wastes (see Table 10.1).

## Flue gas treatment

A number of physical and chemical processes are used in the capture/destruction of the pollutants that are present in the flue gases following the combustion of MSW. A variety of filtration devices are available for the removal of particulate matter (PM) from the flue gases, while acid gases, namely, HCl, SO<sub>2</sub>, HF, are absorbed by alkali reagents. Table 10.2 shows the capability of such devices. The capture of volatile organic compounds (VOCs), including dioxins and furans (PCDD/F) plus mercury compounds is realised through adsorption by Activated Carbon or HOK (a less expensive carbon product). Table 10.3 lists reagents used in FGT systems.

Nitrogen oxides, principally, NO and NO<sub>2</sub>, (NO<sub>x</sub>) levels can be lowered by various incineration combustion methods. However, as emission limit values for NO<sub>x</sub> are set lower, supplementary techniques become necessary. NO<sub>x</sub> is reduced to nitrogen, N<sub>2</sub>, when reacted with ammonia or urea. NO<sub>x</sub> levels lowered using a catalyst is termed 'selective catalytic reduction' (SCR). The injection of reagents into the flue gas at locations within the furnace/boiler is labelled 'selective non-catalytic reduction' (SNCR).

Table 10.2 Pollutant capture capability of abatement devices.

Abatement device	Symbol	Capability	Comments
Cyclone	Cy	Coarse PM	Mostly used as 1st stage on fluidised-bed combustor
Electrostatic precipitator (dry)	ESP	PM	General purpose particulate matter (PM) collector; long pedigree
Electrostatic precipitator (wet)	wESP	Aerosols	Used for capture of sub-micron PM and acid mist
Fabric filter	FF	PM	General purpose PM collector; much used on MSW Incinerator FGT systems; sensitive to condensation
Scrubber, wet	WS	PM;gases; VOCs	Several different designs; wide range of uses; materials of construction are important; needs water treatment plant
Spray dryer absorber	SDA	Contactor	Used to achieve interaction between reagents and pollutants, e.g., lime with acid gases
Selective catalytic reduction	SCR	NO <sub>x</sub> ; PCDD/F	Effective DeNO <sub>x</sub> controller especially for low emission limit values; destructs PCDD/F; life span dependent on effective pre-cleaning of gas
Selective non-catalytic reduction	SNCR	NO <sub>x</sub>	Injection of ammonia or urea in furnace/boiler. Ammonia 'slip' may be a concern; higher reagent consumption than SCR

Table 10.3 Reagents used in EfW flue gas treatment systems<sup>1</sup>.

Reagent	Formula	Application
Lime	CaO	Neutralisation of acid gases (HCl, HF, SO <sub>2</sub> / SO <sub>3</sub> , etc.)
Hydrated lime	Ca(OH) <sub>2</sub>	"
Limestone	CaCO <sub>3</sub>	"
Magnesium oxide	MgO	"
Sodium bicarbonate	NaHCO <sub>3</sub>	"
Sodium hydroxide	NaOH	"
Ammonia <sup>2</sup>	NH <sub>3</sub>	Reduction of NO+NO <sub>2</sub> to N <sub>2</sub>
Urea <sup>2</sup>	H <sub>2</sub> NCONH <sub>2</sub>	"
Activated carbon HOK	Carbon Lignite coke	Capture of dioxins/ furans, VOCs and mercury

- <sup>1</sup> The quantity of reagent consumed to achieve EC Incineration of Waste Directive (2000/76/EC) emission limit values (air) varies significantly with the type of flue gas treatment devices/system employed
- <sup>2</sup> Used as a direct injection into flue gas (SNCR) or in conjunction with a catalyst (SCR). SCR can also be used for destruction of PCDD/F

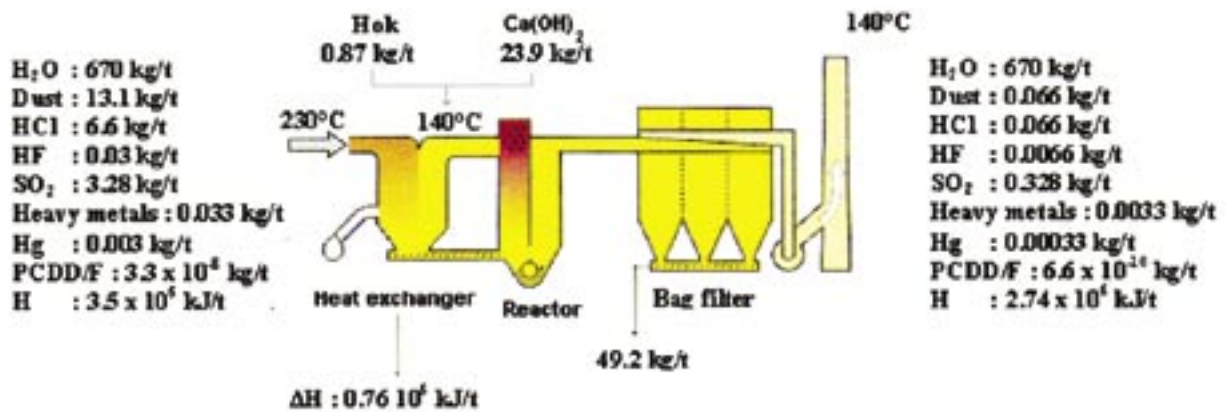


Figure 10.1 Mass and thermal balances of a Dry flue gas treatment system per tonne of MSW fired.

### Flue gas treatment systems

The type and architecture (sequence) of devices/equipment selected to control the pollutants have a direct bearing on FGT system potential for emission compliance reliability and the nature and amount of residue/by-products generated. There are three basic categories of FGT systems in common use on MSW incinerator applications at this time, namely, dry, semi-dry and hybrid.

### Dry flue gas treatment systems

As the name implies, 'dry' type systems function with dry reagents (hydrated lime, activated carbon) being injected, in a controlled manner, into the raw flue gases with the resulting solids, comprising a mixture of reaction products, fly ash and excess reagents being removed from the flue gases by means of a fabric filter (see Figure 10.1). The retention of the reagents in the filter cake formed on the filter surfaces contributes to an additional pollutants capture capability, particularly for dioxin/furan (PCDD/F) and mercury (Hg) compounds. Low temperature dry FGT systems i.e., systems that incorporate a heat recovery component, have a higher acid gas removal efficiency which offers operation at a lower stoichiometry. Mercury removal efficiency also benefits from lower flue gas temperature regimes.

Sodium bicarbonate is an alternative reagent for the capture of acidic gases which has been used selectively in dry systems. The bicarbonate residue solubility issue (as regards disposal) has been mitigated by at least one supplier who operates a residue takeback service.

Where it is necessary to supplement furnace control of NO<sub>x</sub> levels, both SNCR and SCR are technologies which can be applied. The effect of ammonia 'slip' (see Odour section later in this Chapter) on the residue and stack emissions needs to be addressed in the FGT selection process. The mono-residue generated by dry systems has a high potential solubility coefficient and consequently severe heavy metals leachability. Dry systems residue in the UK is landfilled in hazardous waste landfills. In several other countries, dry system residue has to be processed to provide a more stable material before being admitted to any class of landfill.

### Dry system byproduct

Dry systems offer an improved energy recovery opportunity compared to semi-dry systems, but less than certain Hybrid systems. There is no direct material byproduct to be obtained from this type of flue gas treatment system.

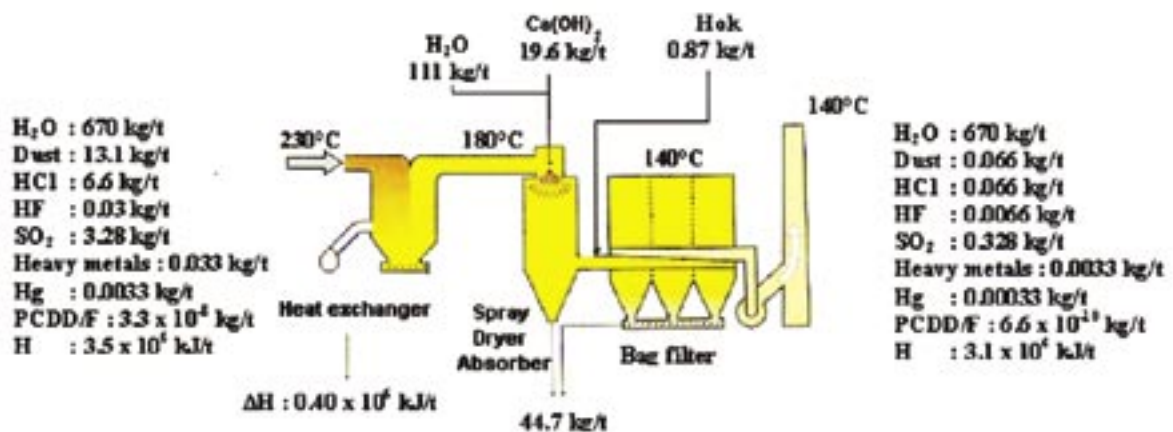


Figure 10.2 Mass and thermal balances of a semi-dry flue gas treatment system.

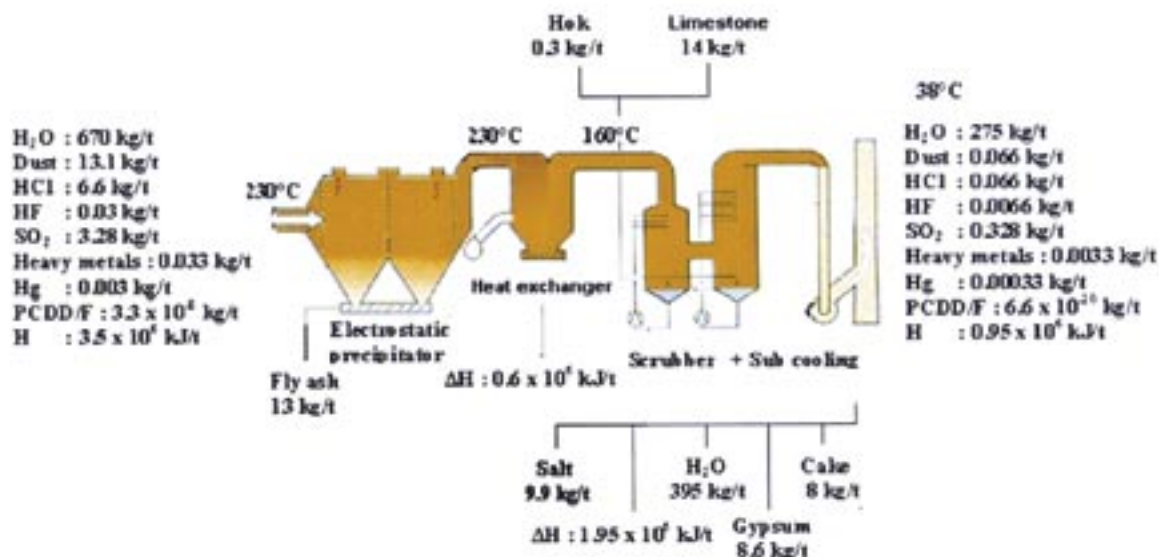


Figure 10.3 Mass and thermal balances of a hybrid flue gas treatment system per tonne MSW fired.

### Semi-dry flue gas treatment systems

Semi-dry flue gas treatment systems operate by injecting a water-based slurry of lime into the flue gases by means of a rotary atomiser(s) or dual-fluid nozzles (water/air) mounted on a spray dryer absorber (SDA) vessel. The regulated slurry spray is distributed throughout the flue gas and liquid-gas reactions and drying takes place, accompanied by cooling of the flue gas (see Figure 10.2).

A portion of the fly ash, the generated reaction solids and excess reagent(s) are deposited in the base of the spray dryer absorber vessel before being extracted by means of an air lock device. On exiting the spray dryer absorber vessel, the flue gases enter the fabric filter where the entrained pollutants are removed. In the semi-dry system, removal of mercury compounds and PCDD/F is achieved through contact with activated carbon injected into the flue gases before the filter either as a powder or combined into the lime slurry at the SDA (see Figure 10.3). As in the Dry FGT system, the cake on the fabric surfaces contribute an important pollutant capture capability for semi-dry FGT systems and a residue is generated that has to be disposed of in hazardous waste landfills.

#### Semi-dry system byproduct

Due to the thermal energy required to completely evaporate the water slurry injected into the flue gas in the SDA, semi-dry systems provide the least energy recovery. There is no direct material byproduct to be obtained from this type of flue gas treatment system.

### Hybrid flue gas treatment system

Hybrid is a term used herein to denote flue gas treatment systems that incorporate both dry and wet techniques and is aimed at maintaining reliable compliance with emission limit values while consuming the least possible amount of reagent and providing by-product options and consequently minimal quantities of residue for disposal.

The structure of a hybrid FGT system (see Figure 10.3) employed on MSW incineration applications begins with a dry particulate removal device, usually an electrostatic precipitator (ESP) for capture of the flyash. MSW flyash has a significant alkali content which can be extracted by washing then used as reagent to absorb HCl and HF in the first stage wet scrubber. The washed flyash can be of a quality suitable for direct admission to appropriately licensed landfill without further treatment.

On exiting the ESP, the flue gases enter the first stage of the wet scrubber where the flue gases are quenched to the adiabatic saturation temperature by means of water sprays. The high solubility of HCl and HF in water ensures that the rapidly fluctuating concentrations of HCl and HF are absorbed. The pH of the first stage water circulation circuit is controlled by the addition of reagents i.e., lime or limestone, caustic soda or flyash alkali.

The second scrubber circuit is maintained at the optimum pH for the removal of SO<sub>2</sub>. Calcium-based reagents, lime or limestone are usually employed in the second circuit which permit the production of gypsum from the captured SO<sub>2</sub> if desired. Magnesium oxide and sodium compounds can also be employed as reagents.

The combination of dry and wet techniques ensure capture of heavy metals and volatile organic compounds; however, to satisfy compliance with environmental regulatory controls, activated carbon or HOK (an inexpensive coke) is used to absorb Hg and PCDD/F. Where the supplementary DeNO<sub>x</sub> technique is used upstream of the wet scrubber, the unreacted ammonia is absorbed in the wet scrubber.

#### Hybrid system by-product

Hybrid flue gas treatment systems have been designed to provide a range of commercial grade products. From flue gas HCl, salt and hydrochloric acid and gypsum from the SO<sub>2</sub> can be derived. Utilisation of fly ash alkali in the wet scrubber reduces the consumption of reagent used to control emissions of acid gases.

