Waste Pre-Treatment: A Review

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WASTE PRE-TREATMENT
A Review

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CONTENTS

Page

LIST OF FIGURES **iii**

LIST OF TABLES **iv**

GLOSSARY **v**

1 INTRODUCTION **1**

2 MATERIALS RECOVERY FACILITIES AND RECYCLING **3**
2.1 Introduction 3
2.2 Technology 3
2.3 Technology Status 4
2.4 Implementation Issues 7
2.5 Contribution to Targets and Policies 11

3 COMPOSTING **14**
3.1 Introduction 14
3.2 Types of Composting Plant 14
3.3 Technology Status 19
3.4 Implementation 27
3.5 Contribution to Targets and Policies 32

4 ANAEROBIC DIGESTION **36**
4.1 Introduction 36
4.2 Anaerobic Digestion Processes 37
4.3 Technology Status 48
4.4 Implementation 55
4.5 Contributions to Targets and Policies 61

5 INCINERATION **66**
5.1 Introduction 66
5.2 Technology Status 74
5.3 Implementation 79
5.4 Contribution to Targets and policies 86

6 GASIFICATION/PYROLYSIS **90**
6.1 Introduction 90
6.2 Technology Status 92
6.3 Implementation 94
6.4 Contribution to Targets and Policies 98

BIBLIOGRAPHY **102**

FIGURES

Figure 3.1	Schematic representation of batch tunnel composting	25
Figure 3.2	Capital costs of in-vessel composting systems in Europe	26
Figure 3.3	Gate fees for in-vessel composting systems in Europe	26
Figure 4.1	Anaerobic digestion process	41
Figure 4.2	Schematic of Dranco process	42
Figure 4.3	Commercial AD plant construction	49
Figure 4.4	Cost of Biowaste digestion in Europe	50
Figure 4.5	Costs of Danish CAD plants	53
Figure 4.6	Unit cost of Danish CAD plants	54
Figure 5.1	Typical mass burn incineration plant	67
Figure 5.2	Schematic of bubbling fluidised bed combustor	68
Figure 5.3	Schematic of circulating fluidised bed combustor	69
Figure 5.4	Typical coarse RDF system	70
Figure 5.5	Flowline for floc RDF production at NSP French Island	71
Figure 6.1	Schematic representation of the gasification process	90
Figure 6.2	Schematic representation of pyrolysis process	91

TABLES

Table 2.1	Staff employed in MRFs	9
Table 2.2	Summary of criteria assessments - Materials recycling facilities	13
Table 3.1	Type of composting plants for controlled waste in the UK 1988	15
Table 3.2	Mixed waste composting in Europe	20
Table 3.3	Recoverable and composted organic wastes in EU countries	22
Table 3.4	Collection of waste for composting in England and Wales	23
Table 3.5	Types of waste composted at UK sites (Composting Association)	23
Table 3.6	Composting systems used in various European countries	25
Table 3.7	Summary of criteria assessments - Composting	34
Table 4.1	Operating parameters of anaerobic digestion systems	37
Table 4.2	Typical Operating Parameters of the DRANCO Process on MSW-Derived Feedstocks	42
Table 4.3	Analysis of Typical UK Waste and Estimates of Biodegradability	45
Table 4.4	Typical Heavy Metal Concentrations in the Digestate from MSW-Derived Feedstocks	48
Table 4.5	Cost data for mixed waste digestion plants	51
Table 4.6	Gas and energy production for mixed waste AD	52
Table 4.7	Compost and residues from mixed waste digestion	52
Table 4.8	European CAD plants	53
Table 4.9	Amiens digestate quality	57
Table 4.10	Summary of criteria assessments - Anaerobic digestion	64
Table 5.1	Current emission standards for non-hazardous waste incineration facilities	72
Table 5.2	Extent of waste incineration in Europe	75
Table 5.3	EfW plant in the UK	76
Table 5.4	Capital cost breakdown for UK incineration plant	77
Table 5.5	Operating costs for UK incineration plant	77
Table 5.6	RDF Capital and operating cost	78
Table 5.7	Recycling of combustion ash	85
Table 5.8	Summary of criteria assessments - Incineration	88
Table 6.1	Typical emissions from advance thermal conversion plant	97
Table 6.2	Summary of criteria assessments - Gasification/pyrolysis	100

GLOSSARY

Aggregates	Sand, gravel or crushed rock used by the construction industry.
Anaerobic digestion	A process where *biodegradable* material is broken down in the absence of oxygen in an enclosed vessel. It produces carbon dioxide, methane and solids/liquors known as digestate, which can be used as fertiliser and compost.
Best Practicable Environmental Option (BPEO)	The BPEO procedure establishes the waste management option, or mix of options, 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 (See Waste Strategy 2000, Part 2 section 3.3 for more detail).
Biodegradable	Capable of being broken down by plants (including fungi) and animals (including worms and micro-organisms). In *municipal solid waste*, the property is generally attributed to the following fractions: paper and card, food and garden waste and a proportion of textiles, fines and miscellaneous combustible waste, including disposable nappies.
Biological Treatment	Any biological process that changes the properties of waste (e.g. *anaerobic digestion*, *composting*). Biological treatment includes *landspreading* activities that are *licensed*.
Bring (drop-off) Recycling	Recycling schemes where the public bring material for recycling to centralised collection points (e.g. bottle and can banks) at *civic amenity* sites, supermarket car parks and similar locations.
Civic Amenity Waste (CA Waste)	A sub-group of *household* and *municipal solid waste*, normally delivered by the public direct to sites (civic amenity sites) provided by the Local Authority. It consists generally of bulky items such as beds, cookers and garden waste as well as recyclables and ordinary dustbin waste.
Combined Heat and Power (CHP)	The generation of electrical power and usable heat from a combustion process. CHP is more efficient than conventional power generation (and has correspondingly lower pollutant emissions per unit of useful energy produced) and can be based on waste incineration.
Composting	A process where *biodegradable* material (such as garden and kitchen waste) is converted, in the presence of oxygen from the air, into a stable granular material which, applied to land, improves soil structure and enriches the nutrient content.
Compost Plant	A facility for carrying out *composting*. Large-scale schemes may handle kitchen and garden waste collected directly from households and civic amenity sites and may also accept suitable waste from municipal parks and gardens.
Controlled Waste	The UK term for wastes controlled under the Waste Framework Directive: any household, industrial or commercial waste.
DETR	The Department of the Environment, Transport and Regions (now DEFRA – Department for Environment, Food and Rural Affairs)
DTI	The Department of Trade and Industry

EU Directive	A European Union (formerly EC-European Community) legal instruction, binding on all Member States but which must be implemented through national legislation within a prescribed time-scale.
Energy Recovery	The recovery of useful energy in the form of heat and/or power from burning waste. Generally applied to incineration, but can also include the combustion of landfill gas and gas produced during *anaerobic digestion*.
Environment Agency	The principal environmental regulator in England and Wales. Established in April 1996 to combine the functions of former waste regulation authorities, the National Rivers Authority and Her Majesty's Inspectorate of Pollution. Intended to promote improved waste management and consistency in waste regulation across England and Wales.
EWC	European Waste Catalogue. A list of codes and waste descriptions establishes under European law. It includes the hazardous waste list.
FBA	Furnace Bottom Ash produced mainly by coal-fired power stations along with PFA but also by other combustion processes.
Grey Waste	Residual waste from the household after materials have been separately collected for recycling.
Groundwater	Extractable, underground water that is held in the soil and in pervious rocks.
Hazardous Waste	See *Special Waste*. Defined by EU legislation as the most harmful wastes to people and the environment.
HIC	Household, Industrial and Commercial Waste
Household Waste	It includes domestic waste from household collection rounds, waste from services such as street sweepings, bulky waste collection, litter collection, hazardous household waste collection and garden waste collection, waste from civic amenity sites and wastes separately collected for recycling or composting through bring or drop-off schemes and kerbside schemes.
Incineration	The burning of waste at high temperatures in the presence of sufficient air to achieve complete combustion, either to reduce its volume (in the case of *MSW*) or its toxicity (e.g., for organic solvents and *PCBs*). MSW incinerators recover heat and/or power. The main emissions are carbon dioxide, water and ash residues.
Industrial Waste	Waste from any factory or industrial process (excluding mines and quarries).
Inert Waste	Chemically inert, non-combustible, non-biodegradable and non-polluting waste defined in the EU Directive on the Landfill of Waste.
Integrated Pollution Control (IPC)	A system introduced under Part 1 of the Environmental Protection Act, designed to ensure best available techniques not entailing excessive costs, are used to prevent, or where that is not practicable, to reduce emissions from a range of the potentially

	most polluting industrial processes, including some waste management facilities. Gradually being replaced with Pollution, Prevention and Control requirements under the EU IPPC Directive.
Integrated Waste Management	Consideration of all the wastes produced in an area and the methods for their management, either alone or in combination. This normally leads to utilising a mixture of waste management options.
Kerbside Recycling	Collection of recyclable or compostible wastes usually from the pavement (hence the name) outside premises, including collections from commercial or industrial premises a well as from households.
Landfill (Sites)	Licensed facilities where waste is permanently deposited for disposal.
Land Use Planning	The development planning system that regulates the development and use of land in the public interest.
Licensed Site/ Waste Management Facility	A waste disposal or recovery facility licensed under the Environmental Protection Act.
Life Cycle Assessment (LCA)	The systematic identification and evaluation of all the environmental benefits and disbenefits that result, both directly and indirectly, from a product or function throughout its entire life from extraction of raw materials to its eventual disposal and assimilation into the environment. LCA helps to place the assessment of the environmental costs and benefits of these various options, and the development of appropriate and practical waste management policies, on a sound and objective basis. (See Waste Strategy 2000, Part 2, paragraph 3.11 for more detail).
Life Cycle Inventory	An environmental balance sheet that lists all the emissions released or saved and resources used or saved as a result of a particular activity (e.g. waste collection, recovery and disposal). The inventory shows individual flows (e.g. sulphur dioxide released, bauxite saved). Impact assessment aggregates these flows into emission impact categories such as atmospheric acidification and greenhouse gas emissions.
Material Recycling Facility **MRF**	Facility that sorts, grades and prepares waste fractions to generate material suitable for onward dispatch to recyclable materials merchants. "Clean" MRFs accept materials from source separation schemes, Dirty or Unsegregated MRF extract recyclables from mixed domestic waste
Municipal Solid Waste (MSW)	*Household waste* and other wastes collected by a waste collection authority or its contractors, such as municipal parks and gardens waste, beach cleansing waste and any commercial and industrial waste for which the collection authority takes responsibility.
Pollution Abatement **PA**	Pollution abatement plant is the equipment installed on waste combustion plant to remove the pollutants from the flue gases.
PCBs	Polychlorinated Biphenyls. An environmentally harmful group of organic compounds that accumulate in the environment and in the food chain. PCBs are no longer manufactured or used but were

	previously used in a wide range of products, particularly in large, electrical transformers and capacitors.
Producer Responsibility	Requires industry and commerce involved in the manufacture, distribution and sale of particular goods to take greater responsibility for the disposal and/or recovery of those goods at the end of their useful life.
Proximity principle	Disposing of waste as near as practicable to its place of production.
Recycling	Involves the reprocessing of wastes, either into the same material (closed-loop) or a different material (open-loop recycling). Commonly applied to non-hazardous wastes such as paper, glass, cardboard, plastics and metals. However, hazardous wastes (e.g. solvents) can also be recycled by specialist companies, or by in-house equipment.
Reduction	Reducing the quantity or the hazard of a waste produced from a process. It usually results in reduced raw material and energy demands – thus also reducing costs.
Re-use	Using materials or products again, for the same or a different purpose, without material reprocessing (e.g. the use of returnable milk bottles).
Separate collection	Schemes where specified materials from household waste are collected and kept separate from the ordinary household collection.
Source separated	Synonymous with separate collection
Special Waste	Defined by the Environmental Protection (Special Waste) Regulations 1996 (as amended) and is broadly any waste on the European Hazardous Waste List that has one or more of fourteen hazardous properties.
Treatment	Involves the physical, chemical or biological processing of waste to reduce their volume or harmfulness.
Waste Collection Authority	A Local Authority (a district, borough or unitary) responsible for the collection of household waste in its area.
Waste Disposal Authority	A Local Authority (generally a county or unitary) responsible for the management of the waste collected and delivered to it by constituent collection authorities. The processing and/or final disposal of the waste is usually contracted to the private sector waste management industry.
Waste Management Licensing	The system of permits operated by the Environment Agency under the Environmental Protection Act to ensure that activities authorised to recover or dispose of waste are carried out in a way which protects the environment and human health.
Waste Transfer Station	A waste management facility to which waste is delivered for separation or bulking up before being removed for recovery or disposal.

EXECUTIVE SUMMARY

The implementation of the EU Landfill Directive will have significant impacts on all waste management operations in the UK, but most significantly on wastes sent to landfill for disposal. Two aspects of the Landfill Directive that will have the greatest impact on current practices are the requirement for reductions in biodegradable municipal solid waste (MSW) sent to landfills and the requirement for all wastes to be treated prior to being sent to landfills.

There are many technologies that can be applied both to treat wastes and reduce the biodegradable content but local authorities and the waste management industry will need to know which technologies are available and how effective they are. Each technology will have to be assessed in terms of meeting Best Practicable Environmental Option (BPEO) requirements so that the most appropriate technology will be employed to reduce environmental impacts at an acceptable cost.

To help in assessing the technology options, this review has been prepared. It identifies options currently available in the UK and provides a brief technical description of each. The technologies considered are **materials recovery facilities**, **composting**, **anaerobic digestion**, **incineration** and **gasification/pyrolysis**. For each option the state of the technology and its current deployment in the UK and overseas is assessed. Issues likely to affect the implementation of the technology are identified and environmental considerations are discussed. Finally the contribution that the use of the technology will make to targets and policy objectives is examined.

1 INTRODUCTION

It is estimated that some 28 million tonnes of domestic refuse (dustbin and civic amenity) are produced in the UK each year. A proportion of this material is recycled through participation schemes such as bottle banks and Local Authority collection schemes but the overall quantity remains less than 10% of the total. The remaining waste is disposed to landfill with a further 7% being incinerated. One of the main reasons for reliance on landfill disposal has been the relative abundance of cheap landfill capacity, which has made alternative treatments uneconomic.

Changes within the UK such as the introduction of more stringent waste disposal regulations and publication of the waste strategy in recent years have significantly improved the prospects of alternative waste treatments. These changes are supportive of the generally accepted European Community Strategy for dealing with waste where the waste minimisation is the most preferred and landfill of untreated waste the least preferred option.

Waste minimisation	most preferred option
Recycling (reuse)	↑
Resource recovery (materials recycling)	
Energy recovery	
Stabilisation	
Landfill	least preferred option

Other changes, which are likely to support the introduction of alternative waste treatment options, are:

- the rising cost of landfill disposal and the impact of landfill tax;
- a generic move towards environmentally sustainable waste management options which also consider factors such as transport and public nuisance impacts;
- the UK Governments commitment to recycling domestic waste;
- the obligations imposed by the UK's acceptance of the European Landfill Directive.

The implementation of the EU Landfill Directive will have significant impacts on all waste management operations in the UK, but most significantly on wastes sent to landfill for disposal. The aim of the directive is to reduce the negative environmental impacts of wastes deposited in landfills particularly on surface and groundwaters, soils and air as well as global effects such as greenhouse gas emissions.

Two aspects of the Landfill Directive that will have the greatest impact on current practices are the requirement for reductions in biodegradable municipal solid waste sent to landfills (Article 5.2) and the requirement for all wastes to be treated prior to being sent to landfills (Article 6a).

To meet the first of these requirements for reductions in biodegradable wastes, local authorities will need to implement major systems for reducing the biodegradable content of the wastes that they dispose of and it is expected that recycling, composting, anaerobic digestion and incineration of municipal waste will increase markedly.

The second requirement for the treatment of wastes prior to landfill applies to all wastes, not just biodegradable wastes (although some inert wastes are exempt). Thus all waste that is not diverted from landfill will require some form of treatment to reduce its negative environmental impacts. The definition of treatment in the Landfill Directive is broad and covers “physical, thermal, chemical or biological processes including sorting that changes the characteristics of the waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery”.

There are many technologies that can be applied both to treat wastes and reduce the biodegradable content but local authorities and the waste management industry will need to know which technologies are available and how effective they are. Each technology will have to be assessed in terms of meeting Best Practicable Environmental Option (BPEO) requirements so that the most appropriate technology will be employed to reduce environmental impacts at an acceptable cost.

To help in assessing the technology options, this review has been prepared. It identifies all the technology options currently available in the UK and provides a brief technical description of each. The technologies considered are physical, biological or thermal processes and for each technology, a number of issues are considered such as state of the technology and its current deployment, implementation of the technology and how use of the technology will contribute to targets and policy objectives.

2 MATERIALS RECOVERY FACILITIES AND RECYCLING

2.1 Introduction

Material Recovery Facilities (MRFs) are places where wastes are deposited and then sorted and separated. The main purpose of a MRF is to sort and separate materials to produce products that meet defined specifications and so can be marketed. This is achieved, particularly in a clean MRF, by sorting the collected material into various products and removing contaminant materials.

2.2 Technology

MRFs can be classified either as clean MRFs, which treat source separated material and recover recyclables, or dirty MRFs which recover recyclable materials and/or a compostible fraction directly from unsorted dustbin waste. The size of a MRF is clearly related to the amount of material it is designed to process, and this can typically range from 10,000 tonnes per year to 50,000 tonnes per year.

2.2.1 Clean MRFs

Clean MRFs can handle material collected through drop-off banks, but a very high proportion of the material they process is from kerbside collection schemes. As a clean MRF can only treat source separated material, it is important that it is able to process all the material that is collected. A clean MRF can be designed to either handle a single stream of materials, i.e. paper is mixed with other materials during collection, or can be designed to process paper separately from other materials.

The design of a clean MRF is usually based on one of two approaches:

- A low-technology MRF where virtually all sorting is done by hand (plants may have a magnet extraction unit to remove steel cans). This approach has a low capital cost, but high labour costs.

- A high-technology MRF, which makes as much use as possible of mechanical sorting equipment, e.g. equipment to separate glass bottles from plastic containers. This results in a higher capital cost, and although labour costs are lower, some handpickers are still required to meet quality requirements.

The potential advantage of the low technology approach is that it is much easier to respond to changes in market conditions. For example, handpickers can be instructed to sort alternative materials, whereas equipment designed for one purpose cannot easily be modified (and will still incur costs even if there is no market for the material it is designed to separate). The method of collection of the recyclables will also affect the design of the MRF.

The number of products that a clean MRF can produce is based on the number of materials collected and the level of sorting undertaken at the MRF. A MRF could separate plastic, ferrous metals and aluminium using an eddy-current separator. The MRF could then either send the plastics to another MRF for separation by polymer, or separate them itself using either handpicking or a plastics identification system. For example, if plastic bottles were being collected along with other materials, the MRF could just separate these into a product, or it could perform further sorting such as sorting by polymer type. The residues could be plastic other than bottles, such as yoghurt pots, or unwanted polymers, for example ABS.

2.2.2 Dirty MRFs

A dirty MRF treats 100% of the collected waste stream and as with clean MRFs, the design of dirty MRFs can be either simple or complicated. The main advantage of a dirty MRF is that there are no additional collection costs, and the recovery/recycling rate is determined by the efforts of the sorters at the plant, rather than by the willingness of the public to participate in a source separation scheme.

However, the main disadvantage is that the recovered materials are not as clean as those recovered from source separated wastes because they have been in contact with other materials, particularly food scraps, in the dustbin. A number of dirty MRFs have been built in the USA, but this is because dustbin waste in the USA has a low proportion of food scraps due to the extensive use of kitchen waste disposal units. The higher organic content of dustbin waste in Europe means that it is unlikely that a dirty MRF will be a suitable approach for recovering clean recyclables in Europe.

Dirty MRFs have also been developed which produce a product that can be composted. However the compost is of low quality which limits the potential market for the product. An alternative form of dirty MRF which could be considered is a plant which produces refuse derived fuel (RDF), as this is able to recover metals and still produce a reject stream which could be composted.

2.3 Technology Status

2.3.1 Development

The technology for separating materials by material type for clean MRFs is well developed, although equipment for sorting plastic by polymer type is less well proven. Consequently clean MRFs that have identified suitable markets for the materials they recover have a high degree of commercial success.

Although technologies for dirty MRFs which recover recyclable materials have been developed, and a number of dirty MRFs appear to be operating satisfactorily in the USA, the problems in identifying markets for materials means that this type of plant currently has a low degree of commercial success.

2.3.2 Deployment

Clean MRFs operate successfully in many countries. A number of dirty MRFs have been constructed in the USA, but these have had difficulties in identifying markets for the separated materials because of high levels of contaminants. Dirty MRFs, which separate a fine fraction, which is then composted, are operating satisfactorily in a number of countries.

Operations in the UK

There are many clean MRFs operating in the UK. All of these are well established and operate satisfactorily with UK waste streams, as the collection procedures used are able to collect separated materials with a low level of contamination.

Portsmouth MRF

This is designed to handle mixed paper, metal and plastic. Material is tipped into a reception area and a preliminary manual sort removes cardboard, plastic carrier bags and any unwanted material. A conveyor then carries the materials to a screen where small items (<50 mm material) are removed for disposal. Material leaving the screen is divided into two streams, which pass across inclined vibrating belts, where the bouncing motion separates bottles and cans from flatter items like paper. The cans/bottles go to a magnetic separator where steel cans are recovered, and the remaining plastic/aluminium material goes to a manual picking area where plastics are sorted by polymer type. The paper stream goes to a separate picking station where it is handsorted into newspapers and magazines, and mixed paper grades. This plant currently employs 64 people, and is processing its full design capacity of 42,000 tonnes per year of kerbside collected material (the plant does not process any material from commercial sources).

A very small number of MRFs have additional equipment, such as automatic sorting of plastic by polymer type. However, as polymers are not biodegradable wastes, such equipment does not affect the recovery rate of biodegradable materials by a clean MRF.

Adur MRF

The Adur MRF processes two streams; paper and a mixture of plastic and metal, and there are 3 processing operations; paper handling, metal/plastic separation, and polymer sorting of plastics. Paper is tipped into a storage area and than loaded into vehicles for transport to a paper mill. The metal/plastics mixture is fed to a separator which produces three products – magnetics, aluminium cans, and plastics. The plastics are then automatically sorted into polymer types using a sorter, which can process 4 bottles a second. The plant produced 14,500 tonnes of recyclables in 1998, and this figure increased in 1999. There are 10 workers and 2 management staff. The level of rejects is between 10% and 15%, and is mainly either yoghurt pots or carrier bags.

Only 1 dirty MRF designed to recover recyclable materials has been constructed in the UK at Ipswich but this has not been able to recover materials of suitable quality for marketing, and has now changed to operate as a clean MRF.

Ipswich unsegregated MRF

The plant now operates as a clean MRF but uses the same process flowsheet as the dirty MRF design. Waste is tipped into a reception area and than fed to a bag splitter. Bulky items are removed, and the material fed to a star screen which splits the waste into 4 fractions; <50 mm, 50-100 mm, 100-150 mm, and >150 mm material. The <50 mm material is rejected and the remaining materials are fed to handsorting areas. Handpickers remove newspapers/magazines, mixed paper, LDPE, PVC and PET. After handpicking, the remaining material is fed to overband magnets and eddy current separators to recover ferrous metal and aluminium. The aluminium is then handsorted to separate foil from cans.

The plant is located at a landfill site (the estimated life of the landfill is 20 years), and in a building which is 75 m by 35 m. The total cost, including the building (but not the land) was £4 million (about 50% for building and 50% for equipment). The plant was originally designed to process 100,000 t yr^{-1} (25 t h^{-1}), but is currently processing about 10 t h^{-1} of the current material, and recovering about 80% of this. 35 people work at the plant; there are 2 shifts with 15 operators per shift (the plant operates 16 hours a day).

A dirty MRF designed to produce material for composting has also been constructed in Lowestoft and appears to be operating satisfactorily. This plant is currently being developed to produce material, which would have a wider range of markets after composting.

Lowestoft MRF

The MRF separates a fines product, which is then composted. It is located in an industrial area, and the building is 75 m x 36 m. The initial design used a macerator (basically a rotating wheel with teeth) and a short trommel. However, in order to increase the amount of fines recovered, a new trommel was installed, 160 feet long (4 sections of 40 feet), a diameter of 4.5 feet, and a screen size is 40 mm.

The fine product was originally mixed with shredded green waste and shredded timber and then composted to produce a "low grade" product which could be used for landfill cover (some landfill tax is paid for this use based on the level of contaminants). Although there are potential markets for the composted product, such as a civil engineering material at new landfill sites and for road schemes, the plant is assessing other options for the fines product such as producing a compost product which would be suitable for agricultural use. The plant operator will consider adding additional recovery facilities such as magnetic extraction from the oversize stream, once the fines processing system has been fully developed.

Scale of UK Deployment

There are 70 MRF plants operating in the UK. The scale and nature of these plants vary considerably. The scale of operations range from a few thousand tonnes per year, bulking station for bring system materials to large complex MRF processing 50,000 tonnes per year with complex sorting equipment. Current facilities process typically 5-10000 tonne per year.

2.3.3 UK Costs

It is difficult to give a good estimate of either the capital or operating cost of a "typical" MRF, as every MRF is different in design and the way it operates. A MRF, particularly a clean MRF can range from a simple low-technology (hand-picking) system constructed in an existing building to a high technology (mainly mechanical sorting) system constructed in a new building which may well include other facilities, education centres, etc. The size of the MRF (in terms of the tonnes of waste processed per day) will influence the amount of sorting equipment required and hence the capital costs. Operating costs will be affected by the numbers of different waste materials to be processed. Investment in a MRF, even the largest is unlikely to exceed £5-6 million but it is quite possible to equip a low-technology MRF for £250,000.

2.3.4 UK Performance – Availability and Experience

Both clean and dirty MRFs have a high availability (estimated at 85%) but MRFs can and do suffer breakdowns, which reduce their availability. Spare parts are generally readily available for dirty MRFs and on-site maintenance staff are able to quickly complete repairs.

Where a MRF has automated sorting equipment (such as equipment to sort plastic by polymer type) repairs may well take longer because of the need for specialised repair staff from off-site. Although the availability of specialised sorting equipment will be lower than that for the simpler equipment such as conveyors and screens, the design of the MRF must allow it to process the bulk of material if the specialised sorting equipment is not operational.

2.4 Implementation Issues

There are a number of implementation issues that should be considered prior to opting for a MRF. Some of these will depend on the waste management strategy adopted but others depend on the risks associated with financing and the operation of the MRF and the markets for the MRF products. The main risk issues for a MRF are the quality of the products, the stability of markets for the products it produces, and the prices that can be obtained for those products.

2.4.1 Financing

Financing the capital cost of a MRF is likely to be undertaken by a private sector company and the financial risks will be assessed within usual commercial constraints. The main advantage to a Local Authority of private sector financing is that they do not have to provide any funding for the MRF, or for any further development that might be required. A MRF may well be built as part of a contract for a waste management strategy, and one issue that might have to be considered would be whether the contractor or the Local Authority owned the MRF at the end of the waste management contract.

The sale of sufficient product and the revenue obtained from these sales clearly helps to reduce the net operating cost of the MRF. Consequently, the financial risk can be reduced if the MRF is able to produce good quality products and achieve a satisfactory income from them.

2.4.2 Quality of products

It is important that the MRF produces high quality material to maintain its markets for the recovered products. For a clean MRF, this will require good quality control during collection to minimise the amount of contaminants that need to be removed from the recovered products. There are also well established standards and specifications for recovered paper and metals, which help to ensure a consistent quality of product.

Materials recovered from a clean MRF will be of high quality and easy to sell provided there are sufficient markets for the recovered products. Markets are readily available for paper and metal recovered through clean MRFs although the revenues obtained may be low.

Materials recovered from a dirty MRF will be of lower quality and more variable because of the level of contaminants which can not easily be separated when the material is recovered. Dirty MRFs, even in the USA, have difficulty in identifying suitable markets for the recovered recyclable materials. In the UK, the Ipswich dirty MRF was unable to identify a market for recovered paper material, and so had to stop recovering it.

Stability of markets for recyclate/products

The main materials which MRFs recover are paper, metals and plastics, although glass and textiles are recovered to a lesser extent There are numerous markets for metal and paper and so consequently the stability of these markets is generally very high. The stability of markets for plastics is low, whilst those for glass and textiles are highly variable.

2.4.3 Planning issues

The main areas of concern in planning applications are visual intrusion and planning permission for the MRF and for the associated storage facilities. MRFs built in industrial areas should be similar in appearance to other buildings in the area to minimise problems of visual intrusion. However, a MRF built by a landfill site will be more visible in the local area and so may have more problems with gaining planning permission. It is difficult to make more precise comments because of different approaches to planning by different Local Authorities.

Land requirements

The amount of land required by the MRF would depend on the type of MFR, the size of the building, the wastes collected and the storage area required. For example, Portsmouth MRF is a 2600 m^2 building and treats 42,000 tonnes per year, but now requires more space. Ipswich MRF (situated at a landfill site) is 75m x 35m, giving a size of 2625 m^2 for 30,000 tonnes per year.

Employment opportunities

The main area for job creation will be in the low technology MRF where hand sorting predominates. Table 2.1 shows the numbers of people employed at typical UK MRFs.

Table 2.1 Staff employed in MRFs

MRF	Capacity	Staff employed
Lowestoft	40,000 tonnes per year	5 staff in total (developing plant)
Adur	14,500 tonnes per year	10 workers and 2 management
Ipswich	30,000 tonnes per year	30 workers (operating in 2 shifts) + management and maintenance
Portsmouth	42,000 tonnes per year	64 people (reduced from 80 people)

Public participation

Clean MRFs require the public to participate by separating out materials that the clean MRF can process. Source separation schemes will only be successful if the public participates fully. The main factor affecting the amount of material recovered is the number of participating households. The results from a number of studies where participation rates have been measured (for voluntary schemes) show that;

- 20% are highly unlikely to participate
- 20% are highly likely to participate
- publicity material should target the remaining 60%, who are more likely to participate if they receive clear instructions (with regular reminders), and regular information on how well the scheme is performing.

