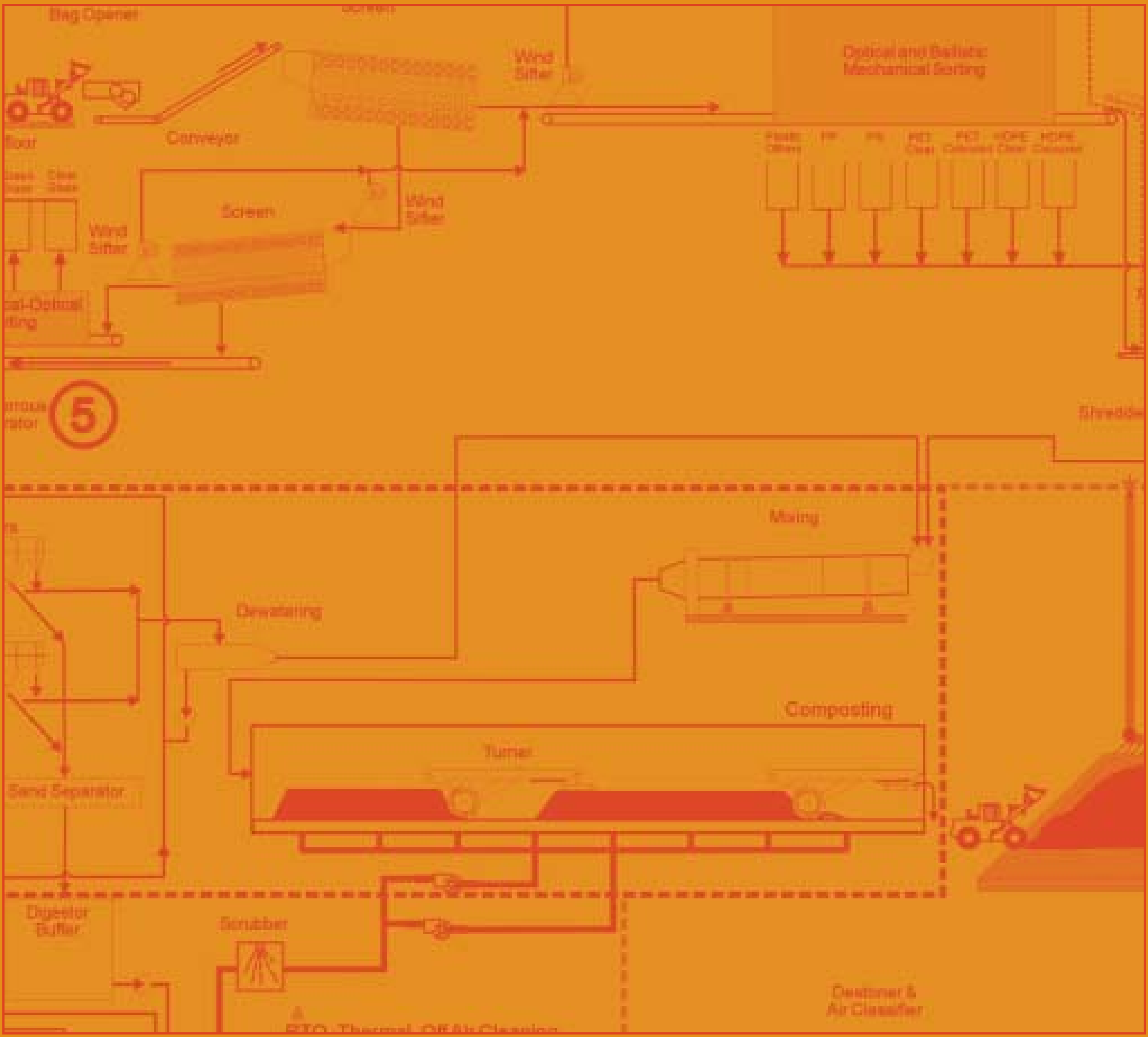
Cool Waste Management

A State-of-the-Art Alternative to Incineration for Residual Municipal Waste

MBT



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Executive summary

The aim of this study is to assess the possibilities for a system for managing residual waste which does not include any thermal treatment process. The study includes a review of mechanical biological treatment (MBT) systems and their potential effects.

MBT systems are not new. In their more primitive guises, they can be considered a basic evolution from the (usually failed) mixed waste composting plants of two decades ago. However, the potential for integrating systems based around biological treatment of degradable fractions with increasingly efficient mechanical separation techniques is a more recent development, as is the tendency to look to employ digestion techniques for the biological treatment phase as opposed to aerobic treatments.

In the system we have proposed, which no doubt can be improved upon, we have suggested that mechanical separation techniques operating on residual waste (i.e. that remaining after source separation) can extract recyclable fractions of glass, dense plastics, aluminium, steel, as well as some paper and card, and plastic films. For the latter two material types, the prospects for market utilisation may not be so great, though the paper and card can be utilised in aerobic composting.

The aim is to cleanse, through removal of useful materials, the residual fraction to leave a biowaste fraction, this being contaminated by the uncaptured materials which the process cannot recycle. In our process, this material is then treated in a digestion process before being stabilised through aerobic treatments (when the paper and card extracted could be re-introduced if there are no markets for that material). It is possible to extract from this material a fine fraction which would be suitable for low grade applications, but which should not be used on agricultural land.

This system, which generates approximately the same amount of energy as it uses (so net energy delivery would be zero), performs well when compared with other residual waste treatment systems despite the fact that other treatments can deliver more energy. Indeed, a basic greenhouse gas balance shows just how well such a system performs precisely because the emphasis is as much (if not more) on materials as it is on energy.

In the worst case scenario, this type of system still requires just less than a third of the output to be landfilled. The material destined for landfill is, however, relatively inert by comparison with untreated waste sent to landfill. The potential for generation of methane, odour and leachate is reduced with the leachate itself being less hazardous than that from other materials when landfilled. The engineering properties are also different, giving rise to reduced problems in respect of settlement (though the material requires slight changes in practice when it is placed in a landfill).

This plant does not provide an alternative to source separation. The quality of materials extracted, notably the paper and card, and organic fractions (both of which are major components of the unseparated waste stream), is lower than that obtained through source separation. It provides ‘back-up’ to that system. Set alongside an intensive source separation system, we estimate that a local authority generating 200,000 tonnes of waste would have to send approximately 15% of the total to landfill. In other words, 85% ‘diversion’ is quite feasible without any need to resort to thermal treatment systems.

Introduction

Mechanical Biological Treatment is not a new technology, but it is one that has been almost completely overlooked in Britain. Until Greenpeace published its waste management "Blueprint" in October 2001, waste managers and politicians were virtually unanimous in insisting that what could not be recycled must be buried or burned. The prevailing belief, justified by reference to an oversimplified and crude "waste hierarchy", was that burning was the preferable option. The result was that literally scores of new incinerators were proposed across the UK.

The situation has now changed. There is a much greater awareness of the environmental impacts of incinerators and this, coupled with their unpopularity, has led to an increased interest in alternative treatment technologies for residual waste. When Greenpeace published its "Blueprint", interest in MBT was immediately strong. But it soon became clear that waste managers wanted more details, particularly on costs and environmental impacts. This report fills that gap.

MBT is not of course a magic box that eliminates the need for a final disposal option. What it does do is greatly reduce both the quantity and toxicity of residual waste. The system outlined in this report, which is designed to deal with what is left after effective kerbside recycling, can enable rates of diversion from landfill that may seem astonishing to those locked into old modes of waste management. Some may be equally surprised that non-recyclable residues from the process are landfilled. Greenpeace does not support the practice of landfilling raw municipal waste, but we do maintain that cleansing and stabilisation followed by landfill is the best environmental option for residual waste. The life cycle and substance flow analyses in this report show that MBT followed by landfill is clearly preferable to incineration in terms of toxic emissions, climate impacts, material conservation and energy conservation.

Unfortunately, largely because of problems associated with plastics recycling, use of MBT to prepare waste for burning is common in Europe. Incineration transforms potential raw materials into pollutants and disperses them, thinly but widely, in such a way that they can never be retrieved and can potentially cause great harm. The recovery of some energy from the process does nothing to mitigate its fundamentally wasteful and polluting nature. For this reason Greenpeace opposes the burning of wastes and we oppose the use of MBT to sort and dry waste for combustion. While fuel preparation may currently look like an economically preferable option for the part of MBT output that will need landfilling, such an approach changes the environmental credentials of the system entirely and plants designed for fuel preparation should not be confused with the system proposed here.

The remaining question then is 'can we afford MBT'?
The detailed breakdown of costs in this report should help decision makers answer that question. Greenpeace concurs with the authors conclusion that the state-of-the-art MBT plant proposed here, which generates all its own electricity and reduces the mass of waste requiring landfill by the same amount as a modern incinerator, is cost competitive and offers an extremely high environmental performance.

Mark Strutt
Senior Toxics Campaigner
Greenpeace

Contents

‘He imagined he was watching the construction of the Great Pyramid at Gaza – only this was twenty-five times bigger, with tanker trucks spraying perfumed water on the approach roads. He found the sight inspiring. All this ingenuity and labor, this delicate effort to fit maximum waste into diminishing space. The towers of the World Trade Center were visible in the distance and he sensed a poetic balance between that idea and this one. Bridges, tunnels, scows, tugs, graving docks, container ships, all the great works of transport, trade and linkage were directed in the end to this culminating structure. And the thing was organic, ever growing and shifting, its shape computer-plotted by the day and the hour. In a few years this would be the highest mountain on the Atlantic Coast between Boston and Miami. Brian felt a sting of enlightenment. He looked at all that soaring garbage and knew for the first time what his job was all about. Not engineering or transportation or source reduction. He dealt in human behavior, people’s habits and impulses, their uncontrollable needs and innocent wishes, maybe their passions, certainly their excesses and indulgences but their kindness too, their generosity, and the question was how to keep this mass metabolism from overwhelming us.’

Don de Lillo, Underworld (describing Fresh Kills landfill in Manhattan)

1.0 Techniques for treatment of residual waste

Those developing waste strategies which aim at high rates of recycling tend to be motivated by environmental goals. This being the case, an important question is 'what should be done with residual waste'? By residual waste, we refer to the waste which remains after the implementation of best practice schemes for source separation.

High diversion and Zero Waste strategies will seek continuous improvement in the performance of source separation systems. Both are likely to emphasise waste minimisation in the strategy and so would like to witness a declining quantity of residual waste to be landfilled over time. This places a premium on treatments which are relatively flexible, which do not demand a constant throughput of material, and which are environmentally friendly.