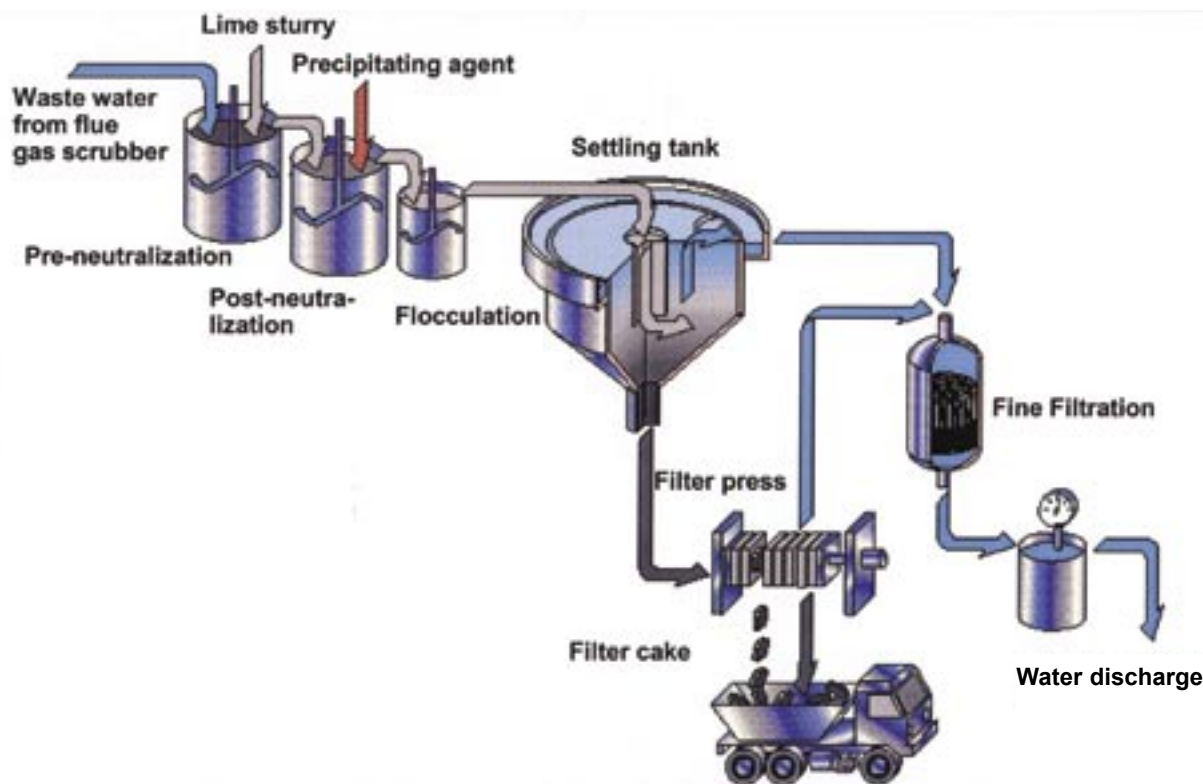


Figure 10.4 Schematic diagram of a wet scrubber wastewater treatment plant aquatic discharge.

A number of Hybrid FGT systems have incorporated a sub-cooling circuit linked to a heat pump in order to extract the maximum energy from the MSW fuel. This energy 'bonus' is fed to district heating systems which can result in an energy utilisation of over 90%. A by-product of sub cooling is the condensation of significant quantities of water.

### Wastewater treatment

A wastewater bleed stream is produced by the wet scrubber component of hybrid flue gas treatment systems. Wastewater bleed streams can be accommodated in a number of different ways, the choice being dependent on prevailing environmental and commercial circumstances. Discharge to an aquatic environment has been a favoured option in continental Europe, however, a number of EfW facilities have opted for a zero discharge approach. A by-product-zero discharge route requires an evaporator unit in order to produce a commercial quality salt, NaCl or CaCl<sub>2</sub>. One of the important considerations in adopting the by-product-zero discharge route is an officially sanctioned access to the market place. The alternative zero-discharge option is for the wastewater stream to be evaporated by injecting it into the flue gas upstream of a Particulate Matter (PM) removal device.

Where wastewater from an EfW hybrid device is to be discharged to an aquatic environment, it must be treated to achieve the permitted emission limit value, which is at least equal to the standard set out in Article 8 of the Incineration of Waste Directive and the associated Annex IV.

The wastewater treatment system shown in Figure 10.4 is typical of the designs employed for EfW applications. Since the volume of the wastewater bleed stream to be treated is usually engineered to be low, the resulting treatment plant is comparatively small and can be sited at an appropriate location. The wastewater treatment chemistry is well established and reliable. Consumption rates of readily available reagents is modest, while the filter cake, containing encapsulated pollutants extracted from the wastewater, can be disposed of in a landfill without further stabilization treatment.

### FGT system – emission monitoring

The measurement requirements for EfW plant compliance with pollutant emission limit values for both air and water are stipulated in the facilities permit conditions and are also extensively detailed in EC Incineration of Waste Directive, Articles 10 and 11. There are a number of Directive requirements that foreshadow the progressive nature of the compliance regime. To obtain a valid daily average value measurement, no more than five half-hourly average values shall be discarded due to malfunction or maintenance of the continuous measurement system in any day. Similarly, no more than 10 daily average values shall be discarded per year due to malfunction or maintenance of the Continuous Emissions Monitoring equipment (CEM). These and other such requirements place a major onus on the accuracy and reliability of data acquisition and processing systems and their preventative maintenance.

### Odour

Flue gas treatment systems that employ post-combustion SNCR technique that utilises ammonia/urea reagents to achieve NO<sub>x</sub> emission compliance standards are a potential source of an odour problem. SNCR systems need to have a feedback control link

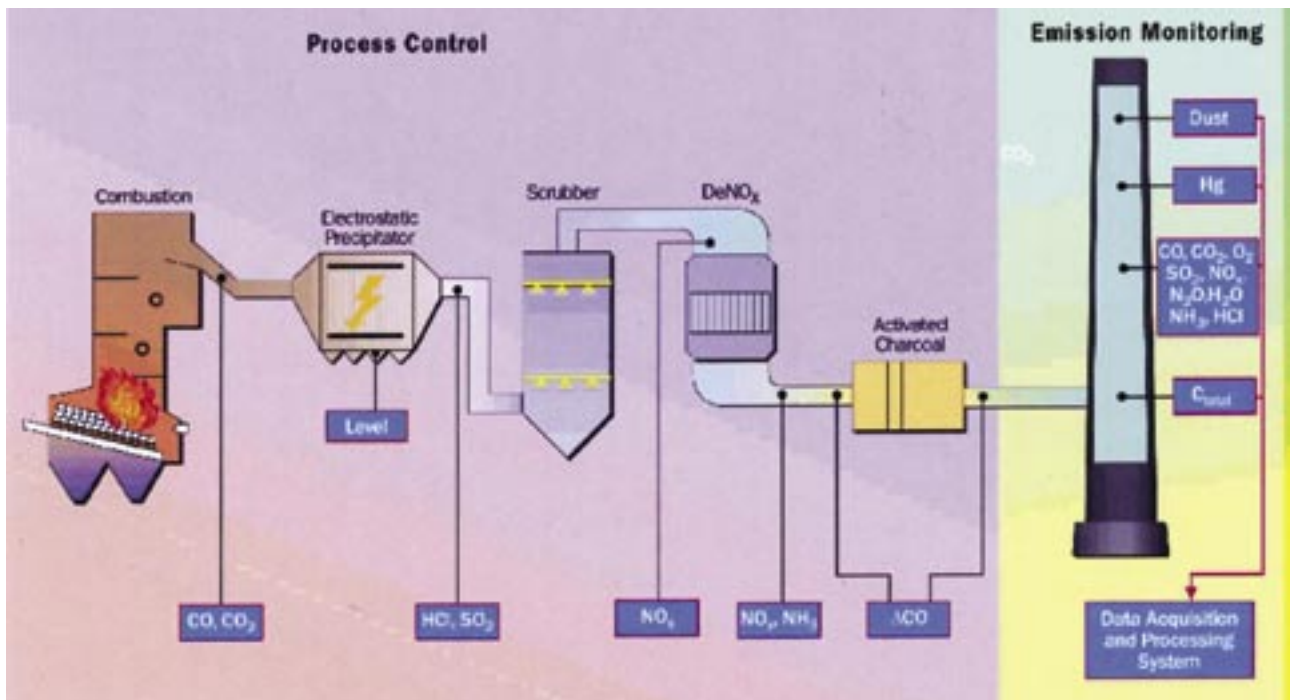


Figure 10.5 Schematic diagram of control and compliance analyser locations.

with the stack mounted NO<sub>x</sub> emission monitor, so as to regulate and optimise the amount of reagent injected into the flue gas at points in the furnace/boiler. The rapid, substantial variations in NO<sub>x</sub> concentrations and distribution generated by the combustion of MSW gives rise to an inherent problem for SNCR systems, since the stack NO<sub>x</sub> signal measures an event that has happened at some previous time. This feature can lead to the injection of an excessive amount of reagent resulting in a quantity of unreacted ammonia being present in the flue gas, 'ammonia slip'. Ammonia slip can give rise to two problems, namely, a residue odour problem (principally with Dry and Semi-dry FGT type systems) and an ammonia based aerosol emission problem. SCR type DeNO<sub>x</sub> systems positioned in 'clean gas' avoids the residue odour problem and NO<sub>x</sub> levels can be measured upstream of the SCR unit which benefits the accuracy of reagent injection.

## Noise and vibration

MSW incineration facilities have noise limit conditions incorporated in both planning permits and operating authorisations (see chapters 4 and 5). Prevention of noise at source is achieved by specifying low-noise equipment. Where such low-noise equipment cannot be supplied, acoustic enclosures may be fitted to equipment that generate troublesome noise. The primary potential source of excessive noise produced by FGT systems stems from the induced draught fan. While careful noise-level design specification is standard practice, equipment, especially ducting, configurations can lead to excessive noise conditions being experienced. Modifications to the FGT systems to incorporate a silencer at the tailend of the system will assist in compliance with the specified noise standard. Vibrations may be controlled by fitting appropriate control devices (damper mountings) and or providing separate base plate foundations.

## Study of recent FGT system projects

EU member States are required to adopt and comply with EC Directives within a stipulated timescale. The current trio of Directives that are undergoing this process (IPPC, Incineration of Waste, Landfill) incorporate statutory provisions that can influence the role and design of EfW flue gas treatment systems.

A recent study of flue gas treatment systems installed on both new and existing continental EfW plant was carried out in order to determine whether there were any common features. Table 10.4 shows a part listing of the projects examined in the study. The conclusion of the analysis was, in short, that there is no comprehensive design consensus. However, whilst the study embraced several countries with known distinctive regulatory environmental policies, there was evidence to indicate a degree of commonality or purpose for several system features:

### System preference

The key drivers are:

- Reliable compliance with emission limit values
- Minimise consumption of reagents
- Minimise quantity and harmfulness of residues
- Maximise energy recovery
- Recovery of byproducts, e.g., Gypsum.

Thus, a preference for hybrid-type systems was found in the survey. Generally the treated wastewater from the hybrid systems was discharged to an aquatic environment.

Table 10.4 Selection of recent MSW incinerator FGT system architecture (as at 3/2003).

Facility	SNCR	SDA	EV <sup>1</sup>	ESP	AC	FF	wetS	wESP	FF	SCR	WT <sup>2</sup>
Azalys (F) 2 x 7.5 tph				✓			✓	✓		✓	(Salt)
Fribourg (CH) 1 x 15 tph				✓			✓	✓		✓	(TIL- WD) <sup>3</sup>
INDAVER (B) <sup>4</sup> 2 x 20 tph			✓		✓	✓	(Gypsum)				
ISSEANE (F) 2 x 30.5 tph				✓		✓				✓	
Malmo (S) 1 x 25 tph				✓			✓	✓		✓	(WD)
SRS (D) 1 x 16 tph		✓			✓	✓					
St.Ouen (F) <sup>4</sup> 3 x 28 tph				✓			✓			✓	
Taejeon (K) 1 x 8.3 tph		✓			✓	✓				✓	
Toulouse (F) 1 x 14 + 3x8 tph	✓				✓	✓	✓				(WD)
Wels (A)				✓			✓		✓	✓	(WD)

#### NOTES

- 1 Evaporator for waste water bleed stream.
- 2 Wastewater treatment plant.
- 3 A flyash washing unit to recover alkali that is used as reagent in a wet scrubber for neutralising captured acid gas pollutants; wastewater treatment plant discharge to aquatic environment.
- 4 These projects are upgrades on an existing facility.

#### DeNO<sub>x</sub>

A clear majority of the project's studies had incorporated SCR technology for DeNO<sub>x</sub>. Many of these SCR systems are designed for limiting NO<sub>x</sub> emissions to 70 mg Nm<sup>-3</sup> or less. Since SCR technology economics is heavily weighted by catalyst lifespan, the SCR units were usually located at a 'clean' gas location. By January 2003, the original catalyst installed at the Spittelau EfW plant in Vienna was still in effective operation after 105 000 hours online. The catalyst at Spittelau and other 'SCR' plants, is also used to control emissions by destruction, of dioxins/furans (PCDD/F).

#### Summary

The present list of pollutants and specified emission limit values may well be increased in the future. Polycyclic aromatic hydrocarbons (PAH) are likely candidates, but other pollutants may also be included. Similarly, the severity of certain emission limit values may also be increased. Current opinion suggests that the NO<sub>x</sub> emission level will lead the way.

The need to keep the plant operational is paramount for the well being of EfW facilities. This well being is becoming more exposed and dependent on the accuracy and reliability of measurement systems for control and compliance. On-line regulation, which has already been employed in some places, may become a requirement in future.

When the Environment Agency guidelines together with the EC Best Available Techniques reference (see chapter 4) documents for the incineration and landfilling of waste become available, the way forward for EfW plant and flue gas treatment systems, in particular, should come into focus. Meanwhile, consideration ought to be given to examining the various options for a future strategy.

The complex technical and economic influences to which developers and operators of EfW facilities are exposed are, in part, examined through life cycle cost analysis (LCCA). The potential consequences of EC Directives on flue gas treatment system selection, need an added emphasis on the identification and inclusion of all relevant factors related to the choice of flue gas treatment system including their consequential residue treatment/disposal versus cost implications.

# 11. Residue management

Thermal treatment has been adopted by many countries as an integral component of their waste management strategies. Thermal treatment of municipal solid waste (MSW) is dominated by 'moving-grate' incineration technology; however, it must be noted that incineration is not a disposal process. The incineration of MSW gives rise to several forms of residues, those created directly by the process i.e., heat energy in the form of high-temperature flue gas and solid residues, and the residue(s) created by the associated flue gas treatment (FGT) system (see Figure 11.1).

The recovery of the generated heat energy is widely practised and utilised as electricity or combined heat and power. In this context, the treatment of 'waste' has created a sustainable and commercially viable recycled product in the form of energy. The management practices adopted by various countries for solid residues embrace a range of utilisation (products) and disposal (waste) regimes.

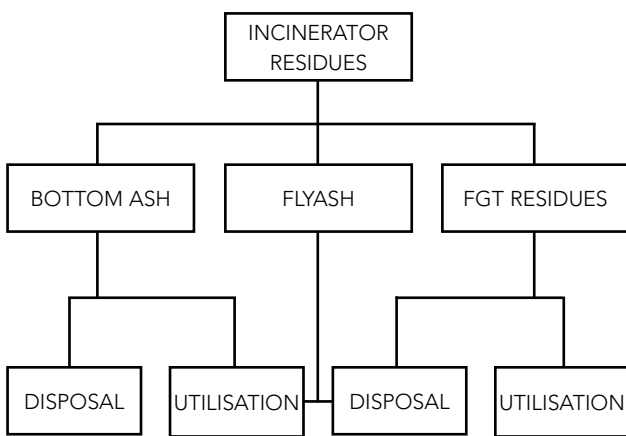


Figure 11.1 Residues from EfW plant and their waste management routes.