A dirty MRF does not require public participation to be successful as whole bin wastes are treated. However, contamination of potentially recoverable materials reduces the quality of the recovered products and may lead to a lower level of income from sales of the products. Organic wastes contaminate recoverable products, particularly paper, and so initiatives to reduce the organic waste in dustbins could be beneficial to the operation and to the amount of material recovered by a dirty MRF.

Education needs

Educating the public to separate out the materials to be collected reduces the amount of sorting required at the kerbside. It also reduces the amount of reject material produced from the MRF when processing mixed recyclables

The public has accepted recycling schemes for dry recyclables although there are still concerns about the locations of some MRFs. Good education has, for example, allowed the public to accept fortnightly collection of organic waste

2.4.4 Transport impacts

Transport impacts will depend on the type of MRF, the waste collection systems in use and the available markets.

In clean MRFs, for example, where bank schemes are used there are some additional transport impacts due to the public making specific journeys to the collection point. Material also has to be collected from the banks and delivered to the MRF. Kerbside schemes, which, for example, use separate vehicles, will also have significant additional transport impacts.

For dirty MRFs there should be no additional transport impacts for the collection of the wastes. There will however be rejects to be disposed of, but siting the dirty MRF at a landfill site would minimise this transport impact.

Recyclable materials have to be transported from the MRF to a market and so the distance from the MRF to the markets (or final processing point, for example, for aluminium cans) can be important and should be considered when siting the MRF.

2.4.5 Environmental impacts

Air emissions

The principal emission to air from MRF operation will be through odour and dust.

Odours

Odours should not be an issue for a clean MRF that only accepts particular waste streams and especially if the amount of reject material is low. There may be more of an odour problem for a dirty MRF which accepts unsorted waste material, but this can be overcome by careful siting of the MRF and control measures to minimise odour impacts.

Dust

Dust can be controlled through ensuring effective ventilation of the MRF both to protect workers and the general public. One aspect of dust that is starting to be of concern is the generation of biologically active dusts, bioaerosols, which pose a potential hazard to workers, but may be dispersed to affect neighbours of the plant.

Water/leachates

Clean MRFs processing source-segregated, dry recyclable materials should not have problems with leachate run-off from the processing. Where dirty MRFs are processing mixed wastes containing a high level of organic contaminants, there may be potential problems from leachate generated by the decomposing organic wastes. This can be collected and treated prior to discharge from the MFR.

Solid residues/hazard

Upto 15% of input material going to a MRF may be rejected and require disposal at a landfill. Reject material consists of material which either can not be separated by, for example, a MRF or which is too contaminated to recover in a dirty MRF. Better education of the public could reduce the amount of material rejected by the MRF.

Handling of rejects and solid residues requires health and safety issues to be considered. If unwanted materials such as glass are found in the waste streams coming into a clean MRF that is not designed to separate glass, then there may be problems handling the glass. The hazards associated with handling and disposing of items such as needles must be considered for dirty MRFs.

Noise

Noise complaints from the public are not likely to be a problem if the MRF is situated at a landfill, or in an industrial area where other activities in the area also create noise, provided the MRF is operating within acceptable noise levels. There may be problems with complaints about traffic noise, even if the MRF is in an industrial area. Traffic movements to and from the MRF are likely to be higher than for a typical factory due to the number of vehicles arriving with waste for sorting.

2.5 Contribution to Targets and Policies

2.5.1 Landfill Directive

The key target for municipal waste in the Landfill Directive is the requirement to reduce the amount of biodegradable waste landfilled. The precise targets are to reduce the biodegradable municipal waste landfilled to 25%, 50% and 65% of the 1995 quantities by 2006, 2009, 2016 respectively. The UK is allowed to extend these dates by upto four years.

The definitions for biodegradable waste and how its biodegradability will be measured have not been set. However, using the definition set out in "A way with waste", the Waste Strategy and discussions with the Environment Agency, an estimate of the diversion possible can be made.

Recycling of glass, plastics and metals does not contribute to this target, as these materials are not biodegradable. Recycling of the paper and card fraction and man made fibres from textiles will contribute to the reduction of biodegradable material being landfilled. Under current systems the majority of dry materials recycled are either glass or paper, with the other materials providing a small proportion of the mass of recyclate.

From a typical UK waste analysis, approximately 32% is paper and 3% is textiles. Assuming that half of the paper fraction can be recovered in an uncontaminated form and that one third of the textiles are natural fibres and can be recovered, this would provide 17% of the whole waste stream being potentially diverted by dry materials recycling. However, estimates of the biodegradable fraction of the wastes vary between 60-65% and thus 17% diversion from the waste stream represents approximately 27% diversion of biodegradable waste. Obviously if higher recoveries can be achieved then a greater diversion will result. Unsegregated MRFs will be unlikely to achieve such high diversions as a greater proportion of the materials recovered are plastics and metals than collected in source separated systems.

2.5.2 Waste strategy

UK Government Waste Strategy targets for recycling are currently 25% by 2005, 30% by 2010 and 33% by 2015. The targets for recovery of waste are 40% by 2005, 45% by 2010 and 67% by 2015.

Recycling contributes towards both the recycling and recovery targets. The contribution provided by the recycling system will be dependent on the collection system adopted. The materials that are recycled will represent some 90-95% of the materials collected through source separated schemes, so long as markets are available.

Unsegregated MRFs recover material from the whole waste and experience has shown that 6-10% of the waste can be collected and sold to market.

2.5.3 Greenhouse gas

The Kyoto protocol established targets of 12% reduction in the climate change gas emissions and subsequent UK policy has set a target of 20% CO_2 reduction of 1990 levels by 2010.

The operation of MRFs is generally a low energy process and consumption is estimated to be 2-5 kWh t^{-1} for source separated materials MRFs, unsegregated material MRFs will have higher energy demands which are estimated to be 5-10 kWh t^{-1}. However, this should be noted that whilst the energy use per tonne processed is similar for the two types of plant, the energy per tonne of material recycled will be significantly higher for the unsegregated MRF due to the much lower recovery rates achieved.

In addition to the emissions due to processing energy use, there are emissions from the collection of the material processed in the plant. This relates to the additional transport over and above that required to collect the waste normally. Thus source separated systems often (but not always) require additional vehicle movements to collect the recyclables and this provides an additional greenhouse gas emission of 0-4.9 kg t^{-1}.

Materials leaving the MRF will need to go to market and for this study these have been assumed to be equivalent to the transport distances to the landfill.

2.5.4 Renewable energy

UK government has set a target of 10% of electricity generation from renewable sources by 2010. Recycling does not contribute any renewable energy and is a net consumer of energy.

Table 2.2 Summary of criteria assessments - Materials recycling facilities

	Clean MRF	Dirty MRF
Economic		
Capital cost Operational cost	£67-177 tpa-$^{-1}$ £35-55 t^{-1} dependant on scale	£40-74 tpa-$^{-1}$ £25-41 t^{-1} dependant on scale
Technical		
Proportion of the municipal waste stream treated	Kerbside collection of dry recyclables maximally 30%, likely to be less due to less than perfect participation	All of the waste delivered but majority of the waste is rejected
Energy production	Energy consumption 2-5 kWh t^{-1}	Energy consumption 5-10 kWh t^{-1}
Land requirements	0.1 m^2 t^{-1}	0.5 m^2 t^{-1}
Operational/risk		
Availability	85%	85%
Quality of products	Generally high	Contamination of materials potentially high, limiting markets
Operations in UK	>70	1
Operation elsewhere	>100	>10
Operational success of commercial plants	Good, but depends on markets	Difficult market, due to poor recovery and limited markets
Planning requirements	Generally small scale odours, noise and bioaerosols issues	Visual impact, bioaerosol and odour issues
Scope for integration	Only treats specific fraction of waste stream	Treats all of the waste and process fraction may be amenable to further processing
Stability of markets for recyclate/products	Reasonable but product quality under constant review	Some materials , marketable, others have difficulties
Education needs	Detailed and intense education required to avoid contamination	None
Public dependence	Dependant on public willingness to participate well	None
Environmental		
Greenhouse gas reduction	8.8-13.7 kg t^{-1} generated	24.7 kg t^{-1} generated
Air quality	Odours and dust	Odours, dust and bioaerosols
Water pollution	Limited	Limited, similar to transfer station
Solid residues/hazard	5-10% residues of contamination	90-94% residues require landfill or treatment
Noise	Some noise issues especially if glass collected	Normal for waste processing facility
Odours	Limited	Potential to cause odours, enclosed plant potential for control
Transport	5-10% rejects to landfill, product to markets	90-94% rejects to landfill, product to market
Resource use	Limited use	Limited use
Policy		
Meeting recycling target	90-95% material recycled	6-10% materials recycled
Biodegradability reduction	27% potential reduction reduced by poor participation	Limited as most materials recycled are non-biodegradable
Public perception	Well viewed	uncertain
Employment opportunities	5.5 jobs ktpa^{-1}	0.4 jobs ktpa^{-1}
Public involvement	High for source separation	None

3 COMPOSTING

3.1 Introduction

Biological treatment of the organic fraction of municipal wastes can be performed by composting. Composting is the **aerobic** decomposition of biodegradable material to produce a residue termed compost with the emission of predominantly water and carbon dioxide.

In technical terms, modern composting is a thermophilic, bio-oxidative degradation process. Which means that the process operates at temperatures in the thermophilic range (45-60°C) and is a biological process that oxidises the organic matter to break it down to a more simple form.

The organisms that carry out composting are ubiquitous in the environment and seldom require introduction to the process. In practical terms, the composting operations must ensure that the microorganisms are kept supplied with moisture, oxygen, food and nutrients and that the conditions such as temperature remain in the optimum range. A large number of procedures and engineered solutions have been developed to achieve these objectives for the treatment of organic wastes.

3.2 Types of Composting Plant

The use of composting in waste management is carried out either by the householder on their premises as home composting or in a centralised system, where collected materials are processed at a purpose built facility.

Home composting

Home composting requires householders to separate and compost their own kitchen and garden wastes and to process these in their gardens to produce compost that they can use on their own garden or allotment. This can be achieved using traditional compost heaps or increasingly popular, home composting units.

The individuals who are willing to carry out this activity are often those who are keen gardeners and have a requirement for the compost. Local authorities may be able to encourage more households to compost their kitchen and garden wastes through education and subsidising the distribution of compost bins. However, diversion of wastes that would have otherwise been sent for landfill disposal will be limited due to the level of effort and commitment required by the householder and the fact that only a small proportion of households will actively participate. In addition, home composting will not be feasible for the people living in flats or householders with very small gardens

It has been estimated that 214 councils in the UK (approximately 40 %) were running, or had run, a home-composting scheme in 1995. Furthermore, between 1995 and 1996, over 80,000 home composting bins were distributed each year by local authorities to householders on a free or subsidised basis.

Centralised composting

Centralised composting can be performed in a un-contained/open system or contained within a vessel or building. A brief description of each follows, but a full description can be found in a review of composting systems published by the Environment Agency. Table 3.1 shows the types of composting plant used in the UK.

Table 3.1 Type of composting plants for controlled waste in the UK 1988

Type of plant	Number	Capacity (1000 tonnes per year)
Open air Windrow	53	800
In-Vessel	2	25
Covered Windrow	4	11
Total	**59**	**835**

Open (non-reactor) composting systems

Open composting has been practised for many years and relies on placing the organic waste in piles exposed to the air. The waste is commonly formed into elongated triangular piles that are called windrows, which allow optimum exposure to the atmosphere whilst minimising the land area taken up. Once the waste is prepared for composting the principal control mechanism for the process is the air requirement of the microorganisms and the dissipation of the heat generated. Introduction of air into the waste can be achieved either though active pumping of air into the waste or through the mechanical lifting and mixing of the waste to introduce air into the pile. These two approaches are called static aerated pile and turned windrow.

Turned windrow composting

The turning of the compost in a turned windrow system is achieved either by a specialised turning machine or by use of general-purpose front-end loaders or 360° excavators. These machines lift and mix the composting waste and introduce air into the pile and release the heat and moisture as water vapour. The turning operation is often characterised by a large cloud of "steam".

The turning operation has to be performed many times during composting and the timing will be determined by the progress of the composting process. In the early stages when composting is very active turning several times per week may be required but at the end of the process during the stabilisation phase turning may only be required every few weeks.

There are many varieties of specialised turning machines which either aerate the pile whilst leaving the pile in the same location or pick up the pile and move it a short distance to one side and thus progress the pile on successive turnings. The choice of machine type is dependent on the design of the site and material flow requirements.

The operation of turned windrow systems can be improved by protecting the composting waste from the rain. Rain will cause the generation of leachate that may pollute surface or ground water if released and introduces variability into the process that affects the final product quality. Protection can be provided through either semi-permeable textile layers placed over the windrows or through the construction of a roofed area where composting is undertaken. The textile approach has a low capital cost but does introduce an additional operational workload and hence increases operational costs whilst the roof option has a higher capital cost. The provision of cover also reduces wind blown litter and provides a degree of odour control

The majority of composting systems in the UK is based on the turned windrow concept due to the low cost of operation.

Aerated static pile composting
Static aerated pile systems, as their name suggests, are not turned during processing and the air is forced through the composting material by means of a fan and perforated pipes or floors. The windrows are formed over the aeration system and then remain there for the composting period of between 12 and 20 weeks, depending of the feedstock, until the active phase of composting is complete. The air is typically blown upwards through the composting mass and the expelled air, moisture, carbon dioxide and heat is allowed to disperse to atmosphere. Alternatively, the air can be sucked downwards so that the air from the composting material is taken through the fan. The advantage of this downwards flow is that any malodorous air can be treated, but there can be problems with compaction of the pile leading to poor air flow and potential for the material to go anaerobic.

In the UK this system is not current employed to any great extent and will not be considered further in this study.

Reactor composting systems
Reactor or enclosed composting is a relatively new composting development that provides a faster active biodegradation process, reducing the area required. The use of a vessel allows much greater control over the process and this helps both with the speed of the process but also the consistency (hence quality) of the compost product.

The reactors come in a variety of forms and have varying degrees of automation. However, the basis of reactor composting is that materials are enclosed in a drum, silo, or similar structure and air is injected into the composting material to maintain the optimum conditions for composting. The simplest systems currently used are the batch tunnel systems. These are essentially large insulated boxes that are filled with a mechanical shovel. Once sealed a computer using temperature, oxygen levels and moisture as control inputs controls the airflow. At the end of the cycle, the material is dug out with a front-end loader. Often the material will require several cycles in the tunnel as the loading and unloading provide a turning function with in the process. The more complex systems provide a complete process, which will manage the aeration and flow of material through the process automatically and thus require a minimum of intervention from the operators. These self-contained systems are obviously more expensive than the batch tunnels. Any air emissions from the reactors are passed through biofilters to prevent odour problems.

The overall scale and complexity of the systems are reflected in the plant scale and appearance and thus very simple systems such as the batch tunnels are not major facilities whilst the more complex systems generally include buildings that enclose the machinery and thus become more imposing facilities.

3.2.1 Wastes treated by composting

Only the organic biodegradable fraction of municipal waste can be treated by composting. This is primarily kitchen and garden wastes, but paper and fines fractions can be treated to an extent, although the degree of degradation achieved is very dependant on the system used.

Essentially there are two forms of feedstock for composting, source separated and un-segregated wastes. Source separation systems rely on the waste being collected separately from the other household waste and can be achieved through civic amenity sites or through kerbside collections in a separate container. Un-segregated waste for composting can range from the whole waste stream without any removal of recyclables to the composting of processed materials that have had the majority of the contamination removed by mechanical means. The benefits of these two approaches are complex and can be summarised as follows:

- The quality of the end product is significantly higher when source separated material is composted and this leads to reduced problems in marketing the compost. Contamination is not totally eliminated by this route and some clean up of the material may be required in the process. The use of un-segregated waste leads to a lower quality product with higher amounts of contamination by heavy metals, glass and plastics. Sorting can reduce this to acceptable levels for some applications such as landfill restoration or motorway sound barriers. However, these are limited markets and material may still need to be landfilled.

- The quantity of material that can be collected through source separation schemes is limited due to the number of householders who will not or cannot participate and the collection of only a restricted range of the compostible wastes. Thus, in un-segregated systems, the whole waste stream is targeted which can ensure 100% participation from the public.

There are differences between source separation methodologies that have implications for the composting process. Source separation in the UK is carried out either at civic amenity sites where the green waste is mainly larger prunings, leaves and garden waste, or by kerbside collection schemes, which consist of smaller, fleshier materials rather than the larger woody materials, and kitchen wastes. This results in the kerbside collected materials being generally higher in moisture, nutrients and rapidly degradable materials but low in the woody components. This leads to a greater propensity for rapid degradation and hence odour generation and the lower woody component gives rise to a less open structure unless mixed with woods chips or green waste. The greater amounts of plant matter will give rise to a higher nutrient content and this will have value in some applications.

Feedstock requirements for composting plants are principally governed by the product quality requirements. However, the performance of the composting process and the quality of the resultant compost are also dependant on factors such as carbon to nitrogen ratio, nutrient availability, moisture content, porosity, degradability etc. To achieve the required performance and compost properties may need the mixing in of materials other than household waste such as sewage sludge, commercial waste or woodchips. This is normally the case with source separated materials rather than un-segregated composting due to the more stringent requirements of the compost product.

3.2.2 Products and residues

Source separated feedstocks

The main product from the composting of waste is compost. This stabilised organic material consists of the refractory and slowly degradable cellulosic materials. The main use of this compost is as a soil improver. The quality of the compost is largely determined by the feedstock provided to the process. Relatively uncontaminated feedstocks will give rise to uncontaminated products and these are generally composted from source separated materials.

The residues from the composting process are those materials that do not readily degrade, such as wood and these can either be returned to the front of the process to be shredded or they can be disposed of. This material can represent up to 25% of green waste feedstock. Contaminants from source separated systems will be relatively low, for example in green waste it will be less than 2% of the feedstock. For kerbside collection schemes contamination can be higher and ranges from 1% to over 10% dependent on a wide range of factors associated with the operation of the collection scheme. The composition of these contaminants will vary with the scheme and will contain almost anything that could be in the mixed waste stream, but will have high concentrations of plastics from plastic sacks used to store/transport the waste and from plastic flowerpots and other plastic garden products.

Mixed waste processing

The primary product from mixed waste processing is the stabilisation of the waste. The composting process will remove the readily biodegradable carbon and the resulting residues will degrade slowly in the environment.

In some circumstances the composted waste can be further sorted to generate a low quality soil improver. The eventual use of this material will be limited to landfill cover or other land restoration projects.

Mixed waste processing will generate a large amount of residues such as the non-organic materials rejected by the sorting process and will mainly consist of metals, glass and plastics. There will be some potential to recycle small proportion of this material, but this will be limited to the ferrous and non-ferrous metals. Materials going into the composting process will consist of paper, kitchen and garden wastes and fines. Sorting after the composting process will remove the materials that have not been decomposed sufficiently and these rejects will contain larger proportions of paper and woody materials but also additional glass and plastics. It would be expected that all of these rejects would be either landfilled or incinerated.

The ratio of soil improver product to reject fractions will vary markedly with the process flowline but typically the product material might only be 10 to 20% of the incoming waste with 15-30% loss of mass through the biodegradation.

3.2.3 Composting plant size

Composting is not a particularly staff intensive operation as the bulk processes occur when the waste is in piles or in the vessel. Estimates of staffing levels vary between different employers, but plants less than 25,000 tonnes per year capacity tend to employ between 2-4 staff, giving staffing rates of between 10 and 1 staff per 10,000 tonne per year capacity. As plants get larger than this the staffing levels can be estimated from a level of 1 staff member per 10,000 tonne per year capacity. There appears to be little evidence from the published data to suggest any differential between the various types of composting plant.

3.3 Technology Status

Three waste composting options are considered as generic examples of composting technology.

3.3.1 Whole waste composting (Mechanical Biological Treatment -MBT)

The composting of whole waste is carried out to stabilise the solid waste and divert biodegradable material away from landfill as low-grade compost. This technology is some times referred to as mechanical-biological (pre) treatment.

The system operates by sorting the waste prior to composting to remove the non-compostible components. This is normally achieved through a homogenisation drum where the waste is tumbled in a rotating drum for periods several hours to several days. The degradation is assisted by the addition of water. After the drum homogeniser, the material is screened to remove the materials that have not broken down. These are principally textiles, plastics and metals, although there are some organic materials mixed with these rejects but the proportion is small and this material is landfilled.

The screened material is then placed in windrows. The windrows are positioned under a covered area to reduce the effects of rainfall on the composting process. The windrows are turned on a programme that initially turns the piles twice a week for the first few weeks and reduces to weekly turning after the initial high-activity phase. The process takes approximately 16 weeks to complete, whereupon the composted waste is screened again to remove more contaminants and may undergo air classification or air tabling to remove glass and plastics depending on the end use of the compost. The reject fractions from these sorting phases will be landfilled.

The compost will then be used in an extensive application such as land restoration or potentially agriculture if the compost quality is sufficient.

Development

As a technology, this is a system from the past, which is now finding a new niche in the waste management market. Mixed waste composting was last seen in the UK at full scale in the Lescost plant near Leicester, which closed in the 1970's. The reason for the closure was the contamination of the compost product making sales of compost impossible. Mixed waste composting has continued in Europe either producing composts for particular agricultural markets such as vine growing or as a pre-treatment option to landfill, so called mechanical biological pre treatment. Table 3.2 shows estimates of mixed waste composting in Europe.

Table 3.2 Mixed waste composting in Europe

Country	Quantity of waste composted in mixed waste systems (tonnes per year)	No. of plants
Austria	253,000 MBT	11
Belgium	25,400	2
France	1,500,000	66
Greece	3,000	1
Germany	653,200 MBT	11
Italy	1,298,000	33
Portugal	420,000	5
Spain	778,300	22
Sweden	70,000	6
Slovak Republic	50,000	no data

Developing countries have continued to install mixed waste composting plants, which have been more successful due to the different nature of the waste. New plants in Western Europe have been largely aimed at pre-treatment of wastes rather than for compost production.

In the UK, mixed waste composting is very limited, with only three plants operating. The Waste Recycling Group operates two facilities, at Alfreton and Lowestoft. The Alfreton plant is based around a vertical composting vessel but is currently not operating. The Lowestoft plant is operating a screening plant where the organic fraction is mixed with green wastes prior to being composted for landfill. At the time of writing (April 2000), both of these projects were early in their development and have to undergo some proving trials before full implementation. The third project is the Isle of Wight composting plant that is processing the fines from the RDF plant for use as landfill cover. The use of the Wright tunnel composters has provided a marked improvement in the fines stability allowing their use as cover materials, making savings on the cost of the landfill tax and operational costs. However, this is only intended as a temporary measure whilst the collection of biowastes is improved to provided sufficient material to compost successfully.

Cost and Performance

The cost of operation and construction of these plants is highly variable depending on the level of complexity of the sorting plant and the desired quality of the compost product. In addition, the cost information tends to be commercially sensitive and thus difficult to gain accurate estimates of the capital and operating costs of plants.

An EU report suggested that the capital cost for mixed waste composting plants ranging from £150 per tonne of capacity for smaller plants (circa 6,000 tonnes per year) down to £80 per tonne of capacity for plants up to 20,000 tonnes per year. The study suggested that for lower grade composts operational costs of £12.50 to £25 per tonne were typical but could rise as high as £60 per tonne for more refined compost products.

The performance of a mixed waste composting plant can be considered in two ways; the diversion of material away from landfill or the production rate of useable compost. In terms of the use of the process as a pre-treatment of waste before landfill the amount of material that is not landfilled is the most important. Whilst, using the process for optimising recycling, production of a useable product (compost and metals) is the main factor.

The performance of mixed waste composting systems is not well reported because in many cases the product going to landfill is not weighed. Results from a study of Austrian MBT (mechanical biological treatment) plants showed that the losses through moisture and carbon loss averaged at 25% but varied considerably (13-47%) between the plants depending on the process used and the wastes processed. This compares with an experimental project carried out by the Department of the Environment where the fines from RDF production at Byker were composted and biological losses were 38%. This is a higher loss than seen in the Austrian plants but given the more concentrated organic feedstock, this can only be expected. The production of compost for use as landfill cover from the Austrian plants is typically 27% and this compares with the RDF fines study that produced on average 25% compost. If recycling of ferrous metal is also performed this will remove upto 5% of the waste depending on the recycling schemes operating in the area.

Thus, this suggests that approximately 50-55% of the waste can be diverted from being deposited in landfill, although approximately half of this diversion may be due to materials used in the restoration or management of the site.

3.3.2 Green waste composting turned windrow

Green waste is generally classified as garden waste generated by households and deposited at civic amenity sites. It contains principally prunings, tree branches and grass cuttings but will contain a range of contaminants from the garden, the amount of these depending on the level of control applied to the collection skips.

The composting of this material is a simple process. The first stage is visual inspection to remove larger contaminants such as plastic bags, metal items and unprocessable large items such as tree stumps. Then the waste is shredded. The shredders are of several basic types; screw shredders that use slowly rotating augers to cut the waste, shear shredders that use slowly rotating knives working in a scissors action, tub grinders that are fed from the top and use rapidly rotating hammers and the horizontal shredders that are fed from the side and use a rapidly rotating toothed drum. The benefits and weaknesses of the various shredder types are well covered by the manufacturers. The main point is that the shredding process increases the surface area of the waste to allow microbial attack and hence degradation.

The shredded green waste is then placed in windrows, which are normally between 2 and 4 m in height and 4 to 6m width at the base. The length of the windrows is dependent on the site topography and the quantity of waste to be processed. The temperature in the pile rises rapidly and the piles are turned several times during the process. Turning of the windrows is performed by either normal waste handling equipment such as front end loaders, 360° excavators etc., or specialist turning machines. The choice of the type of turning machine is an economic one and is largely controlled by the scale of operation, larger facilities can effectively use a specialist machine, whilst smaller plant require the flexibility of multi-use vehicles. The overall purpose of the turning process is to introduce oxygen in to the composting mass and thus encourage the composting process. Large amounts of steam and heat are released in the process and this acts as a control on the temperature.

The frequency of turning varies throughout the process, in the early stages when degradation is rapid the windrows should be turned frequently, 2-3 times a week. Later in the process after 2-3 months, the turning frequency is reduced. After about 16-20 weeks, the composting is completed and the compost is normally screened to remove the larger woody materials that have not been degraded and plastic contaminants. The markets for the compost determine the size of the aperture. In some plants, a single -20mm product is sold as a soil improver whilst other plants generate several sized fractions for use as mulches, growing media or soil improver

The product compost is then sold to the users in bulk or bagged for sale to domestic customers. The oversize reject fraction can be either sent to landfill as a waste or returned to the start of the process for another stage of composting.

Development

Composting of green waste is predominant across Europe. Although source separation at the household is increasing, the quantities collected and composted are currently less than the quantity of green waste composting. Table 3.3 lists the recoverable and composted organic wastes in the EU countries between 1996 and 1997. Application of composting is favoured in countries like Denmark, Austria and Netherlands where over 50 % of (recoverable) organic wastes are treated with the technology. In contrast, only 3 % of the organic wastes are treated using composting in the UK. The table also shows the compost production is approximately 50 % of the organic waste input.

Table 3.3 Recoverable and composted organic wastes in EU countries (tonnes per year)

Country	**Recoverable organic wastes**	**Organic waste composted**		**Compost product**
Austria	2,200,000	1,100,000	50 %	500,000
Belgium	1,670,000	320,000	19 %	160,000
Denmark	900,000	500,000	55 %	250,000
Finland	700,000	70,000	10 %	30,000
France	14,500,000	400,000	3 %	150,000
Germany	9,000,000	4,000,000	45 %	2,000,000
Greece	1,650,000	0	0	0
Ireland	350,000	0	0	0
Italy	9,000,000	200,000	2 %	100,000
Luxembourg	50,000	7,000	14 %	3,000
Netherlands	2,000,000	1,800,000	90 %	650,000
Portugal	1,200,000	0	0	0
Spain	6,600,000	0	0	0
UK	**9,240,000**	**317,000**	**3 %**	**159,000**
Sweden	1,500,000	250,000	16 %	100,000

More recent studies in the UK have shown that the amount of garden waste collected for composting is increasing rapidly with an annual growth rate of approximately 36%. The amount of green waste composted in 1998/9 would appear to be between 490,000 (DETR) and 590,000 tonnes (CA). This green waste represents approximately 53% of the material composted, the remaining 47% are made up of about 31% non-municipal wastes and 16% source separated household organics. The type of site used is principally, open turned windrow, with 53 of the 59 centralised composting sites operating this way.

Table 3.4 Collection of waste for composting in England and Wales

Year	Integrated collection (tonnes)	Separate collection (tonnes)	CA and bring sites (tonnes)	Total collected by LAs (tonnes)	Voluntary & private collections (tonnes)	Total (tonnes)
1996/7	2,000	18,000	261,000	281,000	1,000	282,000
1997/8	4,000	29,000	354,000	387,000	2,000	389,000
1998/9*	5,000	28,000	492,000	525,000	0	525,000

* provisional

Table 3.5 Types of waste composted at UK sites (Composting Association)

Type of waste	**Quantity composted (1000 tonnes per year)**
Municipal waste	
Household garden waste from civic amenity sites	363
Garden and kitchen waste collected from the kerbside	31
Garden waste collected from the kerbside	11
Other household	7
Green waste from LA parks and Gardens	217
Total Municipal	**628**
Non Municipal	
Green wastes from landscaping	40
Industrial processes	146
Other commercial wastes	96
Total non municipal	**282**
Total composted	**911**

Cost and Performance

The cost of open windrow is one of the least expensive process options for treating waste. Gate fees often quoted range between £15 to £25 per tonne. The costs are heavily influenced by the scale of operation and the marketing opportunities .for the compost. The capital costs are made up of:

- land purchase;
- the laying down of the hardstanding that will allow the capture of any leachate and provide a hard surface that the vehicles can work on in all weathers;
- purchase of shredder, screen and loading shovels; and
- for larger plants, dedicated turning machine.

An essential revenue to the plant will be the sale of compost. Prices obtained for the compost can be as high as £80 per tonne for bagged material sold to the public, but bulk sales which comprise the majority of the material sold will rarely achieve an average higher than £10 per tonne. An earlier Environment Agency report suggested that the value of the compost to farmers was only £2 to £5 per tonne.