The way in which this residual waste is treated is no less important than the source separation routes in determining the environmental performance of any strategy. There are two reasons for this:

- Obviously, there are impacts from the treatments themselves and these ought to be minimised; and
- The nature of the treatment, and the degree to which its use implies high unit capital costs, determines the degree to which it forecloses options for dealing with materials in more innovative ways (if not through waste prevention itself).

In this study, funded by the Greenpeace Environmental Trust, Eunomia, along with TBU Austria, has been asked to consider the design of an environmentally sound residual waste treatment which does not make use of thermal treatment technologies. This reflects a view that the treatment of residual waste should seek to minimise the potential for generation of toxic materials.

Eunomia Research & Consulting has carried out a number of major projects on waste policy and economics in recent years. This includes assessments of external costs of treatment technologies and the assessment of the utility of life-cycle based approaches to the assessment of residual waste treatment technologies.

TBU Environmental Engineering is an engineering consultancy based in Austria. The company has 15 years' experience in pre-treatment technologies, and the design and implementation of mechanical biological treatment systems has been core business for the company for around 15 years.

1.1 Residual Waste Treatment Process Fundamentals

1.1.1 Overview

The purpose of most residual waste treatment processes is to reduce the volume of material for final disposal and to stabilise the waste such that the potential for gas formation or pollutant carriage through leachate is minimised.

Residual waste management systems are complex. A wide variety of waste fractions are generated and many types of treatment methods are available. Over the last decade, many new treatment technologies have been developed. Many have failed. The main causes of failure include:

1. Poor understanding of the properties of an inhomogeneous feedstock.
2. Inadequate planning for projected waste flows in the context of waste reduction trends.
3. Lack of comprehensive environmental assessment and understanding of emission trade-offs or regulatory trends.

The four main types of residual waste treatment are:

- Mechanical Biological Treatment (MBT)
- Thermal Treatment (Waste to Energy - WTE)
- Landfilling
- Combination of MBT and WTE

1.1.2 Mechanical-Biological Treatment (MBT)

Mechanical Biological Treatment (MBT) is a term that covers a range of technologies. Most MBT technologies have been derived from mixed waste composting. The aim of the mechanical part of the process is to optimise the material for subsequent processing, by separation (screening) of the material into a number of streams. Even when source separated collection of uncontaminated organic matter is provided, the residual waste contains significant quantities of biologically active material.

1.1.3 Thermal Treatment

Three basic processes can be distinguished: incineration, gasification and pyrolysis. These technologies all produce residues that require disposal, generally in landfills. Increasing attention is being paid to the long-term fate of these residues.

1.1.4 Landfills – Bioreactor and Encapsulation Techniques

Traditional waste disposal practice has relied on landfilling of solid waste. Management practice at modern engineered landfills has improved significantly over the past decade. The two dominant theories emerging in best practice landfill engineering are: encapsulated or 'dry tomb' landfills; and bioreactor landfills.

1.1.5 A case for MBT State-of-the-art Technologies

A number of studies have been carried out in the past 5 years that show that MBT technologies can be an environmentally friendly solution for residual wastes.

In recent work by Eunomia et al, MBT approaches perform favourably compared with other technologies. In particular, in a comparison, the performances of incinerators operating at current UK-standards, and untreated landfills, were worst.[1] Research into combination processes (mechanical-biological treatment plus various options for energy recovery) was carried out on behalf of the BMBF.[2] The study noted:

> *All in all, the investigation which has been presented makes it clear that combination solutions (MBT, landfill, incineration) can achieve ecologically equivalent results in comparison with mono-solutions (incineration), if the environmental protection standards of MBT, landfilling and industrial co-incineration are improved.'*

A study for the Austrian Umweltbundesamt, focusing on comparison of MBT systems with mono-incineration options, made similar statements.[3] Indeed, the study commented that a clear decision as to 'what is best' was not the intention of the study, but the aim was more to see what standards should be set for MBT to ensure performance that was broadly equivalent to incineration solutions. Nolan-ITU conducted a study comparing generic residual waste treatment technologies including a comprehensive environmental assessment.[4] It was based on a review of available information and overseas experience applied to Australian conditions. One of the key findings was that all residual waste treatment technologies are better for the environment than conventional landfilling. The three leading generic technologies were ranked as follows:

1. Aerobic Mechanical Biological Treatment (MBT)
2. MBT with Refuse Derived Fuel Production and Utilisation (MBT/RDF)
3. New Thermal (Waste to Energy) Processes

Each of the above studies was based on techniques less-advanced than those in place today. Since then, technologies have developed, in particular automated sorting technologies have improved (and fallen in cost). Understanding of aerobic and anaerobic biological treatment approaches has also improved over time.

1.2 This Report

The work continues with the following sections:
Section 2: Overview of MBT Processes
Section 3: Process and Air Emissions from MBT Plants
Section 4: Plant Design Issues
Section 5: Cost Assessment
Section 6: Environmental Performance Assessment
Section 7: Conclusions
Appendix: Landfilling of MBT Residues

2.0 Overview of existing MBT processes

Although the term MBT is relatively new in the UK, the approach is actually not so new since it describes a variety of processes, some of which might have fallen under a broad definition of MBT (such as some dirty MRF / ‘composting’ approaches). Indeed, in some countries, the development of MBT has occurred on the back of a realization that mixed waste ‘composting’ is a process which is unlikely to generate valuable end-products because of the levels of contamination which tend to be found in the outputs of the aerobic treatment of mixed residual waste. Alternatively, such plants are ‘adapted’ to treat only source-separated biowastes.

In the 60s and 70s, waste was already being mechanically biologically treated on so-called “composting landfills”. Some of these first plants are still in operation today. Operating experience was gained with concepts and landfills of this sort. The development of MBT is based on experiences which have been gained with biological treatment of waste.

An essential component of the concept is a substance-specific preparation of the waste, in which material flows of differing quality are selected by means of the mechanical stages of the process. In addition to the extraction and treatment of a biological fraction, and the separation of the iron and wood waste, a high calorific fraction is typically obtained which is often incinerated. However the focus of this work is on plants which do not require any thermal treatment process.

Where MBT technology is used as a pretreatment before landfilling, the aim is a safer means of disposal in the long-term. MBT technology should satisfy high standards as regards pollution and occupational protection. This means that all procedures which are relevant as regards emissions must be completely enclosed. It has been known for some time that biological pretreatment of waste considerably improves the behavior of landfill sites in terms of key pollutants, and in so doing reduces pressures on our environment.

MBT plants differ in:

- the type of waste to be treated (only domestic waste, all residual waste, with/without sewage sludge, preparation of waste for reclamation etc.),
- the aim of the preparation and the location of the resulting products (landfill, thermal treatment, energy recovery),
- the duration of the operating license (restricted time-wise as an interim solution, or unlimited, i.e. within the framework of regular depreciation times).

The aim of this chapter is to provide an overview of the techniques employed. There are a range of technology suppliers involved in the development and supply of MBT processes.

2.1 Waste Delivery

Because of the characteristics of residual waste, it is desirable to ensure that the direct handling of the material by operatives is kept to a minimum. Delivery typically occurs in low bunkers. It can be the case that delivery is into buildings maintained at negative pressure (and in some Italian situations, spray droplets are used to minimize problems with flies as the tipping occurs). Some hazardous materials and large metal fractions may be removed by a grab though the extent of this depends upon subsequent preparation.

In most MBT plants, loading of primary shredders is carried out using a grab, though some facilities use inclined conveyors or crane. Quality of removal of hazardous / difficult materials is dependent upon the quality of the operation of the grab, so in some cases responsibility for interruptions at the shredder is assigned to the grab operator (as an incentive to carry out removal of such materials effectively). Of course, it is not always the case that shredders are used immediately following the use of a grab.

2.2 Preparation

Manual separation of materials is to be avoided. Only in very few plants is there any such handling, usually targeted removal of hazardous materials prior to second shredding of the oversieve (sieve overflow) fraction.

As regards household waste, most material is sent for sieving without prior shredding. Primary sieving can reduce the degree to which damaging components affect the shredder, but this makes a second sieving stage necessary.

2.3 Types of Preparation Unit

Since the range of tasks across (and within) MBT plants is being diversified, a range of different units are used to suit the end-use requirements (see Table 1). The choice of units depends upon the nature of the division of materials sought, and the ultimate destination of the separated fractions.

Depending upon whether the MBT system is based upon a ‘splitting approach’ or a ‘stabilisation approach’, initial sieving generally happens before the biological treatment (splitting process) or after the stabilization process (dry stabilization). Many MBT plants use trommel sieves, and depending on the nature of the separation of materials required for each application, the sieving is either in one or two stages. In order to guarantee sufficient separation, care has to be taken in the design of the trommel to ensure sufficient lengths and gauges of sieve and the correct rotational speed. For the avoidance of belt wraps of the rotary screens (mummification), tube-jointed sleeves on the sieve areas appear to be useful, and for easier purification, the achievement of appropriate profiles along the sieve cylinders has also proved effective.

For the targeted separation of the light fractions, air classifiers, pneumatic tables, vibrating tables, ballistic separators etc. are in use in some plants in addition to a rotary screen.

Ferrous metal separation is usually carried out, normally at different stages of the process, and typically with varying quality upon extraction. Because of this, the different streams are sometimes kept separate to ensure the material can be easily marketed. Some, though not all, plants are equipped with mechanisms for non-ferrous metal extraction. Sometimes this occurs in subsequent processing of output material as a fuel.

2.4 Biological Treatment

There are two forms of biological treatment available for dealing with biowaste fractions. They are fermentation (anaerobic process) and aerobic treatment.

2.4.1 Aerobic Treatment ('Composting')

In composting, four lines of development or action have developed. Table 2 shows an overview. The lines of action essentially differ in:

- aim of the process (is the aim to dry the material, or to stabilise it through organic decomposition (in which case, the aim will be to prevent the material from drying out)?)
- the degree of the plant encapsulation (encapsulated, within a building, partially within a building, covered with membrane, open)
- emission standards (nature and extent of waste air capture and treatment through filters)

Four types were outlined by Zeschmar-Lahl et al. They are shown in Table 2 below. In essence, owing to the similarity of the technical processes, the whole range of composting systems which are available on the market are utilized in MBT plants (trommels, tunnel, box, container, clamps in rows, continually turned aerated clamps, aerated clamps etc.)