The influence of political, geological and financial considerations dictate the development and implementation of management strategies for EfW plant residues, which include:

- Regulatory encouragement for recycling
- Potential for reducing disposal costs
- Conservation of natural resources and landfill capacity
- Proximity principle
- Legislative mandate for sustainability.

The incineration of MSW reduces its mass by 65-75% with the several resulting solid residues being partitioned to different parts of the system. IBA is the principal residue stream, accounting for 80–95% of the total weight of residues generated; with boiler ash, flyash and FGT residue(s) making up the balance.

## Incinerator Bottom Ash

Incinerator Bottom Ash (IBA) assumes a pivotal role in the management of incinerator solid residues, partly due to its dominant arisings, and partly due to its physical properties being similar to natural aggregate.

### Physical properties of IBA

IBA can be characterised as a heterogeneous mix of slag, ferrous and non-ferrous metals, ceramics, glass, minerals and other materials. This mix can contain up to 20%, by weight, of oversized (>10 cm) items, e.g., metal objects, construction materials, large pieces of slag. When these materials are excluded, the particle size distribution is similar in classification to sand and gravel (see Figure 11.2).

## Definitions used for EfW plant solid residues

**IBA, Incinerator bottom ash** – IBA is the generic term used to describe the material collectively discharged from the bottom of the furnace. IBA is made up of two residue streams, namely; grate ash, which is the material discharged at the end of the grate, and grate siftings, the material that has fallen through the grate and collected beneath the furnace. Separate collection of these two 'IBA' streams can be beneficial for utilization of either or both streams.

**Boiler ash** – particulate matter (dust) entrained in the flue gas that is deposited in the heat recovery system by the flue gas. Boiler ash is usually discharged with flyash/FGT mono residue (see below).

**Fly ash** – particulate matter (dust) entrained in the flue gas on exit of the heat recovery system.

**FGT mono residue** is defined as the residue generated by single-stage filtration flue gas treatment systems, and comprises fly ash, products of reaction and unreacted reagents used in the pollution control process.

**Combined ash** is the mixture of all incinerator solid residues. This is a residue management practice that has been used in the USA.

**Filter cake** is the term given to the dewatered solid produced by the filter used for separating solids from the underflow of the settling tank of the wastewater treatment plant.

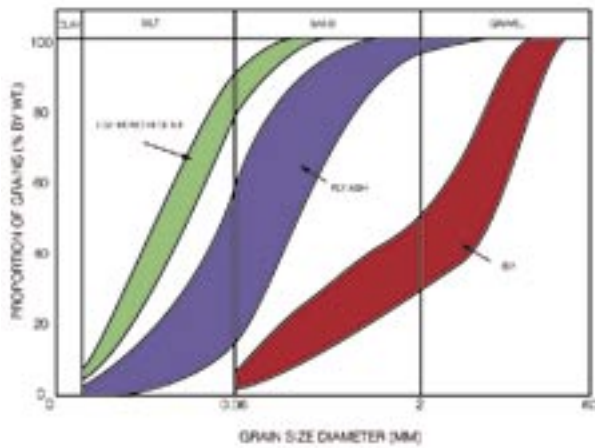


Figure 11.2 Comparison of particle size distribution of moving-grate EfW facilities

The specific gravity of most IBA is similar to porous light-weight aggregate; 1.5–2 for the fine fraction and 1.8–2 for the coarse fraction. IBA tends towards being a rough-textured, granular material with high specific surface areas, typically, 3–50 m<sup>2</sup> g<sup>-1</sup> dry material. The shape and contours of the IBA particles (morphology) are important contributory factors with respect to the physical properties of the material. Moisture plays an important part in compaction of IBA and, therefore, its properties for utilisation. The moisture content of bottom ash can vary widely and is generally considered to be a function of the type of quench tank / discharge system employed. Compacted IBA has good load-bearing capacities with acceptable durability for a number of commercial applications.

### Chemical properties of IBA

The chemical characteristics of IBA largely govern its interactive behaviour. IBA is alkaline in nature with pH values ranging from 9.5 to 11.5, primarily due to a high content of alkaline-earth and alkali elements plus metal oxides that convert to hydroxides after reacting with water. The solubility of IBA is relatively low compared with that of other incineration residue streams, with the material produced from a well-managed grate and furnace type EfW plant displaying a solubility in water of less than 14%.

Table 11.1 Range of concentrations of selected elements in IBA and soils (adapted from Lindsey).

Element	Symbol	IBA (mg kg <sup>-1</sup> )	Soils (mg kg <sup>-1</sup> )
Aluminium	Al	21 900–72 800	10 000–300 000
Arsenic	As	0.12–189	1–50
Barium	Ba	400–3 000	100–3 000
Carbon	C	10 000–60 000	
Calcium	Ca	3 900–123 000	7 000–500 000
Cadmium	Cd	0.3–71	0.01–0.70
Chlorine	Cl	800–4 190	20–900
Cobalt	Co	6–350	1–40
Chromium	Cr	23–3 170	1–1 000
Copper	Cu	190–8 240	2–100
Iron	Fe	4 120–150 000	7 000–550 000
Mercury	Hg	0.02–7.75	0.01–0.3
Potassium	K	750–16 000	400–30 000
Magnesium	Mg	400–26 000	600–6 000
Manganese	Mn	83–2 400	20–3 000
Sodium	Na	2 900–42 000	750–7 500
Nickel	Ni	7–4 300	5–500
Oxygen	O	400 000–500 000	
Phosphorus	P	1 400–6 400	200–5 000
Lead	Pb	98–13 700	2–200
Sulphur	S	1 000–5 000	30–10 000
Silicon	Si	91 000–308 000	230 000–350 000
Titanium	Ti	2 600–9 500	1 00–10 000
Zinc	Zn	600–7 800	60–2 000

The major elements comprising IBA (accounting for ~80% by weight) are oxygen, silicon, iron, calcium, aluminium and sodium. Table 11.1 illustrates the concentration range of (selected) elements found in IBA relative to those commonly found in soils.

The concentration of certain trace metals found in IBA is influenced by the type of combustor used and the quality of combustion. The degree of burnout can affect the quantity of calcium and silicon found in the IBA; while poor burnout has seen higher concentrations of volatile elements, such as cadmium, arsenic and organic carbon in the ash.

Table 11.2 Comparative mineralogy of IBA (all listings in descending order of abundance)\*.

Stämflü 1992	Vehlow et al. 1992	Kirby and Rimstidt 1993 <sup>†</sup>
SiO <sub>2</sub>	Fe <sub>3</sub> O <sub>4</sub>	SiO <sub>2</sub>
CaCO <sub>3</sub>	SiO <sub>2</sub>	CaSO <sub>4</sub> ·2H <sub>2</sub> O
Fe <sub>3</sub> O <sub>4</sub>	(Ca,Na) <sub>2</sub> (Al,Mg)(Si,Al) <sub>2</sub> O <sub>7</sub>	3(Al <sub>2</sub> O <sub>3</sub> )·2(SiO <sub>2</sub> )TiO <sub>2</sub>
Fe <sub>2</sub> O <sub>3</sub>	CaCO <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>
Fe	KA1Si <sub>3</sub> O <sub>8</sub>	FeO
FeO	NaAlSi <sub>3</sub> O <sub>8</sub>	CaSO <sub>4</sub>
Ca <sub>2</sub> Al(OH) <sub>7</sub> ·6.5H <sub>2</sub> O	CaAl <sub>2</sub> Si <sub>2</sub> O <sub>8</sub>	KCl
Na <sub>2</sub> Si <sub>2</sub> O <sub>5</sub>	FeCr <sub>2</sub> O <sub>4</sub>	NaCl
CaSO <sub>4</sub>	Ca(Mg,Fe)Si <sub>2</sub> O <sub>6</sub>	
(Ca,Na)(Al,Si) <sub>2</sub> Si <sub>8</sub> NaAlSi <sub>3</sub> O <sub>8</sub>	Fe <sub>2</sub> SiO <sub>2</sub>	
	Cr <sub>2</sub> O <sub>3</sub>	

\*Source: IAWG

<sup>†</sup> This material contains small quantity of fly ash

The mineralogy of IBA plays an important part in its leaching behaviour. Table 11.2 illustrates the results of three studies into the mineral phases of bottom ash from EfW plant. The data in Table 11.2 is derived from the following studies:

Stämfli (1992) examined IBA for the presence of mineral phases associated with strength development in the ageing process. Vehlow et al. (1992) carried out characterisation studies of three German facilities. Agreement was seen in the relative presence of major phases amongst the three facilities. Kirby and Rimstidt (1993) in their study examined IBA containing small quantities of flyash (see Table 11.2).

A significant fraction of the metals (lead, aluminium, copper and zinc) can be attributed to grate siftings, which are only 1-3%, by weight, of the total IBA. Separate collection of grate ash and grate siftings ought to be considered when residue management strategies are being formulated (see Figure 11.3).

The presence of trace organic compounds has been detected in IBA. The concentrations of these trace organics (PCDD/F, PAH, CB, CP) in IBA from modern grate and furnace EfW plant is low, being similar to concentrations measured in brown-field surface soils.

#### Treatment processes for IBA

It is important to distinguish between the treatment of EfW residues for utilisation and disposal. When treatment occurs for the purpose of disposal, it is economically advantageous to limit the use and cost of process treatment, e.g., additives, while maintaining compliance with the regulations.

In the case of utilisation of IBA, the process economics including the composition of the final product become very different, especially when the IBA component represents only a fraction of the final product.

#### Utilisation of IBA

Pre-processing of IBA by removal of oversized material, including ferrous and non-ferrous metal items, and screening is important. Separate collection of grate siftings and grate ash may be advantageous in certain circumstances, e.g., selected metal recovery from grate siftings.

A number of beneficial reactions take place when IBA is 'aged'. The aging process takes place when the IBA is stockpiled for a suitable period (3 months plus is typical). The water content of the IBA stockpile, c.16%, and exposure to the atmosphere are key elements in the aging process, resulting in oxidation, hydration, carbonisation reactions, and swelling. The formation of calcium silicate phases that are pozzolanic in nature are ascribed to the aging process. The aging process enhances the structural durability and chemical integrity of the IBA.

Stockpiling of ash should be carried out with leachate and run-off collection with suitable management of the liquids. Shelter from prevailing winds minimises wind erosion of the stockpile. The treatment of IBA by the above techniques may be regarded as, low cost, primary processes.

Other concepts that are employed for treating IBA include chemical and thermal procedures. Forced carbonisation of IBA (and FGT residues) reduces alkalinity and can significantly reduce release of some trace metals. Similarly, treatment with selective chemicals can also achieve reductions in trace metal releases.

Thermal treatment of EfW residues can be carried out to achieve sintering, i.e., melting to form a slag or a vitrified material (see below – FGT system residues and byproducts). Historically, the high energy demand and cost of thermal treatment of MSW incinerator residues has limited the deployment of such techniques, Japan being the exception. However, in France, vitrification of the separated fly ash component is now being applied commercially.

Physical utilisation criteria for IBA are mostly based on standard engineering tests. Specific physical requirements will vary depending on the type of application and specific project construction specifications. It is considered important to note that, in several applications, IBA is blended with other materials, e.g., natural aggregate, to achieve specific design criteria.



IBA used in construction material.

IBA that is considered physically suitable for use must be evaluated for its potential impact on the environment. The acceptability of a product for utilisation should be based on the extent of contaminant release anticipated over its lifetime. The acceptability criteria should include contaminant release rate and release potential. Pre-treatment of the IBA to remove soluble salts may be necessary for some applications.

The regulatory and economic circumstances relating to natural resources and civil engineering practices, prevailing in various countries, can reflect the attitude adopted towards the utilisation of IBA. The range of applications for which IBA has been used commercially includes:

- Landfill cover (daily and final)
- Road foundations
- Wind and sound barriers
- Lightweight concrete masonry
- Structural fill
- Aggregate in asphalt
- Shore-line protection
- Marine reefs.

Figure 11.3 Bottom Ash management options

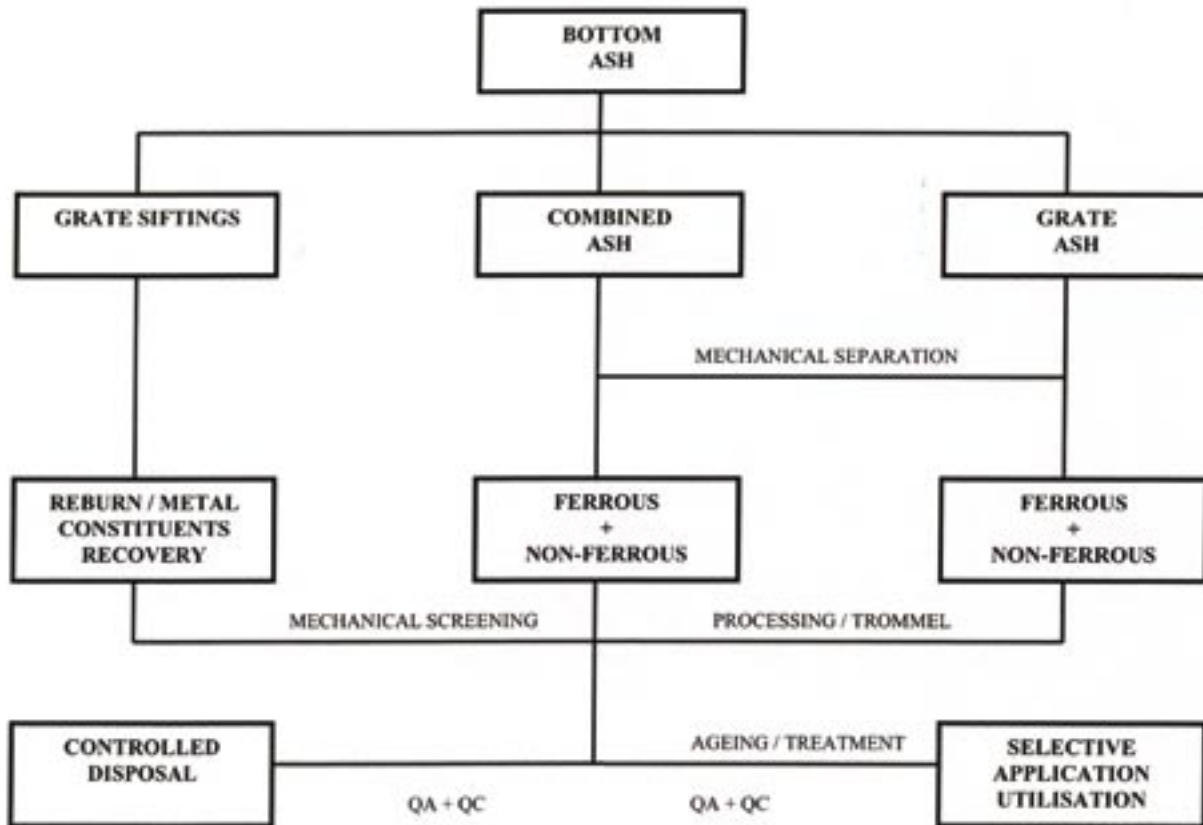


Figure 11.3 Bottom Ash management options

Table 11.3 Typical ranges of physical criteria and properties for (selected) IBA utilisation (Source: IAWG).