The performance of the process is in part dependent on the handling of the reject fractions. Where rejects are recycled in the process the reject fractions will be lower but overall space requirements will be higher. Where rejects are disposed of, studies have shown that these represent up to 17% of the feedstock. The production of compost from these plants is typically 35-50% of the input weight. An industry rules of thumb assumes that one tonne of green waste feedstock will generate one cubic metre of finished compost and this represents approximately 50% recovery as compost.

3.3.3 Green waste composting in-vessel system

In-vessel composting is the same biological process as describe above but enclosed in a vessel or building. There are many designs but essentially four basic types; batch tunnel, progressive tunnel, sequential bay and vertical units are used. The differences between them are minor and related to the engineering rather than any fundamental differences in processing.

The basic operation of the in-vessel systems is to control the ventilation of the composting material and to agitate or mix the material as required. The air used in the composting process is contained and thus allows the control of any odours or bioaerosols emitted during the main composting process. Obviously, the loading and unloading operations will have the potential to release odours and bioaerosols.

The basic principal of the in-vessel systems can be demonstrated by the batch tunnel system Figure 3.1. Here the waste is placed in a large container with a perforated floor. Air is blown through the waste to facilitate the composting. Air is recirculated or sent to the biofilter for treatment and fresh air introduced depending on the composting temperature and oxygen content of the air. The process is often computer controlled. As the material composts it will compact increasing the resistance to air passage and will require turning to introduce porosity and to open up new surfaces for composting. In continuous systems, this is an aspect of the mechanical system and in batch systems the waste is taken out of the tunnel and turned with a shovel loader before being returned to the tunnel. The turning process may be repeated several times depending on the feedstock. The waste will require windrow composting for several weeks after the initial intense composting phase in the composting unit.

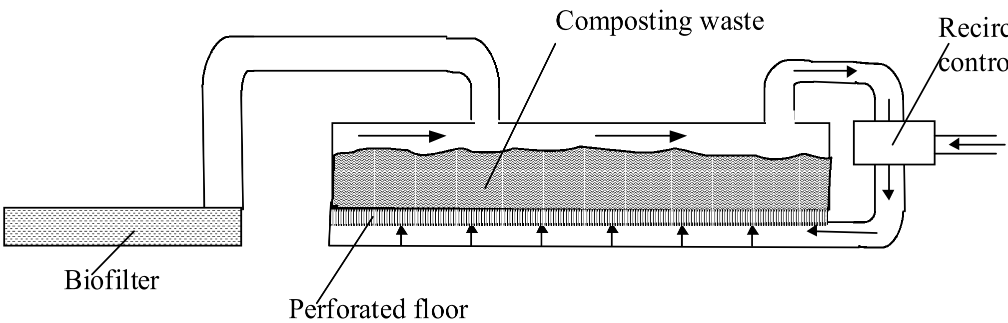

Figure 3.1 Schematic representation of batch tunnel composting

The feedstock to the process will predominantly be green wastes but the inclusion of kerbside collected biowaste can also be incorporated in to the system. The enclosed nature mitigates many of the problems that higher levels of kitchen wastes introduce such as increased potential for odours, leachate generation and attractiveness for vermin.

Development

The development of the technology in the UK is limited, as there are only two plants operating, CDV plant in Ipswich and the Island Waste plant on the Isle of Wight. These two plants have a capacity of 17,000 and 3,000 tonnes per year respectively. The use of in-vessel costing is much more prevalent in Europe where there are many designs in use. Table 3.6 shows the deployment of in-vessel systems in several countries. Germany, Austria, Belgium and the Netherlands have the large proportion of their plants operating with in-vessel systems, whilst many countries have only a few or no in-vessel composting plant.

Table 3.6 Composting systems used in various European countries

Country	**In-vessel**	**Windrow**	**other**	**AD**	**Total**
Austria	9	107	4	1	121
Belgium	6	14	0	1	21
Denmark	3	112	12		127
Finland	2	Most	-	1	3
France	-	Most	-	-	66
Germany	105	263	0	11	379
Netherlands	20	1	0	2	23
Portugal	0	5	0	0	5
UK	2	87	0	1	90
Italy	-	-	-	-	33
Spain	1	23	0	0	24

- insufficent data to complete

Cost and Performance

The lower use of in-vessel systems is in part to their higher costs than the alternative open windrow systems. In-vessel systems are only used where the enhanced environmental protection or the increased capacity provided of the enclosure is necessary. The cost of in-vessel systems has been assessed as part of two studies from 1992 and 1999. These studies have been used to derive Figure 3.2 and Figure 3.3, which are projected costs of capital and operating cost (gate fee) for in-vessel composting facilities in Europe. Comparison with the Ipswich plant capital costs of £1.28m for a capacity 17,200 tonnes per annum and gate fee of £17 per tonne suggest that the costs in the two studies are higher than UK costs. However, costs for UK waste management facilities has often been lower than those on the continent have.

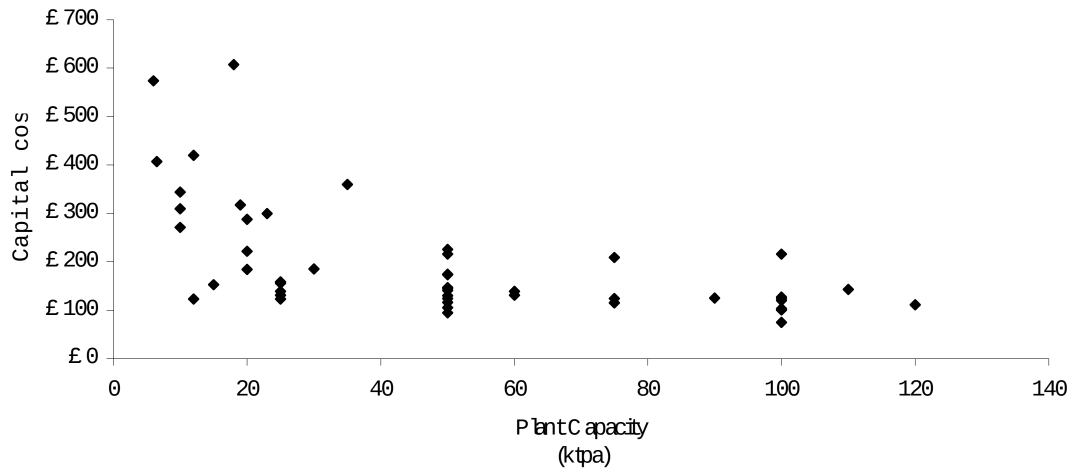

Figure 3.2 Capital costs of in-vessel composting systems in Europe (corrected to year 2000 basis)

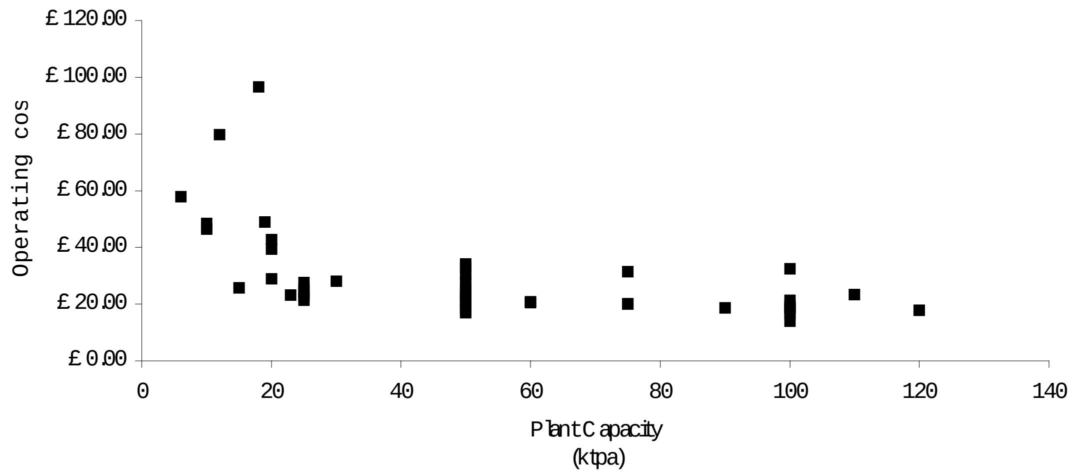

Figure 3.3 Gate fees for in-vessel composting systems in Europe (corrected to year 2000 basis)

The performance of the systems is similar to other composting, as it is the same biological process. Yields of compost product average around 47% but range between 30 and 75%. Reject levels are typically 5%. The main advantage is that composting times are reduced over windrow systems. Typically windrow composting takes between 12 and 16 weeks to complete, whilst the data on in-vessel systems suggest that composting time is reduced to about nine weeks. The use of agitation in the process does appear to influence the process duration with agitated systems having average residence times of around 8 weeks whilst simple aerated systems have residence times of about 10 weeks.

The space requirement for the in-vessel systems appears to be similar to the land take from windrow systems. However, this may be due to plants occupying existing sites and thus not fully utilising the sites. Assessment of the data from many plants in Europe show that the most efficiently used plants occupy only 0.3 m^2 per tonne of plant capacity, whilst open windrow plants tend to have a lower limit of 1 m^2 per tonne of capacity.

3.4 Implementation

The risks associated with composting can be broken down into financial, technical and environmental.

3.4.1 Financial risks

The financial risks of the plant predominantly centre on the gate fee that can be charged and the value or use of the products. The operational costs and capital costs once a project is operational are moderately stable and thus are not "risk" factors. The income from the gate fee is susceptible to competition from alternative disposal options that can either siphon off waste that would have otherwise been processed or result in the gate fee having to be adjusted to remain competitive. In either case, revenue is affected. These risks can be mitigated through design of contracts for the waste supply. The risks to the product revenues/costs are more uncertain.

Source separated waste composting
The largest uncertainties will be the sale value of the finished compost and to a lesser extent the quantity and cost of disposal of the rejects.

The markets for compost are at present limited to existing landscape and horticultural uses and thus is in direct competition with a wide range of virgin and recycled materials such as peat, coir, spent mushroom compost, bark etc. Ultimately these markets are limited and will not accept the quantities of municipal waste derived compost that can (and most likely will) be produced in the UK. Therefore alternative markets will need to be developed and agriculture is the most likely market with sufficient capacity to deal with the quantities that will be produced. The value of these alternative markets are likely to be lower than the smaller scale existing uses and thus it is likely that revenues will reduce as composting expands to meet the requirements of the national and international targets. As revenues decrease the gate fees of composting will rise and will make composting less competitive.

The costs of landfill will rise and this may be an increasing cost for composting plant operators. Current schemes have very low reject rates and thus this is a small element in the cost structure. As efforts are made to separate greater proportions of the waste stream into "clean" fractions the level of contamination will rise and thus the proportion of reject will rise and become more significant in the financial balance of composting plant operation.

Mixed waste composting

The financial risks for MBT will be lower than for source separated composting as the main cost elements will be the landfill of the residue. Whilst landfill prices are expected to rise with time this will be predictable to an extent hence reducing the uncertainty (and hence risk) to plant operation. The principal risk to the operation will be the competition from alternative options such as incineration, which will put pressure on the gate fee. Thus, MBT will be more exposed to landfill charge increases due to the greater proportions of material landfilled, whilst gate fees may not be able to rise to fully compensate for this.

3.4.2 Operational/technical risks

Source separated waste composting

The principal risk to the green waste compost plant operations also come through break down of plant equipment, shredders, loaders etc. This is a manageable process that is controlled by ensuring sufficient capacity on site, ensuring that adequate maintenance is performed and that suitable back-up arrangements are made for inevitable breakdowns. As with other waste operations, plant is based on an availability of 85%, which ensures that there is sufficient slack in the system to deal with mechanical problems.

The technical risks are reduced by the use of the in-vessel system in that the variability of the product is reduced and susceptibility to weather influences is removed. This has benefits for product marketing as the sanitisation can be more easily verified and guaranteed and the product is more consistent, an important parameter for professional users. The potential for mechanical problems is higher due to the use of a mechanical system. However, most plants have several process lines and so mechanical problems are likely to only affect a proportion of the feedstock

Product quality

Green waste is the least contaminated feedstock, although it will still contain contaminants that will require removal. Levels of contaminants can be kept low through good education and supervision of the deposit points at civic amenity sites. The main problem item is plastic film, in which the public often brings the waste to the site. The only effective removal technique is hand picking prior to shredding and screening after composting. This poses little risk to the process, as the product quality is generally high. There is the potential for garden chemicals to be disposed of with the garden waste, which may pose a threat to the performance of the final soil improver. However, the quantities of domestic garden chemical that could get into the process are unlikely to be large. Given that there is significant mixing in the process, this reduces the concentration to a low level. In addition, the composting process will degrade many chemicals thus reducing the risk to product quality still further.

Stability of markets

The market for green waste composts is developing. The existing market for soil improvers and growing media has been estimated between 1 and 2 million tonnes per year. However, this is based on the horticulture, landscaping and retail markets for existing products. The current marketing of green waste composts has emphasised the benefits of compost in general soil health, a role that the public had previously not fully taken on board. Thus, there is potential for some expansion of the domestic market. However, as quantities of compost produced increase due to the impacts of local authorities meeting the Landfill Directive and national recycling targets, the marketing of poorer quality compost will become difficult. Thus, the main risk factor is controllable through efficient operation of the waste collection points and good management of the refining operations during the process.

Mixed waste composting

The operational risks are manageable given that mixed wastes may contain almost anything and hence the plant has to be constructed to withstand the full rigours of waste handling. There are the typical risks due to breakdown and maintenance requirements and it is normal to set plant availability predictions at 85%.

Product quality

Mechanical separation of the contaminants from the compost is never complete and the final compost is contaminated with a glass, plastics and metal fragments that limit the application of the compost from mixed waste. Suitable applications vary depending on the national regulations relating to soil quality and the agricultural needs. In France, Portugal and Italy, compost from mixed waste is used on a number of crops, but particularly in the wine growing areas. In Germany and Austria the use of the compost is limited to landfill cover materials. The range of uses in the UK would be expected to be limited to land restoration purposes, as there is limited vine growing. In addition, extensive use in agriculture may be limited due to the concerns raised by the supermarkets and food processors regarding food quality in the wake of recent food scares, such as BSE, *E. coli* 0157, and dioxins in milk.

The presence of heavy metals in compost has been an issue for many years and the setting of appropriate limit levels has been difficult. A recent report CEN discussed the topic in great depth and it is beyond the scope of this report to discuss this here. However, as a general rule, the greater the degree of segregation of the waste the lower the heavy metal contamination. Thus, mixed waste processing will have the highest metal levels when compared to either green waste or source separated household organic wastes derived composts.

With mixed waste processing the quality of the product is low compared to other waste based soil improvers and thus can only be used in the applications with the lowest demands such as landfill cover or land restoration. The value of these markets is that they can accept large volumes of compost but at a zero price. The benefit to the compost plant operator is the avoided disposal cost that is dependent on local landfill prices. Failure to "sell" the compost in to these applications results in a cost for its disposal.

Stability of markets

The markets for mixed waste composts were assessed in an earlier report which suggested that the UK land reclamation market for compost was only 0.5 million tonnes per year. However, these markets tend to be locally dominant in that a major redevelopment project will require large amounts of compost for a short time during construction and then require no more. Two examples are the Millennium Dome and Bluewater shopping centre, which both used significant amounts of source separated waste derived compost in their development. It is obviously difficult to sustain a business on the highly variable demand that this type of market gives. The other more stable demand is for landfill restoration and this is where most MBT plants in Europe position themselves.

3.4.3 Planning issues

Planning of any waste site is problematical in that public opposition is based on a perception of waste being dirty, causing pollution and affecting house prices. The principal issues are odour, bioaerosols and traffic movements. As with all planning issues they have to be resolved on a case by case basis but the principal method of mitigating the problems is to use sites that are sufficiently distant from housing. It is not possible to guarantee that there will be no odour or bio-aerosol releases, although, good operational practice can minimise these. In-vessel composting significantly reduces these emissions as the emissions are captured and treated. Other planning issues centre on the amount of land required for the composting operations. A typical estimate for open windrow systems is 1 m^2 per 1.5 m^3 per tonne capacity. In-vessel systems have a much lower demand for land and depending on the degree of complexity systems occupy between 0.25 and 0.5m^2 per tonne capacity. Obviously, local conditions and the topography of the site affect this.

3.4.4 Transport

Traffic issues are the same for all waste management facilities and is essentially dependent on the throughput of the plant. Green waste composting will have proportionally higher transport burdens compared to other composting options. The bulk density of the incoming green waste will be in the range 100 to 200 kg per m^3. This is between one third and one half that of normal domestic waste and hence the same weight of waste will require 2 to 3 times as many vehicles to transport it to the plant. The transport of the compost product will require up to five times less vehicle movements as some 40% of the mass will be lost as moisture and CO_2 and the bulk density will increase to 500 to 800 kg per m^3. Markets for composts tend to be local and hence the transport distances for the products will be similar to the distances travelled by the wastes.

3.4.5 Environmental Impacts

Air

Emissions from mixed waste composting plants are similar to those from green and bio-waste composting plants. The emissions of concern have been identified as bio-aerosols, VOCs, odours and dust. The VOC emissions from MBT plants have been monitored in an Austrian study and this indicated that Benzene, toluene, xylene, trichloromethane and vinyl chloride were potentially of concern with emission concentrations of up to 0.068 $\mu g\ m^{-3}$, 0.82 $\mu g\ m^{-3}$, 6.76 $\mu g\ m^{-3}$, 0.012 $\mu g\ m^{-3}$, 0.022 $\mu g\ m^{-3}$ respectively. Emissions of alkanes, alcohols and aldehydes were all effectively controlled using biofilters. However, this study stressed that the data was generally inconclusive and that further studies were needed.

Bio-aerosols are emitted by all waste management facilities and composting is no exception. Open windrow systems will provide a larger emissions source during the turning operations. Emissions from turned windrow operations have been reported to reach in excess of 690 x10^6 cfu m^{-3} of bacteria and 2.7 x 10^6 cfu m^{-3} fungi. Estimates from enclosed systems are currently not available but would be expected to be significantly lower.

The air emission that causes the most complaints is the odour from the composting waste. This can be minimised through good management of the composting process to ensure that the material remains aerobic. However, there are occasions where odour is generated. In open turned windrow systems mitigation is not possible although there are some proprietary spray systems (based on surfactants and oils) that claim to reduce the problem when used in a perimeter spay. Alternatively, the windrows can be covered with geotextiles to reduce the odour problem. In-vessel systems and aerated piles that suck rather than blow the air can treat the odorous air through biofilters or chemical scrubbers to eliminate the odour. Obviously, treatment of the odour will also mitigate the VOC emissions. In relation to other forms of composting, mixed waste composting will have a higher potential to generate odours, but as in most cases the process will be contained this will allow control of the problem that is unavailable to open windrow systems used for green waste composting.

Water

Leachate from composting can be a potential hazard to surface or groundwater if it is accidentally released without treatment. Mixed waste composting has a significant demand for moisture, which is used in the initial pulverisation stage and then evaporated in the composting stage. Thus, any leachate produced can be utilised within the process. Composting of green waste and kitchen wastes has the potential to generate greater amounts of excess liquor especially if conducted in the open. The run off and leachate has the potential to contaminate surface or groundwater. There is a need for all composting processes to be performed on impermeable surface as escape of the run off and leachate could potentially contaminate surface or groundwater.

Soil

The contamination of compost derived from green waste is generally low with inert contaminants (glass, plastics, metals) removed through a combination of visual inspection and screening. Kerbside collected organic waste feedstocks will contain slightly greater proportions of contamination, but will still be within the capabilities of systems to remove them. Mixed waste systems will require extensive sorting to remove the inert contamination and significant amounts will remain. This will result in the composts from mixed waste will only be able to be used in the lowest quality applications such as landfill cover or land restoration.

Heavy metal contamination is an issue with all waste based composts, but green waste is likely to be the least contaminated feedstock and mixed waste the most contaminated. However, in some locations, contamination from atmospheric pollution in urban areas and roadsides (such as motorway verges) results in higher than acceptable levels from green waste sources. There are currently no UK regulatory standards for composts although the Compost Association and Soil Association have each issued their own industry standard. Also, there are numerous standards in other European countries that are useful guides. The subject of standards and the issues in setting them are thoroughly discussed in a report from CEN. The draft Biodegradable Waste Directive identifies quality limits for composts from both source separated and mixed waste compost.

Noise

There are two main noise sources on compost sites, the shredders and the reversing signal for the loading shovels. The noise made by shredders can be up to 90 dB, which is particularly a problem for open systems. However, the windrows can be used as effective sound barriers and appropriate positioning of the shredding operations and windrows can reduce noise complaints to a minimum. The choice of reversing warning signal is vitally important on compost sites as the vehicles spend almost half their time going backwards. Removing the signal altogether has implications for health and safety issues but there are "smart" signals that vary the volume depending on proximity of people and verbal warnings, which are not so penetrating as the high frequency signal fitted to many vehicles.

Pathogen kill

Heat released during composting elevates the compost temperature of the compost. If uncontrolled, the temperature can rise to 80°C or more, but it is normal to limit the temperature to about 50-60°C. This represents a compromise between the optimisation of the speed of composting and the sanitisation of the compost product. Guidance on the precise conditions required for adequate sanitisation vary but range between maintaining the temperature above 55°C for three days and five days at over 60°C. These guidelines are based on the operation of turned windrow systems. Mixed waste composting is most likely to be performed in an enclosed system and these systems offer improved sanitisation due to the greater confidence that all of the waste is exposed to the time-temperature conditions. Thus, this provides greater confidence that the process kills pathogens (both plant and animal). However, mixed waste will contain a wider range of pathogens and thus this increases the need for security in pathogen kill. Overall, mixed waste compost is unlikely to be exposed to the public and thus health risks will be low.

3.5 Contribution to Targets and Policies

3.5.1 Landfill Directive

The key target for municipal waste in the Landfill Directive is the requirement to reduce the amount of biodegradable waste landfilled. The precise targets are to reduce the biodegradable municipal waste landfilled to 25%, 50% and 65% of the 1995 quantities by 2006, 2009, 2016 respectively. The UK is allowed to extend these dates by upto four years.

The definitions for biodegradable waste and how its biodegradability will be measured have not been set. However, using the definition set out in "A way with waste", the Waste Strategy and discussions with the Environment Agency, an estimate of the diversion possible can be made. For mixed waste systems that treat the whole of the waste stream, the compost product can be considered as non-biodegradable and hence the only biodegradable material will be the material in the reject fractions that are sent to landfill. A previous study showed that only 5-10% of the biodegradable material was rejected and not in the compost product. Thus, using this estimate mixed waste composting would provide 90-95% diversion of biodegradable material from landfill. However, the process would only divert approximately 60% of the weight of waste from landfill, as there is no effect on the non-biodegradable materials.

Source separated composting will use the compost product outside of landfill and thus diversion will be, again, limited to the reject fractions. The biodegradable fraction of the rejects from source separated waste will be limited and be less than 5% of the biodegradable content of the supplied waste.

3.5.2 Waste strategy

UK Government Waste Strategy targets for recycling are currently 25% by 2005, 30% by 2010 and 33% by 2015. The targets for recovery of waste are 40% by 2005, 45% by 2010 and 67% by 2015.

Composting of source separated wastes contributes towards both the recycling and recovery targets. However this will depend on the compost being used in a beneficial way. Under normal circumstances all of the material directed to source separated composting facilities will count towards the recovery and recycling target.

The use of mixed waste will result in some or all of the material being used in landfill and hence not "recycling". The precise definitions of this have not been established. For the purposes of this study 50% of the compost product will be considered as recycling and the loss on composting will be considered as recovery (similar to the mass lost during incineration). These estimates may vary once the precise guidance is given and specific projects are considered with planned uses or disposal of the final compost.

3.5.3 Greenhouse gas

The Kyoto protocol established targets of 12% reduction in the climate change gas emissions and subsequent UK policy has set a target of 20% CO_2 reduction of 1990 levels by 2010.

The emission of CO_2 by the composting process is an expected outcome from the process. However, the biodegradable material (i.e. plant matter) is all recently absorbed carbon (termed "short cycle") and thus has little impact on climate change potential. There is an emission of other greenhouse gases such as methane, and N_2O, which contribute to the climate change effects. Emissions of methane have not been measured often, but studies have shown that methane emissions from well operated composting systems are low and below the detection levels. Methane emissions are expected to be present in very small quantities due to the heterogeneity of waste composting but emissions are negligible.

3.5.4 Renewable energy

UK government has set a target of 10% of electricity generation from renewable sources by 2010. Composting does not contribute any renewable energy and is a net consumer of energy. Energy use in composting plants varies considerable between the different technologies used but the simplest systems will use around 5 kWh t^{-1} whilst the more complex systems with shredding and sorting plant may use upto 50 kWh t^{-1}.

Table 3.7 Summary of criteria assessments - Composting

	Green waste	In-vessel system	Mixed waste (MBT)
Economic			
Capital cost Operational cost	£25-90 tpa-$^{-1}$ £15-25 t^{-1} dependant on scale	£100-300 tpa-$^{-1}$ £19-45 t^{-1} dependant on scale	£85-150 tpa^{-1} £14-25 t^{-1} dependant on scale
Technical			
Proportion of the municipal waste stream treated	Approximately 40% of civic amenity waste equates to 10% of MSW	Kerbside collection of organics and green waste maximally 35%, likely to be less due to less than perfect participation	All of the waste delivered but majority of the waste is rejected in the initial sorting, 50% of waste processed
Energy production	Energy consumption 25 kWh t^{-1}	Energy consumption 25 kWh t^{-1}	Energy consumption 50 kWh t^{-1}
Land requirements	2 m^2 t^{-1}	0.5 m^2 t^{-1}	0.4 m^2 t^{-1}
Operational/risk			
Availability	85%	85%	85%
Quality of products	Generally high	Generally high but potential for some contamination	Contamination high but sorting may improve quality to be acceptable for low grade uses
Operations in UK	>50	>10	1
Operation elsewhere	>100	>100	>100
Operational success of commercial plants	Good	Good	Some difficulties due to markets but plant are still operational
Planning requirements	Generally small scale odours and bioaerosols issues	Visual impact, bioaerosol and odour issues	Similar to other large scale waste systems, reduced compared to incineration
Scope for integration	Only treats specific fraction of waste stream	Treats upto one third of waste stream, some flexibility regarding paper and other organics	Accepts whole of waste stream thus can rejects suitable for other options
Stability of markets for recyclate/products	Reasonable but product quality issues (consistency) an issue	Reasonable stable but product quality (contamination) require constant attention	Product quality likely to make markets poor for soil improver/land restoration
Education needs	Education publicity at CA sites	Detailed and intense education required to avoid contamination	None
Public dependence	Dependant on public willingness to participate well	Dependant on public willingness to participate well	None

Table 3.7 continued

	Green waste	In-vessel system	Mixed waste (MBT)
Environmental			
Greenhouse gas reduction	325 kg t^{-1} Significant car transport emission in "collection" of waste	16 kg t^{-1} energy use and kerbside collection use energy	42 kg t^{-1} more energy use in processing, limited energy in collection of waste
Air quality	Odours and bioaerosols	Odours and bioaerosols	Odours and bioaerosols, contained
Water pollution	Exposure to rain-potential loss of leachate	Enclosed system little chance of release	Enclosed system little chance of release
Solid residues/hazard	Low contamination of product, small amounts of residues	Low contamination of product, small amounts of residues	Contaminated product, majority disposed to landfill
Noise	Exposed operation, potential for nuisance	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance
Odours	Potential to cause nuisance	Enclosed plant potential to control odour	Enclosed plant potential to control odour
Transport	1% rejects to landfill, 50% product to market	1% rejects to landfill, 50% product to market	50% reject to landfill, 15% product to market
Resource use	Limited use	Limited use	Limited use
Policy			
Meeting recycling target	All material recycled	All materials recycled	Metals recycled
Biodegradability reduction	All material recycled	All material recycled	Reject fractions contain some biodegradable material
Public perception	Well viewed	Well viewed	Well viewed, unknown technology
Employment opportunities	0.2 jobs $ktpa^{-1}$	0.33 jobs $ktpa^{-1}$	0.33 jobs $ktpa^{-1}$
Public involvement	Limited to civic amenity separation	Detailed involvement with kerbside collection	No involvement of the public

4 ANAEROBIC DIGESTION

4.1 Introduction

An alternative to composting for the biological treatment of waste is anaerobic digestion (AD). AD is analogous to composting but is an **anaerobic** decomposition and thus is performed in the absence of air. The main products from this degradation process are a solid residue similar to compost called digestate, biogas a mixture of methane and carbon dioxide and a liquid fraction containing water and nutrients.

4.1.1 Biology of Anaerobic Digestion

Anaerobic digestion (AD) is a biological process where organic substrates are degraded by microorganisms in the absence of free oxygen producing methane and carbon dioxide. Anaerobic digestion (AD) occurs naturally in oxygen free environments such as under-water sediments or landfill sites.

The theory and mechanisms of the digestion of organic substrates by anaerobic microorganisms have been extensively covered in the literature, however for clarity a short synopsis of the process is given here.

The process is carried out in four main steps:

(a) Hydrolysis or liquefaction, in which the complex primary polymers of carbohydrates, lipids and proteins are solubilised by enzymes secreted by hydrolytic bacteria, thus converting the insoluble biological polymers to soluble organic compounds.

(b) Acidogenesis, in which soluble organic compounds, including the products of the hydrolysis (soluble monomers) are fermented to various intermediate products such as short chain organic acids (called volatile fatty acids or VFA's) and alcohols.

(c) Acetogenesis, in which the alcohols and volatile fatty acids are converted into acetic acid, carbon dioxide and hydrogen by acetogenic bacteria.

(d) Methanogenesis, in which the methanogenic bacteria complete the process by converting acetic acid and hydrogen to methane and carbon dioxide.

Each of these steps is performed by groups of bacteria, which are grouped by their trophic (feeding) requirements.

There are other many other reactions which make the process more complicated, such as the action of the sulphate reducing bacteria or the homoacetogens. These organisms compete with the methanogens for some substrates such as formate as well as controlling the hydrogen balance of the system by producing acetic acid from hydrogen and carbon dioxide. However, in general the groups of bacteria are mutually beneficial and interdependent i.e. removing inhibitory products of other bacterial groups and/or producing substances for other bacterial groups.