It is important to note that it would usually be the case that, where residues from the biological treatment process were to be landfilled / used for landscaping, it would be expected that any anaerobic phase would be followed by an aerobic treatment (to stabilise the output material).

The system ultimately used is typically decided on the basis of:

- planning permission requirements.
- site conditions;
- cost targets (investment and operating costs).

The systems which are offered differ as regards operating and investment costs. The differences in the specific investment costs have a strong effect in terms of either determining or restricting the possible retention times in the composting system. The higher the specific investment, the shorter the economically justifiable resting time in the system

Table 1: Overview of units in MBT plants.

Function	Unit
Primary shredding	Crushers, worm mills, rotor shears, percussion grinders
Secondary shredding	Worm mills, hammer mills
Sieving, classification	Rotary screens, 1 and 2 staged, perforation 40-300 mm
Classification	Air classifier, pneumatic tables
Fe-separation	Magnetic separators
Non ferrous-separation	Eddy current separators
Compaction of coarse fractions	Compression containers, bales (rolled bales, or bales bound with wire)
Loading of fine fractions	Open containers with HGV transport, conveyor belt transport
Mobile equipment	Wheel loaders, grab excavators, fork-lift trucks, container trucks, dumpers

Table 2: Lines of Development in Aerobic Treatment of Residual Waste

Type A:	Encapsulated, static primary composting for dry stabilization with retention time of 1-2 weeks
Type B:	One-stage, encapsulated, quasi-accelerated composting with active aeration and waste air capture, regular turning intervals (as a rule weekly, in some case every 5 days)
Type C:	Two-stage composting with a short encapsulated primary composting (static or quasi-dynamic) with composting periods of between 1 and 5 weeks and a downstream secondary composting of varying duration (7 – 26 weeks) and technique (open, covered; un-aerated, aerated; with or without turning)
Type D:	Open, static composting without active aeration and as a rule without turning, with composting times of 12 – 18 months)

Source: Zeschmar-Lahl et al. (2000) Mechanisch-Biologische Abfallbehandlung in Europa,
Berlin: Blackwell Wissenschafts-Verlag GmbH.

will be. This in turn has implications for the degree of stability which can be attained in a given treatment for a specified cost since the longer the retention time, the greater the level of stability attained (though the rate at which the material is stabilised varies across processes).

Retention Time and Level of Stability

In MBT systems, the level of stability or maturation of the material which has been subjected to the biological treatment process is measured through various criteria. Discussions continue about which measure is most appropriate in a given situation. However, the intention is to specify a minimum level so as to ensure that the process contributes to the reduction of the potential for harm caused by subsequent landfilling of residues, or their use in restricted applications (such as for landscaping).

The duration of the composting until the alternative maturation criteria are reached (RS4, GF21, TOC) is dependent on the operating management and the system selected. As a rule the following applies:

- the more dynamic the process, the shorter the composting time; and
- the shorter the time in the (quasi) dynamic system, the longer the secondary composting required in the static system.

The minimum composting times which are finally required, in order to be able to definitely meet specified ‘disposal criteria’ with sufficient operational safety, are still the subject of current research projects. Comparison of the measurements from various plants and laboratories is still difficult since there is no agreement on a standardized methodology for analysis. Furthermore, because of these debates, it is uncertain as to what the appropriate criteria should be for material to be landfilled. This is discussed in more detail in Section 4.

Type of Aeration and Composting Control

The aim of the aeration is:

- the safeguarding of sufficient oxygen content in the clamp,
- the avoidance of anaerobic areas,
- the dissipation of the CO2 which has built up,
- the dissipation of the heat which has been released by the reaction,
- plants which prepare material for incineration make use of drying through the heat generated by biological activity.

These aims must be brought into line with the competing aim of the minimization of evaporation loss. When choosing an aeration system, and in particular the aeration base, care is to be taken that suction and pressure aeration are possible. The aeration is carried out in accordance with the activity of the material in the course of the composting. For this, segmentation of the composting areas into separately adjustable aeration fields is required. The amount of air per aeration field is adjusted by means of frequency-regulated ventilators, depending on the temperature and the oxygen content. Alternatively, phase operations are also in use.

With both encapsulated and housed systems which run a suction operation, conclusions are drawn as to the conditions in the clamp by means of measurements of the parameters of the waste air from the clamp. The correlation between the temperature in the waste air and in the clamp is, however, subject to fluctuations. It is influenced by the situation in the clamp (temperature level, water content, evaporation rate), the location of the point of measurement, and the location of the aeration pipes (warming by the sun, or cooled by the effects of frost).

On the basis of the various influencing factors, certain limits are set for the automated running of the process. The continual measurement of temperature and oxygen in the waste air has proved to be a useful means of controlling the process, beyond this, the actual control of the process lies within the area of responsibility of the operation manager.

Prefabricated Components for the Composting Process

The prefabricated components of the housed and encapsulated systems are carried out in concrete or in steel. Corresponding requirements for protection against corrosion are to be taken into account with both materials. The concrete components must, amongst others things, satisfy requirements as regards ammonium and sulphate corrosion. Some plants have added additional composting sheds made of synthetic materials. (Oberpullendorf (A), Mailand (I)).

Insulation of Composting Sheds

In order to ensure the required air-changeover rates in sheds, as a rule external air is drawn into the sheds over venetian blind flaps. Because of this, a considerable cooling of the sheds can occur in the winter, which impedes the operating ability of the units (e.g. interruption in the energy chain).

On the other hand, in the summer a considerable warming of the atmosphere in the sheds can occur due to sunshine.

For the improvement of the climate in the sheds, insulation of the roof and walls of the sheds has proved worthwhile. Increased investment costs are offset by clear advantages in the efficiency of the operation.

2.4.2 Anaerobic Digestion / Fermentation

In the area of fermentation there are several system suppliers on the market. Until now there have been few experiences of large-scale operations with residual waste. The various processes include:

- dry and wet processes
- mesophilic and thermophilic processes
- one and two stage processes
- percolation, hydrolysis and fermentation of the aqueous phase
- interval processes (aerobic – anaerobic – aerobic)

In Germany, fermentation of residual waste has only taken place in the experimental plants at Münster as well as Bassum RWT (Residual Waste Treatment Plant). At Bassum, the fermentation is carried out according to the so-called

Dranco process (dry anaerobic composting: a one-stage, thermophilic dry fermentation). After the positive experiences in the experimental operation in Münster, mesophilic wet fermentation should also now be possible commercially. A fermentation stage is an essential component of the plant concept in the planned Pohlsche Heide MBT in the administrative district of Minden-Lübbecke. In the Netherlands a fermentation process is used at the VAGRON MBT plant.

The facility at Amiens in France is a digester equipped to deal with residual waste, and though not generally considered as an MBT process, this is effectively what the plant is designed to achieve. Wannholt suggests that of the 72,000 tonnes per annum sent to the plant, 2,500 tonnes of metals and 6,500 tonnes of glass are produced. 11,000 tonnes is currently landfilled.[5] This leaves 52,000 tonnes to enter the digestion process. This results in 37,200 tonnes of output material from the process. In France, because of the somewhat lax standards applied to the utilization of compost, this material is used in arable cropping and viniculture. An additional 9,400 tonnes of residue are produced.

In comparison with pure composting processes, combined anaerobic – aerobic processes have tended to imply higher investment and operating costs. On the basis of the strong competition between the process suppliers and the improvements made in process control at fermentation facilities, the cost differences appear to be diminishing. Futhermore, the extent to which the higher specific costs of fermentation can be compensated by means of a corresponding shortening of the composting time in the secondary composting is at present being investigated (e.g. Bassum RWT). Lastly, in some countries, the potential to derive additional revenue from the sales of energy derived from digestion plants tends to reduce the cost differential between combined anaerobic / aerobic, and aerobic systems.

Further advantages of fermentation can arise in the area of the purification of waste air. Since with fermentation – in particular in thermophilic fermentation – volatile components are also carried out via the biogas path, there can possibly be savings potentials with waste air treatment in secondary composting. In practice, analytical proof of this is yet to be found.

2.4.3 Treatment of Air Emissions

With encapsulated and covered plants, the treatment of waste air used to be carried out only by means of humidifiers and biofilters. Usually, the biofilter takes the form either of a filter in an open or roofed type of construction, or as an encapsulated room filter. Table 3 shows design examples.

The experiences with biofilter technology in MBT plants which have been gathered until now can be summarized as follows:[6]

- the combination of washer and biofilter for the treatment of waste air with the aims of separating off dust and minimizing odour has proved extremely worthwhile. According to the information available the study notes that the legal requirements of the German TA Luft regulation can be fulfilled with biofilter technology. However, the biofilter does not meet the expectations for an effective reduction of all critical organic matter of Class I and II according to Article No. 3.1.7 of the German TA Luft.
- Problematically, ammonia and organic nitrogen compounds crystallize out, and they can have a hindering effect on the breakdown of materials. In such cases, the odour concentrations in the pure gas can also exceed the limit. Methane is not converted in the biofilters of the investigated MBT plants.

In many existing MBT plants, there is little or no waste air purification. In more recent plant, the biofilter is the norm, which in most of the MBT plants is supported by an upstream humidifier. The use of the term, “washer,” or even “biowasher,” which is used in many publications and descriptions of plants, is unclear, because in filter technology clearly more extravagant controlled systems are to be understood by this term.

Table 3: Construction and process variants of biological waste air purification at mechanical-biological treatment plants (examples).

Plant	Lüneberg MBP	Friesland/Wittmund MBP	Bassum RWT
Dust separation/ humidification	Spray washer	Spray washer	Two parallel spray washers
Biofilter system	Simple open area filter	Covered area filter with sprinkling	Closed room filter with sprinkling
Filter material	Coarsely broken root timber	Bark with ceramic packing	Broken root timber
Filter volume load	67 $m^3/(m^3h)$	<280 $m^3/(m^3h)$	<60 $m^3/(m^3h)$
Filter area load	100 $m^3/(m^2h)$	<280 $m^3/(m^2h)$	<190 $m^3/(m^2h)$
Direction of flow	⬇	⬆	⬆
Dissipation of pure gas	Open, near-surface	Covered, near-surface	Contained, via flue

Research into plants which are operating in Germany and Austria shows that biofilters, when they are present, show a remarkable difference in construction or sizing. Biofilters, in a similar way to physical or chemical filters, need to be constructed with regard to the appropriate dimensions relative to the waste air which they are to purify. The key issue is to guarantee a certain retention time of the waste air in the filter, in order to actually achieve a comprehensive substance exchange between the filter medium and the waste air.