Requirement	Asphalt pavement	Concrete	Structural fill
Particle size distribution	Specific to location and application design. Uniformity coefficient (d60/d10) can be specified. Total content of fines (<60µm) <10% including all materials	Specific to location and application design. Uniformity coefficient (d60/d10) can be specified. Fines <10% (<60µm)	Specific to location and application design. Uniformity coefficient (d60/d10) can be specified. Fines <10% (<60µm)
Loss on ignition	<3%; lower values are preferred	<3%; lower values are preferred	<5%; lower values are preferred
Moisture content	< 15% (geotechnical); as dry as practical is preferred	< 15% (geotechnical)	
Durability	Specific to location and application design	Specific to location and application design; applicable to end product	Specific to location and application design Shear strength
Expansion	Ageing for >3 months at >16% moisture	Ageing for >3 months at >16% moisture	Ageing for >3 months at >16% moisture
H <sub>2</sub> evolution	Metal recovery for ferrous and non-ferrous metals recommended	Metal recovery for ferrous and non-ferrous metals required	Metal recovery for ferrous and non-ferrous metals recommended
Water retention and transmission			Hydraulic conductivity. Capillary suction.

## Incinerator Bottom Ash – a UK profile

IBA has assumed a pivotal role in the management of EfW residues in the UK (see Table 11.4). The reasons for the focus on IBA are two-fold:

- Its dominant arisings
- The similarity of its physical properties to natural aggregate.

Table 11.4 Estimated MSW incinerator solid residues arising in the UK in 2002.

IBA utilised	210 000 tonnes
IBA landfilled	240 000 tonnes
FGT mono-residue	95 000 tonnes
Non-ferrous metal	2 400 tonnes
Ferrous metal	1 000 tonnes

### UK case studies of IBA utilisation

#### Case study 1: Brownfield remediation, 2001, Middlehaven Dock Remediation Project, Middlesbrough

The original site was opened in 1842 as a coal port serving the Stockton–Darlington railway and was closed in the early 1980s. The surrounding area was derelict and required extensive reclamation and remediation. Harbour and General were appointed as main contractors by English Partnerships to carry out the project. Excavated silt was blended to the following proportions: 76% silt: 20% IBA: 4% O.P. cement, by weight. The material was then used as a stabilised engineering material. The work was carried out in accordance with the draft Contaminated Land Exposure Assessment standards with the full approval of the Environment Agency.

#### Case study 2: Road sub-base, 1999



#### Bypass road contract, Waltham Abbey

The work comprised a 4 km bypass to Waltham Abbey. The road was originally designed to Volume 7, Design Manual for Roads and Bridges, but subsequently modified with approval of Essex County Council, to obtain benefits. IBA was processed to meet the requirements of BS882, and was used as the aggregate with OPC 42.5 N Cement to provide the medium strength lower roadbase, meeting CBM 3R design criteria.

#### Case study 3: Car park basecourse, 2001

A 53 000 m<sup>2</sup> area, comprising heavily trafficked car park areas and distribution roads, utilised 2000 tonnes of IBA as a 20% replacement of primary aggregate (limestone) in the manufacture of the base course asphalt (BS4987).

#### Case study 4: Landfill liner overlay, 2000.



Cell construction at Burnhill landfill site

A fine aggregate was designated as overlay to the heavy duty plastic liner for the construction of a cell for the Burnhill landfill site at Brownhills, Tyne and Wear. Following the evaluation of test data, some 6000 tonnes of IBA (<6 mm) was used in this project. The IBA was laid and consolidated in a 300-mm layer over a HDPE liner on a 1:2.5 slope, in compliance with the Environment Agency guidelines for liner protection. The lower bulk density of IBA, compared with sand, meant that if sand was to be used for the same purpose, 8 000 tonnes would have been required.

#### Flue gas treatment system residues and byproducts

Guidelines for the implementation of EC Directives: IPPC, Incineration of waste and landfilling of waste have not, at this time, been finalised; therefore this section will, generally, reference practices adopted by other EU States for managing grate and furnace EFW plant residues and by-products generated by flue gas treatment (FGT) systems.

MSW energy from waste plant FGT systems give rise to residues that, with some exceptions, require treatment, to mitigate potential environmental impact, before being accepted for utilisation or disposal. The treatment processes for managing FGT system residues fall into three categories:

- Selective separation
- Stabilisation-solidification
- Vitrification.

#### Characteristics of FGT system residues

The character and number of residues generated by FGT Systems are influenced by the type and architecture of the abatement system. For example, fly ash may be removed before the acid gas cleaning stage; or alternatively, it may be captured along with the other designated pollutants, as in single-stage abatement systems, to form a mono residue. Hybrid FGT systems that incorporate a wet scrubber component can be arranged to provide commercial products, e.g., salt and gypsum. This significantly lowers the quantity and 'harmfulness' of the final residue (filter cake). The treated water bleed (liquid residue) from wet scrubbers may be evaporated by injection into the flue gas upstream of a dry PM collector, or, treated for discharge to an aquatic environment, e.g., sewer or river.



Landfill – Single stage FGT system residue (UK)

The chemical composition of FGT system residues is dependent on the composition of the incinerator feedstock as well as the type and architecture of the abatement system. Table 11.5 presents a comparative, element-based, composition of typical FGT systems operating on mass-burn MSW incinerator plant.

Table 11.5 Comparative composition ranges for FGT system residues from mass-burn MSW incinerations—partial element listing<sup>1</sup>

Element	Fly ash (mg kg <sup>-1</sup> )	Dry and semi-dry FGT mono residues (mg kg <sup>-1</sup> )	Fly ash/wet scrubber FGT system mixed residues <sup>2</sup> (mg kg <sup>-1</sup> )
Al	49 000–90 000	12 000–83 000	71 000–81 000
As	37–320	18–530	130–190
Be	–	0.5–0.9	1.5–1.9
Ca	74 000–130 000	110 000–350 000	93 000–110 000
Cd	50–450	140–3000	220–270
Cl	29 000–210 000	62 000–380 000	48 000–71 000
Cr	140–1 100	73–570	390–660
Cu	600–3 200	16–1 700	1 000–1 400
Hg	0.7–30	0.1–51	38–390
Mn	800–1 900	200–900	1 400–2 400
Na	15 000–57 000	7 600–29 000	28 000–33 000
Pb	5 300–26 000	2 500–10 000	5 000–8 300
Se	0.4–31	0.7–29	12
Si	95 000–210 000	36 000–120 000	120 000
Sn	550–2 000	620–1 400	1 000
Zn	9 000–70 000	7 000–20 000	20 000–23 000

## Notes

<sup>1</sup> Source: IAWG.

<sup>2</sup> Values shown do not represent wet scrubber systems which generate by-product(s) or systems that utilise flyash alkali as reagent for partial neutralisation of acid gases.

## Leaching tests

Leaching tests are used to predict the short and long term potential for pollutant release from FGT residues. Numerous leaching protocols have been developed to predict various aspects of leaching behaviour. Currently, there is no EC standard leaching protocol for FGT residues; each member State having to establish its own leaching test methodology.

Table 11.6 Leaching test results for typical FGT system residues by AFNOR X31-210 test protocol.

Component		'Dry' FGT mono residue	'Semi-dry' FGT mono residue	Untreated fly ash
Soluble fraction	%	85.0	69.0	25.6
Chloride	mg kg <sup>-1</sup> dry	380 000	245 000	105 000
CrVI	mg kg <sup>-1</sup> dry	110	200	800
Pb	mg kg <sup>-1</sup> dry	1 650	2 630	5 750
Zn	mg kg <sup>-1</sup> dry	7 200	6 100	10 550
Cd	mg kg <sup>-1</sup> dry	125	107	215
Ni	mg kg <sup>-1</sup> dry	53	275	56
As	mg kg <sup>-1</sup> dry	12	18	28
Hg	mg kg <sup>-1</sup> dry	11	18	20
COD	mg kg <sup>-1</sup> dry	1 860	1 980	1 850

It is self-evident that, for the proper management of FGT residues, it is necessary to employ a leaching criteria as part of the evaluation procedure to ensure that the residue is subjected to the treatment appropriate for utilisation or disposal. As the potential for leaching can change significantly over time and under different conditions, it has been suggested that more than one test be used, so as to provide the information necessary to assess potential leaching behaviour. Table 11.6 shows typical leach test results for FGT residues based on the AFNOR X31-210 leaching protocol.

## Selective separation

Selective separation is defined, herein, as a methodology that isolates specific constituents from the flue gases, generated by the incineration of MSW, by physical and/or chemical processes, in order to realise:

- Recovery of materials for utilisation
- Minimisation and/or conditioning of component(s) for disposal in compliance with regulations.

The technical and economic parameters for achieving the aims of selective separation is substantially influenced by the type and configuration of the FGT system employed.

**Fly ash**

Separate removal of the fly ash from the flue gases, provides several utilisation options:

- Washing of fly ash yields an alkaline water stream that can be used in a wet scrubber to remove acid gases and provide make-up water for the water evaporated in quenching the flue gases. Removal of the soluble constituents, by controlled washing, benefits the subsequent management of the fly ash, e.g., international experience has seen treated fly ash mixed with IBA to produce civil engineering products.

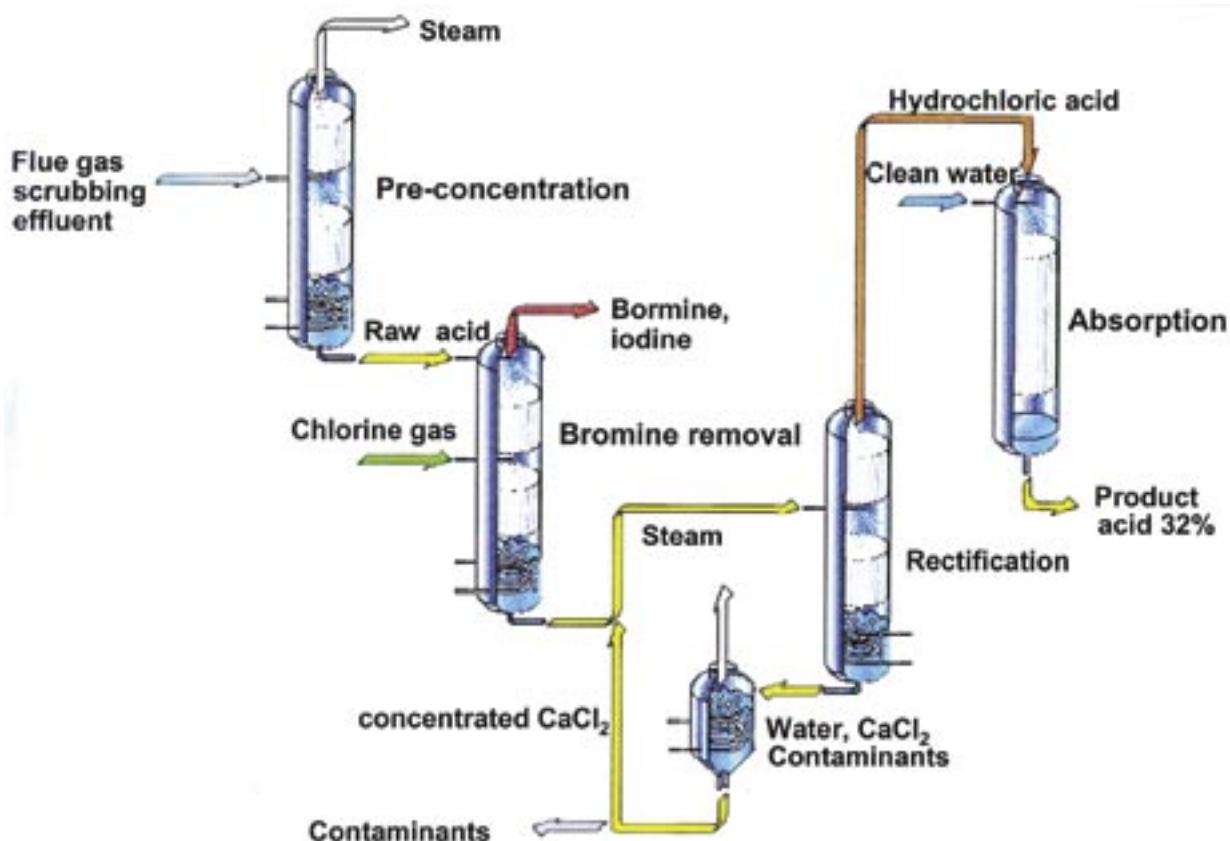


Figure 11.4 Hydrochloric acid production from MSW incinerator acid gas.

- The processing of fly ash in order to recover selected metal constituents is also being practised in certain locations.
- Fly ash is vitrified in some instances (see Vitrification section of this chapter).

**Acid gases**

The principal acid gases found in MSW incinerator flue gas are, nitrogen oxides ( $\text{NO} + \text{NO}_2 = \text{NO}_x$ ), hydrogen chloride (HCl), and sulphur dioxide ( $\text{SO}_2$ ). In addition, there are minor concentrations of hydrogen fluoride (HF) and sulphur trioxide ( $\text{SO}_3$ ) present. Although a major pollution factor,  $\text{NO}_x$  is not considered for

selective separation as defined herein. Separate extraction of HCl and  $\text{SO}_x$  ( $\text{SO}_2 + \text{SO}_3$ ) offers residue streams for the production of commercial grade products (see Table 11.7). To obtain a salt product, a dedicated wet scrubber circuit, using either a calcium or sodium-based reagent, is used. A number of European MSW incineration plants process the hydrogen chloride to produce hydrochloric acid (see Figure 11.4). The efficiency of the selective separation of  $\text{SO}_2$ , by a dedicated wet scrubber circuit using lime or limestone as reagent to produce gypsum, requires the circuit liquor to be at an optimum pH.

Table 11.7 Commercial products and markets for acid gases recovered from MSW incinerator flue gases.

Acid gas	Product	Market
HCl	NaCl	Road treatment (winter) Secondary aluminium smelting Animal hide treatment Water softening
HCl	$\text{CaCl}_2$	Road treatment (winter) A/C dessicant Soil stabilisation Lightweight concrete Coal washing
HCl	Hydrochloric acid	Regeneration of cationic exchangers for boiler feedwater Electroplating
$\text{SO}_2$	Gypsum	Building products Blender in cement manufacture

## Heat recovery

The energy content of the exit flue gases from the (conventional) heat recovery plant used on MSW grate and furnace EfW plant, is of the order of  $3.2\text{--}3.5 \times 10^6 \text{ kJ t}^{-1}$  of MSW combusted; the flue gas energy ('FGT energy') is of the order of 20% of the calorific value of typical MSW.