The important point is therefore, that the process is dependent on the correct balance of each of these groups of bacteria because any one group will not operate alone. For example, if the slower growing methanogenic bacteria are removed then acetic (and other) acids will not be degraded and the system will become increasingly acidic. Eventually bacterial action is stopped when the pH reaches inhibitory levels for the acetogens and acidogens.

Anaerobic digestion will operate over a wide range of temperatures, however there are two temperature ranges where the digestion is most rapid, mesophilic (about 35^oC) and thermophilic (about 55^oC).

4.2 Anaerobic Digestion Processes

4.2.1 Technology

To facilitate the digestion of wastes the engineering is required that provides the correct feedstock and maintains the conditions for the biological processes to proceed optimally. The engineering solutions to this problem are many and varied and there are a wide range of process designs, each capable of handling the waste stream in a different way, but with the end result of degrading them anaerobically and recovering biogas. Most of these processes are proprietary designs and thus are only supplied by one manufacture. However, the various designs tend to follow some basic principals, but have advantages and disadvantages in various aspects and there are no single "best" designs.

As a broad guide to the anaerobic digestion systems used for MSW treatment these can be divided into a number of types, depending on four basic parameters, solids concentration, temperature and mixing system and number of stages. Using these parameters can describe most of the systems of the market today, although some systems still fall between these categorisations.

Table 4.1 Operating parameters of anaerobic digestion systems

Temperature	Solids concentration	Mixing	Stages
Mesophilic (~35°C)	Low solids <10% DS	Mechanically mixed	single stage (one vessel)
Thermophilic (~55°C)	Medium solids<10% ->25 % DS	Gas mixed	Multi stage
	High solids >25% DS	Plug flow	
		Batch	

Temperature

There are two main operational temperature regimes centred around 35^oC and 55^oC called mesophilic and thermophilic respectively. The advantage of mesophilic (35^oC) operation is that it is well understood, requires less heat to maintain operation, achieves a greater degree of stabilisation and is said to be more stable or robust due to the larger diversity of bacteria. However thermophilic (55^oC) operation is said to operate at a faster rate and the arguments of decreased stability have not been borne out by practical experience. In addition, the thermophilic regime achieves more rapid/complete sanitisation of the waste.

The precise choice of system is a balance between many specific conditions for the location and application of the digester. A thermophilic system will be able to treat a greater quantity of waste due to the higher reaction rate but the digestate may require a longer maturation stage to take into account the remaining undegraded material. However if this is coupled to a composting system to improve the quality of the digestate, mesophilic operation may not leave sufficient readily biodegradable organics to support composting.

In many European countries a sanitisation stage is require for certain wastes where the waste is heated to 70°C for one hour. Having heated the waste there is an energy balance argument to use the heat to operate thermophilicly and thus thermophilic operation is becoming more common. Even when a separate sanitisation stage is not require sanitisation is greater than under mesophilic and thus this enhances the marketability of the compost product.

Solids concentration

Traditionally sewage sludge and waste water digestion operate at very low solids concentration typically less than 5% TS. This is a consequence of the feedstocks being dilute. With solid wastes the opportunity of increasing the solid concentration has the benefit of increasing the concentration of organic matter with a vessel, which will have two effects of increasing the gas production rate per unit volume of digester and reducing the heating requirements of the feedstock. Thus both of these factors increase the cost effectiveness of the process. However, there are limits to the increasing solids concentration. Biologically, the organisms require a free liquid and the concentrations of salts and acids can become toxic if too concentrated and thus this limits the moisture content with MSW feedstock to approximately 50-60% (40-50% TS). More importantly there is a requirement to be able to get the waste into and out of the digester vessel and this imposes a limit on the pumpablity of the waste and using a concrete pump the DRANCO system operates at 30-35% TS. If mixing is required, then lower solids concentrations are needed. As the concentration becomes lower (i.e. more dilute) the mechanical problems of handling the waste become less but the digester tank sizes and water heating requirements become greater and it is a commercial/technical compromise for each process. Some processes avoid the problem of pumping the waste and treat the waste as a solid with shovels and conveyors to fill and empty the digestion vessels on a batch basis.

Mixing systems

The need to mix the waste within the digestion vessel is driven by the requirement for the organisms to be brought in to contact with the waste and to avoid excessive local concentrations of degradation products. Also the mixing is to ensure that inappropriate separation of the light and heavy fractions of the waste does not occur. In addition in most systems there are some difficulties in releasing the gas generated from the waste mass either through scum formation or from the flow characteristic of the waste.

Some systems avoid the technically demanding task of stirring within the vessel by either utilising a plug flow system where no mixing occurs or by "leaching" the solid waste.

There are essentially two systems for mixing the waste within a vessel, mechanical or gas mixing. Mechanically stirring the waste with a paddle or propeller. Obviously there is potential for these to get clogged by items in the waste and effective control of the feedstock should minimise this. Gas mixing uses high pressure bursts of the biogas from the base of the digester to mix the waste. Care in the design is required to ensure that this does not induce stratification of the waste with heavy particles such as glass collecting at the bottom of the vessel. However, there are systems that utilise this as an additional technique of removal of heavy contaminants.

Plug flow systems tend to avoid the difficulties of mixing within the digester and effectively use the recirculation and feedstock mixing as the mixing system. This arrangement has the advantage of keeping the equipment outside of the digester and hence open for maintenance. Also plug flow does provide some confidence in the minimum residence time that may be required for sanitisation.

Staging

The conditions for the various stages of the degradation process have slightly different optimum conditions. This results in a compromise in the operating conditions of a single vessel. Staging of the process into separate vessel such that the hydrolysis/acid forming stages are carried out separately from the methane forming stages can lead to more efficient processing. There are cost implications from having more vessels but the higher rates and throughputs that can be achieved may outweigh this.

Probably the most common form of staging are the processes where the solid waste is only treated in the hydrolysis stage and the liquor from the hydrolysis is then treated in standard waste water methanogenesis stage.

The advantage of single vessel digestion, which is the most common process, is the simplicity. The complexities of dealing with waste demand that unnecessary complexity is avoided and thus the prevalence of single stage systems on the market.

4.2.2 Process arrangements

Anaerobic digestion has been practised for many years on organic waste streams, the most notable is the digestion of sewage sludge, which has been a major treatment method for many years. Industrial wastewaters have also been processed by anaerobic digestion including wastes and effluents from dairies, breweries, sugar refineries, soft drinks, starch and paper mill effluents. Solid wastes have been treated by in-vessel anaerobic digestion, although to a much smaller extent. The best examples of this type of technology are agricultural waste digestion processes, which have been operated for several years on farm manures and abattoir wastes. However, the technology has not become widespread in the UK due to the marginal economics of treating these wastes. However as agriculture faces more stringent environmental controls, wider adoption of this technology can be expected as already seen within Denmark.

The UK’s growing interest in engineered in-vessel anaerobic digestion systems for MSW is still fairly recent despite some earlier attempts to commercialise the technology in the 80’s and early 90's. The UK research experience in this area is more detailed, but most academic and commercial experience rests in the anaerobic digestion of domestic and industrial effluents. It is therefore generally necessary to look overseas to learn more about some of the development activities in this area.

Anaerobic digestion in waste management can operate in a number of ways. The three main options discussed here are:

- digestion of "biowaste", source separated organics (kitchen waste and small garden waste) from households,
- digestion of organic components from mixed municipal solid waste (MSW) to generate low value soil improver or as a pre-treatment to landfill disposal,
- centralised anaerobic digestion (CAD) where source separated municipal wastes are digested in combination with other wastes principally agricultural waste but possibly including sewage sludge and industrial organic waste as well.

Biowaste Digestion Systems

Source separated feedstocks are processed by AD in much the same way as biowastes are composted and as such are competing processes. The principal difference is that the process is necessarily enclosed and there is an energy product.

The process proceeds by comminution of the feedstock to reduce the particle size and increase the surface area of the waste. Contaminants, such as metals, plastics and glass, may be removed at this stage through a combination of manual and automated systems. The shredded waste is then mixed with digested material and liquid to inoculate it with the digestion micro-organisms. The control of the recirculation of material can be a critical control factor in the process. Once the feedstock is mixed it is introduced to the digestion vessel where the organisms start the degradation and gas production processes.

The digestion normally will take between 14 to 28 days by which time about half of the organic matter will have been degraded. The residue will be the refractory lignocellulosic parts of the organic waste.

The digested waste will be more liquid than when it went in to the process due to the loss of organic matter but effectively no loss of water and thus the waste may require dewatering prior to use of the digestate. The requirement for dewatering is dependant on the market with agricultural markets being able to accept and use slurries whilst most of the uses of the digestate will require the liquid and solids separated.

The dewatering will be undertaken through a screw press and in some processes the liquor will go through a centrifuge as well. This can be an expensive part of the process as flocculants are often used to improve the performance.

The liquor contains nutrients and residual organic matter and could be used as a fertiliser, but due to national regulations is often disposed of to sewer after treatment. The solid residue requires a short aeration stage (one - two weeks in windrows) before it is screened to remove contaminants and sold as compost.

The biogas product is a valuable energy resource and can be either burnt for heat or electricity or can be upgraded by removal of the carbon dioxide for injection into the natural gas grid or for use in standard CNG (compressed natural gas) vehicles.

This process is shown graphically in Figure 4.1.

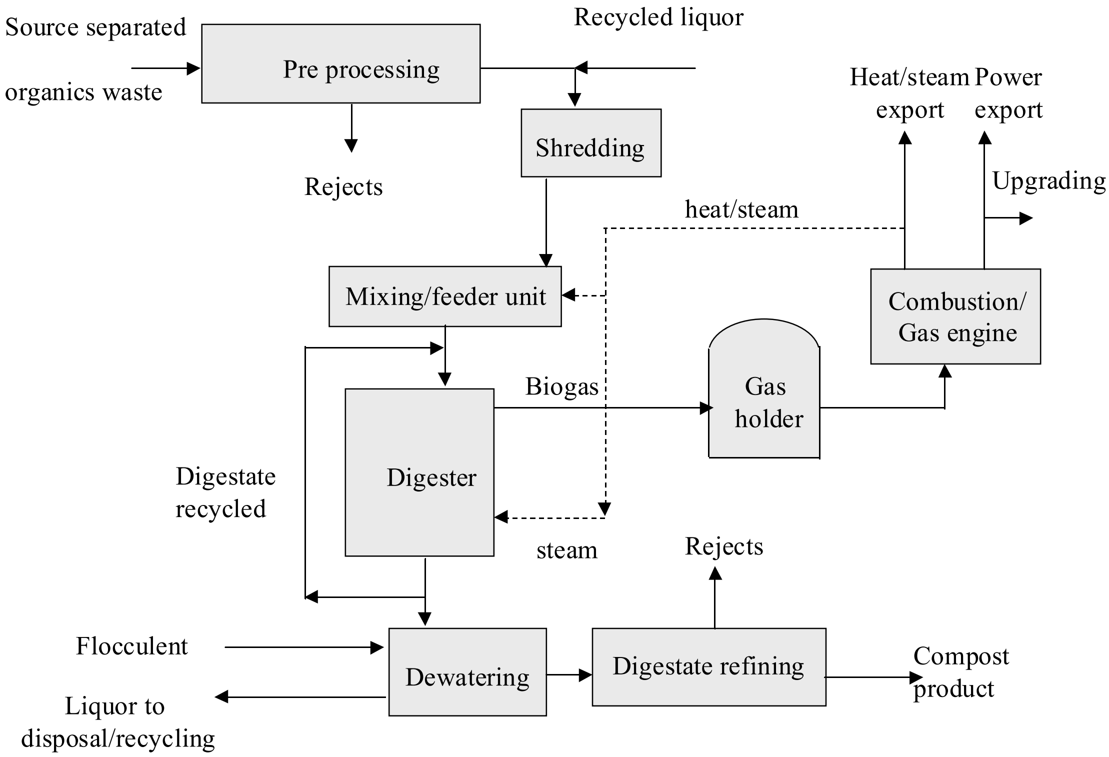

Figure 4.1 Anaerobic digestion process

The processes that are used for biowaste digestion are probably the most varied, with systems using almost all the combinations of process type listed in Table 4.1. There are over 40 suppliers of processes on the market who have built systems but there are a few market leaders who for commercial and technical reasons have started to build larger numbers than other suppliers. However, there is a large number of "home built" digesters on farms (particularly in Germany) processing small amounts of biowaste and whilst they might be more correctly considered as CAD plants they are often similar in many respects to commercial designs.

The main processes that are the market leaders for MSW biowaste digestion are Dranco, Steinmuller Valorga, Kompogas and BTA. These systems are briefly described below.

The Dranco Process

The DRANCO process uses an unmixed downflow digester with recycle of digestate (liquors and solids) for inoculation and water management. The process operates at upto 30% total solids and uses a modified concrete pump to transport the feedstock to the top of the digester. The process is thermophilic with the feedstock being heated with steam produced from the biogas. Figure 4.2 shows a schematic representation of the process. Table 4.2 shows typical performance data from the plant when digesting the organic fraction from mixed collection and source-separated MSW-putrescibles i.e. vegetable, fruit and garden (VFG) wastes with and without waste paper.

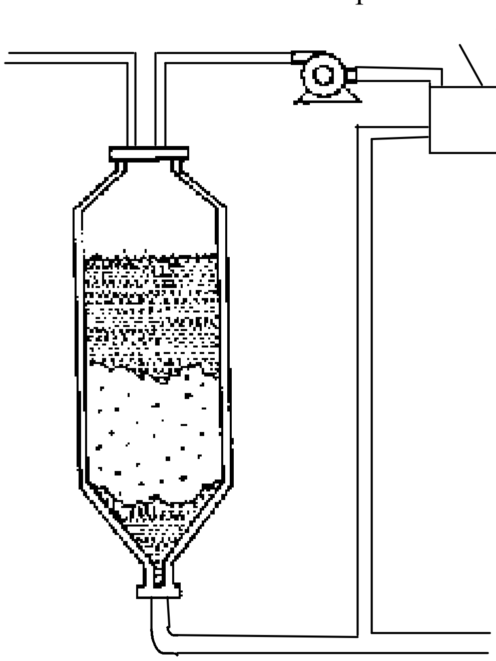

Figure 4.2 Schematic of Dranco process

Table 4.2 Typical Operating Parameters of the DRANCO Process on MSW-Derived Feedstocks

	Mixed Collection MSW	Separated VFG	Separated VFG+Paper
Feedstock			
Total Solids	55%	32%	43%
Volatile Solids	36%	18%	27%
Loss-on-Ignition	65%	57%	63%
Kjeldahl Nitrogen (mg l^{-1})		5620	4570
C/N Ratio		14-16	29
DRANCO Process			
Loading Rate (kgTS m^{-3}.d)	15-20	13	19
Retention Time (days)	18-21	25	20
Biogas Productivity (m^3 m^{-3}.d)	5-8	3.2	5.1
CH4 in biogas	55%	55%	55%
CH4 Production (m^3 wet $tonne^{-1}$)	90	41	62
CH4 Production (m^3 tonne TS^{-1})	164	129	143

The Valorga Process

This process is now developed and marketed by Steinmüller Rompf. The process is a thermophilic process, which operates within a single digester, which is mixed by the high-pressure injection of biogas. The digester is typically operated at solids concentration of 25-35%. Whilst the digester is intended to be fully mixed the tank is divided by internal baffle to avoid short-circuiting of feed stock to the outlet.

Once the digestate leaves the digester it is dewatered and the liquor is recycled to dilute the incoming feedstock. The solid digestate is stabilised by aeration and then used as compost.

The biogas production rates vary between the plant depending on the feedstock; biowaste feedstocks generally generate 80 to 110 m^3 t $feedstock^{-1}$.

Kompogas

This is a Swiss developed process and operates around a horizontal plug flow digester. The digester is agitated by a horizontal paddle stirrer, which ensures the gas is released from the waste. Solid concentrations for the feedstock in to the digester are approximately 20%. The process is operated at thermophilic temperatures.

Kompogas has been prominent in the development of biogas upgrading for fuel use and is developing a network of filling stations in Switzerland.

BTA

BTA provide a range of systems for biowaste, but predominantly they offer a one or two stage low solids concentration system. The digesters are essentially mechanically stirred tank containing the pulped organic waste. The feedstock is pulped and brought to 10% TS slurry that can be easily pumped.

The single stage process extracts methane from the vessel with the slurried waste in it. Residence time is upto 21 days. In the two stage system the first stage is carried out for 4-10 days and after this the slurry is dewatered and the liquid fraction taken on for methane production. The solid residue is composted and sold.

Mixed Waste Digestion - Mechanical Biological Treatment

Digestion of mixed MSW is not currently widespread. The early experiments (Pompano Beach, Solicon, IBVL, etc) into AD as a waste management technology did operate on mixed waste but the economics and technical difficulties made these experiments difficult to develop further. However, some projects have continued with the Valorga Amiens plant and more newly constructed plants at Bottrop and Gronigren. These are operating providing low quality soil improvers from the mixed waste stream. One advantage of AD over composting of mixed waste is that there are additional options for the sorting of the waste and thus there is more potential for higher quality composts than would be achieved through composting.

The AD technology itself is essentially the same as that used for biowaste processing. However, the key difference is the sorting that surrounds the biological processing. The sorting processes will be aimed at removing a high proportion of the non-degradable materials but keeping the organics and paper fractions, which can be degraded. Processing after digestion will include hydro cyclones for removal of the sand and fine glass and floatation for removal of plastics. The most recent example of this technology is the Vagron plant in Groningen, Netherlands.

The Vagron Plant

This plant is a newly constructed (opened April 2000) plant based on grey waste processing. It is based on the CiTEC Waasa process, developed in Finland from an existing sewage sludge digestion system. The process is based on a mixture of sewage sludge and the municipal waste after intensive source separation recycling (grey waste). The plant operates with a feedstock at 12-15% solids, processing 230,000 tpa of refuse from Groningen area. After sorting, approximately 60,000 tpa is processed through the digestion plant. The whole process is integrated with a processing plant where refuse derived fuel (RDF), metals, sand and paper/plastic concentrate are recovered.

The process operates at thermophilic temperature (55°C) and has a retention time of 18 days. The digestion occurs within four 2750 m^3 vessels, which have internal sections to improve digestion. Mixing within the sectioned digestion vessel is by gas injection. Approximately, 8.5 million m^3 of biogas is expected to be produced.

Centralised anaerobic digestion (CAD)

Centralised anaerobic digestion plants (CAD) operate where wastes from many different sources are combined in one plant. These are invariably based around an agricultural waste digestion system where several farms co-operate by treating their animal wastes in a single facility. Industrial and municipal wastes are taken in to the plant at upto 10% of the plant feedstock. This provides additional revenue from the gate fee and additional gas generation. The solid residue is distributed back to the participating farms. This approach has been extensively adopted in Denmark where there are 20 CAD plants in operation. Other examples can be found elsewhere in Europe, but Denmark has been pre-eminent in developing this approach.

The principal technology used for CAD plants is traditional manure based systems which are inherently low solids systems. Here shredded MSW-derived feedstocks are diluted with large volumes of water to provide a 5-10% slurry, which is digested using modified sludge digestion technology from the wastewater industry. The practicality of these CAD plants relies on the organisation arrangements for the supply of waste and the guaranteed market for the digestate provided by the co-operating farms.

4.2.3 AD feedstocks

Raw domestic (unsorted) refuse is generally not a good feedstock for anaerobic digestion plants or any other biological treatment. The analysis in Table 4.3 shows typical UK refuse. Of this 28% is not readily degradable and a further 50% is only partially/slightly degradable. If we assume that half of the material in the categories noted as partially/slightly degradable is biodegradable, then the total readily biodegradable material would be only 47%. Hence, unsorted raw refuse does not make best used of the costly and limited digester volume.

Table 4.3 Analysis of Typical UK Waste and Estimates of Biodegradability

Category	Assay %	Readily Degradable
Paper	31	partially
Plastics	8	no
Textiles	3	slightly
Miscellaneous Combustibles	5	slightly
Miscellaneous Non-Combustibles	3	no
Glass	8	no
Putrescibles	22	yes
Metals	9	no
Fines	11	partially

A more efficient use of anaerobic digestion plant is to feed concentrated feedstocks that contain as few inert components as possible. This ideal situation can be achieved with selected industrial and agricultural wastes but is much more difficult with mixed waste streams such as MSW. Therefore, the refuse has to be sorted to provide concentrated feedstocks to the anaerobic digestion plant. This can be achieved by several strategies.

Source Separation

Source separation relies on the public to separate recyclable materials from the waste stream. The majority of schemes in the UK collect materials such as glass, paper, metals or plastics although there are some, which collect the biodegradable materials for composting or anaerobic digestion. For schemes that only collect inert materials such as metals, paper, plastics etc. the residual waste stream (called grey waste) will become more concentrated with degradable organic fractions and hence become more amenable to biological treatment.

The quality of source separated organics will be high as there will be few inert particles or potentially toxic elements (PTE's) such as heavy metals. However, the general quantity of this feedstock will often be low and the quality will be heavily dependent on the nature of biodegradable components collected by the individuals concerned. In addition, such schemes rely on public participation (which is never 100%).

If the residual fraction from an inert material based source separation scheme is to be treated as an AD feedstock it will need to be treated in the same way as normal mixed waste (via physical separation plant) to remove potential contaminants. However, this will usually result in a higher yield of feedstock for digestion.

Mechanical Separation

Mechanical separation of organics for anaerobic digestion can be performed as part of two different feedstock utilisation strategies:

i) as a stand alone process which tries to maximise gas yield by recovering all of the available biodegradable material from the waste stream;

ii) as a process to recover the organic rich rejects of another process (e.g. RDF fuel recovery) and so some biodegradable materials may be lost to the other process.

In practice, the two approaches are tending to come together. Systems, which initially attempted to digest MSW after only minimal or no pre-treatment, have built up selective separation processes upstream and are adopting energy recovery by direct combustion and materials recovery modules. Systems which were primarily developed for maximising fuel and/or materials recovery are now considering anaerobic digestion, not just for organic rich residues but also for some components currently directed to combustion. Recognition that no one conversion option can deal effectively with all the components in mixed waste is central to any waste management strategy where resource recovery is a prime consideration.

Complementary Feedstocks

There may be technical and economic benefits in combining the organic wastes from other sources such as sewage sludge, selected industrial organic wastes and agricultural wastes. Sewage sludge in particular has many processing problems in common with MSW in terms of PTE's but is well established in use of the digestate for land application.

There may also be financial benefits from treating industrial organic wastes as these will introduce additional revenues and increase the scale of the plant and thereby spread the overhead costs more widely.

4.2.4 Products

Anaerobic digestion of MSW has three products, biogas (a mixture of methane and carbon dioxide), liquid effluent and a solid residue generally termed digestate.

Biogas

Biogas is a mixture of methane 55-65% and carbon dioxide (35-45%) with small quantities of other gases such as hydrogen, hydrogen sulphide or ammonia. The gas is saturated with water and any use of the gas requires removal of the water and hydrogen sulphide to prevent corrosion.

Use of the biogas is normally easy as it can be burnt and therefore has the same potential uses as any other combustible gas, e.g. for space heating, provision of process steam or for process heat such as used in a cement or brick kiln. However, the cost of piping the gas can be prohibitive if the user is some distance away. If no suitable user is within a reasonable distance the fuel can be refined for use as a vehicle fuel or for distribution via the natural gas grid, or converted into electricity for distribution via the national grid.

Upgrading the gas for vehicle fuels or pipeline quality is at present an expensive process as the specification required is very high. However, There are many schemes across Europe and USA where biogas is upgraded on a commercial basis. The largest networks for CNG (compressed natural gas) from biogas (both from landfill gas and in-vessel digester gas) are in Sweden, Switzerland, Czech Republic and France. Pipeline injection from biogas is mainly carried out in USA and Netherlands. More work is required to evaluate this process to determine whether it is viable in the UK.

Conversion into electricity is generally a simpler task, although not without problems such as emission standards, corrosion and mechanical failure. Although not entirely the same, landfill gas is similar to biogas and in the UK there are few, if any, landfill gas to pipeline quality gas conversion facilities. However, there are landfill gas generators that produce electricity for the national grid.

The choice of whether or not the gas is converted on site will be determined by factors such as availability of a local gas user, sale price of produced electricity or pipeline quality gas. However it must be noted that there will be in-house gas requirements for digester heating and drying of the digestate. Thus in-house combustion of some of the gas output is necessary and the economics of a combined heat and power could be attractive.

Liquid
The liquid effluent contains a large proportion of the nutrients from the waste and can be used as a fertiliser. The liquid has benefits over compost in that it can be applied at all times of the agricultural cycle. There are demonstrations of use of the effluent as a hydroponic media for the growth of horticultural and other crops. Recent advances in Denmark (the "Biorek" process) suggest that this can be further refined to produce nutrient concentrates similar to chemical fertilisers. However, many countries prohibit the use of this fraction and hence it must be disposed of either by further aerobic treatment or disposal via the sewage system.

Solid digestate - Compost
The solid digestate is the other product of anaerobic digestion and this can be used as a soil amendment in a similar manner to waste derived composts. However if this material is contaminated (particularly with heavy metals), as may be the case with mixed waste feedstocks, the use of this material may be limited or precluded by legislation. Therefore, some form of refining of this product will be necessary for digestates from mixed waste sources in order to remove inert particles (glass and stones) and PTEs such as heavy metals. Obviously, the extent of contamination will affect the potential end uses of digestate derived compost because of marketing problems even if legislation does not.

Table 4.4 shows typical heavy metal concentrations in the DRANCO system digestate from the three different feedstocks. Source separation aids in providing a better quality digestate (less metals and less broken glass) and inclusion of some waste paper soaks up excess moisture and aids water management in the plant.

Table 4.4 Typical Heavy Metal Concentrations in the Digestate from MSW-Derived Feedstocks, mg kg-1 (dry basis)

	Mixed Collection MSW	Separated VFG	Separated VFG+Paper
Cadmium	2	2	1
Zinc	1020	138	85
Copper	101	20	14
Lead	522	67	61
Nickel	42	25	7

Note: VFG – Vegetable fruit and garden waste

4.3 Technology Status

Anaerobic digestion (AD) has been used to manage wastes and generate energy for centuries. It is widely used in Asian villages, where the climate is suitable for low technology designs, to produce biogas, which is then used for heating and cooking. More recently AD has been developed into an industrial process for large scale waste treatment and energy recovery.

AD of MSW is often described as "emerging and progressing towards full scale commercialisation". For agricultural wastes the technology is more advanced but the economics are such that it still requires some government support.

As discussed there are three main approaches to the digestion of MSW, biowaste, mixed waste, and CAD.

4.3.1 Biowaste digestion

Development

The market has many suppliers of AD systems. Most of these suppliers have built very few plants but most are distinct technical systems with some merit for particular circumstances. However, as the market develops a smaller number of key developers are emerging with many plants to their name. This experience is allowing these developers to improve the process such that they are cheaper to build and operate as well as being more efficient at dealing with the waste.

The IEA has identified about 100 biowaste AD plants spread across the world. The rate of construction, Figure 4.3, has increased since the early 1990's reflecting the introduction of regulations for increased control on waste management in many European countries. The plants now operating are treating approximately 2.2 million tonnes of source separated biowaste

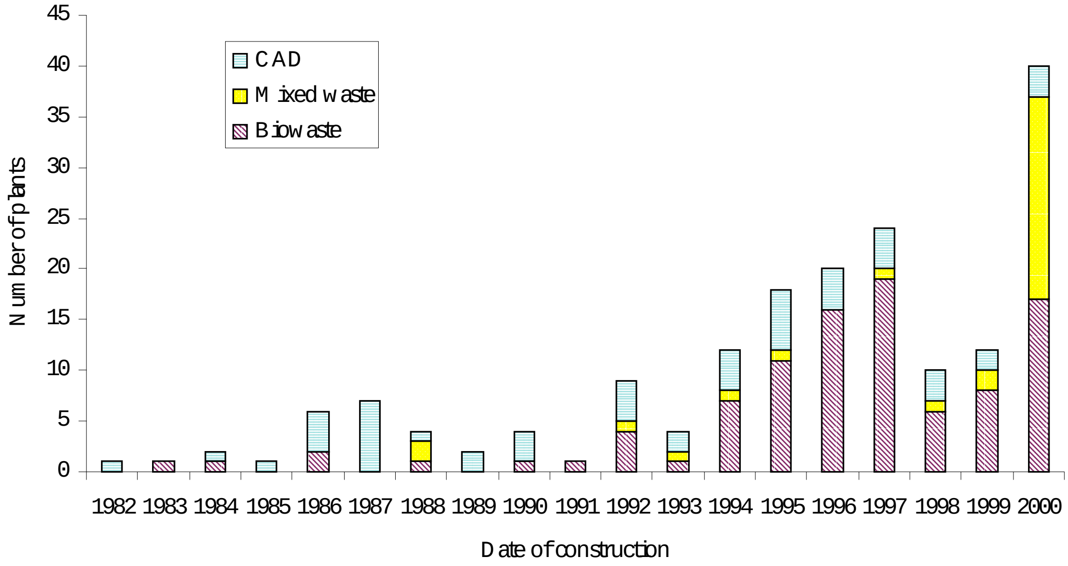

Figure 4.3 Commercial AD plant construction

Biowaste digestion in the UK has not developed yet. There is only one plant operating on source separated waste. The plant is operating on waste from a small trial separation in Ludlow. The process, developed by Greenfinch, is aimed small communities and is currently processing approximately 1000 tonnes per year. The main innovation of this plant is that it combines the growing of plants and fish together with the digestion of organic waste which provides the nutrients and energy needs of the fish farming and plant growth.

One further project for digestion of kerbside collected organics in Leicester is under discussion under the PFI initiative.

Cost and performance

The cost of biowaste digestion is somewhat difficult to asses with any degree of precision as cost information is difficult to obtain due to commercial concerns and in other countries different cost structures exist in terms of tax, legislative and environmental controls. The IEA has carried out a review of cost of biowaste digestion and this is shown in Figure 4.4. This shows that costs for plants are reducing as the technology develops and also shows the marked improvement in gate fee with increasing scale.