The contact times in the biofilter are, in turn, achieved mainly by the relationship between the filter size (in m^3), pore volumes and the waste air which is to be purified (in m^3/ unit of time), as well as (to some extent) the presence of pressure differentials within the biofilter. Because of the variation in investment into filter dimensioning in MBT plants, contact times are sometimes under 30 s, but values over 100 s are also observed.

In addition to sufficient dimensioning of the biofilter, the construction of the filter is of importance for the purification effect. This is because it has been shown that the influence of weather in open types of construction (which currently, if there are filters present, represent the control variant) is very high. For this reason, in the cold seasons, but also in very hot and too damp weather conditions, interruptions in the performance of the filter may occur.

Recent developments include the use of thermal filters. These operate so as to effectively crack the organic components of exhaust gases. A recent Austrian study suggests that the emissions reductions achieved through this process include (quoted relative to standard biofilters, and biofilters alongside ammonia scrubbing, respectively):

- Reductions in NMVOCs (90% reduction and 80% reduction respectively):[7]
- Reduction in CFCs as follows (98% reduction in both cases);
- SOx (50% reduction in both cases)
- Ammonia (75% reduction and 0% reduction)
- N_2O (100% reduction in both cases)

This occurs at the expense of an increase in CO_2 emissions and an increase in NOx emissions associated with energy use in running the plant.

In some countries, notably Germany, there have been calls for the establishment of more stringent limits in a new regulation for MBT plant emissions. This is frequently misinterpreted as a politically motivated, skillfully packaged attack on MBT, although there are certainly interests which would like to see such regulations effectively pricing MBT plants out of the existing market.

Zeschmarr-Lahl et al report that the air quality conservation measures which are being put into action today are, from the investment and operating point of view relatively low to insignificant at German MBT plants. Even in the plants with humidifiers, closed biofilters etc., the operating costs (including depreciation) are below 3% of the total operating costs. Frequently the operating costs as regards waste air are below 1% or are not even calculable (because they are nonexistent). Such figures clearly indicate a very low proportion of expenditure in environmental protection as compared with other branches of industry and indeed, as compared with other (non-landfill) waste treatments.

Table 4 indicates the costs for a waste air volume of 60,000 m^3/h with otherwise normal capital and operating fund costs.

The figures from Table 4 are not calculated for MBT per se but for use of this type of technique. It is not expected, however, that MBT will make fundamentally new demands on such types of purification techniques. However, the ranges quoted might narrow with better information. Even the ranges shown, however, illustrate that there are interesting alternatives to the biofilters in which even the upper end of the quoted ranges imply not unreasonable levels of cost (less than 10% of the MBT treatment costs), particularly when they are successful in reducing the specific amount of waste air to be treated. For this reason, some operators have begun to replace biofilters with these more effective (though more costly) techniques.

2.4.4 Personnel Requirements

The personnel requirements of MBT plants are dependent on various factors, such as, for example, the size of the plant, the number of operating units and operating times (1 or 2 shift operation). For a mechanized MBT plant with fermentation, in a 1-shift operation the personnel requirements listed in Table 5 arise.

For the assignment of personnel, a system of giving clear assignments and responsibilities for defined functions has proved worthwhile.

With increasing demands on the treatment of waste air and process control, it becomes more necessary for the plant to hire sufficient staff of its own. For increased control over its own operations, MBT plants may have to carry out some basic laboratory analysis in house, analogous to some sewage treatment plants. Much depends upon the nature of the regulatory system applied and the destination of end products.

Table 4: Annual total costs from waste air purification plants, state of business 1993 [47].

Process	Annual total costs
Catalytic afterburning	0.11-0.99 million DM/a
Thermal afterburning	0.15-1.26 million DM/a
Regenerative afterburning	0.35-0.96 million DM/a
Stage biofilter	0.12-0.50 million DM/a
Area biofilter	0.09-0.30 million DM/a

Table 5: Personnel requirements of a mechanized MBT with fermentation.

Number	Function	Responsibility
1	Operating manager	Whole plant
1	Deputy operating manager	Fermentation
1-2	Electrician, electronics engineer	EMSR[a]
1	Fitter	Maintenance, repair
3-4	Mobile equipment operator	Wheel loader, grab excavator, container vehicles
2-3	Cleaning staff	Daily cleaning and cleaning of the grounds, externally if necessary
Proportional	Laboratory staff	Process control, material analysis
Proportional	Replacement	Estimation: ~ 25-30%
Proportional	Administration	
Proportional	Weighbridge, workshop	
Proportional	Data administration, marketing	

a Electrical, measurement, control and regulation technology

3.0 Process air emissions from MBT plants

As discussed above, the air emissions from MBT facilities have traditionally been subject to relatively weak controls, but this is now changing with combined biofilter and scrubbing systems, and more recently, thermal systems, being used to clean exhaust gases.

This Section reports on some of the emissions reported thus far in various studies.

3.1 Carbon Dioxide and Methane

The carbon dioxide emissions from aerobic MBT plants are significant, but the CO_2 emissions are all from biogenic materials. The quantities released in the pre-treatment process depend upon the nature of the process, its duration and the composition of the material itself. In general, the longer the process, the more of the carbon will be mineralized, principally as carbon dioxide as long as conditions are optimized. The emissions from components of this material, once landfilled, are discussed later in this document.

As regards MBT processes which incorporate an anaerobic phase, clearly where the aim is to generate energy, the aim is to make use of the methane generated from the process, in doing which, methane is converted to carbon dioxide.

Some studies have sought to relate the gaseous emissions from biological treatment back to the waste composition, though generally only for the methane and carbon dioxide components and rarely in the case of MBT plants. Usually, such studies have looked at the emissions from plants treating source-separated materials. The work underpinning the Swedish ORWARE model relates the emissions back to the class of organic materials being degraded (lignin, starch etc.). In the United States, work on the modelling of compost plants has concentrated on the emissions of carbon dioxide based upon the garden waste, paper and kitchen waste components.

One attempt to model emissions of carbon dioxide from aerobic MBT plants was that of AEA Technology.[8] The results of this attempt are shown in Table 6. The three cases considered were:

- **Case 1. Highly Stabilised MBT Compost,** in which about 5-10% of degradable organic carbon has been estimated to remain in highly stabilised MBT compost. The study adopted the results of the laboratory trials which suggested that MBT eliminates about 90% of the CH_4 forming potential of MSW. The rate of formation of the residual CH_4 was assumed to be such that oxidation by micro-organisms in the landfill soil was able to completely convert the CH_4 to CO_2. No CH_4 emission thus occur so there are no greenhouse gas emissions associated with landfilling of MBT residues. Remaining short-cycle carbon is assumed to be sequestered.
- **Case 2. Less Stabilised MBT Compost.** A shorter duration MBT process was assumed, resulting in some remaining CH_4 emission. This was simulated by using the same CH_4 forming potential as in Case 1, but assuming that only 25% is oxidised to CO_2 by a combination of microbial oxidation and gas collection and oxidation in bio-filters, the remaining 75% escaping to the atmosphere. Flaring would have the same overall effect but MBT compost was considered unlikely to produce landfill gas with a high enough CH_4 content (ie less than about 17% by volume) to allow combustion without a pilot fuel.
- **Case 3. MBT compost used as a surface dressing for landfill site remediation or as a restoration layer, acting as biofilter, to reduce CH_4 emissions.** In these applications, decomposition of the compost continues aerobically and resistant organic matter that would have been sequestered under anaerobic conditions decomposes. In the absence of better data, the study's authors assumed that decomposition would occur at the same rate as high-quality compost applied in an agricultural setting. This assumption implied that 8% of the carbon in the non-dissimilated degradable carbon applied in the compost would remain in the soil outside the 100 year time horizon for sequestration.

Further information on the rationale for this approach can be found in the AEA study. However, the important points to note are:

- Since the study uses as its baseline a view that 'biogenic emissions of carbon dioxide' constitute a 'zero baseline', the carbon remaining in landfills over a period of 100 years (a time-horizon chosen in the study to differentiate 'short' and 'long-term' emissions) represents sequestered carbon, so a negative contribution to emissions.
- Because of:
  (a) this sequestration effect; and
  (b) the fact that combusting material effectively releases all carbon with immediate effect. Even accounting for emissions avoided when electricity is produced at a subsequent thermal treatment plant, the greenhouse gas emissions from MBT plants, according to the study, are most favourable when the residues are landfilled. They become less favourable when residues are combusted, yet they are still more favourable than the situation in which waste is incinerated directly.

Another attempt was made in the study by AWS et al.[9] This study suggested that greenhouse gas emissions from MBT-based systems in the pre-landfilling phase would be less than for incinerator based systems, consistent with the above. However, the modeling carried out in the study went on to suggest that once landfilled, the MBT residues would continue to generate significant proportions of methane (approximately half those which were projected for untreated landfill systems over a hundred year period). This is somewhat strange, and appears to run counter to all the empirical evidence, as well as to the other modeling studies mentioned.

Table 6: Emission factors for wastes processed through MBT (kg CO_2 eq/t material or MSW treated).

Waste management option	Waste component	Short cycle CO2	Fossil CO2				Short cycle C sequestered	Sum of fossil C and sequestered C	CH4 emission	N2O emission	Total GHG flux
		(GWP=0)	Process	Energy use	Avoided energy and materials	Transport / mobilisation	(GWP=-1)		GWP=21	GWP=310	
MBT treatment with landfill of rejects and recycling of metals											
	Paper	396	0	22	-6	4	-786	-765	206.6	0	**-559**
	Putrescible	441	0	22	0	4	-251	-224	0.0	0	**-224**
	Plastic	0	0	22	0	4	0	27	0.0	0	**27**
	Glass	0	0	22	0	4	0	27	0.0	0	**27**
	Metal	0	0	22	-3038	10	0	-3006	0.0	0	**-3006**
	Textiles	147	0	22	-16	4	-503	-492	526.1	0	**34**
	Other	226	0	22	-6	4	-369	-349	206	0	**-143**
Case 1	MSW	286	0	22	-162	5	-364	-500	97	0	**-403**
Case 2	MSW	276	0	22	-162	5	-364	-500	171	0	**-329**
Case 3	MSW	551	0	22	-162	5	-99	-234	97	0	**-137**
Mean of Cases 1 & 2	**MSW**	**281**	**0**	**22**	**-162**	**5**	**-364**	**-500**	**134**	**0**	**-366**
MBT treatment with landfill of rejects and recycling of metals											
	Paper	580	0	22	-51	4	-629	-653	0	3	**-650**
	Putrescible	441	0	22	0	4	-251	-224	0	0	**-224**
	Plastic	0	2237	22	-703	4	0	1560	0	15	**1575**
	Glass	0	0	22	0	4	0	27	0	0	**27**
	Metal	0	0	22	-3038	10	0	-3006	0	0	**-3006**
	Textiles	718	718	22	-326	4	0	420	0	15	**434**
	Other	285	63	22	-26	4	-213	-149	0	5	**-144**
Case 1	MSW	358	205	22	-241	5	-289	-298	0	3	**-295**
Case 2	MSW	349	205	22	-241	5	-289	-298	74	3	**-221**
Case 3	MSW	604	205	22	-241	5	-23	-33	0	3	**-30**
Mean of Cases 1 & 2	**MSW**	**353**	**205**	**22**	**-241**	**5**	**-289**	**-298**	**37**	**3**	**-256**

Source: Smith et al (2001) Waste Management Options and Climate Change, Final Report to DG Environment, European Commission.