Grate and furnace EfW plant that operate on a combined heat and power energy concept, are in a position to recover a substantial proportion of this 'FGT Energy' by using a hybrid flue gas treatment system that incorporates a wet scrubber. Wet scrubber operation can convert sensible heat of gases into latent (water vapour) heat for the recovery of 'FGT energy'; an additional closed-loop water circuit, linked to a heat pump, is installed downstream of the wet scrubber. Plants with this configuration recover around  $1.95 \times 10^6 \text{ kJ t}^{-1}$  MSW, i.e., around 50% of the 'lost energy'.

A by-product of this supplementary energy recovery concept is that around  $300\text{--}400 \text{ kg t}^{-1}$  of water is produced through condensation of flue gas water vapour. In some regions, this water by-product could be important.

## Stabilisation-solidification

Stabilisation of FGT residues is considered to be a treatment that uses reagents to chemically transform soluble constituent pollutants into a less soluble form. Solidification of FGT residues is the physical encapsulation of the residual material with binders, e.g., cement, to reduce leaching of constituents. Solidification may also have a chemical influence, which may further reduce the solubility of constituent pollutants, particularly for target metal species.

While the disposal practices for fly ash and the other FGT residues vary in different countries, most have strict regulations governing the practices due to the presence of significant concentrations of leachable toxins. In the UK, the present (2003) approved management practices governing FGT residues dominated by mono residues from Semi-dry FGT systems, which is classified as hazardous waste is recorded as:

- Conditioning before disposal in dedicated mono-fill landfill
- Utilised as lime substitutes at liquid (acids) waste treatment plants.

The Waste Acceptance Criteria (Landfill Directive) and the provisions of the IPPC and Incineration of Waste Directives, when fully implemented, will have an influence on the existing disposal regime for FGT residues. This treatment may increase the weight and/or volume of the treated residue, thus leading to higher disposal costs.

Internationally, there are a number of stabilisation-solidification treatments being applied to FGT residues. Cost is one of the key drivers in the selection process as to which treatment process to use. Cement is, generally, a competitive product, for which there is a wealth of knowledge as to its chemical behaviour and a broad band of application experience, to support its preferred basic binder status for treating FGT residues. The selection of the appropriate type of cement is of the utmost importance, as are the preparation, manufacturing and curing procedures overseen by responsible quality control standards.

The solubility of the chloride salts, particularly  $\text{CaCl}_2$ , contained in significant quantities in FGT residues, can inflict serious damage to the physical strength and the durability of the stabilised-solidified product.

Pre-treatment of the FGT residue by washing, has been shown to have a beneficial effect on the strength and durability characteristics of stabilised-solidified products. A number of stabilisation processes have been/or are under development for treatment of MSW residues, including FGT residues.

Such processes are aimed, particularly, at reducing the solubility of selected metal constituents of residues. Stabilisation treatment alternatives (as with other treatment options) need to be assessed against the specific requirements of each situation, with regards to compliance with regulatory standards, efficiency and cost.

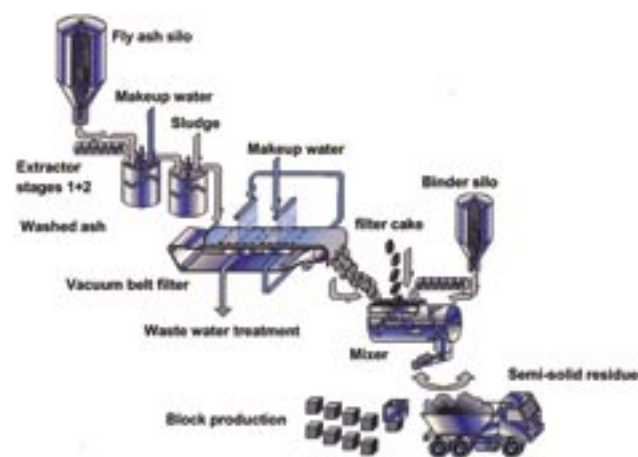


Figure 11.5 Solidification process for boiler ash and residue from Dry and Semi-dry FGT systems

## Vitrification

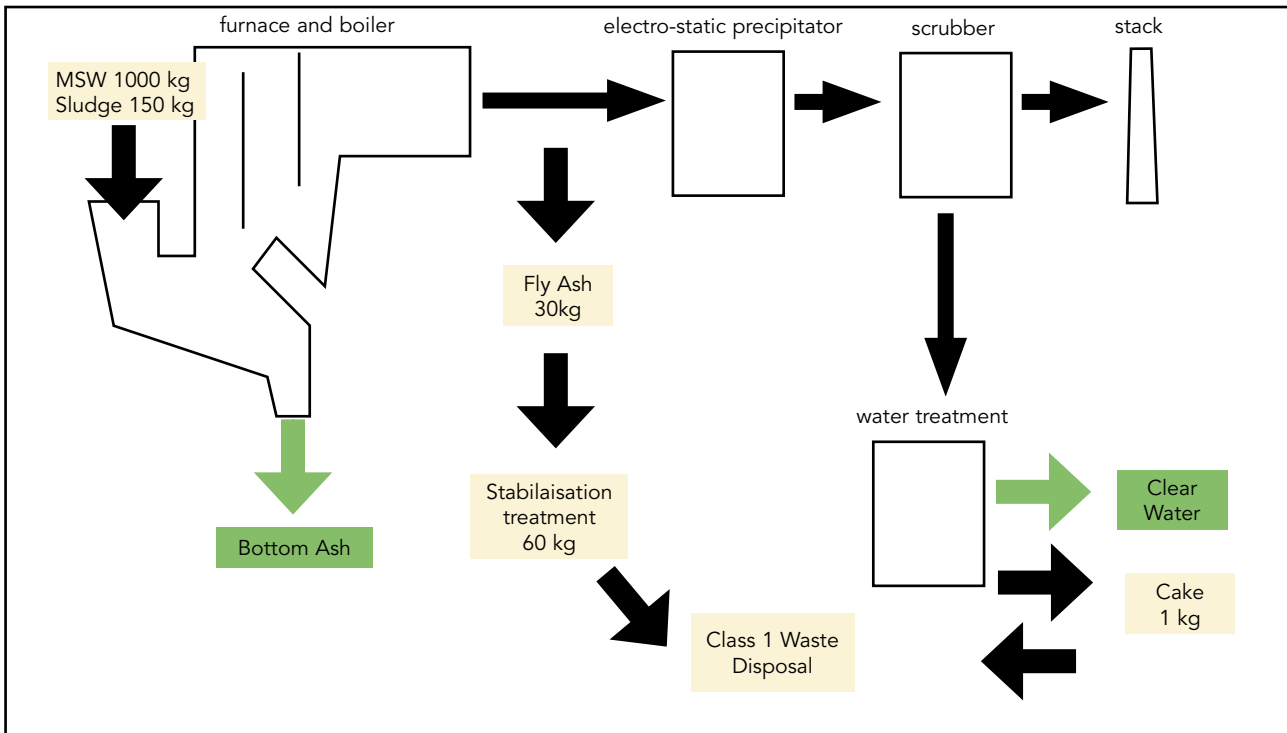
Various vitrification processes are being used to stabilise and solidify incineration residues. In Japan, due to the combination of geology and environmental attitude, vitrification of IBA and fly ash has been practiced for a considerable time.

At the present time, there is only one European facility that employs vitrification on a fully industrial scale to treat MSW incineration residue (fly ash). The CENON incineration facility ( $120\,000 \text{ tpa}$  MSW plus  $18\,000 \text{ tpa}$  sludge) is owned and operated by a company controlled by the Greater Bordeaux Metropolitan Community. The CENON vitrification unit commenced trial operations in 1997 and now operates on a 24 hour, 7 days per week schedule. The CENON vitrification unit employs a plasma torch to melt the fly ash, which is continuously injected into the reactor vessel. The resulting vitrified product has an appearance and properties similar to glass.

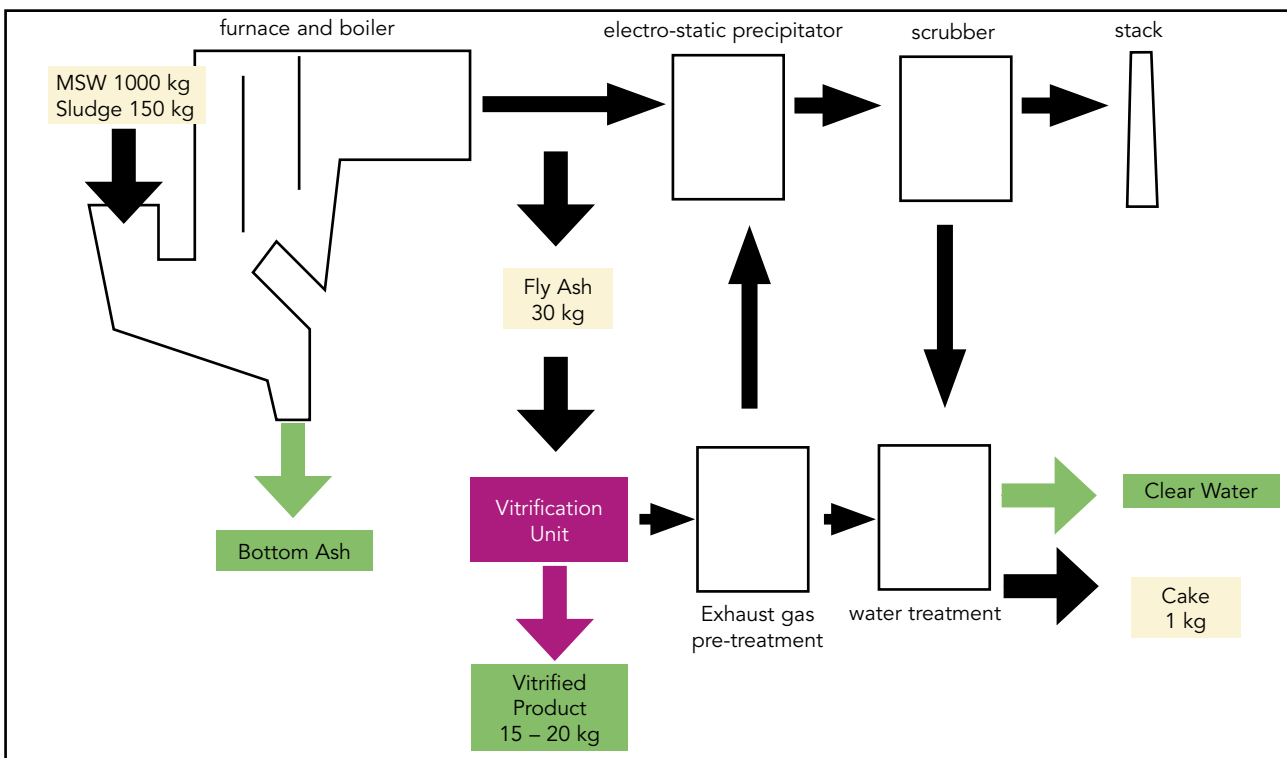
The justification for selecting the vitrification route for treating the fly ash at the CENON facility has been stated to be a combination of factors. French regulations stipulate stringent safety standards for the management of hazardous wastes that are to be disposed of in landfills. Stabilisation-solidification treatments of hazardous waste can substantially increase the mass of the material to be managed. The estimated cost of treating the fly ash from CENON by a stabilisation-solidification process and the cost of the tipping fee was calculated to be similar to that of vitrification.

The Greater Bordeaux Metropolitan Community desired that the final residue would be, inherently, environmentally benign, and, preferably, a safe material for commercial use. An extensive testing campaign has been carried out which verified the desired properties of the vitrified material. The use of the material as surface dressing for concrete products has also been realised.

A vitrification of incinerator fly ash programme has been launched (2002) at the St. Ouen, Paris, MSW facility (690 000 tpa) as part of the upgrade project.



Cenon plant WITHOUT vitrification of fly ash.



Cenon plant WITH vitrification of fly ash.

## 12. CHP/district heating

When considering the potential for waste to energy as a key component in the waste management hierarchy, the trend in the UK, guided by the various structural inducements and developer sensibilities, has been towards the generation of electricity. The development of integrated heat and power schemes has been restricted in the UK to a few cases where a sizable load of potential energy consumption infrastructure is in place, such as in Nottingham and Sheffield and in those areas where there are strategic or economic advantages such as island communities, e.g., Shetland. This aspect is not reflective of the wider European context, where it is estimated that 100 million people work in buildings supplied by district heating, a significant component of which is provided by EfW schemes.

The development of district or community heating schemes in the UK, whether serviced by conventional or waste-driven production, is limited. Although as demonstrated by current practice in Europe (Paris, Malmö, Stockholm etc), there is immense scope for larger non-fossil-fuel-fired schemes in major conurbations, only about 2% of the UK heating need is currently met by community Energy schemes.

When considering the opportunity for developing community energy on the back of existing EfW or as an integral component of a new scheme, the developer is faced with the same barriers as those faced by the developers of conventional, fossil-fuel-fired schemes. This adds to the intricacies of project development and, therefore, to development risk and cost.

EfW and Community Energy can however be mutually beneficial components of a wider business strategy over the long term. In order to fully appreciate the benefits attributable to integrated developments, we need to understand the various components that make up a Community Energy scheme and how they might interact with the use of waste as a source of energy. Indeed, schemes that are in place tend to expand the district heating network over time; the Paris district heating scheme is growing by 10% annually (largely provided by four EfW plant) and the Onyx Sheffield scheme is also expanding in terms of access and coverage (see case study).

### What is community energy?

In general terms community energy is the integrated provision of energy services (heat, power, cooling), from a central energy source, to multiple users, preferably across a number of market sectors. The community energy system is made up of three principal elements as shown in Figure 12.1.



Figure 12.1 The components of the Community Energy scheme.

Dealing initially with the technical solution, from the perspective of the EfW plant, the development of integrated energy services relies on the means of distribution and supply. That is the district heating (DH) mains and the systems transferring energy from the DH mains to the user. Figures 12.2 and 12.3 show examples of two components.



Figure 12.2 District heating mains being installed.



Figure 12.3 Domestic sized 'consumer' connection.

The fundamental technical components for distribution and supply have been in use for many years and the technology is well proven and provides the mainstay for heating provision in Scandinavia. However, other factors, not the technical components of the system, provide barriers to the development of integrated schemes.

## The market environment

Every home and business requires energy in the form of heating and cooling in some form or other. Conventionally, fossil fuels (and electricity in the case of cooling systems) meet this need. Community energy relies on the economies of scale brought about by the grouping of a number of heat users. The market is therefore as wide as the demand for heating and cooling. For commercial installations, there are greater economies in terms of cost and space saving for district heating schemes.

However, there are some prevailing issues that may hinder the development of community energy schemes. The market for the provision of heating is served predominantly by natural gas and there is a limited history of community energy, particularly in the private sector. This is partly attributable to the suppression effect of the previously nationalised coal and electricity industries. Therefore, the customer perception is of energy use as the combustion of fuel, as opposed to achieving a level of comfort.

The second problem relates to the perception of community energy itself. Due to the historical development of such schemes, community energy is predominantly public sector based and as such is viewed as suitable only for that sector. Thirdly, gas pipework infrastructure has, for the most part, been subsidised. This has allowed gas prices to remain suppressed thus hindering the development of capital intensive district heating systems as an alternative.