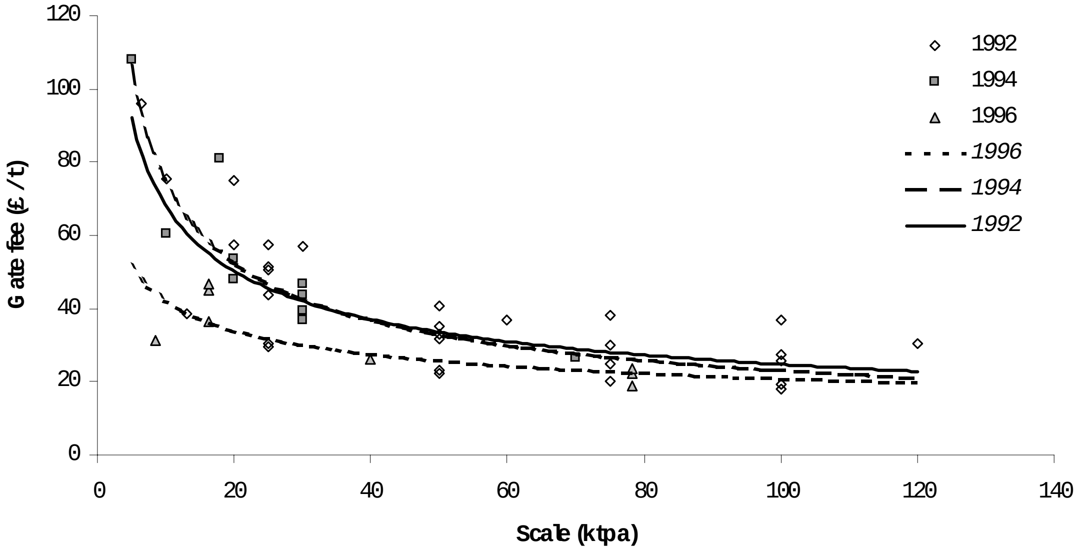

Figure 4.4 Cost of Biowaste digestion in Europe

The biogas production from biowaste does vary depending on the technology used but typical gas production rates are 70 to 120 m^3 t^{-1} (as received). The gas is approximately 55% methane. The energy content of the gas is directly related to the methane content and at 55% the energy content is 21 MJ m^{-3}. Approximately one thirds of the energy generated is required for the process, but the remainder is available for export. From a plant processing 20,000 tpa of biowaste approximately 400 kW of electricity could be exported (4.7 million kWh yr^{-1}) and a further 750 kW of heat. Alternatively, the gas could be processed to provide the equivalent of 1.4 million litres of diesel fuel each year.

The production of compost will vary with the feedstock composition but will be typically 40-70% of the feedstock. The compost once aerated can be sold into the same markets as for aerobic composts

The rejects from the system will primarily be small quantities of glass, plastics and metals and will be the same as compost operations between 1 and 10%. This will require disposal either through landfill or incineration.

The liquid fraction produced will be between 10 and 30% of the input waste and will require a market or disposal. The potential markets for the liquid are currently limited and application to agricultural land is the principle option. Developments on the use of the liquor are on-going and possible options include hydroponics and aquaculture to concentration and treatment to provide fertiliser concentrates. In the short term this liquor will most likely be disposed of to sewer until these applications are more fully developed.

4.3.2 Mixed waste digestion

Development

The development of mixed waste digestion initially started with the Refcom project in the late 1970's and this and similar projects generally failed due to the inability to produce acceptable quality digestate. Interest in the treating of mixed waste for grey waste has increased recently due to the requirement for pre-treatment of waste for landfilling. The development of plant construction is shown in Figure 4.3, which shows that a large number of plants have been constructed in the last year as a response to the demands of the Landfill Directive.

Most of the plants under recently constructed or under development are linked to sorting plants that extract recyclables and other wastes for treatment elsewhere and only the organic rich fraction is treated in the AD plant. The most widely reported is the Vagron plant in Groningen, which is briefly described in section 4.2.2. These new plants can be considered as MBT plants as the digestate is destined for landfill uses.

There are no UK plants currently in operation, although a DTI DEMOS funded plant operated in Irvine for a year as a small scale demonstration project. There are two projects that are at an advanced stage of planning at Oxford and Southampton.

The Oxford plant is to be operated by Thames Waste Management and will use existing sewage sludge digestion capacity. The process will extensively sort the waste from Kidderminster to remove the contaminants prior to digestion. It is then mixed with sewage sludge and digested in a conventional sewage sludge digestion system. The resultant digestate is then sold to farmers for land application as a fertiliser.

The Southampton project, proposed as part of the Integra project, is expected to process 30-40,000 tpa of pre-sorted waste (grey waste) and this will generate electricity for injection in to the grid. Heat supply into the existing geothermal heat network is being investigated. The digestate product will be used for engineering purposes on landfill.

Cost and performance

Cost data for these plants is difficult to obtain as the majority of plants are relatively new and true operational cost have not been established or published. Table 4.5 provides some indicative data for AD plants processing mixed wastes. Care should be taken with the Ashford and Vagron data as the Ashford plant did not proceed and the gate fee is derived from a statement that the gate fee was competitive with the alternatives available at the time and thus have been estimated to be £30-35 t^{-1}. The Vagron plant cost is for the whole sorting plant that treats 230,000 tpa of waste but only 60,000 tpa are digested and thus this cost includes a significant sorting cost but not the combustion costs of the RDF fraction

Table 4.5 Cost data for mixed waste digestion plants

Plant/date	Scale ktpa	Capital cost	Operating cost	Gate fee
Vaasa 1994	40	£4.2 million FIM 40 million	£26.50 t^{-1} FIM 250 t^{-1}	£26.50 t^{-1} FIM 250 t^{-1}
Amiens 1988	72	£10.66 t^{-1} ((£0.8 million) 111 FF t^{-1}	£33.23 t^{-1} 346 FF t^{-1}	£25.55 t^{-1} 266 FF t^{-1}
Ashford **1999**	40	~£8 million		est £30-35 t^{-1}
Vagron 2000	230 whole waste 92 in to digester	£12.9 million 45 million NLG		

The performance of these plants can be measured either in terms of the gas production or through the diversion of biodegradable materials from landfill. The Vaasa and Amiens plants both generate composts for use in agriculture and as such are diverting most of the organic matter from landfill. The Vagron plant is investigating the markets for its compost but it is hoping to find application in forestry and other less demanding uses such as landfill cover.

The gas production rates and energy production for the mixed waste plants are shown in Table 4.6, also shown are some estimated production figures for a UK plant derived from manufacturer predictions. Similarly the compost and residue information is provided in Table 4.7. These show that the out put from these plants is highly variable. This is a consequence of the differences in design and waste (greywaste, unsorted waste or organic concentrate). However, the electricity production is between 50 and 150 kWh t^{-1} and the residues landfilled are between 13 and 70 % of the feedstock waste.

Table 4.6 Gas and energy production for mixed waste AD

Plant	Scale ktpa	Gas production	Export energy
Vaasa	40	1.95million m^3 y^{-1}	2000 MWh y^{-1} electricity 5700 MWh y^{-1} heat
Amiens	72	7.9 million m^3 y^{-1}	40530 MWh y^{-1} process steam
Vagron	92	8.8 million m^3 y^{-1}	14000MWh y^{-1} electricity
UK plant	78	6.1 million m^3 y^{-1}	7100 MWh y^{-1} electricity 14000 MWh y^{-1} heat

Table 4.7 Compost and residues from mixed waste digestion (tonnes)

Plant	Compost produced	Use of compost	Residues for disposal	Other products
Vaasa	11400	landfill cover	25000 3400 wastewater	
Amiens	37200	agriculture (cereals, wine)	9400	
Vagron	23000	unknown	23000 37 wastewater	9000 sand
UK plant	30600	landfill cover	34000 4700 wastewater	5200 Fe

4.3.3 CAD - Centralised Anaerobic digestion

Development

The development of CAD plants has primarily been in Denmark where there are now 20 plants processing a mixture of agricultural wastes together with industrial or municipal solid waste. Three of these CAD plants currently process source separated organic waste as one of the additional sources of feedstock, whilst the remaining 17 accept only industrial (food processing) solid wastes. There are a further 16 plant In Europe currently in operation but there are many more planned in several countries. Table 4.8 shows the distribution of plants.

Table 4.8 European CAD plants

Country	Number of plants
Austria	0
Denmark	20
Finland	0
Italy	5
Netherlands	0
Portugal	4
Spain	0
Sweden	4
Switzerland	3
UK	0

In the UK there have been some 18 proposals for CAD plants, 6 of which have Non Fossil Fuel Obligation contacts, but none of these have currently progressed to an advanced stage of development and none are planning to accept municipal solid waste. This does not detract from the potential of this technology to provide a route for digesting source separated municipal wastes as demonstrated by the experience from Denmark.

Cost and performance

The cost of Danish CAD plants is shown in Figure 4.5 and Figure 4.6 shows that there are large cost savings by constructing larger plants and hence the need for farmers and waste producers to co-operate so that cost saving can be achieved. The Danish plants were all constructed with grant support of between 40 and 20% of the capital cost. Even with these government support grants a study of 1998 performance of these plants showed that 8 out of 17 were not achieving break even performance.

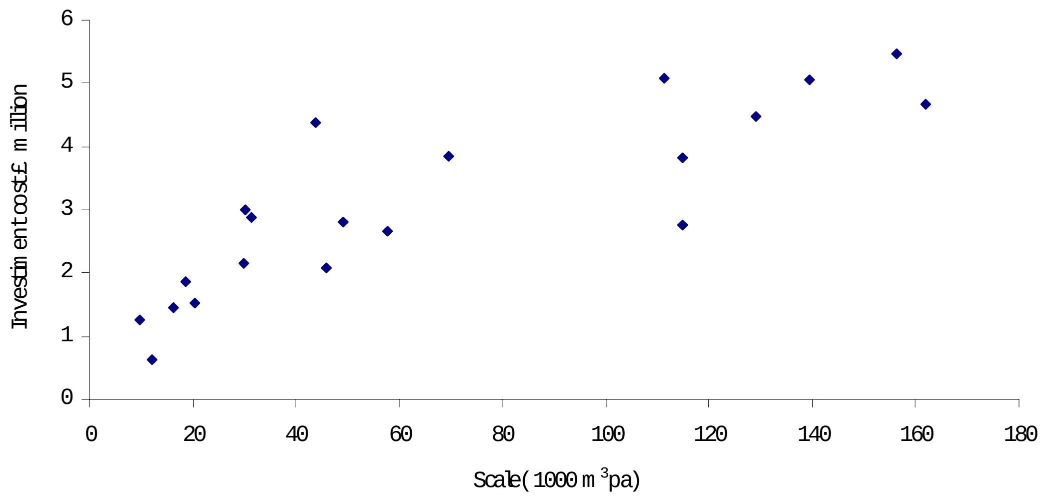

Figure 4.5 Costs of Danish CAD plants

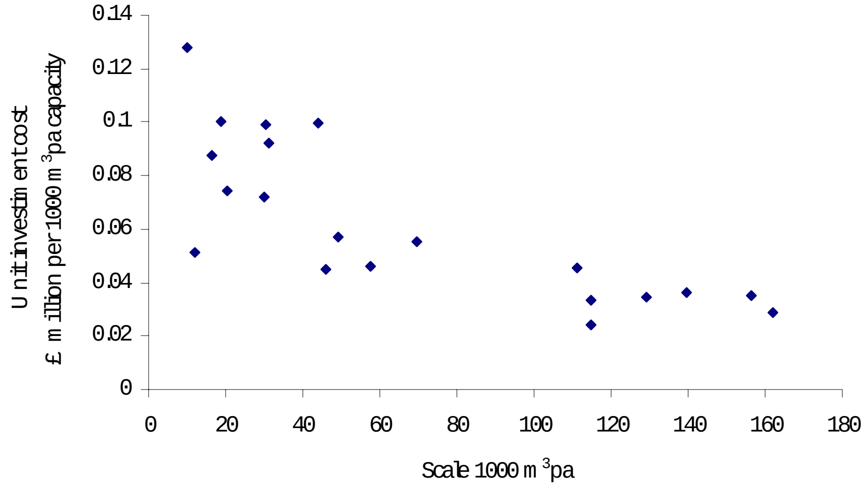

Figure 4.6 Unit cost of Danish CAD plants

In the UK the cost of CAD plants is expected to be similar and an ETSU review suggested that manure only CAD plant would require high electricity sale prices (6.3 -8.3 p kWh^{-1}) to be successful. These high prices are not currently achievable in the UK. The financial performance would be improved by the addition of solid organic waste as these have limited additional capital expenditure requirement but increase gas yields considerably and the projects currently being considered in the UK all have significant (upto 20%) proportions of the feedstock from industrial or municipal sources. In the UK heat as hot water is not an easy to market commodity due to the limited network of district heating schemes and thus whilst heat sales would improve the economics it can only be an opportunistic market and thus cannot be generally applied.

The gas generation from CAD plants varies greatly as the gas generation rate varies depending on the specific wastes processed. On average gas generation rates from Denmark are 37m^3 m^{-3} of feedstock but this can vary from 23 m^3 m^{-3}up to 90 m^3 m^{-3} depending on the additional feedstocks. The baseload manure digestion generates about 20 m^3 m^{-3} and the rest is due to the additional waste used. The fraction of the feedstock at the three plants operating using biowaste in Denmark are all less than 2% and as such do not contribute strongly to the overall gas yield.

The digestate .is generally applied to farmland, as the main ingredient is animal manure that would otherwise be applied to land. Mass loss will be directly proportional to gas yield and thus loss would be expected to be between 1.6% and 8% . The generated gas can be used for any application in the same way as biogas from other sources, e.g. heating, steam, electricity, pipeline, or vehicle fuel.

4.4 Implementation

The risks for AD are essentially similar to those of composting and can be considered as

- financial
- technical and operational
- environmental.

4.4.1 Financial risk

There is still some apprehension over investing in AD as a result of some poor performance in the past. Operational guarantees will be required and smaller companies may find it difficult to support these. Some countries have introduced mechanisms to aid financing. In Denmark there are special funding schemes with low rate indexed loans for community schemes.

As with any project the key factors in the financial risks are the risks of capital and operating cost variations and the potential for the revenues from the product to alter.

Capital costs

The capital costs of plants are becoming established and plant suppliers are now of a size that guarantees provided can be backed with appropriate financial measures. This obviously reduces the risk element for the construction of AD plants. The rise of modular plant will also help to reduce the cost and uncertainty of installation. The greatest degree of confidence is in the CAD installations as these are only minor modifications of existing farm waste digestion designs. The most uncertain aspect is in the construction of mixed waste digestion plants as the experience is more limited and thus retrofits and adjustments are more likely to be incurred.

Operational costs

The main risks to the operational costs will be the potential for downtime due to maintenance and breakdown and the cost of disposal of the residues. The operational costs will be largely dependent on two elements, the robustness of design and the quality of the waste feedstock.

Providing the design is robust then there should be good expectation that the maintenance, staff levels etc should remain within the constructor estimates. The confidence in this is increased through the expanding number of plants that have operated for some time. The greatest experience will be for the agricultural /CAD plants and the biowaste digestion plants now have constructors with many plants in their reference list. Obviously the least experience is from the mixed waste digestion plants that are more limited in number and are adaptations of the biowaste designs.

The effects of feedstock on the operational costs will be more consistent as the designs are tailored to the expected difficulty of the feedstock. Therefore variations from the envelope of normal feedstock will pose a similar risk of disruption to plant operations.

The other aspect of operational costs is the disposal cost of the residues. Landfill and wastewater disposal costs are unlikely to be reduced in the future and increases in the landfill tax will increase the costs to the plant. The plants with the smallest proportion of residues will be the least vulnerable to these price rises and thus the mixed waste plants will be the most vulnerable. Improving the cleanliness of source separated biowaste will also reduce this risk for biowaste plants.

Revenues

AD has three products, energy (biogas), compost and waste treatment. The revenue from each of these is important to the financial stability of the plant. The biogas is probably the most stable of the three in that energy prices are well established. Whilst there may be some desire to increase the price charged for this energy due to the "green" credentials this can be more problematic. Also the often small scale of generation can make overheads such as network connection or vehicle filling stations a significant disincentive to exploiting the more valuable markets. However, there is support in many countries including the UK for renewable energy production and this manifests itself in support for the electricity price.

The compost sales are the most uncertain. There appears to be sufficient market for the composts derived from source separated municipal wastes at the current rates of production. However, additional effort will be required to develop new markets when the implications of the Landfill Directive and recycling targets promote more composting and anaerobic digestion of waste. The biggest issue is contamination, which can make the compost unsaleable, and securing the market for the compost is a vital part of the developing of a project. The least contaminated composts will be derived from agricultural and industrial wastes and hence the CAD plants will be exposed to the least risk to the sales of their compost. The co-operation of farmers in a CAD project will also tie-in customers who have land to accept the compost and as such they will be a significant part of the market for CAD plants. Biowaste plants will generate acceptable composts and thus will be a large part of the revenue for the plant but there will be risks from competition from other wastes (sewage sludge, forestry wastes, spent mushroom compost, etc) which may depress the values attainable. Mixed waste composting plants will generally expect the product composts to be contaminated and thus will not plan for high (or any) revenues from the use of the compost. The key factor will be to ensure that markets are found that avoid the compost becoming a reject requiring disposal. Thus it is essential that the mixed waste plants obtain long term contracts for the compost, otherwise the risks to the financial stability of the plant will be large.

The gate fees for treating organic waste in to the process will depend on external factors such as competing disposal options and the landfill tax as well as the local availability of suitable waste. The precise competitive balance cannot be determined theoretically but the general trend will be as landfill costs rise, the relative costs of alternative disposal routes will fall and this differential will be proportional to the diversion away from landfill.

4.4.2 Technical and operational risks

Product quality

The quality of the biogas product is to most designs fairly constant at about 55% methane. Improvements on this can be achieved for upgrading to pipeline or vehicle use quality. The technology for this is being developed and demonstrated across the world and is essentially similar to the technologies used to clean natural gas at the well head. The main contaminant is hydrogen sulphide, which is removed to reduce corrosion in the combustion equipment.

Whilst inconvenient this contamination can be removed to low enough levels with appropriate systems such as iron sponge filters, air injection etc.

The compost from the digestion of source separated wastes will be, by and large, the same as compost from similar wastes that are composted. Hence the issues of inter contaminants and heavy metals will generally lie in the same range. The standards for composts have been extensively discussed by CEN and limits for the composts have been proposed in the draft Directive for Biodegradable Wastes. Meeting of these limits is dependant on the feedstocks being kept clean rather than the technology for digestion or composting. Whilst there are technical measures (floatation, hydrocyclones, heavy metal precipitation) that could be employed to improve the compost from digestion above that from composting, but at the moment these are not used extensively for source separated waste. The methods currently used to remove contaminants are those also used for composting such as screening and classification of the digestate after aeration.

CAD plants will only accept source separated materials due to the use of the digestate on agricultural land and given the dilution with manures contamination is rarely a problem.

Mixed waste digestion will generate a compost product that is contaminated with metals, plastics and glass and the sorting within the process will reduce this contamination. As opposed to mixed waste composting the digestate can be of an acceptable quality for certain applications and this is demonstrated by the use of the compost from the Vaasa and Amiens plant in horticulture and agriculture. The Vagron plant product is intended for use in land restoration but has not yet achieved permits for this. This apparent success of these digestates is limited in that whilst these composts are used they tend to be at the margins of acceptability and are under some pressure to be more limited. The analysis of digestate from Amiens in Table 4.9 shows that it would not meet the proposed compost limits in the draft Directive for Biodegradable Waste. Overall this shows that whilst mixed waste digestion does not meet the quality standards required of composts they can be processed such that the contamination is less than would be achieved if only dry processing is adopted.

Table 4.9 Amiens digestate quality mg kg^{-1}

Parameter	Amiens	Draft Directive for Biodegradable Waste		
		Compost	Stabilised Biodegradable Waste	
	Digestate	Class 3	Type A	Type B
Copper	135	300	600	1000
Lead	635	250	500	750
Chromium	292	300	600	1000
Nickel	52	100	150	300
Cadmium	2.5	3	5	10
Mercury	1.7	2	5	10
Zinc	533	600	1500	2500

Sanitisation and Pathogen Kill

The process must ensure a high level of pathogen kill to limit the risk of passing on infection to the soil, plants or animals. Similarly weed seeds also need to be inactivated if soil conditioners are to be produced from digestate. There is concern from some researchers that sanitisation is not guaranteed in mixed digester systems as a proportion of the material leaving the digester has only been processed for a short time. Temperature is also a key factor, hence the increasing use of thermophilic operation for digesters.

In most of the countries that use digestion a hygienisation stage is demanded where the waste is heated to 70°C for 1 hour either before or after digestion. This ensures that all of the pathogens in the waste are deactivated. In the last few years the regulation demanding this has been relaxed in Denmark where extensive work by the veterinarian authorities has demonstrated that thermophilic digestion with appropriate feeding control can provide a similar level of pathogen kill as the 1 hour 70°C treatment. The principle benefit of digestion is that within the tank all of the material is exposed to the temperature conditions and the chemical conditions also provide an enhancement to the pathogen kill process. Obviously these requirements are wholly dependant on the end use of the compost and thus if the compost is to be used on land appropriate sanitisation standards will need to be met irrespective of the type of feedstock or system used.

Stability of markets

The biogas product can have an easy and stable outlet in the form of electricity generation to the grid. The prices offered competing against existing electricity capacity is generally unattractive and thus in many countries the renewable aspect of the fuel is rewarded by government support. One of the major benefits of the UK NFFO scheme was that it provided a long term contract and hence stability to the projects awarded contracts. The subsequent scheme is likely continue this trend. In Europe various mechanisms have been adopted and generally have been time limited in that there is a reduction in support as the projects progress. The value of this electricity market is generally low but secure, higher value markets are in the direct sale of gas to users or through the upgrading of gas to pipeline of vehicle standards. The dependability of these markets is less certain due the individual contracts that have to be entered into. Thus these markets tend to be opportunistic when the user is located close to the plant. The sale of heat from the digestion plant is also dependent on a local market, as piping hot water becomes prohibitive over long distances. Where the linking of power and heat generation (CHP) can be achieved often offers the best balance between stability and value.

The market for biowaste composts is developing. The existing market for soil improvers and growing media has been estimated between 1 and 2 million tonnes per year. However, this is based on the horticulture, landscaping and retail markets for existing products. The current marketing of composts has emphasised the benefits of compost in general soil health, a role that the public had previously not fully taken on board. Thus, there is potential for some expansion of the domestic market. However, as quantities of compost produced increase due to the impacts of local authorities meeting the Landfill Directive and national recycling targets, the marketing of poorer quality compost will become difficult. Thus, the main risk factor is controllable through efficient operation of the waste collection points and good management of the refining operations during the process.

The markets for mixed waste composts were assessed in an earlier report which suggested that the UK land reclamation market for compost was only 0.5 million tonnes per year. However, these markets tend to be locally dominant in that a major redevelopment project will require large amounts of compost for a short time during construction and then require no more. Two examples are the Millennium Dome and Bluewater shopping centre, which both used significant amounts of source separated waste derived compost in their development. It is obviously difficult to sustain a business on the highly variable demand that this type of market gives. The other more stable demand is for landfill restoration and this is where most more recent mixed waste digestion /MBT plants in Europe position themselves. The draft Biodegradable Waste Directive will influence this market. The potential for additional sorting technologies to be applied to digestates does offer some benefit in that higher qualities will be achievable, but inevitable these will still not be as clean as composts produced from source separated materials and thus will still be at the margin of acceptability.

The liquor from the dewatering stages is likely to remain a waste but development of this product as a fertiliser may well improve the economics and environmental impact of digestion. However, this development will be primarily down to regulation and the development of the market in agriculture. The technical developments that are being developed to concentrate the nutrients from liquor may improve the prospects for this product. However, this is unlikely to be widespread for many years to come.

4.4.3 Planning

Planning of any waste site is problematical in that public opposition is based on a perception of waste being dirty, causing pollution and affecting house prices. The principal issues for digestion will be odour, combustion emissions and traffic movements. As with all planning issues they have to be resolved on a case by case basis but the principal method of mitigating the problems is to use sites that are sufficiently distant from housing. It is not possible to guarantee that there will be no odour releases, although, good operational practice can minimise these. The enclosed nature of the process will minimise odour emission, but the main point of odour will be the aeration of the digestate where ammonia can be release.

The combustion of the biogas will provide some emission although these are likely to be low and similar to natural gas combustion apart from the effects of residual hydrogen sulphide and good scrubbing of the biogas should under normal circumstances be an appropriate control measure. Emission limits are proposed in the draft Directive for Biodegradable Waste and these are likely to pose a problem for most plants unless the gas is mixed with landfill gas.

Other planning issues centre on the amount of land required for the composting operations. Typically demand for digestion plants do not vary greatly between the designs and range between 0.25 and 0.5m^2 per tonne capacity. Obviously, local conditions and the topography of the site affect this.

4.4.4 Health and safety

Care must be taken in all waste management processes where personnel come into contact with MSW and organic wastes from either agricultural or industrial origin. This is due to potential microbial infection hazards and the potential for physical injury arising from sharp contaminants. AD has the added hazard of producing a gaseous product in the form of biogas that can be both an asphyxiation and explosion risk where pockets of gas accumulate. For this reason the plant must be well ventilated particularly in areas handling post-digested sludge. The use of wall-mounted and or personal detectors/ alarms in plant areas is common to warn operators of potential atmospheric hazards. Special attention must be given to maintenance work requiring work in confined spaces and to the removal of all ignition sources.

4.4.5 Transport

Traffic issues are the same for all waste management facilities and is essentially dependent on the throughput of the plant. Organic wastes collected as part of a separate collection system may have higher bulk densities than MW due to the concentration of wet materials. However, given that refuse collection vehicles tend to fill to their weight limit it is unlikely that savings on transport will be achieved. The transport of the compost product will require up to five times less vehicle movements as some 40% of the mass will be lost as moisture and CO_2 and the bulk density will increase to 500 to 800 kg per m^3. Markets for composts tend to be local and hence the transport distances for the products will be similar to the distances travelled by the wastes.

4.4.6 Environmental impacts

Emissions of air pollutants

From the combustion of the biogas there will be emissions of nitrogen oxides and sulphur oxides, as well as a range of minor combustion products. These emissions will be similar to those from natural gas combustion but will contain higher levels of SOx emission due to the content of hydrogen sulphide. Controls in most countries are limited due to the low risk from these emissions, so long as H_2S removal is performed. Landfill gas whilst similar does have the potential to contain a wide range of contaminants due to solvents and other wastes being present in the landfill. The control of the feedstock to an AD plant will limit this type of contamination. Mixed waste digestion may have some potential for some contamination but if the waste is constrained to household waste the risk of contamination should be low.

These emissions can be offset against reduced need for energy generation elsewhere. Emissions (per unit of electricity generated) from biogas combustion will tend to be higher than for energy generation from high efficiency natural gas plants but lower than generation with coal fired plants.

Odours from the plant will be generated during the feedstock processing and in the digestate treatment where waste in not enclosed in the digester. These parts of the process are normally enclosed within a building and so long as appropriate operational procedures are adopted this should not cause odour problems. The air extracted from the processing areas of the plant is then treated by biofilter of chemical scrubbing. The success of these control measures can be observed at several European biowaste digestion plants that are situated on industrial estates without complaints from the neighbouring factories and offices. In these locations the distances to the neighbouring buildings can be less than 10m.

Water pollution

If the excess liquor is disposed of rather than used then about 100 to 300 kg of surplus water per tonne of incoming wastes will still require treatment and disposal. This can occur on-site or via the domestic sewer system, discharge consents permitting.

The treatment of source separated waste will tend to generate greater proportion of excess liquor as the feedstock is generally wetter than mixed waste. Some mixed waste plants produce no or little excess liquor (Amiens, Vagron) whilst others dispose of higher amounts. The Vaasa plant generates about 100 kg t-1 but the feedstock does contain a large proportion of sewage sludge, which obviously increases the moisture content of the feedstock.

Digestate Application to Land

Soil contamination through heavy metals or other compounds can be caused through the use of composts from wastes. The risk of this contamination is very much reduced with the use of source separated materials. Mixed waste composts would obviously require more extensive monitoring to ensure that damage to the soil does not occur. Whilst there is no official UK standard for composts the Composting Association have issued their own industry standard. In addition the European Commission have suggested limit values for composts and digestates in their draft Directive for Biodegradable Wastes.

The benefit of using waste derived soil amendments in terms of the recycling of organic matter to soil is recognised but not quantified. MAFF have noted a decline in soil organic matter levels since the war (WWII). It is known that organic matter increases moisture retention, improves soils structure, increases soil microbial activity and enhances the effectiveness of applied inorganic fertilisers by reducing wash out, whilst having a small slow release fertilising value itself. These benefits of waste derived soils amendments are seldom given any quantitative form. There is a need for hard information about the effects of added organic matter to the soil so that use of these materials can be compared to alternative agricultural strategies and the costs/benefits assessed.

Noise

The enclosure of AD plants generally limits the noise emission from operations such as shredding and processing of the waste or digestate. Operational plants have problems from complaints about noise. The most likely noise problem will be from the operation of fans and pumps during the night period when background noise is less and sensitivity is higher.

The main source of noise on site will be the generator burning the biogas for electricity. These engines can generate noise levels over 100dB at 1 meter and suitable acoustic enclosures have to be constructed around these units to avoid problems. The use of silencer on the exhaust is also necessary to avoid problems.

4.5 Contributions to Targets and Policies

4.5.1 Landfill Directive

The key target for municipal waste in the Landfill Directive is the requirement to reduce the amount of biodegradable waste landfilled. The precise targets are to reduce the biodegradable municipal waste landfilled to 25%, 50% and 65% of the 1995 quantities by 2006, 2009, 2016 respectively. The UK is allowed to extend these dates by upto four years.