Note that the data are expressed per tonne of material in question. For MSW, the emission factors are estimated from the sum of the constituent waste components multiplied by their relative proportion in the waste stream.

3.2 Ammonia NH_3

MBT plants show, according to technique, specific amounts of waste air etc., a high ammonia contamination (NH_3) of the crude gas from 10 to 200mg/m^3. High crude gas values can lead to the damaging of biofilters (to the point where they become ineffective).

An additional problem is represented by the partial oxidation of NH_3 to N_2O, which is linked to the damaging of filters. This is also a potent greenhouse gas, so the minimization of this secondary emission is also of relevance. Another secondary emission is that of nitrosamines, the formation of which has been observed in biofilters.

Controlled acidic washers of a simple construction can certainly maintain values below 10 mg/m^3 of waste air. With input values below 10 mg/m^3 the danger of the filter being damaged is minimized and the remaining ammonia is more likely to be oxidized by the intact biofilters. In this way it is ensured that the MBT does not exceed an ecologically justifiable emissions level (for NH_3).

3.3 Organic Materials (TOC)

A summary of the pollutant *concentrations* which occur in the *crude gas* from mechanical biological waste treatment plants was given in a publication by Fricke et al. The data was representative of the situation as at January 1997 and was based on test results from five more detailed investigations. For all the investigated elements/compounds, the highest discharges were established within the first 14 days (the maximum values of the individual substances are in brackets):

- *Aldehyde:* maximum value > *100 mg/m^3* (Acetone: 140 mg/m^3; 2-butanone: 55 mg/m^3)
- *Terpenes:* maximum values > *50 mg/m^3* (Limonene: 56 mg/m^3; π-Pinene: 14 mg/m^3; ß-Pinene: 6.4 mg/m^3)
- *Aromatics:* maximum values > *30 mg/m^3* (m-, p-xylene: 38 mg/m^3; ethyl benzene: 13 mg/m^3; toluene: 11.5 mg/m^3; o-xylene: 10 mg/m^3; styrene: 5.9 mg/m^3; benzene: 0.3 mg/m^3
- *Acetates:* maximum values > *30 mg/m^3* (ethyl acetate: 32 mg/m^3)
- *Alkanes:* maximum values: > 1*0 mg/m^3* (nonane: 12 mg/m^3; decane: 43 mg/m^3)
- *CFCs:* maximum values: > *1 mg/m^3* (R11: 3.1 mg/m^3; R12: 1.7 mg/m^3)
- *Alphatic chlorinated hydrocarbons:* maximum values: > *1 mg/m^3* (tetrachlorethene: 2.7 mg/m^3; trichlorethene: 1.38 mg/m^3), evidence of di- and trichloromethane, 1,1,1-trichloroethane, 1,1-dichlorethene.

The above figures represent maximum values in the *crude gas.* There still appear to be gaps in knowledge concerning the emissions of Total Organic Carbon and the emissions values for individual materials.

A comparison between the maximum crude gas loads calculated from the tests carried out in the aforementioned study and the measurements at commercial MBT plants revealed that the loads actually emitted through the crude gas turn out lower than was established on the basis of model tests as carred out by Doedens et al.[11]

Data from the Austrian Federal Environment Office for Kufstein MBT and Allerheiligen MBT also suggest that the crude gas from MBT contains a multitude of individual organic compounds, sometimes in very high concentrations/loads, although with varying concentration profiles. The TOC (total organic carbon) presents itself as a useful monitoring parameter, which records the entirety of the organic components. The measured value of the TOC can be expressed by means of a conversion factor based on the gaseous (= volatile) organic substances emitted (hereafter referred to as VOC, volatile organic compounds). The value suggested by Zeschmar-Lahl et al for MBT is 1.25.[12]

Generally, one finds that in life-cycle analyses for the POCP category where this is applied to combination concepts, the MBT stage of the total treatment can be by far the most dominant component. An NMVOC[13] (or VOC) limit can clearly reduce this negative effect, implying the need for effective process management (for example, to prevent anaerobic conditions) and treatment of exhaust gases.

The NMVOC loading of the MBT waste air (crude gas) lies in the area of approximately 100 mg/m^3 to 500 mg/m^3, a mid-range being of the order 50-200 mg/m^3.

3.4 Methane (CH_4)

It is not yet certain whether the non methane content (NMVOC) will need to be recorded within a VOC limit. In the event of such regulations, compliance could be achieved relatively easily using optimised washer/biofilter systems. A calculation of the methane (which from the human-toxicological point of view is irrelevant as a trace element), would also lie within the logic of TA Luft (effect orientation).

Methane is a potent greenhouse gas. Life cycle assessment calculations show that the methane concentrations of from 1,000 to >50,000 mg/m^3, which are possible with open-air composting, or housed-in systems which are insufficiently supplied with oxygen (or with waterlogging in the biofilters), would have a formative influence on the results and exclude the equivalence of the measures.

In Appendix 1, we investigate in further detail the emissions following landfilling of material. Clearly, in the process stage, the aim is to minimize the potential for anaerobic conditions to develop, with the obvious exception of those plant designs where anaerobic treatment forms a part of the biological treatment process. In this case, the aim is to ensure full capture and as complete a combustion of the gasses as possible to ensure a) maximum recovery of energy; and b) a reduction in the potential for environmental damage through conversion of methane to carbon dioxide.

3.5 CFCs

The few measurements available show that CFC loads of 1-10 g/Mg input can be released from an MBT plant, dependent on the type of waste being processed (Table 7). Indicator substances here are, as expected, the frequently used old CFCs, R11 and R12.

Our life cycle assessment calculations have indicated that emissions on this scale have a noticeable influence on the total result for the greenhouse effect and potential ozone-depletion effect categories. Within the framework of equivalence considerations and sustainability aims, a reduction of these emissions should therefore be called for. On the part of the biological waste air purification processes, an effective reduction of emissions is not adopted.

Care therefore needs to be taken with MBT to ensure that waste containing CFCs is as far as possible excluded or filtered out early, but at all events that it does not enter the biological stages.

It is sometimes pointed out that the old CFCs referred to have in the meantime been banned. With that is linked the expectation that the topic of CFCs is no longer relevant for the waste industry.

Investigations relating to this show, however, that the CFCs used in building in the 1970s and 1980s are still “stockpiled” in considerable amounts (buildings, products, trade). The German Federal Office for the Environment has estimated the R11 reservoir in rigid foam up to 1986 at 70,000 tonnes (lower limit). Of this 50,000 tonnes are stored up in the building industry alone (insulation). These amounts will be introduced into the waste stream within the next 10 to 50 years.[14]

For the future, an increase of the partially halogenated CFCs/FHCs in the waste is to be reckoned on, since these are replacing the fully halogenated replacements in many areas of use. This may bring about the use of chemically related substitutes, which although they show a lower potential for the destruction of the ozone layer, also show a high greenhouse potential, particularly the partially halogenated CFCs and partially fluorinated FHCs. For this reason, the topic of CFCs/FHCs for MBT can also, for the future, not be seen as defused. The exhaust air purification of an MBT plant ought, therefore, to ensure a high separation efficiency for this type of pollutant.

Table 7: CFC emission loads from MBT plants (crude gas) – current measurements of the Austrian Federal Office of the Environment.

Parameter (g/Mg)	**Allerheiligen**[a] (Tunnel waste air)	**Siggerwiesen**[b] (Waste air – composting trommel)	**Siggerwiesen**[c] (Waste air – composting trommel)	**Siggerwiesen**[d] (Shed waste air)	**Kufstein**[e] (waste air composting module)
Sampling _	**spring**	**winter**	**summer**	**winter**	**Summer**
CFC					
R11	n.n	8.5	4.1	0.4	2.2-2.3
R12	n.n	11.3	0.2	0.4	1.3-1.4
R21	n.n	n.n	-	n.n	n.a
R113	n.n	n.n	<0.05	n.n	1.9
R114	n.n	n.n	0.2	0.4	1.2-1.4

a 7,000 m^3/tonne; b 710 m^3/tonne; c 480 m^3/tonne; d 1,100 m^3/tonne; e 6,000 m^3/tonne

4.0 Plant design issues

4.1 The Objective

The brief asked for the development of a 'best practical option' which should include mechanical separation of dry recyclables, followed by biological treatment of the biodegradable fraction. Thermal treatment of any fraction should be avoided.

4.2 Key Criteria

All mixed municipal waste must be expected to have some environmental impact, which is why the objective of an environmentally sound waste strategy should be a continuously diminishing residual waste stream, with the ultimate objective being zero waste (or as close to zero as possible). In this framework a residual waste treatment would have the following characteristics:

1. Wherever practical material not separated at source should be recovered for recycling and markets for recyclate should be actively sought and developed;
2. Subject to avoiding the potential for build up of potentially toxic elements in soils, organic residues should be used to increase / replenish soil organic matter levels;
3. Emissions to the atmosphere should be minimal and have minimal impact on human health and the environment;
4. Emissions to soil should have minimal impact on human health and the environment; and
5. Emissions to water should have minimal impact on human health and the environment;
6. The assessment of the potential for harm to the environment and health should recognize the uncertainties surrounding such assessments, not least in respect of chemicals suspected of presenting significant risk on exposure to human and other life forms, or possessing intrinsically hazardous properties such as environmental persistence or potential to bioaccumulate;
7. The plant's operation should minimize the exposure of operatives to handling materials / emissions from the plant's treatment;
8. The plant should seek to minimise use of energy;
9. Any residues should be minimised and their toxicity should be minimised. Their final disposal should have regard to the potential for pollution following disposal;
10. The plant should be flexible with respect to changing waste composition.