There are other barriers to the wide-scale development of community energy that relate to the deployment of the technology, the need to consider projects on a long-term basis and the cost of the infrastructure in the UK when compared with the rest of Europe. Despite this, there is a potential market, which, once serviced by community energy, is unlikely to disappear and can provide a sound basis for long-term revenue generation.

## Demarcation

There is a distinct line of demarcation between the management/treatment of waste and energy services. In terms of the infrastructure of supply, there is a distinct point at which energy is transferred from the EfW plant to the energy services systems. In the case of Nottingham, for example, steam is supplied from the EfW facility and the point of demarcation is at the start of the primary steam main. This can leave the responsibility for the production and distribution of heat and power separate from the waste treatment facility.

It is, however, the commercial demarcation that can provide the developers of EfW plants with a structure for developing integrated energy services. The provision of energy services via community heating need not be the responsibility of the EfW developer. By ring-fencing this component of the system, the EfW operator can focus on the activity of waste treatment whilst providing an economic benefit to the community.

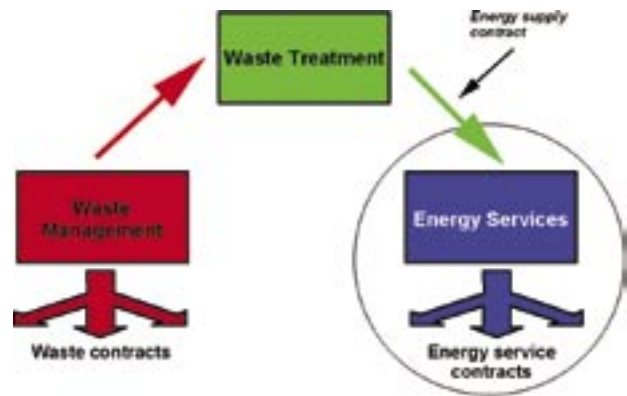


Figure 12.4 Demarcation between waste management and energy systems.

## Community heating and Energy from Waste

The provision of energy services depends on a reliable and cost-effective source of heat. The EfW plant is an effective mechanism for providing this. The two main community-heating schemes in the UK are powered by EfW incinerators. Nottingham and Sheffield are prime examples of the integration of the supply of heat and power, utilising waste as a prime fuel source. These schemes benefit from a flexibility afforded by the ability to manage output, with regard to either heat or power generation. The schemes do not rely on a single source of revenue, over and above that generated from waste management services.

In the case of Nottingham, the EfW plant was built after the community-heating scheme. This is similar to the majority of similar schemes in Europe, where the existence of large-scale community heating provided a basis on which to develop EfW (in parts of Scandinavia however, there are other additional incentives such as tax relief and no indigenous gas).

In the current UK environment, there are implications of developing large-scale community energy in conjunction with or subsequent to the development of EfW schemes. Developing an EfW facility may be problematic in its own right, without any added complication associated with integrated energy services development, such as:

- Managing the sale of heat, power and cooling
- The high capital investment required
- The need for a long-term strategy
- The need to secure the customer base
- The risk to revenue streams associated with utility services.

However, without the use of the heat from an EfW plant the energy/heat production efficiency of the facility is greatly reduced and the environmental benefits derived from the process similarly lessened. So what are the implications of applying the principles of CHP and community energy to EfW schemes? The following analysis of a typical application is based on a number of specific project developments. Applying the principles of CHP/Community Energy to EfW

The following is a review of the broad potential for developing an integrated energy scheme, based on energy supplied from an incineration facility.

### Scheme outline

The two components of the scheme are the EfW facility and the demand for heating and cooling. Table 12.1, below, shows the constituent elements of each component.

Table 12.1 Energy from Waste facilities and energy demand.

EfW plant	Energy demand
150 000 tpa	Mixed urban development
12 MWe	20 MW heat and 4 MW cooling
£42/MWh average electricity sales price	36 GWh heat use and 6 GWh cooling use
	Mixed refurbishment/retrofit

### Energy market

The energy market is currently served from conventional sources, gas boilers for heating and electric chillers providing the cooling demand. The cost of these conventional supplies is given in Table 12.2.

To serve this market, particularly in the early market entry stage, the service provider will need to show substantial cost benefits to users. In addition the revenues generated from the sale of energy must be sufficient to fund the investment, net of cost. A competitive charging structure can be considered as:

Heat supply	£20/MWh (18% saving)
Cooling	£35/MWh (16% saving).

### Costs

The principal costs associated with the integrated supply service are finance and energy. The finance element is defined by the cost of capital and extent of investment, as shown in Table 12.3.

Table 12.2 Conventional energy costs.

Heat costs				Cool costs			
Heating costs		£/yr	p/KWh	Cooling costs		£/yr	p/KWh
Fuel		222,923	1054	Elec. Day		259,227	2.18
Maintenance		37,433	0.26	Elec. Night		34,317	0.29
Replacement		56,250	0.39	Available charge		43,650	0.37
Insurance		11,230	0.08	Standing charge		783	0.01
				Meter Charge		543	0.00
				Maintenance		48,950	0.41
				Replacement		73,500	0.62
				Insurance		11,125	0.09
Sub total		327,835	2.26	Sub-total		472,095	3.96
CCL (y/n)	y	27,865	0.19	CCL (y/n)	y	27,659	0.23
<b>TOTAL</b>		<b>355,701</b>	<b>2.45</b>	<b>TOTAL</b>		<b>499,754</b>	<b>4.20</b>

NB: CCL is Climate Change Levy, y/n is yes/no

Table 12.3 Capital investment for community energy scheme

	Investment (£)	Specific cost (£/MW)
Heat only boilers	635,000	32
Civil work	210,000	11
Electrical	75,000	4
Heat storage	295,000	15
Candl	70,000	4
Chillers	230,000	12
Mains	2,200,000	110
Consumers	625,000	31
<b>Sub-total</b>	<b>4,340,000</b>	<b>217</b>

The cost of energy will depend on the marginal cost of heat supplied from the incinerator. This is a balance between the level of demand and the value of electricity generated relative to the technical specification of the power train. Based on a typical power train arrangement, designed to operate in CHP mode, Figure 12.5 shows the marginal cost of energy supplied to the community energy scheme for various power prices. Based on a core price of £42/MWh, the marginal cost of heat would be £0.61/MWh.

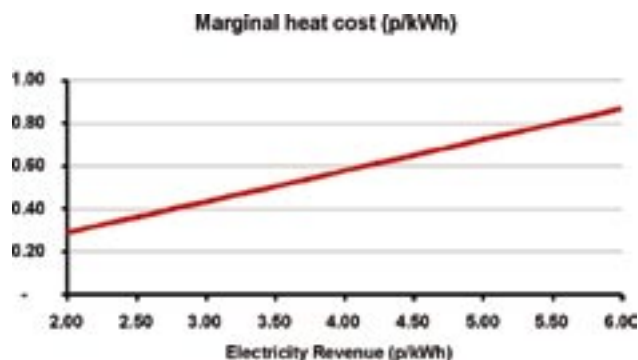


Figure 12.5 Marginal heat cost calculation.

## Cash flows

The consequence of developing an integrated scheme, is set out in Table 12.4.

Table 12.4 Simple cash flow analysis

Revenues	MWh	£/MWh	£/yr
Heating	36,000	20.00	720,000
Cooling	6,000	35.00	210,000
<b>Total</b>			<b>930,000</b>
<b>Costs</b>			
Capital			629,300
Energy	48,000	0.61	29,217
Maintenance			144,250
Operation			35,000
<b>Total</b>			<b>837,767</b>
<b>Margin</b>			<b>92,233</b>
			10%
<b>Return on investment</b>			<b>15.7%</b>
<b>CCL benefit</b>	<b>82,395</b>	<b>4.3</b>	<b>354,301</b>

The analysis shows an additional climate change levy benefit. This relates to the potential for the incinerator power train to operate as 'good CHP' as defined under the chpQA criteria. This would enable the electricity generated to be exempt from CCL, enhancing overall financial benefits. The criteria for Climate Change Levy (CCL) exemption is based on overall fuel efficiency as shown on Figure 12.6. If the annual level of heat sales falls between 49 and 70 GWh, then the criteria will be met, providing additional financial benefits to the power producer.

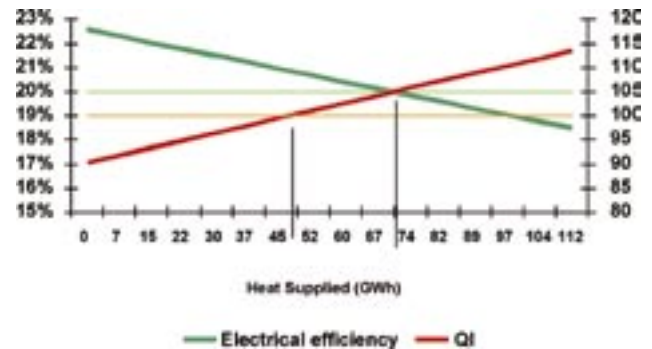


Figure 12.6 Good CHP criteria, 150 000 tpa incinerator.

## Sheffield Heat and Power

### Key success factors - Sheffield Heat and Power

Sheffield Heat and Power Ltd was established by Sheffield City Council in the 1980s, in response to the Government's private finance initiative (PFI), to implement an urban-scale district heating scheme using EfW. The key issue was to provide a district heating service in Sheffield that met guidelines requiring joint ventures between public and private sectors to be financed on a limited recourse basis, offering investors no greater level of security on investment than if the investment had been pure private sector.

Sheffield had been one of six cities studied by the Government as being suitable for urban scale combined heat and power and district heating and cooling (CHP/DHC). The existence of the MSW incinerator close to the city centre provided a readily available heat source. The incinerator had been planned as an EfW facility back in the late 1960s so the next step was a natural progression.

Confidence to proceed with development came from the Council's partners EKONO-Oy of Finland who had a track record of implementing successful CHP/DHC schemes worldwide and from the Department of Chemical and Process Engineering at the University of Sheffield, which provided independent confirmation that the technology was proven and that the proposed development plan was sound.

Careful planning and consultation was necessary because the general population was not aware of CHP/DHC and information had to be provided that enabled all stakeholders to make informed judgements. The joint venture was fortunate to receive the support of Lord Ezra who became Chairman of the limited company and who was instrumental in raising the necessary finance on a limited recourse basis (i.e., no subsidies or guarantees).

The company and the DHC network commenced heat delivery in April 1988 and have operated successfully up to present day, returning quality profits on a sound commercial basis each year. As a result of the Council's integrated waste management strategy the company is now owned by Onyx Sheffield Ltd, which continues to invest in the system and to manage the successful operation. A new incinerator is due to come into operation by the end of 2005.

The scheme now comprises 43 km of installed network, delivers 115 000 MWh of heat annually to 122 buildings including Sheffield and Hallam Universities, hospitals, commercial premises, leisure facilities and approximately 1 000 houses. The energy supplied annually from the MSW incinerator saves around 150 000 MWh of fossil fuels and subsequent CO<sub>2</sub> and NO<sub>x</sub> emissions.

In summary, the early planning done by the Sheffield Council and the partnership with the private sector created the opportunity for what is now the leading CHP/DHC project in the UK.

## Conclusions

There is a definite opportunity for the development of integrated energy and waste incineration schemes, based on the principles of community energy. The development of such schemes depends on a fine balance being achieved between the two principal components, waste treatment and energy services. The schemes that are in existence in the UK are successful in their own right and can provide an incentive to those considering new development opportunities.

The key factor in the development of integrated schemes is the need for a long-term commitment to the principles of integrated energy services, as demonstrated in both Nottingham and Sheffield (see over). In addition, a wider perspective is needed of both the range of opportunities and benefits that can accrue from such schemes, particularly for the consolidation of the waste treatment process. These include: increased efficiencies; the fact that CHP energy is now exempt from the Climate Change Levy; enhanced business opportunities; mixed revenue streams; a more positive environmental contribution from the process; and an enhanced perception of the industry as a whole.

# Appendix A. Glossary and Acronyms

## Glossary

Acid gases	A general term used to cover sulphur dioxide, hydrogen chloride, hydrogen fluoride and nitrogen oxides
As received waste combustion	The process of combustion of municipal waste in the same form as delivered to the facility (no significant pre-processing required)
Boiler ash	Particulate matter deposited in the heat recovery system by the flue gas
Best available technique (BAT)	The main basis for determining standards in IPPC under the PPC Regulations, defined as 'the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole'
Best Practicable Environmental Option (BPEO)	A BPEO is the outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term
Calorific Value (CV)	The heat liberated when a unit mass of a substance is burned as fuel under standard conditions
Climate Change Levy (CCL)	The levy chargeable on the industrial and commercial supply of taxable commodities for lighting, heating and power for certain sectors of business
Co-incineration	The combustion of more than one category of fuel in the same plant
Combustion air	The air that is supplied to allow the combustion of fuel to take place
Combined Heat and Power (CHP)	The production and utilisation of heat and power from a combustion process
Dioxins / furans	The generic name applied to two chemically distinct groups of compounds: polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)
District heating schemes	The heating of multiple community premises from a dedicated heat source
Electrostatic precipitator	A device, in which intense electric forces remove solid or liquid pollutants from flue gases.
Emerging technologies	Technologies that are either still at a developmental stage or have only recently started operating on a commercial scale on a municipal waste feedstock
Energy from Waste (EfW)	The production of energy from the thermal treatment of municipal wastes
Environmental Impact Assessment	An assessment of the environmental impact of a proposed development in compliance with legislative requirements
Environment Statement (ES)	The report on the results of an Environmental Impact Assessment
Filtration	The separation of solids from fluids
Filter cake	De-watered solid produced by the filtration process
Flocculation	The bringing together of finely divided material to allow solids to be removed from liquids
Flue Gas Treatment (FGT)	The techniques used to remove pollutants from flue gases to achieve compliance with emissions to atmosphere
Flue Gas Treatment mono-residues	The residue generated by single-stage filtration flue gas treatment systems, comprising fly ash, products of reaction and unreacted reagents
Fluidised-Bed Combustion (FBC)	A combustion technology in which a bed of particles (sand) is fluidised by injection of air, heated to temperatures high enough to support combustion, combustible material is added and the process becomes exothermic
Fly ash	Particulate matter (dust) entrained in the flue gas on exit of the heat recovery system
Gasification	The process by which a solid or liquid feedstock is converted to a gaseous product by partial oxidation under the application of heat
Incineration	A method of treatment of waste by combustion
Incinerator Bottom Ash (IBA)	The generic term used to describe the material collectively discharged from the bottom of the furnace
Integrated Pollution Control (IPC)	The regime, introduced from Part 1 of the 1990 Environmental Protection Act
Integrated Pollution Prevention and Control (IPPC)	A general term used to describe the regulatory regime applied to Part A installations under the PPC regulations which give effect to the IPPC Directive
Landfill Directive	A European Directive [1999/31/EC] intended to reduce the amount of biodegradable MSW sent to landfill
Landfill tax	A tax that is chargeable on waste disposed at landfill
Leaching	The removal by water of any soluble constituent from material
Life Cycle Analysis/Assessment (LCA)	An assessment of the environmental burdens associated with a product, process or activity, throughout its lifetime