The definitions for biodegradable waste and how its biodegradability will be measured have not been set. However, using the definition set out in "A way with waste", the Waste Strategy and discussions with the Environment Agency, an estimate of the diversion possible can be made. For mixed waste systems that treat the whole of the waste stream, the compost product can be considered as non-biodegradable and hence the only biodegradable material will be the material in the reject fractions that are sent to landfill. The rejects from the digestion process will be similar to those rejected from composting and thus it can be assumed that only 5-10% of the biodegradable material is rejected and not in the compost product. Thus, using this estimate mixed waste digestion would provide 90-95% diversion of biodegradable material from landfill. However, the process would only divert approximately 60% of the weight of waste from landfill, as there is no effect on the non-biodegradable materials. In some plants more aggressive sorting is undertaken and organic materials e.g. paper are also directed to recycling or combustion as RDF. An example of this is the Vagron plant where out of 230,000 tonnes of greywaste (organics already source separated) 92,000 tonnes were fed to the digester and there were 32,000 tonnes of rejects and 23,000 tonnes of compost

Source separated digestion will use the compost product outside of landfill and thus diversion will be, again, limited to the reject fractions. The biodegradable fraction of the rejects from source separated waste will be limited and be less than 5% of the biodegradable content of the supplied waste.

4.5.2 Waste strategy

UK Government Waste Strategy targets for recycling are currently 25% by 2005, 30% by 2010 and 33% by 2015. The targets for recovery of waste are 40% by 2005, 45% by 2010 and 67% by 2015.

Digestion of source separated wastes contributes towards both the recycling and recovery targets. However this will depend on the compost being used in a beneficial way. Under normal circumstances all of the material directed to source separated composting facilities will count towards the recovery and recycling target.

The use of mixed waste will result in some or all of the material being used in landfill and hence not "recycling". The precise definitions of this have not been established. For the purposes of this study 50% of the compost product will be considered as recycling and the biogas produced will be considered as recovery (similar to the mass lost during incineration). These estimates may vary once the precise guidance is given and specific projects are considered with planned uses or disposal of the final compost.

4.5.3 Greenhouse gas

The Kyoto protocol established targets of 12% reduction in the climate change gas emissions and subsequent UK policy has set a target of 20% CO_2 reduction of 1990 levels by 2010.

The emission of CO_2 by anaerobic digestion is an expected outcome from the process. However, the biodegradable material (i.e. plant matter) is all recently absorbed carbon (termed "short cycle") and thus has little (although not zero) impact on climate change potential. There is an emission of other greenhouse gases such as methane, NH_4 and N_2O, which contribute to the climate change effects. Emissions of methane, from leaks and accidents will poses the highest impact on climate change potential. Estimates of these releases are not available but given that even small leaks would pose serious health and safety concerns through explosion or asphyxiation hazard the estimated release would be much less than 0.1% of the biogas produced.

Other impacts will be derived from the collection and supply of waste and the delivery of products to market.

Counteracting the impacts from methane and transport will be the energy generation, which will offset fossil fuel energy production. The process will generate between 75 and 150 kWh t^{-1} and thus will offset the fossil CO_2 from the generation of this electricity.

The use of the nutrients from the digestion process would offset the production of fertilisers and the associated energy use etc, but in this study these effects have been ignored.

4.5.4 Renewable energy

UK government has set a target of 10% of electricity generation from renewable sources by 2010. Composting does not contribute any renewable energy and is a net consumer of energy. Energy generated in AD plants varies considerable between the different technologies used but the simplest systems will generate around 75 kWh t^{-1} whilst the more complex systems that fully utilise the waste and manage the energy flow well generate upto 150 kWh t^{-1}.

Table 4.10 Summary of criteria assessments - Anaerobic digestion

	Biowaste	Mixed waste (MBT)	CAD
Economic			
Capital cost	£70-200 tpa^{-1}	£90-140 tpa^{-1}	£25-90 tpa^{-1}
Operational cost	£22-30 t^{-1} dependant on scale	£17-22 t^{-1} dependant on scale	£17-22 t^{-1} dependant on scale
Technical			
Proportion of the municipal waste stream treated	Kerbside collection of organics and green waste maximally 35%, likely to be less due to less than perfect participation	All of the waste delivered but majority of the waste is rejected in the initial sorting, 50% of waste processed	Kerbside collection of organics and green waste maximally 35%, likely to be less due to less than perfect participation. Majority of waste agricultural
Energy production	110 kWh t^{-1}	100 kWh t^{-1}	90 kWh t^{-1}
Land requirements	0.5 m^2 t^{-1}	0.4 m^2 t^{-1}	0.5 m^2 t^{-1}
Operational/risk			
Availability	85%	85%	85%
Quality of products	Generally high but potential for some contamination	Contamination high but mechanical separation may improve quality to be acceptable for low grade uses	Generally high
Operations in UK	0	1 in advanced planning	0
Operation elsewhere	>100	20	20
Operational success of commercial plants	Good, depends on good energy prices	Some difficulties due to markets but plant are still operational	Good, dependant on local factors and grants
Planning requirements	Combustion emission and odour issues	Similar to other large scale waste systems, reduced compared to incineration	Generally odours and combustion emissions issues
Scope for integration	Treats upto one third of waste stream, some flexibility regarding paper and other organics	Accepts whole of waste stream thus can rejects suitable for other options	Treats up to quarter of waste stream, slightly more limited due to quality concerns
Stability of markets for recyclate/products	Reasonably stable but product quality (contamination) require constant attention	Product quality likely to make markets poor for soil improver/land restoration	Stable market once plant established with co-op concerns if biowastes included
Education needs	Detailed and intense education required to avoid contamination	None	Detailed and intense education required to avoid contamination
Public dependence	Dependant on public willingness to participate well	None	Dependant on public willingness to participate well

Table 4.10 continued

	Biowaste	Mixed waste (MBT)	CAD
Environmental			
Greenhouse gas reduction	28-33 kg t^{-1} reduction due to energy production	13kg t^{-1} reduction	24 kg t^{-1} reduction
Air quality	Odours and ammonia combustion emissions	Odours and ammonia combustion emissions	Odours and ammonia combustion emissions
Water pollution	Small quantity of high strength liquor for processing	Limited production of liquor	Liquor disposed of to agricultural land with manure
Solid residues/hazard	Low contamination of product, small amounts of residues	Contaminated product, majority disposed of	Low contamination of product, small amounts of residues
Noise	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance
Odours	Enclosed plant potential to control odour	Enclosed plant potential to control odour	Enclosed plant potential to control odour
Transport	1% rejects to landfill, 50% product to market	50% reject to landfill, 15% product to market	1% rejects to landfill, 50% product to market
Resource use	Limited use	Limited use	Limited use
Policy			
Meeting recycling target	All materials recycled contributes renewable energy	Metals recycled contributes to recovery renewable energy	All material recycled contributes renewable energy
Biodegradability reduction	All material recycled	Reject fractions may contain some biodegradable material	All material recycled
Public perception	Unknown technology, over optimistic expectations	Unknown technology, over optimistic expectations	Unknown technology, over optimistic expectations
Employment opportunities	0.4 jobs $ktpa^{-1}$	0.33 jobs $ktpa^{-1}$	0.4 jobs $ktpa^{-1}$
Public involvement	Detailed involvement with kerbside collection	No involvement of the public	Detailed involvement with kerbside collection

5 INCINERATION

5.1 Introduction

Incineration is a long established thermal treatment process. The technique is widely and reliably implemented across Europe and the United States. Increasingly stricter European legislation has in recent years forced significant progress on incinerator combustion performance and flue gas quality.

The first fully functional waste incinerator was built in Manchester, England in 1876. This facility operated for 27 years and the ash residues were used as a building material. In 1885, the world's first waste-fired electricity generation plant opened in London. Considerable technical developments followed, particularly of waste feeding and residue removal mechanisms, and by 1910 there were 194 waste incinerators established in England.

In continental Europe, the growth of incineration began with the operation of City of Hamburg's first incinerator in 1895. Shortly after incinerators were established throughout Europe, particularly in Germany and in major cities including Brussels, Stockholm and Zurich.

These early designs of incinerator were based on a batch-wise operation necessitating frequent stops and starts in operation. Control over combustion was also ineffective which resulted in significant amount of combustible material left in the waste residues and stack gases. Consequently, public complaints about odour and smoke were not uncommon. Significant improvements in combustion and emissions were made in the 1920s and 1930s with the development of mechanical grate systems to provide automatic, continuous waste feeding and better control over combustion air.

In the UK, the growth of consumerism and increased use of packaging in the years following the end of the Second World War led to a dramatic increase in the volume of wastes produced. These increases and a lack of concern for waste minimisation or recycling led to a wave of construction of new waste incinerators particularly in the 1960's and the early 1970's. The design of these incinerators was essentially the same as those built in the 1920's with little attention paid to environmental factors. Indeed, at the time of their construction the prevailing philosophy was disposal of waste at the lowest possible cost with an emphasis on achieving a bulk reduction in the waste volume rather than efficient incineration or combustion. Consequently poor environmental performance by these incinerators, in particular in relation to dioxin emissions, led to wide-spread and vociferous public opposition in the late 1970,s and early 1980's. Subsequently, the EU took action to environmental standards for waste incineration with the introduction of EC Directives 89/369 and 89/429 in 1989.

In the late 1970's after the oil crisis, waste was viewed more as an energy resource and technologies for converting waste in to fuels were investigated. These development programmes gave rise to the refuse derived fuel systems that range from the simple "Blue Circle" approaches to the highly processed pelletised fuels produced at Byker and similar plants.

5.1.1 Mass burn systems

Mass burn incineration (or energy from waste) is the term that relates to the whole of the waste supplied to the plant (black or grey waste) being burnt. The grate systems that are commonly in use can be divided in to three generic types

- fixed grate
- rotary "kiln" grate
- fluidised bed

Within each of these grate designs there are sub divisions, which will have specific advantages or disadvantages over the others, but overall the differences are minor and do not affect the use of the technology. The only exception to this is that fluidised beds are more amenable to accepting processed fuels and thus are more suitable to refuse derived fuels (RDF).

Fixed grate

Overall the flow of waste within an incinerator is shown in Figure 5.1. This diagram shows a fixed grate system and the waste is fed via a hopper to the top of the sloping grate where it is dried and ignited. The grate is equipped with moving parts that agitate the waste to ensure that it flows and is broken up to make sure all of the waste burns. The wastes move down the grate under the influence of gravity and the action of the grate movement. At the bottom of the grate the waste should be completely burnt and consist of ash which then is quenched in a water bath and removed from the incinerator. Air is blown both through the grate and in to the combustion zone to facilitate the combustion. The combustion gases are mixed above the burning waste and then passed through the heat recovery boiler and to the pollution abatement equipment. The boiler and pollution abatement equipment are essentially the same for all systems.

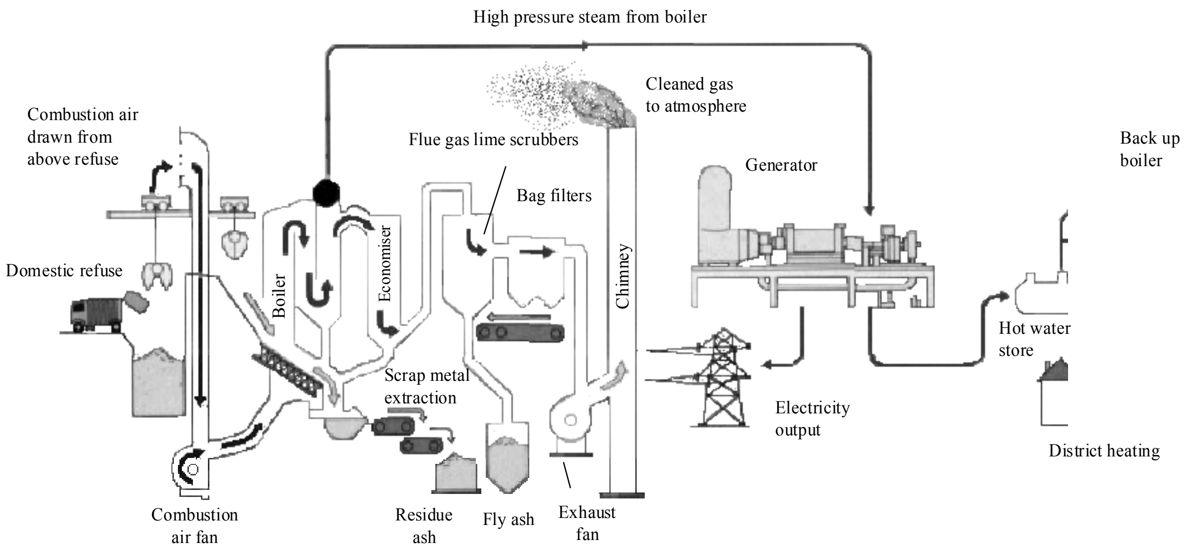

Figure 5.1 Typical mass burn incineration plant

Rotary grate

The rotary grate is a sloping cylinder which rotates, agitating the waste to liberate and mix the waste in the same way as for fixed grate systems. This design type is characterised by the Westinghouse system, but cement kiln combustion of RDF uses the same principles.

Fluidised bed

In a fluidised-bed combustor, instead of a grate or hearth supporting a bed of solid fuel, the furnace section contains a bed of refractory sand or limestone supported by an air distributor plate or nozzle system. Air is passed through the bed material at velocities sufficient to fluidise the material. Auxiliary burners heat the bed and fuel is introduced either by dropping it onto the top of the fluidised bed or injecting it from below where it mixes with air. Under these conditions, air and products of combustion pass through the bed in the form of bubbles.

Fluidisation occurs as the pressure drop of the air traversing the bed equals the weight per unit of bed cross-sectional area. The air velocity at the point where fluidisation begins is termed the minimum fluidisation velocity. Increasing the velocity from this point causes the bed to expand to allow the air to bubble through it. At approximately one to two times the minimum fluidisation velocity, the bed resembles a violently boiling liquid. It is in this region that conventional fluidised bed combustors (also called fixed bed or bubbling bed) operate.

Increasing the air velocity beyond levels utilised in bubbling bed combustors leads to increased entrapment of bed material, until a significant portion of the bed is being carried from the fluidised bed furnace. The circulating fluid-bed (CFB) combustor operates in this region, with air velocities up to twenty times the minimum fluidisation velocity.

Types of FBC Systems

There are generally two different types of FBC systems in use today: the bubbling fluid bed (BFB) and the circulating fluidised bed (CFB), shown in and respectively.

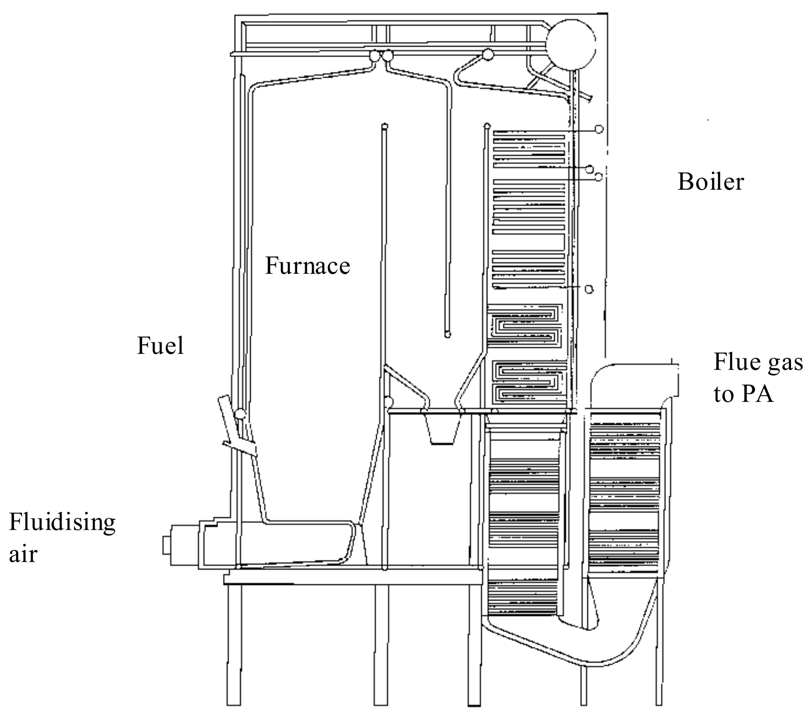

Figure 5.2 Schematic of bubbling fluidised bed combustor

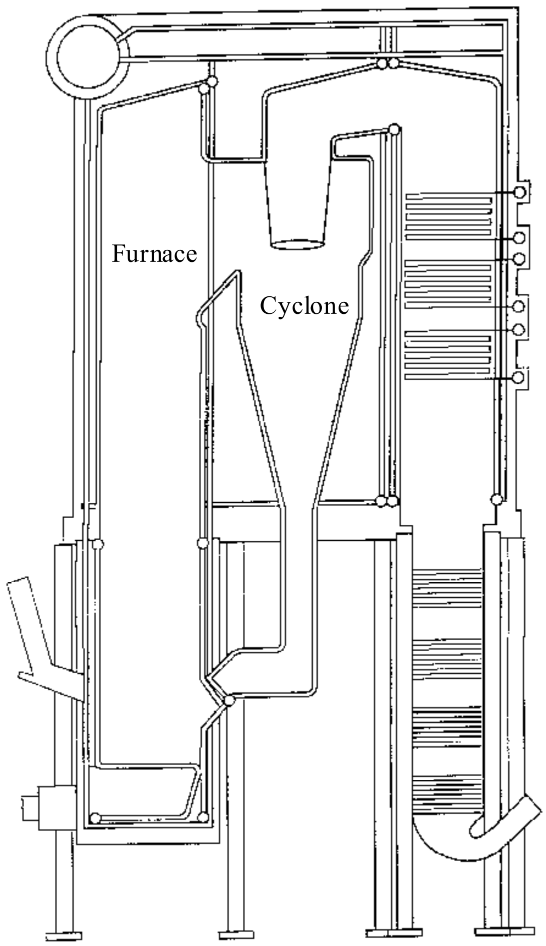

Figure 5.3 Schematic of circulating fluidised bed combustor

Depending on the design of the BFB, heat transfer is effected by means of a combination of in-bed heat transfer surface, radiant surface in the freeboard, and convective surface external to the combustor. A schematic representation of this type of system is shown in Figure 5.3. Where fuel quality is extremely low due to high amounts of non-combustibles or moisture, heat transfer surface within the bed is not used. The combustor may consist of a simple refractory-lined vessel with an external waste heat boiler. In extreme cases, auxiliary fuel may be introduced into the bed to sustain combustion and/or bed temperature. This configuration has been widely used to burn sewage sludge having 85% moisture content.

In addition to the bubbling and circulating bed designs, a “twin inversion fluidisation” (TIF) design has been used in Japan, which is an enhancement of the bubbling bed design. In this system, offered by Ebara, differential fluidising air velocities across the air distributor system are used in combination with bed containment vessel geometry to induce a higher degree of lateral mixing than that which is found in conventional BFBs. This allows the discharge of the non-combustibles from the sides of the bed rather than from the centre as for conventional BFBs.

5.1.2 Refuse Derived Fuel

Refuse derived fuel (RDF) is a wide term to describe wastes that have been processed to improve the fuel characteristics. This provides a very broad spectrum of systems varying in the intensity of separation used. The aim of producing RDF is to maximise the energy recovery from the waste whilst minimising the cost and size of the combustion and heat recovery plant. The systems can be essentially split in to three distinct groups, coarse, floc and densified RDF.

Coarse RDF

This is the simplest implementation of RDF technology and was first seen in the UK at the Blue Circle cement works. The waste was shredded, passed under a magnet to remove ferrous metals and fed into the cement kiln. This plant operated successfully for several years until the value of the lost cement production capacity outweighed the benefits of burning the waste. The processing of the waste does allow further sorting of the waste so that recyclables such as paper and card removed from the waste prior to shredding. This option will depend on the markets for these materials and can be used or not as the market values fluctuate.

To improve the flue quality non-combustible material can be removed through a various mechanisms such as screens or classifiers. The finer and heavier fractions of the waste will be lower in heating value and higher in ash and thus there is benefit from removing these materials. One typical flowine is shown in Figure 5.4.

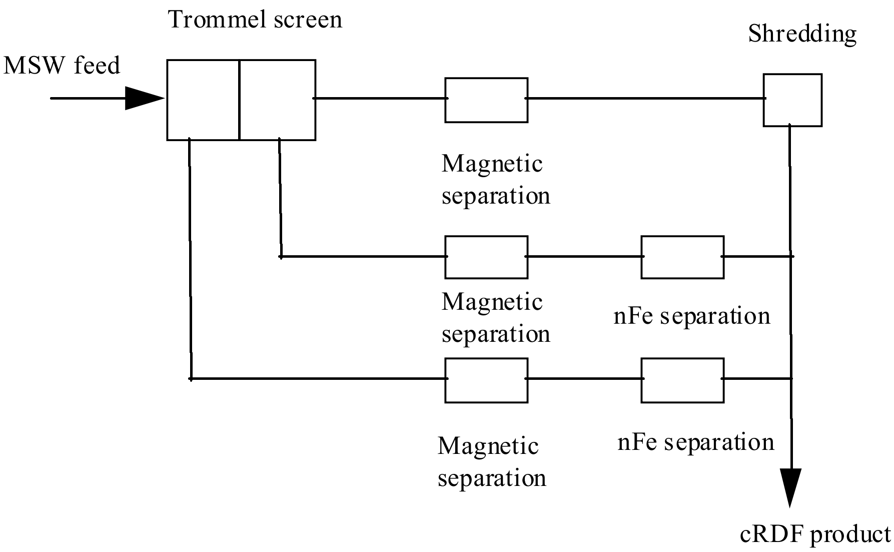

Figure 5.4 Typical coarse RDF system

The combustion of the coarse RDF (c-RDF) is performed in traditional mass burn or FBC units. This is because of the large particle size and low bulk density of the c-RDF. The combustion of this waste will be more consistent than unprocessed waste and this will improve the performance of both the pollution abatement plant and the boiler. Alternatively it can be mixed with other fuels and burnt in large solid fuel boilers such as coal fired electricity generating plant or cement kilns.

Floc RDF

Floc RDF is a stage on from the coarse RDF and is somewhat of an arbitrary distinction in that there are a multitude of flowlines of varying degrees of complexity and the distinction can be somewhat blurred. For this report the distinction is made where the waste is shredded to less than 100mm and therefore would require a second stage of shredding. The shredding of the waste has the benefit of improving the homogeneity of the waste and thus combustion is more even as well as liberating some of the materials and improving the flow characteristics. However, shredding tends to reduce the physical differences between material types and hence make sorting more difficult. The development of flowlines has been a compromise between the improved sorting capability from raw waste against the improved flow characteristics and homogeneity. This results in the delay of shredding to the final size until late in the process and is responsible for the wide range of flowlines used. A more complex flow sheet for floc RDF production used at the NSP French Island, USA fluidised bed combustor is shown in Figure 5.5.

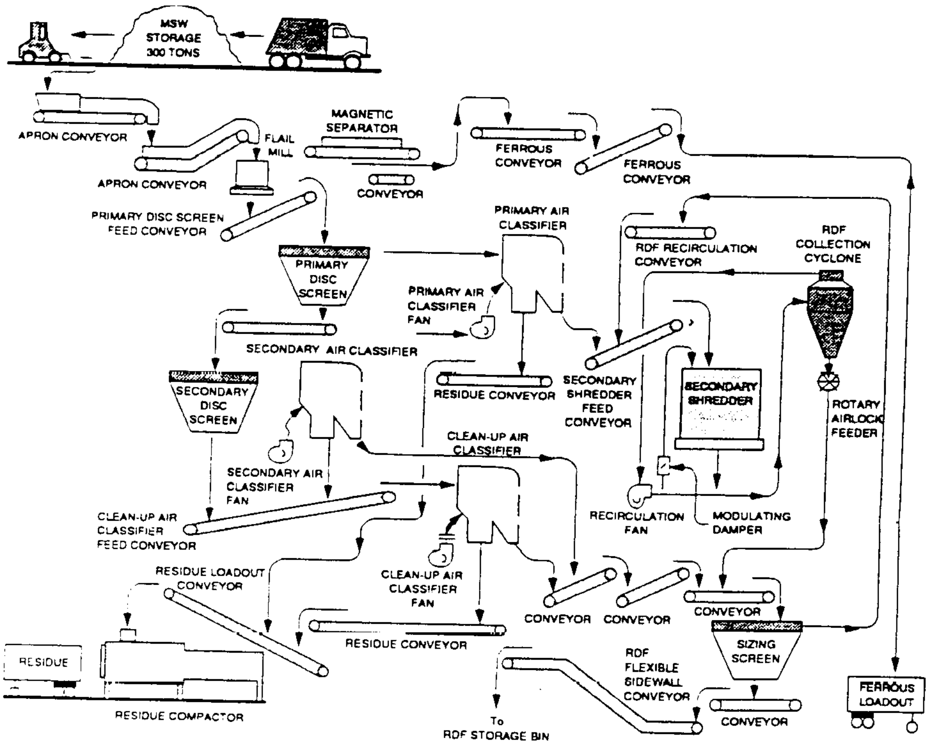

Figure 5.5 Flowline for floc RDF production at NSP French Island

The combustion plant for floc RDF is generally specifically designed units that can deal with the light nature of the fuel and keep the fuel within the bed rather than moving with the air flow in to the pollution abatement plant. These plants tend to utilise a degree of suspension firing or use heavier fuels to mix with the floc RDF to weigh down the RDF on to the grate. Once the combustion has taken place the boilers and pollution abatement are the same as the other systems.

Densified RDF

The main distinction of densified RDF (d-RDF) is the production of a compact pellet or briquette. The original intention of d-RDF production was to generate a fuel that could act as a coal replacement fuel in conventional steam raising boilers. Unfortunately, the demands of the fuel combustion require significant modification of the combustion units and hence the combustion is limited to dedicated units. The processing involved in the manufacture of d-RDF take the floc RDF one stage further. The densification process cannot tolerate hard dense items and thus these have to be removed by classification. Following this, the waste dried and the densified. The process will reject a significant proportion of the waste through this final classification and this fraction contains a significant heating value from plastics and textiles.

The combustion plant required for the burning of d-RDF is similar to coal combustion, but the air injection is markedly different in that additional is require in the gas phase combustion zone and additional cooling is also required to avoid deposition of alkali metal salts on the boiler tubes.

5.1.3 Pollution abatement plant

An important part of the combustion of waste is the removal of pollutants from the combustion gases prior to release through a chimney. There are several stages to the process that can be adopted.

- combustion control
- acid gas removal
- dioxin and volatile metal capture
- particulate removal
- nitrogen oxides control

These processes need to be used to achieve the limits from legislation (Table 5.1) and appropriate systems exist to carry this out.

Table 5.1 Current emission standards for non-hazardous waste incineration facilities (all values expressed at reference conditions of STP, dry and 11% oxygen concentration)

Pollutant	Current UK standards	New Directive	Typical emissions	Units
Particulate Matter	30	10	2	mg m^{-3}
Total Organic Carbon	20	10	3	mg m^{-3}
Hydrogen Chloride	50	10	5	mg m^{-3}
Hydrogen Fluoride	50	1	0.1	mg m^{-3}
Sulphur Oxides	2	50	30	mg m^{-3}
Nitrogen Oxides	300	200	350[a,] <200[b]	mg m^{-3}
Dioxins	1	0.1	<0.1	ng I-TEQ m^{-3}
Cadmium	0.1	0.05	<0.05	mg m^{-3}
Metals[1]	1	0.05	<0.05	mg m^{-3}

[1] Metals includes Sb, As, Cr, Cu, Co, Mn, Ni, Pb, V and Sn

a for plant without de-NOx

b for plant with de-NOx

Note: All UK plant will install de-NOx equipment to meet Directive limits.

Combustion control

Control of the combustion conditions is vital in the maintenance of low pollutant emission. Complete combustion of the organic chemical will be required or hydrocarbons and soot will be generated which can have significant environmental impacts. Also incomplete combustion will lead to the generation of carbon monoxide. The destruction of toxic organic compounds is highly regulated and thus a minimum residence time of 2 seconds at 850°C. However, high temperatures can oxidise the nitrogen from the air and generate nitrogen oxides, which are hazardous to the environment. Thus, careful control of the combustion process is required to ensure that the combustion is complete by ensuring the mixing and air supply is sufficient and that the temperatures are sufficiently high to destroy the pollutants but not so high that NOx formation becomes a problem. On modern waste combustion plants complex control systems are employed to ensure that these combustion processes are performed at the correct condition.

Acid gas removal

The principal acid gases in the flue gas are hydrogen chloride and nitrogen and sulphur oxides. Removal of the sulphur oxides and hydrogen chloride is achieved by passing the flue gas through a scrubbing tower where an alkali is sprayed in as powder, slurry or a solution of lime or other alkali. As the flue gas and the reagent react a high degree of removal can be achieved. This results in a residue high in lime that requires special disposal. This residue is collected at the base of the scrubbing tower or is captured as particulate later in the process.

Dioxin and volatile metal capture

Toxic micro-organic pollutants such as dioxins and furans are captured but the introduction of activated carbon in to the flue gas either in the scrubbing tower or just after it depending on the precise design of the system. It is important that the gas temperature is below 200°C as dioxin formation can occur above this temperature. The organic compounds are adsorbs to the activated carbon. Volatile metals such as mercury are also difficult to capture as they are in a vapour form and the addition of carbon also captures the mercury. The carbon along with the adsorbed pollutants is then removed along with the particulates.

Particulate removal

Particulate matter can be removed by two systems, electrostatic precipitators or bag filters. Electrostatic precipitators were used alone on older plants built in the 1970's. However, they were not capable of achieving the low emission limits required by modern legislation. Bag filters provide a fabric filter on to which the particulate matter is trapped. The material builds up forming its own filter bed and thus can achieve very low particulate emission. The particulates collected in this way will include the lime particles from the acid gas removal and the carbon from the dioxin and mercury removal stages and thus will require specialised disposal.

Nitrogen oxides removal

Nitrogen oxides generated in the combustion process can be controlled by two methods, catalytic and non-catalytic. Both methods rely on the injection of ammonia in to the flue gas and this causes the reduction of NOx to Nitrogen. The catalytic process uses a fixed catalyst through which the flue gas passes and the reaction with the injected ammonia is promoted. This reaction is very effective but unfortunately expensive. The non-catalytic process relies on injecting the ammonia in to the combustion zone and the reduction reaction occurs at the high temperatures in this zone. This is a less expensive option but does not provide such low NOx emissions and tends to release a greater proportion of the ammonia to the atmosphere.