These characteristics establish broad parameters for the assessment of plant designs.

4.3 Elements of MBT

4.3.1 Overview

Most MBT technologies have been derived from mixed waste composting. The concept of mixed waste composting (i.e. composting of unseparated municipal waste) is largely discredited since the process fails to generate valuable end-products because of the levels of contamination which tend to be found in the end-product. The aim of the mechanical part of the process is to attain optimisation of the material for the biological processes by separation (screening) and shredding to extract useful materials in the process.

Even when source separated collection of uncontaminated organic matter is provided, the residual waste contains significant quantities of biologically active material. The existence of a separate collection for dry recyclables as well as for organic materials tends to lead to biowaste concentration in residual waste being greater than would be the case if no separation of dry recyclables existed. Even the best performing source separation schemes have 10-20% biowaste in the residual. Biological treatment usually results in:

1. Reduction in the weight of waste requiring disposal by approximately 30%
2. Reduced landfill gas generation
3. Reduced leachate generation
4. Higher density of landfilled material (by 30-40%)

Biological waste stabilisation also provides an opportunity to co-treat with sewage sludge, a material which can cause serious problems in landfill management, especially in large quantities. This is of particular relevance in areas where the re-use of sludges is limited due to hygienic and contamination concerns or legislative and market constraints. This occurs mostly in urban areas with high population density and/or where industries are connected to the sewerage system.

The following sections describe typical elements of MBT systems:

Mechanical Extraction of Remaining Recoverable Materials

With a residual waste stabilisation plant as a front-end facility for a landfill, opportunities exist to extract recoverable materials which have not been separated at source. This is done by means of a magnetic separator for ferrous metals, or by diverting recyclable (or inert) items with other machinery.

Biological 'Inerting' through Decomposition of Easily Degradable Substances

MBT aims to reduce the organic carbon fraction to a minimum by means of biological decomposition. This is usually realised by the following steps:

1. mechanical separation and preparation of the residual waste;
2. intensive decomposition of the mechanically pre-treated residual refuse in a closed system (with the objective being to decompose the organic contents); and
3. open surface curing of pre-composted material with the objective of further stabilisation of remaining putrescible contents.

Easily degradable substances such as sugars, proteins, and starch are the components first attacked by micro-organisms. To have these components degraded in a controlled process means that the ‘stability’ of the residual waste can be significantly increased within a very short time frame (compared to the degradation of these substances in a landfill). ‘Inerting’ means that these components are completely broken down into, primarily, carbon dioxide and water.

Anaerobic Digestion

Anaerobic digestion is a natural process in which microbes convert complex organic matter in the absence of oxygen to simple, stable end products. In the process, methane and carbon dioxide are produced.

Traditionally, in-vessel anaerobic digestion is primarily used to process liquid wastes and relatively dilute slurries of organic materials. There are only a few MSW treatment facilities of this type worldwide.

The first proof of concept MSW anaerobic digestion facility was trialled at Pompano Beach in Florida from 1978-85. Since then, various groups have developed the technology to commercialisation. In 1993, about 15 plants (of significant capacity) were in full-scale operation worldwide and almost 20 more were planned or under construction. These included plants using registered process names such as Dranco, Funnell, Valorga and Kompogas.

4.4 Development of The State of the Art MBT

4.4.1 Conceptual Design

In accordance with the brief, a ‘theoretical best’ MBT has been developed. It is based on conceptual design principles as described above, and on the experience TBU has gained over the past 15 years in the design and optimisation of residual waste treatment facilities. A number of facilities are in operation or are planned which feature several of the conceptual design principles described in this Section.[15,16,17,18] The conceptual design for a plant with a capacity of 100,000 tonnes per annum is illustrated in Figure1 and described below.

4.4.2 Reception Hall

At the plant, the reception hall is a tipping floor in a covered building which is operated under negative pressure (this is indicated in the Figure of the plant by a dotted grey line).

The waste is unloaded on the tipping floor. Hazardous items are removed for special treatment/disposal. Bulky items are also separated. Untreated wood is shredded and added to the composting process, whilst metal items go to the metal recycling containers.

4.4.3 Material Pre-treatment

Once the material has passed through the reception stage, material is extracted from the waste by mechanical means.

The material passes through a bag opener and Screen 1 with an aperture of approximately 180 – 200 mm. The oversize is windsifted.

The heavier fraction of the oversieves predominantly consists of dense plastics (ie. plastic bottles, other dense plastic packaging material), larger metal containers, some composite material and other, undefined large items. This stream passes through an automated sorting system employing NIR (Near InfraRed) Technology which is now also being used in some new German DSD (Duales System Deutschland) sorting plants.[19] This technology combines tried and tested optical and mechanical sorting technologies in a new form, permitting sorting based on material properties. This enables the identification and separation of all types of plastics and coated liquid paperboard packaging *(Output 1).* The light fraction from the windsifter consists of paper, cardboard and plastic film *(Output 2).*

The undersize of Screen 1 also passes through a windsifter. This windsifter removes plastic bottles and other lightweight packaging of <200 mm from the stream. This material is diverted to the oversize from Screen 1 for further separation.

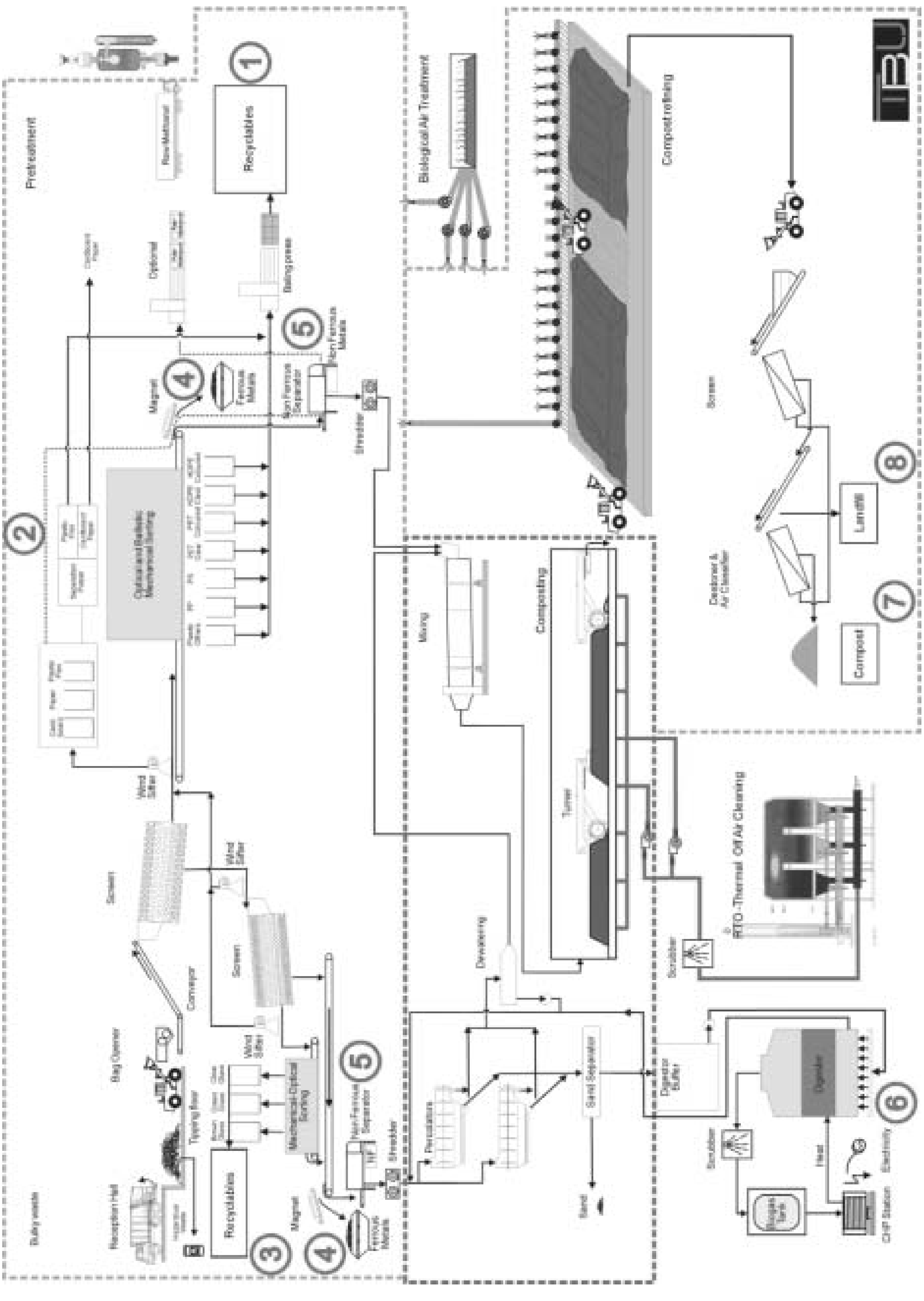
The remainder of this stream passes through a second screen (Screen 2). The oversize contains most of the glass. It is windsifted and undergoes optoelectronic sorting of the glass *(Output 3).* Subsequently, over- and undersize of Screen 2 are combined and metals separated by one magnetic and one eddy-current separator *(Outputs 4 and 5).* A similar metal separation is installed after the opto-mechanical sorting line of the Screen 1 oversize.

The material is then shredded and fed into the percolators.[20] This relatively new technology was trialed in Buchen/Germany for two years.[21] Another, similar technology was developed by the Wehrle-Company[22] and Komptech.[23] The principle is to separate easily degradable organic substance from the waste stream which is fed into a digester for biogas production.

In the percolators, water is added and the material mixed. Liquids are removed separately, the sludge is conveyed to a screw press where more liquid is removed. In the CHP (combined heat and power) plant, biogas is cleaned, stored and converted to steam and electricity *(Output 6).* Some of the generated heat (steam) is used for temperature adjustment in the anaerobic digester(s).