Local Authority Pollution Control (LAPC)	The regulatory regime introduced under Part 1 of the EPA 1990, alongside IPC, and carried over (with some modifications) to co-exist alongside IPPC as implemented under the PPC regulations
Mass burn	Facilities that combust waste 'as received' with associated energy recovery
Mechanical biological treatment (MBT)	A process where a mechanical stage separates the recyclable and reject material to leave an organic fraction that is biologically treated to partially stabilise or prepare a feedstock for another biological or thermal treatment process
Moving grate	The most common type of grate mechanism in an EFW plant designed to carry the waste feed stock through the furnace.
Municipal Solid Waste (MSW)	In the UK, MSW includes household waste and any other wastes collected by a Waste Collection Authority, or its agents. The definition varies in other European Countries
Non-Fossil Fuel Obligation (NFFO)	A scheme whereby electricity generated from sources other than the burning of fossil fuels gains preferential rates. Now replaced by the Renewables Obligation
Oscillating kiln	Furnace that demonstrates an oscillating motion to distribute and combust waste feedstock
Pollution Prevention and Control (PPC)	The UK regulations implementing the requirements of the IPPC Directive
Proximity principle	The principle that states waste should be managed and disposed of as close to the point of production as possible
Pyrolysis	The process by which the feedstock is thermally degraded in the absence of an oxidising agent (air or oxygen)
Reference document of BAT	Details what is to be accepted throughout Europe as BAT for a particular process such as EFW.
Refuse derived fuel (RDF)	Combustible waste turned into a fuel, which can be stored and transported, or directly used on site to produce heat and/or power
Regional self-sufficiency	The principle that regions should have the capability to manage waste arising within their area of production
Renewables Obligation	Requirement that electricity generators increase electricity sales from a choice of eligible renewable sources
Residual waste	The proportion of waste left after the re-usable, recyclable and compostable waste elements have been separated
Scrubber	Apparatus for removing impurities from gas or vapour
Sedimentation	The removal by gravity of solids carried in a liquid
Thermal efficiency	The ratio of useful energy gained to the energy value of the fuel supplied
Thermal treatment	The treatment of wastes through combustion or heating
Trommel	A revolving cylindrical screen used for size classification of material
Vitrification	The process of making a glassy non-crystalline solid from materials capable of vitrifying when heated into their vitrification range
Waste Acceptance Criteria (WAC)	Criteria that waste must meet if it is to be accepted at a landfill site under the Landfill Directive
Waste Incineration Directive (WID)	An EU directive [2000/76/EC] to prevent/reduce the negative effects on the environment caused by incineration by establishing stringent emission limits
Waste Hierarchy	Environmental solutions, in order from most effective: Reduction: reduce the amount of waste generated; Reuse: where further reduction is not practicable, reuse products and materials, either for the same or a different purpose; Recycling, composting, EFW: value should be recovered from the waste, through recycling, composting or energy recovery from waste; Disposal: only if none of the above offer an appropriate solution should waste be disposed of
Waste Integrated Systems Assessment for Recovery and Disposal (WISARD)	A life-cycle assessment tool developed by the Environment Agency to assist in the comparisons of different waste management options

## Acronyms

AC	Activated Carbon
APC	Air Pollution Control
BAT	Best Available Technique
BFB	Bubbling Fluidised Bed
BPEO	Best Practicable Environmental Option
BREF	BAT Reference Note / Document
CEM	Continuous Emissions Monitoring
CCL	Climate Change Levy
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
CIWM	Chartered Institution of Wastes Management
CV	Calorific Value
DOE (NI) EHS	Department of the Environment's (Northern Ireland) Environment and Heritage Service
DRDF	Densified Refuse Derived Fuel
EA	Environment Agency
EIA	Environmental Impact Assessment
EfW	Energy from Waste
EfWi	Energy from Waste Incineration
EfWg	Energy from Waste Gasification
EfWp	Energy from Waste Pyrolysis
EP	Electrostatic Precipitator
EPA	Environmental Protection Act
ESA	Environmental Services Association
FGR	Flue Gas Recirculation
FGT	Flue Gas Treatment
HCL	Hydrochloric Acid
HF	Hydrofluoric Acid
IBA	Incinerator Bottom Ash
IPC	Integrated Pollution Control
IPPC	Integrated Pollution Prevention and Control
LAPC	Local Authority Pollution Control
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
MBT	Mechanical Biological Treatment
MJ	Megajoule
MRF	Material Recycling Facility
MSW	Municipal Solid Waste
MWe	Megawatt Electricity
MWMS	Municipal Waste Management Strategies
NGO	Non-Governmental Organisation
NIMBY	Not In My Back Yard
NFFO	Non-Fossil Fuels Obligation
Nm <sup>3</sup> h <sup>-1</sup>	Normal Metres Cubed Per Hour
NO <sub>x</sub>	Nitrogen Oxides.
PAH	Polycyclic Aromatic Hydrocarbons
PFI	Private Finance Initiative
PM	Particulate Matter
PPC	Pollution Prevention and Control
PPP	Public Private Partnership
PRN	Packaging Recovery Note
RDF	Refuse Derived Fuel
RFB	Revolving Fluidised Bed
RTAB	Regional Technical Advisory Board
ROC	Renewable Obligation Certificate
SCNR	Selective Non-Catalytic Reduction
SCR	Selective Catalytic Reduction
SDA	Spray Dryer Absorber
SEPA	Scottish Environment Protection Agency
TEQ	Toxic Equivalent
TPA	Tonnes Per Annum
UA	Unitary Authority
VOC	Volatile Organic Compounds
WAC	Waste Acceptance Criteria
WCA	Waste Collection Authority
WDA	Waste Disposal Authority
WID	Waste Incineration Directive
WISARD	Waste Integrated Systems Assessment for Recovery and Disposal
WPA	Waste Planning Authority

# Appendix B Human Health Impacts of Energy from Waste Processes

## Introduction

Most EfW plants are based upon incineration and studies of health effects have tended not to distinguish between older mass burn plants without energy recovery, and the more modern and better managed and controlled EfW plants. Care must therefore be taken in reviewing and interpreting the results of relevant research work. Pyrolysis and gasification technologies are relatively new and studies of health effects specific to plants using these technologies have yet to be undertaken.

There are two primary methods of evaluating the health effects of waste treatment plants. The first examines the prevalence of diseases that could plausibly be linked with emissions from the plant and looks for spatial patterns which would indicate a link with plant emissions. This method is termed spatial epidemiology. The other approach is to start from knowledge of the pollutant emissions from the plant and to calculate ground level concentrations and thus estimate both direct human exposures through inhalation, and where relevant indirect exposures through the food chain. From the magnitude of these exposures the magnitude of health outcomes can be calculated.

## Epidemiological studies

The vast majority of epidemiological studies have focused on older generations of incinerators and there are none specific to modern EfW plants. The studies have looked for spatial patterns in three categories of disease viz, cancer, respiratory and reproductive diseases. A typical approach is to construct concentric bands around an incinerator looking for differences in the prevalence of disease, with proximity used as a surrogate for pollutant exposure. There are a number of difficulties and drawbacks associated with this approach, not least of which is that there is frequently a gradient in the social make-up of populations such that there is a higher level of deprivation, itself associated with a higher frequency of disease irrespective of the presence of the incineration plant, closer to the plant compared with further away. Studies which have carefully controlled for so-called socio-economic confounding have generally failed to find any convincing evidence of an adverse health outcome associated with living in close proximity to an incineration plant.

## Calculation of impacts from emissions data

Incineration emits a wide range of typical combustion-generated pollutants in line with other major combustion plant. The main difference between modern incinerators and, for example, power stations is that incinerators tend to have more sophisticated pollution abatement technologies. The most important pollutant emissions include sulphur dioxide, oxides of nitrogen, particulate matter, hydrogen chloride, hydrogen fluoride, a range of trace metals, dioxins and furans. Estimation of the impact involves calculation of both short-term and long-term average ground level concentrations. If the short-term peak concentrations lie within health-based air quality standards it is unlikely that significant adverse health effects will occur. The long-term concentrations are nonetheless associated with adverse health effects which can be calculated using exposure-response functions which have generally been determined from air pollution epidemiology involving entire urban populations exposed to pollutants predominantly from road traffic. Such calculations demonstrate that an EfW plant will generally be associated with less than one additional hospital admission for respiratory or cardiovascular disease and less than one death brought forward per year. Calculation of population exposures to chemical carcinogens including arsenic, nickel, chromium and PAH shows a negligible impact on cancer rates. For dioxins and furans direct exposure through inhalation is a small contributor to exposure, which is dominated by exposure through foodstuffs. Calculation of dioxin and furan transfers through the food chain into home-grown produce indicates that the maximally exposed individuals around a modern incinerator receive well under 1% of their total dioxin intake as a result of incinerator emissions. Since the tolerable daily intake for dioxins is designed to be protective against both reproductive and cancer effects, it is unlikely that exposure as a result of incinerator emissions is a significant contributor to these diseases.

# Appendix C Environmental Impacts of EfW processes

## Introduction

The environmental impact of EfW plant will vary depending on the type and scale of facility, its location, the waste feedstock and operational regime, residue management techniques employed, environmental amelioratory measures, the pollution control mechanisms and configuration of the plant.

The regulation and monitoring of EfW processes is undertaken by the relevant Environment Agency (see Chapter 4), which issues licence conditions under which plant must operate and these include environmental controls. Before the development of an EfW facility an Environmental Impact Assessment (EIA) is usually required, which will involve the examination of potential environmental effects from the facility and take account of mitigating measures. The output from the EIA, the Environmental Statement, is used by the Waste Planning Authority as part of its assessment of whether the proposed facility should receive planning permission. Any waste management facility will have some environmental impact, and the key areas which require control and regulation for EfW facilities are categorised within this section as impacts to: air; water; land; and 'other' relevant impacts.

## Impacts to Air

The principle perceived environmental impact from EfW facilities is the emission from the stack. A variety of gases and particulate matter arising from waste combustion pass into the flue gas treatment process before emission from the stack. The stack emissions are monitored in accordance with the requirements of the relevant regulatory authority, its associated guidance and the Waste Incineration Directive (see Chapters 4, 10 and appendix D).

As part of the Environmental Impact Assessment, the air quality impact of the proposed EfW facility is examined and this will often include a study of prevailing winds and potential pollution dispersion modelling. These studies will indicate the appropriate height of stack required to minimise any air quality and potential health impacts from the plant.

Emissions to air from EfW plant often form a focus of debate and there has been extensive research published on historical pollutant emissions from EfW facilities. Tables C1 and C2 and Figure C1 illustrate the efforts made by the waste management industry in improving emissions from EfW through stringent environmental controls and flue gas treatment systems (see Chapter 10). Table C1 shows emission data for EfW facilities, Waste Incineration Directive (WID) requirements, UK 1991 mean data, and the UK percentage reduction currently achieved over 1991 levels. These levels have recently been made tighter through the implementation of the WID (see column 4).

When the respective emission concentrations are compared, for example, between incineration and gasification technologies, gasification flue gas volumes per tonne (equivalent) of input waste (processed MSW) are up to 40% less than those for EfW. Care is needed in interpreting emissions data for different technology options, as there may be additional environmental impacts arising from obtaining the processed MSW feedstock used in some advanced processes (see Chapter 9) and in subsequent utilisation of combustible products.

Table C1 Emissions to air from EfW plant and Waste Incineration Directive Limits.

Component	Emission to air (mg Nm <sup>-3</sup> ; dioxins in ngNm <sup>-3</sup> ; 11% O <sub>2</sub> , dry gas)				UK 1991 Mean emissions (mg Nm <sup>-3</sup> )	% Reduction (based on 1991 values)
	Measured (UK Best Practice) (1)	Austrian (2)	Dutch (3)	Waste Incineration Directive (4)		
Particulates	0.9	0.5	2.2	10	500	99.8
HCl	20	0.6	1.6	10	689	97.1
HF	<0.1	0.05	0.03	1	NA	-
SO <sub>2</sub>	36	3.5	7.2	50	338	89
NO <sub>x</sub> as NO <sub>2</sub>	274	31	29	200 (plant >3 tph)	NA	-
CO	5	30	-	50	220	98
VOC	<5	0.3	-	10	NA	-
Hg	<0.02	0.006	<0.001	0.05	0.26	99
Cd	<0.001	0.001	<0.001	0.05 (Cd and Tl)	0.6	99.8
Heavy metal summation ∑ 7HM ∑ 12 HM	<0.1	0.02	0.16	0.5	>11.0	99
Dioxin (I-TEQ)	0.006	0.032	<0.01	0.1	>225	99.9
NH <sub>3</sub>	-	0.5	<0.1	-	-	-



Dust monitoring station.

## Dioxins

A key issue raised with regard to air emissions from combustion processes is that of dioxins. The total dioxin contribution from municipal solid waste incinerators operating in the UK is now less than 3 g (TEQ) per year and is likely to fall further given the new controls on incineration processes under the Waste Incineration Directive. Table C2 and Figure C1 show comparative and historical emission levels, over time, and across sectors, respectively [Environment Agency database]. It should be noted that the data reflect both a fall in the number of plant as well as significant advances in emissions controls over this period. The Agency recently cited in their 'State of the Environment' report, 2002 that EfW plant contributed less than 1% of the dioxin into the environment of the processes that they regulate. There are significant additional dioxin emissions arising from other activities not regulated by the Environment Agencies such as bonfire night and other uncontrolled combustion activities.

Table C2 Dioxin releases from regulated processes

Sector	Dioxin releases in 1990 (g)	Dioxin releases in 1999 (g)	Percentage reduction
MSW incineration plant	594	2.8	99.4
Other incineration plant	57	35.0	38.6
Iron and steel	69	55.0	20.3
Non-ferrous	34	24.0	29.4
Power stations	34	17.0	50.0
Industrial combustion	80	48.0	40.0

Source: DEFRA consultation on dioxins, 2002.

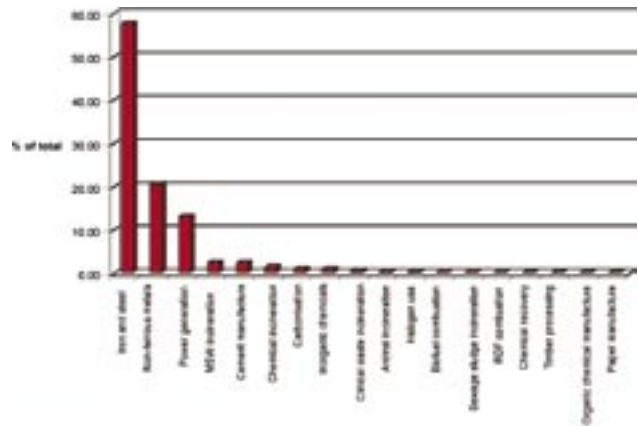


Figure C1 Dioxin emissions by sector.

As is illustrated above, statutory limits for emissions to air have tightened considerably over the last ten years. Older UK plant incapable of meeting new standards were forced to close in the mid-1990s when European emissions limits first began to improve the environmental performance of EfW plant. Since then, standards have tightened further and the controls for EfW plant are amongst the tightest of all combustion and power plant operating in the UK. This aspect therefore represents a positive environmental impact on the power generated from EfW plant as opposed to conventional power stations (however, this would clearly not be the case when compared with other renewable power sources such as wind or solar where there would be a minimal environmental emission to air). The use of district heating and CHP would further enhance this positive aspect.