5.2 Technology Status

In 1994, the SELCHP plant, in South East London, was commissioned. This was the first new mass burn plant to be built in the UK for more than 20 years. SELCHP is an energy from waste (EfW) facility and was the first of a new generation of incineration plant, which used advanced flue gas abatement techniques in order to meet stricter emissions standards, which were introduced from December 1996.

The latest generation of incineration plant use relatively sophisticated combustion control techniques and typically feature; selective non-catalytic reduction (SNCR) for NOx, acid gas scrubbers, activated carbon injection and fabric filter abatement technologies. In addition, all the new generation of plant feature energy recovery to generate power and/or heat for export. The sale of recovered energy is integral to the economic viability of these plants.

RDF technology has in the past been centred on d-RDF with the development of the Byker, Pebsham and Newport, Isle of Wight plants as well as the closed plants at Doncaster, Huyton, Castle Bromwich, Grimsby. Modern RDF plants are being planned to combine energy recovery with recycling and composting activities such as the Dundee and Kent protects and new recycling projects that plan to incorporate an element of floc or densified RDF combustion such as the Wrexham or Neath-Port Talbot proposal.

5.2.1 State of deployment - Europe

In comparison with the UK most European countries incinerate a far greater proportion of their waste, rather than landfill. A comparison of the proportion of municipal waste incinerated within countries of the European Union is provided in Table 5.2.

Table 5.2 Extent of waste incineration in Europe

Country	% of waste incinerated	Amount incinerated (1000 tonnes)
Austria	14	565
Belgium & Luxembourg	33	1,734
Cyprus	0	0
Czech Republic	6	180
Denmark	54	1,598
Estonia	0	0
Finland	2	45
France	46	15,396
Germany	17	7,926
Greece	0	0
Hungary	7	320
Ireland	0	0
Italy	6	1,703
Netherlands	27	2,630
Poland	0	0
Portugal	0	0
Slovenia	0	0
Spain	4	601
Sweden	42	1,756
United Kingdom	7	2,019

5.2.2 State of deployment - UK

Mass burn technology using moving grates, where unsorted waste is combusted, is the most common form of incineration employed in the UK is well developed and established. Currently there are 13 established large scale MSW incinerators operating in the UK, of which all but one are mass burn facilities utilising moving grates.

RDF technology is being adopted at the Baldovie Incinerator in Dundee where incoming waste is pre-sorted, for removal of ferrous metals, and before it is fed to a fluidised bed boiler. Whilst the Dundee plant is the only municipal waste incinerator in the UK to employ fluidised bed technology, use of fluidised bed incinerators, with waste throughputs of between 75,000 and 120,000 tonnes per annum, is well established in Scandinavia and Japan.

Densified RDF production in the UK is limited with the Byker plant recently ceasing production and only two remaining operating plants at Newport and Pebsham. New facilities are in the pipeline with projects under development at Wrexham and Neath/Port Talbot for dirty MRF systems that direct their residues to RDF production and combustion.

A summary of current operation UK Incineration plant is presented in Table 5.3.

Table 5.3 EfW plant in the UK

Incineration plant		**Capacity (1000 tonnes per year)**	**MWe output**
In operation			
New:	SELCHP	420	25
	Tyseley (Birmingham)	350	28
	Cleveland	220	20
	Lerwick	26	heat only
Redeveloped/upgraded	Coventry	220	13
	Edmonton	600	27
	Nottingham	150	7
	Sheffield	135	8
	Dudley	90	6
	Stoke	200	13
	Bolton	130	11
	Wolverhampton	105	8
Under construction	Huddersfield	135	8
	Basingstoke	90	5
Proposed	Southampton	180	10
	Colnbrook	440	25
	Surrey (2)	425	24
	Portsmouth	180	10
	NE Lincolnshire	225	13
	Hull	220	13
RDF Plant			
Operating	IOW	36.3	2.1
	Pebsham	80	pellets
	Dundee	120	8
Proposed	Kidderminster	120	7
	Byker (redeveloped)	80	5
	Kent	500	29
	Port Talbot	143	8.2
	Wrexham	30-50	1.5-2

5.2.3 UK Costs

Table 5.4 presents a breakdown of capital costs for a modern waste to energy incineration plant. A range of costs is presented for installed incineration capacities of 100, 200 and 400 kilotonnes per year. These figures provide guidance only since actual costs will be site specific. Similarly, Table 5.5 presents the estimated annual operating costs for each plant.

Table 5. 4 Capital cost breakdown for UK incineration plant

Item	Units	Capital Costs		
		100 kt yr^{-1}	**200 kt yr^{-1}**	**400 kt yr^{-1}**
Waste handling, combustion, boiler and power generation plant (67%)	£M	22.5	33.7	57.8
Flue gas treatment plant (17%)	£M	5.7	8.6	14.7
Civils (16%)	£M	5.4	8.1	13.8
Project development – 5% of capital	£M	1.7	2.6	4.4
Total Electricity only	**£M**	**35.3**	**53.0**	**90.7**
Heat Export facilities	£M	5.8	9.9	15.4
Total CHP	**£M**	**41.1**	**62.9**	**106.0**
Costs per tonne capacity				
Electricity only	£ t^{-1}	353	265	227
Total CHP	£ t^{-1}	411	314	265

Table 5.5 Operating costs for UK incineration plant

Item	Units	Operating Costs		
		100 kt/y	**200kt/yr**	**400kt/y**
Labour	£M yr^{-1}	0.8	1.0	1.2
Maintenance	£M yr^{-1}	0.8	1.7	2.5
Residue Disposal (£10/t)*	£M yr^{-1}	0.3	0.8	1.6
Other	£M yr^{-1}	0.4	0.9	1.3
Total Electricity only	£M yr^{-1}	**2.4**	**4.4**	**6.6**
Total CHP	£M yr^{-1}	**2.6**	**4.7**	**7.2**
Costs per tonne capacity				
Electricity only	£ t^{-1}	24	22	17
Total CHP	£ t^{-1}	26	24	18

* Excludes landfill tax levies

(Source: Tables 5.4 and 5.5 based on Municipal Solid Waste Combustion: Economics and Projections for Energy Recovery to the Year 2000, Patel N.M and Higham I R).

RDF costs are more variable and Table 5.6 shows the capital and operating cost for coarse and floc RDF plants at 200, ktpa and for a d-RDF plant at 100 and 200 ktpa. It should be noted that the costs for the d-RDF facility do not include the combustion plant costs or revenues.

Table 5.6 RDF Capital and operating cost (1992 data)

	Units	coarse RDF	floc RDF	d-RDF	
	Ktpa	200	200	100	200
Capital cost	£m	31.4	41.7	11.2	18.1
Operating costs	£m	4.7	5.1	2.4	4.3
Revenues	£m	1.3	2.2	0.7	1.4
Gate fee	£ t^{-1}	28.62	26.19	27.57	25.11

Note these figures are based on ETSU reports from 1992/3 and have not been adjusted to current basis, also the d-RDF figures do not include the combustion facility costs or revenues

5.2.4 UK Performance

UK waste incineration facilities typically operate 24 hours per day, six or seven days per week in order to be available when refuse collections are taking place. The mass burn technologies and the flue gas abatement techniques currently employed on mass burn plant are well proven and reliable, much more so than the previous generation of incinerators.

Most new plants are effectively operated as small power stations with an emphasis on efficient energy production. Maintenance and repairs are scheduled to occur during periods where there are no refuse collections, e.g. Sundays. Most plants typically feature two incineration units or streams, therefore essential major maintenance and repairs are scheduled so that at least one unit is fully operational at any point in time. Unscheduled shutdowns or repairs are handled as quickly as possible as the sale of energy output (electricity or heat) is integral to the economic viability of the plants and therefore prolonged periods of plant down-time would give rise to significant losses of revenue.

Most incinerators have facilities for on-site storage of several days refuse collections in case of plant breakdown. Typically incinerator operators also have contingency plans, generally including agreements with other incinerator or landfill operators, to handle waste in situations where the incinerator will be unavailable for pro-longed periods of time.

Typically the availability of both incineration and RDF plants are planned at 85% but often achieve better than this getting upto 90%. Much higher availabilities are not normally possible due to the planned maintenance shutdowns.

The energy production from incineration plants are limited due to the corrosive and difficult nature of the combustion gases, which result in the steam temperatures being limited to 450-500°C. These temperatures are lower than would be used with gas or coal combustion and hence electricity production is reduced. Electricity production from mass burn incineration plant varies with the waste that is burnt but typically 450 kWh t^{-1} of electricity can be exported. FBC plants due to the additional gas mixing and more stable combustion due to burning a processed fuel can operate at slightly higher steam temperatures and thus electricity output is higher, between 475 to 500 kWh t^{-1}.

The electricity production from RDF production is generally lower than mass burn as not all the waste is burnt. Highly processed forms such as d-RDF only burn about one third of the waste and have energy demands from consequently a proportionally reduced electricity output.

5.3 Implementation

5.3.1 Financial and Technical Risks

The construction of a modern waste to energy facility is a major engineering and capital cost project with costs typically in the order of £40 million to £100 million. These costs exceed the financial resources of most Waste Disposal Authorities (WDA) and consequently most new incineration facilities are implemented with private sector expertise and finance with collaboration by the WDA and sometimes with partial WDA funding. Potential funding mechanisms include:

- Joint venture arrangements using private finance initiative (PFI) funding. A joint venture company is formed between a WDA, or group of WDAs, and a private sector partner.
- Fully private sector funded with Local Authority collaboration. Typically the Local Authority will invite private sector companies or consortia to bid for the provision of a waste incineration facility. The successful bidder is contractually guaranteed, by the WDA, a minimum amount of feedstock (waste), over period of years, typically 25-30 years.
- Fully public sector funded. WDAs within in a region collaborate and jointly fund new facilities.

The financial risks associated with the construction of a new incineration plant are similar to those for any large-scale engineering project. However, the construction contractors usually assume the risks associated with the plant design and construction.

The financial risks associated with the financing of the project are assumed by the organisation sponsoring the project. Where the sponsor is a joint venture company, between the private sector and a WDA then the WDA will retain some of the risk. However, in these circumstances, following successful completion of the project and subsequent operation, the WDA would also normally receive a share in any profits made.

The financial risks associated with the operation of the plant include costs of technical failures, inability to operate to design specification and insufficient waste feedstock.

The risk of technical failure will be minimised through the choice of appropriate proven technologies with a good history of reliable performance. In choosing the appropriate technologies consideration must be given to the required plant capacity (e.g., a technology may be well proven but not on the scale required) and current and future legislative requirements, in particular in relation to air emissions.

The financial risk of technical plant failures may be transferred to the plant constructor or individual equipment suppliers by ensuring that guarantees are obtained on equipment performance and technical support for at least the first few years of the plants operation. However, in the event of long term or recurrent plant performance the WDA may be forced to find alternative methods of waste disposal and may also be, in the long term, liable for the costs of maintaining unreliable and/or inappropriate incineration plant costs following expiry of equipment. Therefore the best option is to ensure proven and appropriate technology is specified in the planning stage, instead of relying on contractual clauses to provide, albeit time limited, financial protection.

Each incineration plant is designed to handle a particular minimum quantity of waste. If a plant were to receive less waste than planned then it would also receive less income from gate fees and energy sales (since energy output is dependent upon the amount and calorific value of the waste combusted) and subsequently the operation of the plant may not be economically viable. These risks can be mitigated through careful and thorough specification of the incineration plant. To address these risks, incineration operators agree long term contracts obliging WDAs to guaranteeing minimum tonnages of waste. However, these agreements can also transfer the risk to the WDA. For example, if a WDA fails to deliver a contractually agreed amount of waste it may be liable to the payment of penalties to the Operator. Similarly where the WDA is part of a joint venture company to incinerate wastes, it will also share in any economic failure of the company.

These difficulties are avoidable through careful specification of the plant capacity. When specifying the capacity of plant to be installed, the current amount of wastes collected in a given area must be carefully assessed and account must be taken of the effects of likely future strategies, policies and targets e.g. recycling targets. This process of assessment must include consultation with the key stakeholders, including in particular the WCAs, to agree a waste management strategy and therefore to facilitate a reliable prediction of future waste disposal requirements.

5.3.2 Planning issues

The construction and operation of a waste incinerator is classified as a Schedule 1 development within the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988 and therefore an environmental assessment, or environmental impact assessment (EIA), is mandatory. The report on the EIA (usually called an "environmental statement") of a proposed development must be forwarded to the planning authorities as part of the application for planning permission. Even though an EIA may indicate a negative impact on the environment by the proposed development, this alone is not sufficient grounds for refusal of planning permission. In considering the application the planning authority must not only examine the environmental impacts of the proposed development but also any social, economic, safety and health considerations. Following the consideration of these issues together with local development plans, central government policies, and a period of consultation with other public bodies and with limited involvement with members of the public, the local planning authority decides whether to grant permission or to refuse it.

Local authorities can effectively grant themselves planning permission for any land within their area in which they own or intend to develop. The local planning authority passes a resolution to seek planing permission then publicises the application. After taking account of any representations as material considerations it may then pass a second resolution, granting planning permission. The subsequent planning permission is deemed to have been granted by the Secretary of State, therefore it can only be challenged by judicial review.

All the new incineration plant constructed to date in the UK has been built upon land associated with industrial use or is a development of an existing municipal waste incineration site. In general, the use of such sites has the advantage that the new development does not entail substantial (or in many cases any) change of use of the land and (dependent upon the relative size of the facility) does not result in significant changes to the local environment. Many new plant have been constructed using as much as of the existing infrastructure and buildings as possible, hence avoiding much of the cost, noise, dust and local nuisance associated with demolition.

Energy from waste plants (EFW) are often highly visible due to their size and the presence of a large chimney. They are also often sited close to the communities that they serve, in accordance with the proximity principle, to minimise the distance travelled by refuse collection vehicles. Consequently these facilities may receive more public attention than other waste management facilities. Where the incinerator is situated close to residential areas there may also be concerns over noise, odour, traffic movements and stack emissions. All these factors can create public concern about proposals for EfW plant that may be expressed during the planning process. Similarly the public has the opportunity to comment on the application for process authorisation, under the Environmental Protection Act, 1990.

Detailed consultation with local residents associations, local government associations and environmental groups before a planning application is submitted will enable the prospective developer to identify local concerns at the earliest possible stage. Consequently the developer will have the opportunity to address these concerns in the application for both planning permission and for the authorisation to operate and may significantly reduce the chances of refusal. Similarly, on-going liaison with local interest groups throughout the construction and operational phases of the development would facilitate the acceptance and integration of the facility into the local community.

5.3.3 Transport impacts

Large incineration plant will inevitably give rise to a large number of vehicular movements, bringing waste into the plant and taking solid or ash residues away from the plant. Vehicular traffic can be a source of noise pollution, air pollution through exhaust emissions, be a nuisance, increase traffic congestion, cause damage via vibration, and increase the accident risk to pedestrians. These impacts can be reduced through thoughtful siting of the plant and planning of transport routes.

Where possible, incineration plant should be sited away from residential areas in zones where there already exists a good transport infrastructure, including transport mechanisms and routes other than roads.

In comparison to other treatment or processing facilities the number of transport movements will be lower as the mass reduction caused in the process is much greater than caused in composting, anaerobic digestion or recycling. The ash and other residues are generally between a quarter and one third of the weight of the waste processed. The bulk density of the material leaving the incinerator is significantly higher than the incoming refuse and thus both of these factors result in the number of vehicle movements leaving are 20-30% of those bringing wastes.

RDF systems will generate process residues, the proportions depending on the type of system, which require disposal. These residues will be of similar bulk density to that of the incoming waste and thus the number of vehicle movements will be increased in relation to the amount of waste not burnt.

5.3.4 Environmental Impacts

Releases to Air

Table 5.1 provides a summary of current and future stack gas emission standards. One of the biggest issues of concern over EfW plants relates to the stack gas emissions. In part this concern arises from the poor historical reputation of waste incinerators particularly in relation to dioxin emissions. Dioxins and the other principle pollutant from incineration are discussed below.

Carbon Dioxide

Although carbon dioxide (CO_2) is the single largest "pollutant" species emitted, typically at around 8% by volume, in flue gases it is not generally regarded as a pollutant provided that the stack gases are adequately dispersed on discharge to the atmosphere. CO_2 is a "greenhouse gas" and the carbon from recently adsorbed organic materials (e.g. paper) are termed short cycle carbon and have little impact on climate change. Carbon from fossil sources (e.g. plastics etc) will contribute to the atmospheric load of greenhouse gases. Approximately half of the carbon in MSW and about 40% of the energy is of a fossil origin. If the waste was not incinerated, but landfilled, the organic matter would have the potential to generate methane which has a significantly greater climate change potential than carbon dioxide.

In addition, if waste is treated in a EfW facility providing heat and or power, then the CO_2 arising from these activities could be used to off set some of the CO_2 that would be produced by the combustion of fossil fuels, in power stations.

Carbon Monoxide

Carbon monoxide is a colourless, odourless poisonous gas that is known to affect health through the cardio-vascular system. However modern combustion control systems, furnace design and strict emission limit ensure that emitted carbon monoxide levels are less than 0.001% by volume and therefore may be regarded as negligible.

Nitrogen Oxides

Nitrogen oxides (NO_x) exist primarily as Nitric Oxide (NO) and Nitrous Oxide (NO_2) but under low wind speed, stable conditions and sunlight may convert to organic or inorganic nitrates. Nitric oxide is the principle form produced from combustion, however it readily converts to nitrous oxide. NO_2 contributes towards photochemical smogs, acid rain and causes harm to human health and vegetation. NO_x emissions are effectively controlled today by careful control over combustion conditions and through the use of reductants such as ammonia or urea injected into the combustion chamber. All UK incineration plant are required to achieve emissions of NO_x of less than 100 parts per million (0.01% by volume) and waste incineration accounts for only 0.5% of total UK emissions of NO_2.

Sulphur Dioxide and Hydrogen Chloride

Sulphur dioxide (SO_2) and hydrogen chloride (HCl) are produced by the combustion of sulphur and chlorine compounds in the waste. On contact with water, they form sulphurous and hydrochloric acids. The sulphurous acid oxidises in air to form sulphuric acid. Both SO_2 and HCl are effectively controlled by modern air pollution control (APC) systems (scrubbing) although care needs to be taken when combusting wastes containing high levels of sulphur (e.g. gypsum) or chlorine (e.g. PVC) to ensure that APC equipment is not overloaded.

Particulate Matter

Particulate matter may exist in the form of grit, soot or dust and is seen, in large concentrations, as smoke. Globally emissions of particulate matter from incinerators are insignificant when compared to wind borne dust from land etc. However, a badly operated incinerator may give rise to localised deposition of particulate matter. Certainly in the past, older plants have drawn complaints about deposition of soots and char in their locality. Established and reliable particulate abatement technologies such as bag filters or electrostatic precipitators effectively control particle matter emissions to negligible emission levels.

Heavy Metals

Incineration of municipal solid wastes releases many of the metals within that waste including lead, nickel, cadmium, mercury, arsenic and chromium. These metals and their compounds are widely recognised as being significantly detrimental to human health. In the past incinerator emissions of mercury and cadmium account for a significant proportion of total UK emissions to air of these pollutants however, these metals and their compounds are now effectively removed from the flue gases by carbon injection and particulate removal used in modern APC equipment.

Dioxin and Furans

Dioxin and furan emissions are one of the most controversial environmental issues that are associated with municipal solid waste incinerators. The term "dioxin" is used to describe a group of compounds with the chemical name polychlorinated dibenzo-para-dioxins and is used also to describe polychlorinated dibenzofurans, also known as furans. In total there are 210 known dioxins and furans. Dioxins are formed in trace amounts by combustion and other high temperature processes that involve chlorine and organic compounds. Dioxins may be released into the environment by a range of industrial processes, including waste incineration. Since the initial discovery of dioxins in stack gas and residues from MSW incineration in 1977, older incinerators have been identified as one of the major sources of dioxins in the environment.

Dioxins can reach man through the food chain, by inhalation or through the skin. The United States' Environmental Protection Agency (USEPA) claims that even the smallest concentrations of toxic dioxin isomers in the environment are of detriment to human health and there is considerable evidence to suggest that these dioxins attack the human immune system, reduce sperm count and cause fertility and birth defects.

Significant reductions in dioxin formation from incinerators can be achieved through ensuring good combustion conditions, minimising contact time between fly ash particles which catalyse dioxin formation and minimising the time the stack gas spends at the critical temperature range for maximal dioxin formation. Modern incinerators also use activated carbon injection to remove remaining dioxin from the stack gas. Consequently, dioxin emissions from modern incinerators are now about 0.5% of emissions from older incinerators, achieving the standard proposed in the draft Incineration Directive of 0.1 ng I-TEQ Nm^{-3}.

Odour

Compounds within MSW that may give rise to offensive odours are destroyed by efficient incineration, therefore odours that do arise are likely to come from fugitive emissions from the plant or waste handling facilities but are unlikely to arise from the stack. The emissions of odours are regulated under the Environmental Protection Act 1990.

Good plant design, waste handling practices and generally good housekeeping can enable odour emissions to be kept below nuisance levels or even eliminated. For example many new incineration facilities extract the odorous air over the waste feed and storage pits to provide primary combustion air within the furnace unit, hence removing fugitive emissions of odours. In addition, by enclosing all waste handling processes and keeping them under efficient fume extraction, further odour emissions can be eliminated. Finally, good housekeeping such as keeping the plant and its surroundings tidy and litter free will not only aid the elimination of odours but will improve the appearance of the plant.

Releases to Water

Liquid effluents arise from the use of wet or semi-wet gas scrubbers and comprise containing spent scrubber solution and fine fly ash particles. The usually caustic scrubber effluent will contain significant concentrations of heavy metals and organic micro-pollutants. Currently most UK plant employ dry or semi-dry scrubbers which do not give rise to liquid effluents, however the wet scrubbing process is more efficient and is likely to supersede the dry systems as emission limits further tighten.

Liquid effluents also arise from grate ash quench tanks, used to cool the grate ashes. The grate ash effluent will contain only small concentrations of heavy and currently disposal of these effluents may take place by discharge to a river or estuary, under consent from the Environment Agency or by discharge to the sewerage system.

Releases to land

The incineration of municipal waste in a modern incineration plant gives rise to bottom ash, the coarse residues falling off the end of the grate, and fine particulate matter collected by the APC equipment called fly ash or simply APC residues. Lime and activated carbon that are deliberately added to clean the flue gases is also trapped with the fly ash.

The bottom ashes contain the majority of the metals emitted from the incinerator but these are largely inert, and have been widely used in Europe as building aggregate. In particular, the Netherlands uses some 90% of EfW bottom ash in this way.

Bottom ashes can be used as secondary aggregate in road foundations and other constructional projects. The only treatment required is removal of ferrous and non-ferrous metals and ageing to allow the ash to stabilise. Large amounts of ash are recycled in this way outside the UK and details are shown in Table 5.7.

Table 5.7 Recycling of combustion ash

Country	Amount used	Application
Denmark	420,000 t/y (90% of grate ash production)	road sub-bases
Germany	About 50% of grate ash	road bases
Netherlands	90% of grate ash production	road bases, wind and noise barriers, aggregate in asphalt and concrete
Sweden	Development work taking place	road bases
USA	Development work taking place	road bases

Tests have been carried out in the UK using grate ash in car park and road bases. These applications are being monitored. Following the success of these tests two incinerator operators have built ash recycling plants.

Onyx SELCHP and ARC Ltd formed a joint venture company to process 120,000 tpa of bottom ash. This will generate

- 4800 tpa ferrous metal;
- 1080 tpa of non-ferrous metal; and
- 34,000 tpa of saleable aggregate.

London waste Ltd operators of the Edmonton incinerators have let a contract to process 140,000 tpa of bottom ash.

The aggregates produced will be suitable for use in road base layers and blockmaking. The material can be processed to meet BS3797:1990 “lightweight aggregates for masonry units and structured concrete” and the CBM UK national road building specifications. Ashes from ACT systems have not been tested in these roles.

The APC residues, about 3 tonnes for every 100 tonnes of waste processed, principally contains spent lime but also organic compounds and appreciable amounts of metals. The fly ash or APC residues should be landfilled as special waste.

The total mass of metals within the ashes is no greater than the total mass of metals that existed within the waste prior to incineration. However, since incineration of typical MSW waste achieves a reduction in volume of around 90-95% then the metals within the residues are much more concentrated. Although the bottom ash is generally viewed as being inert, the APC residues are designated as special waste.

RDF production residues will tend to concentrate the inter components such as glass and metals and the low heating value fractions containing the wet organic fractions. Disposal of these may require further treatment such as biological stabilisation of the organic fractions. The inert fractions will tend to be amenable to disposal without further treatment.

Noise
All process plant using mechanical equipment will generate noise and incinerators are no exception. The major sources of noise from incineration plant are usually from fans in the combustion, gas cleaning and emission systems. However, good plant design can reduce this noise to acceptable levels. For example, fans can be housed in sound proofed enclosures and simple measures such as earth banks and trees can further attenuate noise levels. In addition, the specification and purchase of new equipment (e.g. fans) should take noise considerations into account with preference given to quieter running machinery.

Visual Impact
The visual impact of any new development is an extremely important element in planning considerations - no one wants an "eye sore" on their doorstep. The visual impact of an incineration plant depends upon its siting, physical size and design. Indeed the visual impact of the majority of current UK incineration plant depicts a very poor image.

An incineration plant should, ideally, be located in an area where it will have minimal visual impact, such as in a major industrial landscape and built to a design sympathetic with its surroundings. Indeed, in their report the Royal Commission recommended that: "the siting of large incineration plants should reflect their character as major industrial enterprises, and that local planning authorities should ensure suitable areas are identified during the preparation of development plans".

Traditionally, MSW incineration plant design has been largely functional and built with little aesthetic consideration. However, much can be done to minimise the visual impact of a plant. The individual plant operations and ancillary equipment, such as pollution abatement plant, can be "shielded" within a single structure. Aesthetic considerations should be given to the materials used to construct or clad the building. Landscaping may also be used to screen the plant by use of earth slopes and/or tree planting. However, all large incineration plant will incorporate high stacks or chimneys, which are likely to be visible over large areas. The height of the stack is determined by statutory dispersion modelling and will be above local buildings and topology and therefore makes the visual impact of the stack difficult to diminish.

5.4 Contribution to Targets and policies

5.4.1 Landfill Directive

The key target for municipal waste in the Landfill Directive is the requirement to reduce the amount of biodegradable waste landfilled. The precise targets are to reduce the biodegradable municipal waste landfilled to 25%, 50% and 65% of the 1995 quantities by 2006, 2009, 2016 respectively. The UK is allowed to extend these dates by upto four years.

The ashes and APC residues will be biologically stable when landfilled. However, the APC residues will have chemical reactivity from the lime present and thus will require specialised disposal. The residues from RDF production will vary depending on the intensity of the process. Some fractions will be rich in glass stones and metals and as such will have a low level of biodegradability and as such will contribute to the reduction of landfill of biodegradable materials. Other fractions, principally the initial fines fraction will contain a high proportion of organics and thus will provide a more concentrated fraction for landfill and it may be necessary to compost this material prior to landfill. Overall the RDF fraction will remove biodegradable material from the waste stream and thus the total amount of biodegradable material remaining for landfill will be reduced. The precise degree of this reduction will depend on the process adopted and the quantity and nature of the rejects generated.

5.4.2 Waste strategy

UK Government Waste Strategy targets for recycling are currently 25% by 2005, 30% by 2010 and 33% by 2015. The targets for recovery of waste are 40% by 2005, 45% by 2010 and 67% by 2015.

Incineration does not contribute to the recycling target, as it is a recovery process. Recycling is performed on the ferrous metal extracted as part of the waste processing or the ash processing and this contributes 3-5% recycling. The use of the bottom ash as a construction material is not included within the recycling definition, but does divert an additional 10-15% of the waste away from landfill. The current definitions for recycling and recovery do allow for double counting of waste and a more rigorous interpretation may be helpful (but may be difficult to implement).

RDF processing enables additional recycling to be performed. Options for the recovery of non-ferrous metals and the recovery of plastics and textiles and small amounts of paper/card are possible through mechanical and manual processes. Experience from dirty MRF operations and proposals for plants under consideration would suggest that a further 5-8% of recyclables could be extracted through this route. The reject fractions from the processing could be directed to other processes such as AD or composting to produce further products or reduce the pollution potential.

5.4.3 Greenhouse gas

The Kyoto protocol established targets of 12% reduction in the climate change gas emissions and subsequent UK policy has set a target of 20% CO_2 reduction of 1990 levels by 2010.

The emission of CO_2 by combustion of MSW is an expected outcome from the process. About half of the carbon dioxide emitted is of fossil origin and thus given a carbon content of 24% for typical UK MSW. This would generate 440 kg per tonne of waste burnt of fossil CO_2 and 440 kg per tonne of waste burnt of short cycle CO_2 that has minimal effect on climate change potential. There will be also CO_2 derived from the collection and supply of waste and the transport of ash, residues and recyclables to their market or disposal point.

Counteracting the impacts from the emitted fossil carbon dioxide and transport will be the energy generation, which will offset fossil fuelled energy production. The process will generate between 450 and 500 kWh t^{-1} and thus will offset the fossil CO_2 from the generation of this electricity.

5.4.4 Renewable energy

UK government has set a target of 10% of electricity generation from renewable sources by 2010. Incineration and RDF do generate a proportion of renewable energy. Using data from the National Household Waste Analysis Project it can be estimated that 60% of the calorific value of waste is derived from renewable materials (40% is derived from plastics and half of the textiles and miscellaneous combustible fractions). Given that mass burn incineration will generate 450-500 kWh t^{-1}, then 270-300 kWh t^{-1} of renewable energy is generated by energy from waste. RDF systems that generate lower amounts of electricity will provide proportionally lower amounts of renewable energy.