The remaining solids including less degradable organic substances (with a moisture content of 40 to 50%) are mixed with the remaining screen oversize after material recovery and fed into an enclosed composting hall. A turner is used for material movement and agitation. The pile (windrow) is aerated through a suction flow system. After a minimum retention time of four weeks, the material is sufficiently stable to undergo further maturation in the open, without any significant odour emissions. In the Austrian MBT Guideline,[24] the suitability of the material for maturation in non-enclosed

Figure1: The 'Ideal' MBT Plant



areas is determined by the respiratory activity, with a threshold of 20 mg/O_2/g DS over four days. This threshold can be achieved within four weeks of intensive composting.

We do not envisage any problems with this material achieving standards for 'pasteurisation' of materials which might flow from the Biowaste Directive. The regulations as they might apply under a biowaste Directive are as in Box 1. In addition, under the proposed amendment to the Animal By-products Order, there would not appear to be issues arising with the treatment process described as long as all the processes are carried out under cover (they are), and especially if the material is ultimately destined for landfill disposal. If the latter is the case, under the proposed Amendment as it currently stands, it would seem unlikely that any issues would arise. If the material was destined for use as landfill cover or for landscaping, however, it would be subject to time restrictions during which the land could not be grazed by livestock (see output 7).[25]

The temperature / time profile achieved depends very much on the mode of operation of the plant, notably, for the aerobic process, the amount of air sucked through the material. In the experience of TBU, the oxygen demand from the biowaste in the material needed to facilitate decomposition is much less than that required for cooling of the biomass (to maintain optimum conditions).

Depending on space requirements and local conditions, the outdoor maturation pile (windrow) can either be aerated or not. In our design, we have assumed the maturation area is roofed. The outdoor maturation takes an additional 10 weeks before the parameters are achieved for landfilling according to Austrian legislation implementing the EC Landfill Directive.[26] From the mature (stabilised) material, a better quality fraction may be separated *(Output 7)* and used for non-food applications (landfill cover, recultivation, erosion control etc.). The remainder is stabilised material, stripped of recoverable materials as far as possible and suitable for environmentally compatible landfilling *(Output 8).* Over time, with more materials being diverted at source, a refined technology and producer responsibility driven eco-design, this landfill fraction will be minimised.

If legislation required the maturation phase to be undertaken in an enclosed hall (to prevent access to the material by vermin etc.), we estimate that this would add less than £1 per tonne to the cost of the facility as set out in Section 5.0 below.

Box 1: Extract from Biowaste Directive 2nd Draft
Process management

Composting

The composting process shall be carried out in such a way that a thermophilic temperature range, a high level of biological activity under favourable conditions with regard to humidity and nutrients as well as an optimum structure and optimum air conduction are guaranteed over a period of several weeks.

In the course of the composting process the entire quantity of the biowaste shall be mixed and exposed to an appropriate temperature as in the following table:

	Temperature	Treatment time	Turnings
Windrow composting	≥55°C	2 weeks	5
Windrow composting	≥65°C	1 week	2
In-vessel composting	≥60°C	1 week	N/A

Anaerobic digestion

The anaerobic digestion process shall be carried out in such a way that a minimum temperature of 55°C is maintained over a period of 24 hours without interruption and that the hydraulic dwell time in the reactor is at least 20 days.
In case of lower operating temperature or shorter period of exposure:

- the biowaste shall be pre-treated at 70 °C for 1 hour, or
- the digestate shall be post-treated at 70 °C for 1 hour, or
- the digestate shall be composted.

Mechanical/biological treatment

Sanitation to be obtained as in [section for composting] in case of aerobic treatment or [section for anaerobic digestion] in case of anaerobic treatment.

4.5 Outputs and Material Properties

The plant is being assessed as a treatment to deal with municipal wastes. We have taken the output from work undertaken by Julian Parfitt of WRAP as being the most representative data for municipal waste in the UK. This was based on local authority compositional data where analysis was available for more than one season. It is based upon household waste composition, but it seems likely that this provides as good a representation as we have of the up-to-date waste analysis. The analysis is shown below:

Table 8: Waste Composition, Municipal Waste (assumed as household waste)

	'BIN WASTE' RCV residuals + kerbside recycling & non CAS bring recycling			**CIVIC AMENITY SITE WASTE Total CAS residuals + Recycling Excluded: building rubble**		
Category	**Tonnes**	**Kg/Household**	**% wt**	**Tonnes**	**Kg/Household**	**% wt**
Newspapers & Magazines	1,501,462	71	8.1%	71,319	3	1.3%
Other recyclable paper	1,072,998	51	5.8%	51,875	2	0.9%
Liquid cartons	77,373	4	0.4%	1,081	0	0.0%
Board packaging	228,123	11	1.2%	89,701	4	1.6%
Card and paper packaging	645,512	31	3.5%	2,161	0	0.0%
Other card	28,956	1	0.2%	5,404	0	0.1%
Non-recyclable paper	637,612	30	3.5%	13,878	1	0.3%
Plastic Bottles	387,574	18	2.1%	7,432	0	0.1%
Other dense plastic packaging	394,718	19	2.1%	9,890	0	0.2%
Other dense plastic	114,269	5	0.6%	32,637	2	0.6%
Plastic film	732,585	35	4.0%	17,764	1	0.3%
Textiles	588,806	28	3.2%	110,970	5	2.0%
Glass bottles and jars	1,463,119	69	7.9%	68,688	3	1.2%
Other glass	94,792	4	0.5%	12,718	1	0.2%
Wood	506,776	24	2.7%	488,479	23	8.8%
Furniture	49,050	2	0.3%	255,344	12	4.6%
Disposable nappies	443,532	21	2.4%	0	0	0.0%
Other Miscellaneous combustibles	110,558	5	0.6%	126,569	6	2.3%
Miscellaneous non-combustibles	381,812	18	2.1%	827,140	39	15.0%
Metal cans & foil	621,705	29	3.4%	528	0	0.0%
Other non-ferrous metals	0	0	0.0%	4,761	0	0.1%
Scrap metal/white goods	543,958	26	2.9%	535,017	25	9.7%
Batteries	0	0	0.0%	11,786	1	0.2%
Engine oil	0	0	0.0%	6,626	0	0.1%
Garden waste	2,823,990	134	15.3%	2,077,970	98	37.6%
Soil & other organic waste	210,524	10	1.1%	624,462	30	11.3%
Kitchen waste	2,234,428	106	12.1%	16,654	1	0.3%
Non-home compostable kitchen waste	1,865,300	88	10.1%		0	0.0%
Fines	681,657	32	3.7%	49,957	2	0.9%
TOTAL	**18,441,188**	**872**	**100.0%**	**5,520,811**	**261**	**100.0%**

The sorts of capture which could be achieved under much-enhanced source separation schemes were estimated and applied to the above data. This left a residual waste composition as illustrated in Table 9 below. The effect of the source separation schemes is to reduce the biowaste fraction in residual waste from 39% to 19%. This is in line with well-functioning schemes in Austria and Italy. As regards biodegradable municipal waste, the diversion rate is 74% of what is in the initial waste stream. Again, this is in line with well-operated collection systems in Austria, Italy and Flanders.

This compositional data has been used to generate a dataset for the ultimate physical and chemical composition of the input residual waste to the plant (on an ‘as received’ basis). For mass balance calculations, it is this waste composition which has been used. In addition, the separation characteristics of screens for the various components of the waste stream have been applied as tested in various trials and studies carried out by TBU for the design and/or optimisation of residual waste treatment plants.[27]

These compositional data by material and by physical / chemical characteristic constitute the basic material which the plant is required to deal with. Clearly, the physical and chemical characteristics cannot be specified completely owing to the inherent variation in the categories which are specified in the composition data. Furthermore, the physical and chemical analyses do not always refer to the same categories as we are considering, whilst problems may also arise from the vintage of some of the data. The analyses we have reviewed include data from the UK, Germany, Austria, Netherlands and Sweden.

Assumed separation efficiencies of metal separators and windsifters are also based on trials and experience. More information is provided in the description of the outputs below.

Table 9: Composition of Residual Waste After Effective Source Separation Schemes

Material	**% Composition of Residual**
Newspapers & Magazines	6.13%
Other recyclable paper	5.01%
Liquid cartons	0.53%
Board packaging	1.04%
Card and paper packaging	2.62%
Other card	0.19%
Non-recyclable paper	2.75%
Plastic Bottles	2.63%
Other dense plastic packaging	3.74%
Other dense plastic	1.51%
Plastic film	8.58%
Textiles	4.24%
Glass bottles and jars	2.05%
Other glass	0.94%
Wood	5.36%
Furniture	2.04%
Disposable nappies	4.16%
Other Miscellaneous combustibles	2.50%
Miscellaneous non-combustibles	8.44%
Metal cans & foil	2.50%
Other non-ferrous metals	0.02%
Scrap metal/white goods	2.17%
Batteries	0.03%
Engine oil	0.01%
Garden waste	5.18%
Soil & other organic waste	3.08%
Kitchen waste	9.09%
Non-home compostable kitchen waste	7.50%
Fines	5.95%
TOTAL	**100.00%**

4.5.1 Output 1

Output 1 is predominantly made up of the various dense plastic packaging items ie. HDPE and PET which are further separated into coloured and clear. The optoelectronic system sorts the items positively. Apart from the SORTEC System, UNISORT (owned by Waagner Biro Binder Austria) and KUSTA 4002 are some of the systems using an optical multiplexer which enables high speed sorting of a range of plastic types simultaneously.

The process software controls each identified item along the way and triggers pneumatic ejectors which force different plastics into predefined chutesThe chutes open to a conveyor belt from where the plastic types are transported to a baler. The quality of the materials is similar to that of conventional MRFs and therefore, no significant problems are expected for the sale. Assumed prices are listed in Table 10.

The amount of plastic bottles separated for material recycling will be around 2,000 t/a. In addition, around 2,500 t/a of other dense plastic packaging (tubs etc.) will be recovered. The revenue from this output is estimated to be 150,000 £/a.

4.6 Output 2

Output 2 is a mixture of paper/carboard (10,300t/a) and plastic film (5,700t/a). There are currently two ways of dealing with this material that do not include incineration:

1. The material can be landfilled. In some countries the high calorific value of material, or the existence of other bans on landfilling, would prohibit this.

2. The paper and plastic film can be separated. At this stage, only a wet separation system is considered sufficiently developed for separation at a commercial scale. The plastic fraction would need to be dried and subsequently baled for markets. In addition, mixed plastic film is usually only suitable for (material) ‘down cycling’ and does therefore not achieve attractive prices. The paper would either need to be fed into the composting unit of the plant, or sold as sludge to a paper mill. As with the mixed plastic film, the price paid for this sludge would hardly cover the transport costs.