Potentially one of the most significant environmental impacts to air from an EfW plant or indeed any waste management facility not incorporating a sustainable transport infrastructure, is the impact of vehicles delivering waste to the facility and transporting ash off site following combustion. Exhaust gases caused by vehicle movements not only contribute to the release of pollutants to air (primarily carbon dioxide, carbon monoxide, nitrogen oxides, volatile organic compounds, and particulates), but also clearly create traffic nuisance in terms of vehicle movements, congestion, dust and debris transfer, and noise. These aspects should be mitigated by careful planning and design of access routes, scheduling of movements and good on-site management. Consideration of more environmentally sustainable transport alternatives should be undertaken where feasible.

## Impacts to water

The impacts to water from EfW systems can arise from the choice of flue gas treatment system (i.e., wet or hybrid systems can have an excess water element), run-off from ash storage areas, and the EfW process itself will have a water emission from quenching water used in the ash pits.

The wastewater emission from certain flue gas treatment systems may be evaporated off, or injected back into the process in order to achieve a zero discharge. The waste waters may, alternatively, be treated or discharged to an aqueous environment subject to controls of the relevant regulatory authority.

EfW plant will have an external area of hard-standing for the movement of vehicles, contingency operations and ash storage. There are potential water impact issues arising from run-off from these areas, especially with regard to the ash storage piles. Waters collected from these areas may be treated or discharged to sewer in accordance with the requirements of the regulatory authority.

The emission from the ash quenching process tends to be discharged directly to sewer or may be released to controlled waters if approval is given by the appropriate regulatory environment agency. Most advanced thermal treatment processes tend to only have a net wastewater discharge if it arises from the FGT system (if using a hybrid or wet scrubber system) but will have an element of site run-off to manage.

## Impacts to land

This aspect is primarily covered in Chapter 11 as the impacts to land are concerned with the solid residues produced by the process. This section comprises a brief overview of the issues dealt with in detail in previous chapters. The residues from EfW systems typically fall into two categories:

- Bottom ash (IBA)
- Flue gas treatment (FGT) residues.

The bottom ash is commonly re-used in construction applications and is considered non-hazardous in nature, although there may be some leachability issues with regard to heavy metal components, depending on the composition and application of the ash. The recycling of bottom ash into suitable construction applications was subject to an extensive risk assessment by the Environment Agency and it concluded that IBA was appropriate for a variety of applications. The environmental benefits in the recycling of the material are realised through the avoidance of virgin aggregate extraction and reduced landfill requirements.

The FGT residues however, are classified as hazardous and require specialist treatment or disposal to a licensed hazardous waste disposal facility. The composition and characteristics of FGT residues are detailed in Chapter 11. It is possible (depending on the configuration of the flue gas treatment system) to divide various constituents of the FGT residues into usable component parts and products of reaction. Other techniques such as vitrification may be used to reduce leachability of pollutants from FGT residues and render the material 'inert' in terms of environmental impact to land. This, however, involves a high energy usage, (Chapter 11).

Advanced thermal treatment processes (such as pyrolysis and gasification) may produce chars or slags depending on the nature of the process and the feedstock processed, some of which can be of a suitable nature for recycling, either as aggregate or in industrial applications, whilst other processes tend to landfill the residue. Some of these processes may operate at a sufficiently high temperature to produce a glassy residue with very low leachability and consequently low environmental impact.

## Other relevant environmental impacts

Other environmental impacts arising from EfW plant will include the visual intrusion of the facility and, as has been illustrated throughout this publication, great lengths have been explored to develop architectural designs that ameliorate the impact of the building. This will clearly be a factor of the size and location of the facility, as well as its design.

Traffic and congestion impacts will potentially be an issue for new facilities and sufficient account needs to be taken of traffic management, particularly in peak periods and in sensitive locations.

Potential public health impacts are also assessed through the EIA process, including an evaluation of maximum potential exposure of any emission through the possible pathways of transmission, e.g., ingestion, inhalation etc. The typical form of the evaluation is to determine the impact on a maximally exposed individual, i.e., one who lives within the area of greatest exposure / closest proximity to the plant for the duration of their lifetime, consuming all their food from their garden, etc. These assessments usually use World Health Organisation guidelines on acceptable levels of exposure to any particular substance as a basis for evaluation (see appendix B).

Noise, vibration and odour impacts are usually dealt with through good practice in design, and these will also be factors in the Environmental Impact Assessment and measurements will be taken for potential impacts to any nearby receptors. The operation will be housed (commonly under negative pressure to contain odour) and the only significant noise and vibration issues usually arise in the construction phase of the plant (as vibrational dampers and noise minimising techniques should be applied to reduce any impact from the actual operation).

Litter and vermin are potential impacts arising from waste management processes in general and adequate measures need to be set in place to mitigate and control any windblown litter or material transferred off site by vehicles and good housekeeping practice and pest control will tackle any problems encountered with vermin.

Other potential impacts include those of a site specific nature, such as to flora and fauna on the site itself or adjacent to any discharge to controlled waters (regulated by the Environment Agencies) or threats to habitats through construction noise, traffic movements, etc. There may also be cultural environmental impacts on a site specific basis such as the loss or effect on heritage or archaeological sites.

# Appendix D: Annex IV and V of DIRECTIVE 2000/76/EC on the incineration of waste

Only European Community legislation as printed in the Official Journal of the European Union is deemed to be authentic

## ANNEX IV

### Emission limit values for discharges of waste water from the cleaning of exhaust gases

Polluting substances	Emission limit values expressed in mass concentrations for unfiltered samples	
	95 % 30 mg/l	100 % 45 mg/l
1. Total suspended solids as defined by Directive 91/271/EEC		
2. Mercury and its compounds, expressed as mercury (Hg)	0,03 mg/l	
3. Cadmium and its compounds, expressed as cadmium (Cd)	0,05 mg/l	
4. Thallium and its compounds, expressed as thallium (Tl)	0,05 mg/l	
5. Arsenic and its compounds, expressed as arsenic (As)	0,15 mg/l	
6. Lead and its compounds, expressed as lead (Pb)	0,2 mg/l	
7. Chromium and its compounds, expressed as chromium (Cr)	0,5 mg/l	
8. Copper and its compounds, expressed as copper (Cu)	0,5 mg/l	
9. Nickel and its compounds, expressed as nickel (Ni)	0,5 mg/l	
10. Zinc and its compounds, expressed as zinc (Zn)	1,5 mg/l	
11. Dioxins and furans, defined as the sum of the individual dioxins and furans evaluated in accordance with Annex I	0,3 mg/l	

Until 1 January 2008, exemptions for total suspended solids may be authorised by the competent authority for existing incineration plants provided the permit foresees that 80 % of the measured values do not exceed 30 mg/l and none of them exceed 45 mg/l.

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## ANNEX V

## AIR EMISSION LIMIT VALUES

## (a) Daily average values

Total dust	10 mg/m <sup>3</sup>
Gaseous and vaporous organic substances, expressed as total organic carbon	10 mg/m <sup>3</sup>
Hydrogen chloride (HCl)	10 mg/m <sup>3</sup>
Hydrogen fluoride (HF)	1 mg/m <sup>3</sup>
Sulphur dioxide (SO <sub>2</sub> )	50 mg/m <sup>3</sup>
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ) expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	200 mg/m <sup>3</sup> (*)
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity of 6 tonnes per hour or less	400 mg/m <sup>3</sup> (*)

(\*) Until 1 January 2007 and without prejudice to relevant (Community) legislation the emission limit value for NO<sub>x</sub> does not apply to plants only incinerating hazardous waste.

Exemptions for NO<sub>x</sub> may be authorised by the competent authority for existing incineration plants:

- with a nominal capacity of 6 tonnes per hour, provided that the permit foresees the daily average values do not exceed 500 mg/m<sup>3</sup> and this until 1 January 2008,
- with a nominal capacity of >6 tonnes per hour but equal or less than 16 tonnes per hour, provided the permit foresees the daily average values do not exceed 400 mg/m<sup>3</sup> and this until 1 January 2010,
- with a nominal capacity of >16 tonnes per hour but <25 tonnes per hour and which do not produce water discharges, provided that the permit foresees the daily average values do not exceed 400 mg/m<sup>3</sup> and this until 1 January 2008.

Until 1 January 2008, exemptions for dust may be authorised by the competent authority for existing incinerating plants, provided that the permit foresees the daily average values do not exceed 20 mg/m<sup>3</sup>.

## (b) Half-hourly average values

	(100 %) A	(97 %) B
Total dust	30 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Gaseous and vaporous organic substances, expressed as total organic carbon	20 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Hydrogen chloride (HCl)	60 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>
Hydrogen fluoride (HF)	4 mg/m <sup>3</sup>	2 mg/m <sup>3</sup>
Sulphur dioxide (SO <sub>2</sub> )	200 mg/m <sup>3</sup>	50 mg/m <sup>3</sup>
Nitrogen monoxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	400 mg/m <sup>3</sup> (*)	200 mg/m <sup>3</sup> (*)

(\*) Until 1 January 2007 and without prejudice to relevant Community legislation the emission limit value for NO<sub>x</sub> does not apply to plants only incinerating hazardous waste.

Until 1 January 2010, exemptions for NO<sub>x</sub> may be authorised by the competent authority for existing incineration plants with a nominal capacity between 6 and 16 tonnes per hour, provided the half-hourly average value does not exceed 600 mg/m<sup>3</sup> for column A or 400 mg/m<sup>3</sup> for column B.

**(c) All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours**

Cadmium and its compounds, expressed as cadmium (Cd)	total 0,05 mg/m <sup>3</sup>	total 0,1 mg/m <sup>3</sup> (*)
Thallium and its compounds, expressed as thallium (Tl)		
Mercury and its compounds, expressed as mercury (Hg)	0,05 mg/m <sup>3</sup>	0,1 mg/m <sup>3</sup> (*)
Antimony and its compounds, expressed as antimony (Sb)	total 0,5 mg/m <sup>3</sup>	total 1 mg/m <sup>3</sup> (*)
Arsenic and its compounds, expressed as arsenic (As)		
Lead and its compounds, expressed as lead (Pb)		
Chromium and its compounds, expressed as chromium (Cr)		
Cobalt and its compounds, expressed as cobalt (Co)		
Copper and its compounds, expressed as copper (Cu)		
Manganese and its compounds, expressed as manganese (Mn)		
Nickel and its compounds, expressed as nickel (Ni)		
Vanadium and its compounds, expressed as vanadium (V)		

(\*) Until 1 January 2007 average values for existing plants for which the permit to operate has been granted before 31 December 1996, and which incinerate hazardous waste only.

These average values cover also gaseous and the vapour forms of the relevant heavy metal emissions as well as their compounds.

**(d) Average values shall be measured over a sample period of a minimum of 6 hours and a maximum of 8 hours. The emission limit value refers to the total concentration of dioxins and furans calculated using the concept of toxic equivalence in accordance with Annex I.**

Dioxins and furans	0,1 ng/m <sup>3</sup>
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**(e) The following emission limit values of carbon monoxide (CO) concentrations shall not be exceeded in the combustion gases (excluding the start-up and shut-down phase):**

- 50 milligrams/m<sup>3</sup> of combustion gas determined as daily average value;
- 150 milligrams/m<sup>3</sup> of combustion gas of at least 95 % of all measurements determined as 10-minute average values or 100 mg/m<sup>3</sup> of combustion gas of all measurements determined as half-hourly average values taken in any 24-hour period.

Exemptions may be authorised by the competent authority for incineration plants using fluidised bed technology, provided that the permit foresees an emission limit value for carbon monoxide (CO) of not more than 100 mg/m<sup>3</sup> as an hourly average value.

**(f) Member States may lay down rules governing the exemptions provided for in this Annex.**

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# Appendix E Contacts for further information

## **Department of the Environment, Food and Rural Affairs**

web: [www.defra.gov.uk](http://www.defra.gov.uk) email: [helpline@defra.gsi.gov.uk](mailto:helpline@defra.gsi.gov.uk)  
tel. 08459 335577 fax 0207 2383329. For the Incineration Directive part of DEFRA site, see <http://www.defra.gov.uk/environment/ppc/wasteincin/index.htm>

## **Office of the Deputy Prime Minister**

web: [www.odpm.gov.uk](http://www.odpm.gov.uk) for various contact emails (depending on subject): <http://www.odpm.gov.uk/about/email.htm>  
tel. 0207 9444400 fax 0207 9446589

## **Welsh Assembly**

web: [www.wales.gov.uk](http://www.wales.gov.uk) for various contact emails (depending on subject): <http://www.wales.gov.uk/contacts/index.htm> tel. 029 20898200

## **Scottish Executive**

web: [www.scotland.gov.uk](http://www.scotland.gov.uk) email: [ceu@scotland.gov.uk](mailto:ceu@scotland.gov.uk)  
tel. 08457 741741 fax 0131 2448240

## **Department of the Environment's (Northern Ireland) Environment and Heritage Service [DOE(NI) EHS]**

web: [www.ehsni.gov.uk](http://www.ehsni.gov.uk) for various contact emails (depending on subject): <http://www.ehsni.gov.uk/contact/contact.asp> tel. 028 90546533

## **Environment Agency**

web: [www.environment-agency.gov.uk](http://www.environment-agency.gov.uk) email: [enquiries@environment-agency.gov.uk](mailto:enquiries@environment-agency.gov.uk)  
tel. 0845 9333111  
EA Incineration web:  
[http://www.environment-agency.gov.uk/yourenv/eff/resources\\_waste/213982/203410/?version=1andlang=\\_e%20](http://www.environment-agency.gov.uk/yourenv/eff/resources_waste/213982/203410/?version=1andlang=_e%20)

## **SEPA**

web: [www.sepa.org.uk](http://www.sepa.org.uk) email via dedicated enquiry form on this page of SEPA site: <http://www.sepa.org.uk/contact/index.htm>  
tel. 01786 457700 fax. 01786 446885

## **Environment Agency Wales**

web: [http://www.environment-agency.gov.uk/regions/wales/?version=1andlang=\\_e](http://www.environment-agency.gov.uk/regions/wales/?version=1andlang=_e)  
email: [enquiries@environment-agency.gov.uk](mailto:enquiries@environment-agency.gov.uk)  
tel. 0845 9333111

## **Chartered Institution of Wastes Management**

web: <http://www.ciwm.co.uk> email: [technical@ciwm.co.uk](mailto:technical@ciwm.co.uk)  
tel. 01604 620426 fax. 01604 621339

## **Environmental Services Association**

web: [www.esauk.org](http://www.esauk.org) email: [d-dorkin@esauk.org](mailto:d-dorkin@esauk.org) tel. 0207 8248882

## **Health and Safety Executive**

web: [www.hse.gov.uk](http://www.hse.gov.uk) email: [hseinformationservices@natbrit.com](mailto:hseinformationservices@natbrit.com)  
tel. 08701 545500 fax 02920 859260

## **European Commission incineration**

web: <http://europa.eu.int/comm/environment/wasteinc/index.htm>

## Appendix F Further Reading

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