Table 5.8 Summary of criteria assessments - Incineration

	FBC	Fixed grate	RDF
Economic			
Capital cost Operational cost	£190-320 tpa^{-1} £25-35 t^{-1} dependant on scale	£196-313 tpa^{-1} £24-36 t^{-1} dependant on scale	£113-173 tpa^{-1} £33-39 t^{-1} dependant on scale
Technical			
Proportion of the municipal waste stream treated	All of the waste	All of the waste	All waste delivered, but between 5 an 65% rejected depending on system
Energy production	475-500 kWh t^{-1}	450-475 kWh t^{-1}	475-500 kWh t^{-1} of waste burnt, thus 150-475 kWh t^{-1}
Land requirements	0.05 m^2 t^{-1}	0.05 m^2 t^{-1}	0.1 m^2 t^{-1}
Operational/risk			
Availability	85%	85%	85%
Quality of products	Electricity, high quality, low grade heat potentially for CHP	Electricity, high quality, low grade heat potentially for CHP	Electricity, high quality, low grade heat potentially for CHP
Operations in UK	1	12	3
Operation elsewhere	>100	>100	>10
Operational success of commercial plants	Good	Good	c-RDF good success, d-RDF marginal
Planning requirements	Combustion emission, visual impact and traffic issues	Combustion emission, visual impact and traffic issues	Combustion emission, visual impact and traffic issues, (smaller scale reduces traffic and visual impact effects)
Scope for integration	Limited processing may allow recovery of additional materials for other systems, but principally limited to whole or grey waste	Limited to treatment of whole or grey waste	Processing allows integration with other treatment options, but quality of products can be poor.
Stability of markets for recyclate/products	Stable market for electricity, Heat market less secure	Stable market for electricity, Heat market less secure	Stable market for electricity, Heat market less secure
Education needs	None	None	None
Public dependence	None	None	None

Table 5.8 continued

	FBC	Fixed grate	RDF
Environmental			
Greenhouse gas reduction	187-198 kg t^{-1} reduction	176-187 kg t^{-1} reduction	44-187 kg t^{-1} reduction
Air quality	Pollution controlled, but public concerns over emissions	Pollution controlled, but public concerns over emissions	Pollution controlled, but public concerns over emissions
Water pollution	Small quantity of contaminated wastewater to treat/dispose of.	Small quantity of contaminated wastewater to treat/dispose of	Small quantity of contaminated wastewater to treat/dispose of
Solid residues/hazard	Bottom ash possible to recycle, pollution abatement residues are special wastes	Bottom ash possible to recycle, pollution abatement residues are special wastes	Bottom ash possible to recycle, pollution abatement residues are special wastes, Processing residues comprise 5-65% of feedstock.
Noise	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance
Odours	Enclosed plant potential to control odour	Enclosed plant potential to control odour	Enclosed plant potential to control odour
Transport	5-10% rejects and 30% ash to landfill	2-5% reject and 30% ash to landfill,	5-65% rejects and 3-25% ash to landfill, 5-15% recyclable to market
Resource use	Limited use, lime and activate carbon	Limited use, lime and activate carbon	Limited use, , lime and activate carbon
Policy			
Meeting recycling target	All materials recovered, 5-7% ferrous recycling	All materials recovered, 3-5% ferrous recycling	35-95%l materials recovered, 5-15% recycling
Biodegradability reduction	All material non biodegradable	All material non biodegradable	Material combusted non-biodegradable, processing reject, on average similar to MSW
Public perception	Uncertainty over technology, disliked due to air emissions and traffic	Known technology, disliked due to air emission and traffic	Uncertainty over technology, concerns over emissions
Employment opportunities	0.3 jobs $ktpa^{-1}$	0.3 jobs $ktpa^{-1}$	0.45 jobs $ktpa^{-1}$
Public involvement	No involvement of the public	No involvement of the public	No involvement of the public

6 GASIFICATION/PYROLYSIS

6.1 Introduction

Gasification and pyrolysis are two upcoming technologies that promise improved performance over traditional combustion technologies

6.1.1 Gasification

Gasification is the conversion of a solid or liquid feedstock into a gas by partial oxidation under the application of heat and is shown schematically in Figure 6.1. Partial oxidation is achieved by restricting the supply of oxidant, normally air. 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 relatively low calorific value (CV), typically 4 to 10 MJ Nm^{-3} (the CV of natural gas is about 39 MJ Nm^{-3}). This gas, sometimes called producer gas, can be used as a fuel in boilers, internal combustion engines or gas turbines.

Although air is usually used as the oxidant, oxygen enriched air or oxygen can also be used. When not using air, the resulting gas, often called synthesis gas, will have a higher CV (typically 10 to 15 MJ Nm^{-3}) than that formed using air due to the absence of nitrogen.

For most waste feedstocks, the gas will contain tars and particulate matter, which may need to be removed before the gas, is suitable for combustion. The degree of this contamination will depend on the gasification technology used.

Gasification is not a new technology, although its application to waste feedstocks is still being developed. 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.

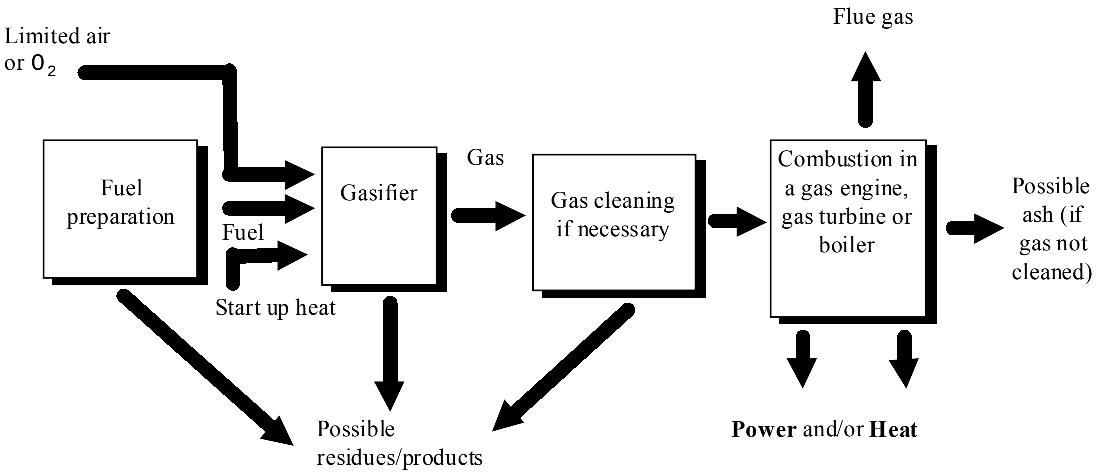

Figure 6.1 Schematic representation of the gasification process

6.1.2 Pyrolysis

Pyrolysis is thermal degradation of a material in the complete absence of an oxidising agent (e.g. air or oxygen). In practice, complete elimination of air is very difficult and some oxidation is likely to occur. The process is shown in Figure 6.2.

Typically the process occurs at temperatures in the range 400-800^{o}C. When applied to waste materials, the action of heat breaks complex molecules into simpler ones. This results in the production of gas, liquid and char. These products can have several uses depending on the nature of the feedstock, however for waste based feedstocks the most likely use is as a fuel for energy generation.

The relative proportions will depend on the temperature the material is subjected to, the time for which it is exposed to that temperature and the nature of the material itself. Long exposure to low temperatures will maximise the production of char whereas ‘flash’ pyrolysis gives up to 80% by weight liquid. Flash pyrolysis involves short exposure (<1 second) to temperatures around 500^{o}C. Rapid quenching is necessary to ‘freeze’ the reactions and condense gaseous species before simple molecules are formed which are naturally gaseous under ambient conditions.

If a gas is the principal product, then it is likely to have a higher CV (typically 15 to 20 MJ Nm^{-3}) than that produced by gasification (in which the gaseous species are partially oxidised).

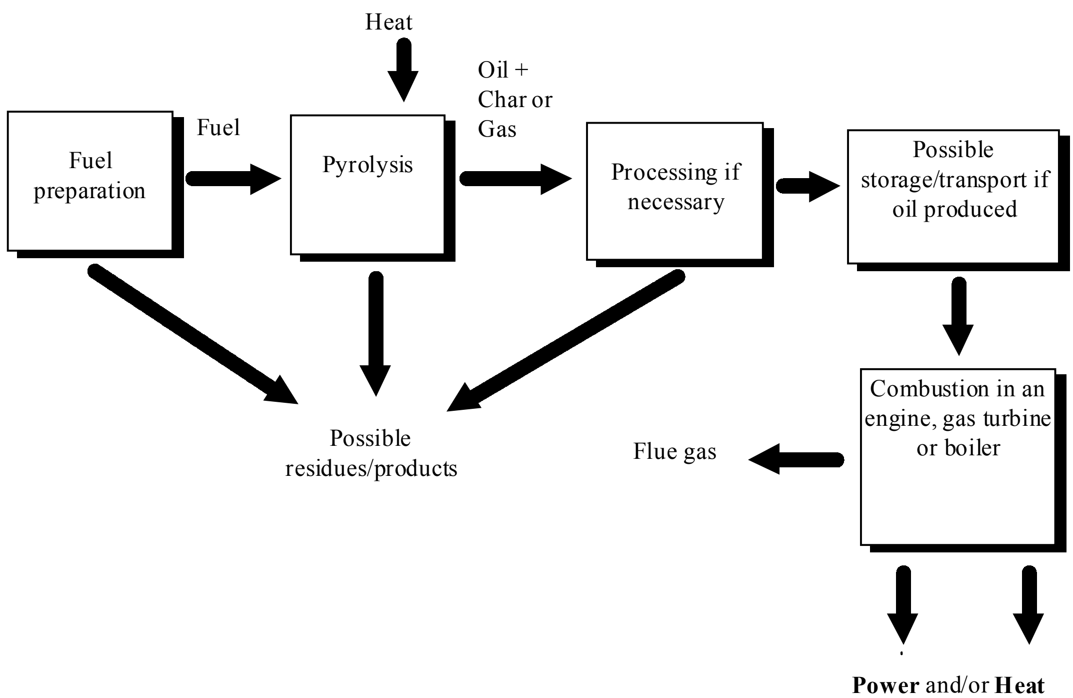

Figure 6.2 Schematic representation of pyrolysis process

6.2 Technology Status

6.2.1 State of deployment in Europe

About forty advanced thermal conversion plants for wastes have been identified and about 26 of these are known to have treated MSW or RDF. The scales range from small laboratory plants to about 50 kt y^{-1} demonstration plant. The two processes at the commercial demonstration phase are the TPS Termiska Processer fluidised bed gasifier and the Thermoselect process. Whilst several other developers are close to having a commercial scale demonstration plant and these include the Lurgi, Siemens and Proler. The majority of the plants being developed are likely to operate commercially at less than 100 kt y^{-1}.

A wide range of companies have been involved in the development of these technologies from individuals to large corporations. As the technologies approach commercialisation, increasingly the larger private companies and public companies are beginning to dominate. This is largely due to the difficulty smaller companies find in accessing the capital required to commercialise these plants.

The development of advanced thermal conversion technologies also requires significant resources. Most of those technologies nearing commercial operation started development in the mid to late 1980s. To finance this process, the resources of a large company or access to public funds has typically been necessary.

Wastes processed

Various developers have tested many different waste types. In deciding which wastes to use as a feedstock, developers consider several factors:

- waste availability;
- likely gate fee;
- waste homogeneity.

Some wastes, whilst potentially being attractive feedstocks, will not be readily available as the collection infrastructure does not exist. Plastics often fall into this category, at present usually being co-disposed with other wastes.

Gate fees are likely to be greatest for those wastes that are more hazardous such as clinical waste. However, the total market size for the disposal of such wastes may not be as large as for MSW and handling difficulties may make them unsuitable for use on pilot plant.

Advanced thermal conversion technologies generally require a reasonably homogeneous feedstock. Large variations in feedstock composition can result in problematic fluctuations in the producer gas or liquid fuel CV. Mass burn combustion systems overcome the difficulties associated with feedstock variations through feedstock mixing and the large size of the combustion chamber. It is likely that gasification and pyrolysis processes will accept a range of wastes rather than just MSW or RDF.

As a result of these factors, the most common feedstocks used with advanced thermal conversion technologies are sorted MSW (RDF) and tyres. Some developers have also tested various industrial wastes, wood waste and automobile shredder residue.

6.2.2 Costs

Capital and operating costs

There seems to be no perceptible difference in capital cost between gasification and pyrolysis systems. Pressurised gasification systems have higher capital costs but offer a potential cost saving at the power generation stage due to the lack of gas compression required and higher system efficiency.

Costs should always be developed in a local context of capacity, construction cost, labour cost, the type of waste processed, the requirements for the flue gas cleaning, the resale and landfill prices for residues and the energy price. However some work has been done to produce generic cost data. From the available literature, the capital costs of advanced conversion systems range from £131- 213 per tonne per year of municipal waste treated. These cost exclude the feedstock preparation plant, which can add a further £50-120 per tonne per year. The operating costs range from £19-44 per tonne per year of municipal waste and the physical processing of RDF manufacture can add upto £18-45 per tonne per year. These operating costs exclude the cost of capital repayment. The costs given here should be treated with care as they have been complied from different desk-based studies, which may not have consistent methodologies and are not based on real plant data.

Gate fees

For many waste treatment plants, gate fees represent the largest source of income and are therefore very important to a plant's economics. From the data available, gate fees for the advanced conversion technologies currently being developed are in the range £22-56 (Euro 35 - 90) per tonne of municipal waste. These gate fees are for plant designed to operate to the emissions levels currently legislated for municipal waste combustion systems in Europe and the USA. Gate fees for plant designed to meet tighter standards introduced by the EU for waste combustion (Table 6.2), are likely to be higher at about £56-88 (Euro90 - 140).

6.2.3 Performance

The energy output is ultimately determined by the feed and processing parameters. Net energy outputs are reported to be in the range of 260 - 1000 kWh of electricity per tonne of MSW derived feedstock (i.e. some figures refer to unsorted MSW and some to RDF). The lower end of the range is for plant designed to minimise environmental impacts to all media and so includes ash vitrification and wastewater treatment. The upper end of this range is for plant utilising combined cycle technology, meeting the current emissions requirements for waste combustion but not going beyond this, and probably result from highly sorted MSW. Materials with higher calorific values such as rubber and plastics are reported to produce up to 3000 kWh of electricity per tonne.

It should be noted that the above figures for advanced conversion technologies are largely based on theoretical predictions. Most of the pilot plants currently operating have not achieved the highest figures above, as the systems have not yet been optimised and combined cycle generation has not been used.

The residues from the gasification and pyrolysis processes will be biologically inert and thus will contribute to methane generation in landfill. However, many of the processes will use RDF pre-treatment and this will result in unburnt residues for landfill or biological treatment.

6.3 Implementation

6.3.1 Financial and Operational Risks

Capital availability is crucial to technology development and commercialisation. The most advanced pyrolysis and gasification technologies have mostly been developed by large engineering companies who have the balance sheets to cover the risks associated with a first-off plant and who have the significant research and development budgets necessary. Public money has also been very important to many developing technologies either through grants or direct R&D in the public sector.

The financial risks are similar to those of incineration and RDF. There are additional risks derived from the untested market position of gasification and pyrolysis and the potential for technical failure of the systems.

Several key areas requiring development can be identified. These are:

- feedstock preparation and handling;
- plant scale-up;
- demonstration of reliability and performance;
- producer gas clean-up;
- demonstration of successful producer gas combustion in gas turbines;
- complete package development;
- by-product market development.

Many of the trials of advanced conversion technologies have been carried out with closely specified and screened feedstocks. Commercial systems will need to be more tolerant of feedstock variation if they are to maximise cost effectiveness.

Materials handling also requires some attention. Mass burn systems rely on a large quantity of waste in a hopper to provide an air seal. Some of the advanced thermal conversion technologies operate at a smaller scale and therefore need to use valves or lock-hopper systems. In addition these technologies require more precise control of air entering the process.

As most of the advanced conversion technologies being reviewed are at relatively small scale, one of the key areas for development is plant scale-up. Typically, scale-up factors of between three and ten times existing plant capacity will be required for commercial plant. Such a scale-up can represent high technical risk.

Many of the trials carried out have been to test specific design aspects. If equipment is to be sold commercially there is a need for longer-term trials to prove reliability and performance in order to give the basis of technical guarantees. As well as meeting customer needs, such guarantees will be necessary if off-balance sheet finance is to be secured.

Producer gas clean-up is another area requiring attention. Many trials have flared the gas, but it may be necessary to remove tars and particulates before the gas is suitable for combustion in a reciprocating engine or turbine. In order to maximise system efficiency the gas should be cleaned hot avoiding the energy losses associated with gas cooling, however cold cleaning may not impact on efficiency too greatly. Hot gas clean-up is being developed for other technologies, especially modern clean coal technologies, but there are still concerns about the performance and reliability of equipment for operating temperatures above about 500^{o}C.

If advanced conversion technologies are to maximise efficiencies, combined cycles will need to be employed. A necessary precursor to this is trials of the combustion of producer gas in gas turbines. As well as gas cleaning, the relatively low CV of producer gas compared to natural gas will be an issue here. Progress has been made in this area and currently the situation looks promising.

More generally, there has been a tendency for technology developers to concentrate on the gasifier or pyrolysis unit. Potential customers are likely to require a waste processing system, which includes all front-end materials handling, ash and other residues handling and energy generation/distribution. Some of these elements have been mentioned above, however it is worth stressing the importance of offering what the market requires in terms of function.

6.3.2 Planning issues

Gasification and pyrolysis units are expected to be established as small scale units that fit within a local waste management strategy, which is not seen as economically possible with combustion systems. Whilst within the planning process the same issues exist with these processes as with combustion the scale factors will reduce the problems in the planning process. The biggest benefits from this approach will be in terms of the traffic and visual impacts although the concerns over air emissions are likely to be equally opposed to advanced thermal processes or combustion.

The UK Strategy for Sustainable Waste Management talks about the "desirability of recovering or disposing of waste close to the place where it is produced". This is the proximity principle which places the responsibility for waste on the communities producing it, aims to minimise environmental impacts through transport of waste and aims to result in waste treatment facilities which are more suited to and acceptable to local communities.

Mass burn combustion (MBC) is generally only economic at greater than about 100 kt y^{-1}. Many advanced thermal conversion plants are being developed to operate at scales below 100 kt y^{-1} and so may be more able to meet the requirements of the proximity principle, especially in rural areas.

6.3.3 Transport

The impacts on transport will be the same as for combustion based processes and thus whole waste treatment will generally have the lowest number of vehicle movements whilst RDF based technologies will be proportionally increased with the movement of residues to landfill or alternative treatment options.

The use of smaller facilities will allow the reduced travel distances between waste producer and the facility and this may reduce the overall traffic burden compared to larger centralised facilities.

6.3.4 Environmental issues

Air emissions
The atmospheric emissions from a process will depend on pollution abatement (PA) plant used, but for pyrolysis and gasification cleaning up the producer gases before combustion offers potential cost savings when compared to MBC. This is because there are lower gas volumes involved (which can be less than one-tenth of those for MBC) and consequently the pollution abatement (PA) plant can be smaller. For some advanced conversion systems, cleaning the producer gas can mean high temperature gas cleaning (cooling gases before cleaning reduces thermal efficiency) which may be a problem.

Some of the advanced conversion plants being developed have inherently lower emissions than MBC and may require less sophisticated PA plant to be fitted. There are several reasons for these lower emissions:

- waste sorting produces a more homogeneous fuel;
- lower gas flows reduce carry-over of particulate matter;
- improved combustion through the production of an intermediate gaseous or liquid fuel.

It should be noted that some advanced conversion technologies produce solid or liquid residues, which are then combusted elsewhere or as a source of heat input into the process. Where this is the case any emissions from such combustion should be included when making comparisons with other technologies.

There is currently limited published data from which to assess the likely emissions levels from advanced thermal conversion technologies. When making comparisons, care must be taken as data are often presented on different bases. For example:

- pyrolysis technologies may produce liquid fuels which may be combusted separately in which case emissions may result from the pyrolysis and combustion processes;
- some data are for combustion gases without any pollution abatement plant and others are post-pollution abatement;
- many feedstocks are often tested on a particular plant, so it is important to be able to identify the feedstock to which the emissions data relate;
- measurements may be averaged over different time periods, which may not be clearly specified.

Within the limitations of the available data, the following tentative observations can be made. Advanced thermal conversion technologies are currently performing within the ranges shown in Table 6.1 with respect to atmospheric emissions (the data presented for measured emissions are intended to be comparable with the limit values also shown). The values in Table 6.1

show that, in general, advanced thermal conversion technologies will be able to meet current emissions standards as they apply to waste combustion. From the limited data available it seems likely that many of the technologies being developed have the potential to meet even tighter limits. Also, due to the lower gas volumes involved with advanced thermal conversion technologies, the pollution abatement plant required should be cheaper than for a conventional combustion plant.

It should be noted that Table 6.1 applies to atmospheric emissions only. There is a strong trend towards consideration of emissions to all media as illustrated by the adoption of the EC Directive on Integrated Pollution Prevention and Control. The rationale behind this approach is that controlling emissions to one media should not result in transferring the pollution problem to another. This makes an assessment of the emissions from advanced conversion processes more complex. As Figure 6.1 and Figure 6.2 show, the various gasification and pyrolysis technologies have the potential for solid and liquid residues from several process stages. Many developers claim these materials are not residues requiring disposal but are products which can be used. However in many cases such claims remain to be substantiated and any comparison of various waste treatment options should consider releases to air, water and land.

Table 6.1 Typical emissions from advance thermal conversion plant

Component	Typical measured emissions[2] (mg Nm^{-3})	89/369/EEC ≥3 t/h new municipal waste plant limits (mg Nm^{-3})	Draft new EC Incineration of Wwaste Directive[4] (mg Nm^{-3})
Total dust	2 to 13	30	10
TOC	2	20	10
HCl	1 to 20	50	10
HF	0.1 to 3	2	1
SO_2	5 to 15	300	50
No_x	70 to 300		200
Hg	<.01 to .07	0.2	0.05
Cd + Tl	<.01 to 7.5	0.2	0.05
Other heavy metals	2.2	6	0.5
PCDD/F	<.02 to 1.2 ng Nm^{-3} ITEQ		0.1
CO	2.5 to 94	100	50

Water emission

The sources of liquid residues from MBC plant are boiler blow down and wet scrubbing systems, when used for flue gas cleaning. Whilst these sources remain for gasification and pyrolysis systems using steam cycles or wet scrubbers, these technologies can also produce liquid residues as a result of the reduction of organic matter. Such residues have the potential to be highly toxic and so require specialised disposal. Any releases of liquid residues into the environment should therefore be carefully considered.

Solid emissions

Gasification and pyrolysis have the potential to produce less ash than MBC and the solid residues, which are produced often, have a market value. There are several reasons for this and the reasons vary with technology. The two most significant factors are firstly, that several technologies involve waste sorting before thermal treatment, hence the fines, which contain a significant portion of the ash forming minerals, are discarded.

The second factor is that some of these processes involve a high temperature stage, which results in ash vitrification (ash is melted and forms a glass-like substance on cooling). Vitrified ash is more likely to pass leaching tests and may therefore be safer to landfill and more suitable for use as a construction material.

Two elements, which are commonly recovered for re-use from advanced thermal conversion technologies, are carbon and sulphur. Sulphur removal from producer gas is relatively simple and the char left by gasification or pyrolysis of many wastes is often predominantly carbon.

Nuisance

Nuisance from gasification and pyrolysis plant from noise, odour and visual impact will be similar to other thermal conversion processes. The noise an odour issues are easily contained, so long as good modern design of the waste reception facilities are adopted. Visual impact issues may well be reduced compared to combustion due to the smaller scale of the facilities, but the difficulties over hiding the chimney will still remain.

6.4 Contribution to Targets and Policies

6.4.1 Landfill Directive

The key target for municipal waste in the Landfill Directive is the requirement to reduce the amount of biodegradable waste landfilled. The precise targets are to reduce the biodegradable municipal waste landfilled to 25%, 50% and 65% of the 1995 quantities by 2006, 2009, 2016 respectively. The UK is allowed to extend these dates by upto four years.

The ashes and APC residues will be biologically stable when landfilled. However, the APC residues will have chemical reactivity from the lime present and thus will require specialised disposal. The residues from RDF production will vary depending on the intensity of the process. Some fractions will be rich in glass stones and metals and as such will have a low level of biodegradability and as such will contribute to the reduction of landfill of biodegradable materials. Other fractions, principally the initial fines fraction will contain a high proportion of organics and thus will provide a more concentrated fraction for landfill and it may be necessary to compost this material prior to landfill. Overall the RDF fraction will remove biodegradable material from the waste stream and thus the total amount of biodegradable material remaining for landfill will be reduced. The precise degree of this reduction will depend on the process adopted and the quantity and nature of the rejects generated.

6.4.2 Waste strategy

UK Government Waste Strategy targets for recycling are currently 25% by 2005, 30% by 2010 and 33% by 2015. The targets for recovery of waste are 40% by 2005, 45% by 2010 and 67% by 2015.

Gasification and pyrolysis do not contribute to the recycling target, as they are recovery processes. Recycling is performed on the ferrous metal extracted as part of the waste processing or the ash processing and this contributes 3-5% recycling. The use of the bottom ash as a construction material is not included within the recycling definition, but does divert an additional 10-15% of the waste away from landfill. The current definitions for recycling and recovery do allow for double counting of waste and a more rigorous interpretation may be helpful (but may be difficult to implement).

RDF processing as a pre-treatment enables additional recycling to be performed. Options for the recovery of non-ferrous metals and the recovery of plastics and textiles and small amounts of paper/card are possible through mechanical and manual processes. Experience from dirty MRF operations and proposals for plants under consideration would suggest that a further 5-8% of recyclables could be extracted through this route. The reject fractions from the processing could be directed to other processes such as AD or composting to produce further products or reduce the pollution potential.

6.4.3 Greenhouse gas

The Kyoto protocol established targets of 12% reduction in the climate change gas emissions and subsequent UK policy has set a target of 20% CO_2 reduction of 1990 levels by 2010.

The emission of CO_2 by the processes is an expected outcome. About half of the carbon dioxide emitted is of fossil origin and thus given a carbon content of 24% for typical UK MSW. This would generate 440 kg per tonne of waste burnt of fossil CO_2 and 440 kg per tonne of waste burnt of short cycle CO_2 that has minimal effect on climate change potential. There will be also CO_2 derived from the collection and supply of waste and the transport of ash, residues and recyclables to their market or disposal point.

Counteracting the impacts from the emitted fossil carbon dioxide and transport will be the energy generation, which will offset fossil fuelled energy production. The process will generate between 260 and 1000 kWh t^{-1} and thus will offset the fossil CO_2 from the generation of this electricity.

6.4.4 Renewable energy

UK government has set a target of 10% of electricity generation from renewable sources by 2010. Incineration and RDF do generate a proportion of renewable energy. Using data from the National Household Waste Analysis Project it can be estimated that 60% of the calorific value of waste is derived from renewable materials (40% is derived from plastics and half of the textiles and miscellaneous combustible fractions). Given that whole waste processing will generate 550-1000 kWh t^{-1}, then 330-600 kWh t^{-1} of renewable energy is generated by energy from waste. RDF systems that generate lower amounts of electricity will provide proportionally lower amounts of renewable energy.

Table 6.2 Summary of criteria assessments - Gasification/pyrolysis

	Gasification/pyrolysis whole waste	Gasification/pyrolysis RDF
Economic		
Capital cost Operational cost	£350-450 /tpa^{-1} £46-61 t^{-1} dependant on scale	£350-450 tpa^{-1} £46-61 t^{-1} dependant on scale
Technical		
Proportion of the municipal waste stream treated Energy production Land requirements	All of the waste 550-1000 kWh t^{-1} 0.05 m^2 t^{-1}	All waste delivered, but between 5 an 65% rejected depending on system 650-1000 kWh t^{-1} of waste burnt, thus 225-550 kWh t^{-1} 0.1 m^2 t^{-1}
Operational/risk		
Availability	85%	85%
Quality of products	Electricity, high quality, low grade heat potentially for CHP	Electricity, high quality, low grade heat potentially for CHP
Operations in UK	1 pilot	2 pilot
Operation elsewhere	6 commercial or demonstration 6 pilot plants	5 commercial or demonstration 8 pilot plants
Operational success of commercial plants	Uncertain	Uncertain
Planning requirements	Combustion emission, visual impact and traffic issues	Combustion emission, visual impact and traffic issues, (smaller scale reduces traffic and visual impact effects)
Scope for integration	Limited processing may allow recovery of additional materials for other systems, but principally limited to whole or grey waste	Processing allows integration with other treatment options, but quality of products can be poor.
Stability of markets for recyclate/products	Stable market for electricity, Heat market less secure liquid and gaseous fuels markets unclear	Stable market for electricity, Heat market less secure liquid and gaseous fuels markets unclear
Education needs	None	None
Public dependence	None	None

Table 6.2 continued

	Gasification/pyrolysis whole waste	Gasification/pyrolysis RDF
Environmental		
Greenhouse gas reduction	242-418 kg t^{-1} reduction	77-220 kg t^{-1} reduction
Air quality	Pollution controlled, but public concerns over emissions	Pollution controlled, but public concerns over emissions
Water pollution	Small quantity of contaminated wastewater to treat/dispose of.	Small quantity of contaminated wastewater to treat/dispose of
Solid residues/hazard	Bottom ash possible to recycle, pollution abatement residues are special wastes higher carbon content than combustion residues	Bottom ash possible to recycle, pollution abatement residues are special wastes, higher carbon content than combustion residues Processing residues comprise 5-65% of feedstock.
Noise	Enclosed operation limited potential for nuisance	Enclosed operation limited potential for nuisance
Odours	Enclosed plant potential to control odour	Enclosed plant potential to control odour
Transport	5-10% rejects and 30% ash to landfill	5-65% rejects and 3-25% ash to landfill, 5-15% recyclable to market
Resource use	Limited use, lime and activate carbon	Limited use, , lime and activate carbon
Policy		
Meeting recycling target	All materials recovered, 5-7% ferrous recycling	35-95%l materials recovered, 5-15% recycling
Biodegradability reduction	All material non biodegradable	Material combusted non-biodegradable, processing reject, on average similar to MSW
Public perception	Uncertainty over technology, disliked due to air emissions and traffic	Uncertainty over technology, concerns over emissions
Employment opportunities	0.4 jobs $ktpa^{-1}$	0.5 jobs $ktpa^{-1}$
Public involvement	No involvement of the public	No involvement of the public

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