For the purpose of this study, it has been assumed that the paper goes to a mill at a cost of £10/t. The mixed plastic film has been assumed to go to landfill at a cost of £30/t, although it may become possible to make use of this material in other (material) applications.

4.7 Output 3

The oversize of Screen 2 has a defined particle size of 80 – 200mm. Two windsifters have removed light material such as plastic film and bottles, paper, cardboard, liquid paperboard etc. From this material stream, an opto-electronic sorting unit will remove glass sorted by colours. For this study, high recycling rates at source (in the households) have been assumed and therefore the proportion of glass in the residual waste is very small. With an efficiency of 60% (which is a conservative estimate), approximately 1,500 t/a of glass can be removed from the waste stream and sold for £20/t (= £30 000 p.a.)

4.8 Output 4

Two magnetic separators are installed in the plant. Each works on a line with defined particle sizes and was assumed to have a 90% efficiency (based upon experience at other plants). In total, 1,530 t/a of ferrous metals will be separated. The material will have some degree of fouling (mainly organic residues) but no major marketing problems are reported from a number of plants we are familiar with. The market price expected is around £ 25/t (= £45 000 p.a.)

4.9 Output 5

Two eddy current separators recover non-ferrous metals. It is expected that close to 2,000 t/a of non-ferrous metals can be recovered at a price of £ 450/t (= £900 000 p.a.)

4.10 Output 6

The liquids from the percolators go to the anaerobic digestion unit. This unit will work reliably because liquids pass through the digesters and not a large proportion of solids as is often the case in conventional anaerobic digestion plants. The digesters will produce approximately 40m^3 Biogas per tonne of (total) residual waste input with a CH_4 content of up to 70%.[28]

Table 11 shows the mass balance through percolation and AD (Anaerobic Digestion). Of the input (63,000 t/a), around 18,000 t/a is process water, some of the material is converted into biogas or degraded to other substances, and some is sand. Most of the process water can be re-used in the stabilisation (composting) process where there is a need for the addition of water to maintain an optimum level of moisture for biological activity over a period of several weeks.

From the biogas, approximately 80-100 kWh of electricity and 100-180 kWh of heat per tonne of total residual waste input can be generated in the adjacent CHP plant. This means there is ample steam for heating of the digester input, and sufficient energy to run the whole of the MBT plant (aeration, shredders, equipment etc.) with the electrical power produced.

Although most of the energy generated is used in the facility, consideration could be given to the developing renewable energy market. Within the UK, the electrical energy from anaerobic digestion of waste attracts Renewable Obligation Certificates (ROCs). These are being used as ‘certificates of compliance’ to show that a designated minimum proportion of electricity has been supplied from renewable resources. The ‘buy-out’ price for ROCs (which can act as a ceiling price, but which equally can be exceeded) is 3p/kWh. Hence, by effectively ‘abitraging’ in the electricity market, it might be possible to make the facility more economical by running it with power bought from a utility provider, whilst in turn selling the renewable energy for a higher price into the grid. This could reduce the cost per tonne of input by £2.40-3.00/tonne.

4.11 Output 7

Output 7 and Output 8 are the end products of the biological stabilisation process. In total, 45,600t/a go into this process. This is made up of the 35,000t/a from the percolators, plus 10,600t/a residues from the automated sorting station. 70% by weight is organic matter. Therefore, this stream is combined with the solids from the percolation and goes into the stabilisation process.

During the stabilisation process (4 weeks intensive degradation in enclosed hall, additional 10 weeks of maturing in a roofed area) a 40% reduction by weight is expected. Most of the reduction is water loss (evaporation), and some of it is degradation of organic matter (CO_2). In conventional MBT systems, this weight reduction is around 30%. In the plant described here, there is more organic content going into the biological process, and the material has a higher initial moisture content. The combined effect results in this higher level of mass reduction. The output of the biological processing step is therefore around 27,000 t/a

This material is suitable for landfilling according to the latest landfill guidelines and ordinances in place in European countries (see Appendix 1). Nevertheless, it is possible to separate out a fraction with higher organic content and lower heavy metal concentrations for use as a compost in lower quality applications (such as landscaping). This can be done by screening the material (e.g. 5 – 15 mm) followed by removal of stones and glass particles in a ballistic separator. The expected yield of this better quality fraction is around 7,000t/a.

It is well known that materials derived from MSW are of inferior quality compared to compost derived from source-separated biowaste. However, the facility presented in this study will have significant removal of non-compostable items, with a high degree of separation of metals (and, with them, batteries) which does reduce the heavy metal concentration of the output relative to treatments which compost all residual wastes without mechanical separation.

4.12 Output 8

This output is the remaining stabilised material after separation of the material. It will amount to around 20,000 t/a. At this point in time, there is nothing one can do with it except landfilling. According to experiences in other MBTs, it is estimated that this output would comply with the relevant Austrian standards ie. the gross CV (calorific value) will be in the order of 6MJ/kg (Lower CV of 2.6MJ/kg). The moisture content will be between 20 and 30%, the loss on ignition, around 35%.

Apart from the stabilised material of the biological stage, Table 12 lists three more waste fractions which may require landfilling. One is a proportion of bulky waste which has been separated in the reception hall and is not recyclable. Another one is sand from the digesters. Finally, if no use for the plastic film is found, this material would be landfilled at £30 per tonne (and this is assumed in the costings below). It is possible that this material could find application. In total, the amount of material requiring landfilling after the mechanical-biological treatment is 25,300 t/a or approximately a quarter of the residual waste input into the plant, excluding plastic film. Including plastic film, the quantity increases to 31,000 tonnes, still less than one-third of the input material. The costs of disposal of these residues have been assumed at £30/t including some transport ie. a total cost of £759,000-930,000 per year.

Table 10: Market Prices for Plastics (indicative ranges)

Material	Colour	Price (£/t)
HDPE bottle	any	100 - 130
PET bottle	clear coloured	90 - 130 0 - 45
PVC		0 - 20
Mixed		0 - 35

Table 11: Mass Balance through Percolation and AD

Percolator Input	
Total tons	62,000
Percolator Output (tonnes)	
Biogas	3,700
Process water	18,000
Sand	3,000
Degradation	2,200
Into Composting	35,000

Table 12: Material requiring landfilling

Material	T/a
Stabilised landfill input	18,729
Bulky waste (50%)	860
Sand (digester)	4,783
(Plastic Film)	(5,700)
Landfill total (excl. film)	24,000
Landfill total (incl. film)	29,700

This may of course increase if the costs of landfilling rise due to scarcity and / or higher landfill taxes, though this fee is towards the upper end of current gate prices. Lastly, the sum assumes that the sand attracts higher rate landfill tax – it may well be that this could be kept sufficiently clean to justify the application of landfill tax at the lower rate (implying a saving of approx £0.50 per tonne of waste input to the plant).

With landfill taxes possibly rising to £35 per tonne, the figures could rise to £1.27 – £1.55 million, increasing the costs stated below by around £5-6 per tonne of waste input to the plant. However, it should be noted that there are interesting policy questions which might reasonably be asked concerning the status of the landfilled MBT waste. In Austria, the Alsag, or landfill tax, is levied at different rates for material which has achieved the stability standards set for waste destined for landfill, and for untreated waste. The current figure for untreated waste is €87 per tonne (approx. £55 per tonne). Where waste is pre-treated so as to meet stability criteria, the rate applied is €21 per tonne (or approx. £13 per tonne). This difference of £42 is more than sufficient to make pre-treatment an attractive (indeed preferable) option to direct landfilling, especially once one considers that for each tonne of material input to a given MBT process, far less than a tonne (depending upon the process) will remain to be landfilled. The fact that such a treatment would also reduce any risk of spread of livestock diseases might also be considered in this context.

Were such legislation to be introduced in the UK, the costs of landfilling the residual material mentioned here might be significantly reduced (the tax differential between active and inert materials at present is £11 per tonne – if stabilised biowastes were included in the materials qualifying for landfill tax at the lower rate, costs of the plant would be approximately £2 per tonne less than estimated below).

5.0 Cost assessment

5.1 Background

The economics of residual waste treatment technologies is very sensitive to site, local and regional issues and to the type of application. Costs are dependent on a range of factors including:

- Type of ownership (private/public) and hence the required rate of return and profit margins;
- Resources necessary to achieve required approvals and permits;
- Level of emission limits for air and water;
- Aesthetic (design) requirements;
- Risk sharing arrangements (level of performance guarantees determines level of built-in contingencies);
- Required buffer and stand-by capacities; and
- Difference between nominal and actual capacity.

It is therefore noted that the costs developed must be seen as guide values only. It should be emphasised that any *prices* that may be discussed in the public arena do not necessarily reflect the *costs* of a certain technology: A manufacturer/vendor's tender price may reflect a long-term marketing strategy and try to establish *a first reference facility* in a country or a region significantly below cost. It is also worth noting that vendors occasionally indicate prices well below actual levels when they are not binding.

Additional factors that frequently add to the gap between system costs and "prices" include:

- Cost of land use either not included or provided for free;
- Use of buildings not included of provided for free or at a reduced price;
- Provision of ancillary services for free or at a reduced price (power, access, wastewater treatment/disposal, landscaping, weighbridges, staff etc.);
- Landfilling of residues for free or not included;
- Vendor/operator may have successfully applied for R&D funds;

5.2 Assessment

A technology cost assessment was conducted based on modelling using the actual costs of plants established throughout the world applied to local installation and operating conditions. For technologies where no large scale plants have been established, cost estimates were based on tenders for 'real projects' and in-house estimates.

The capital expenditure for a 100,000 t/a facility will be almost £30 million. The main capital items are listed in Table 13. More information on the cost assessment and the calculations is summarised in Table 14. The assumptions forming the basis of our assessment are also contained in the Table. In addition, the following assumptions were made:

- Facility throughput of 100,000 t/a
- Interest rate of 7%
- No costs for land use

The results of the cost assessment shows annual costs (including depreciation) of £6 Mio or £60/t. If the revenue from the sale of products is deducted, then the costs amount to approximately £51/t of residual waste input.

We believe these are costed 'on the safe side', though equally, as stated above, some specific cost items are absent.

5.3 Issues of Scale

The facility was costed for 100,000 tonnes capacity. It should be noted that a major advantage of this type of facility is that diseconomies of smaller scale cut in at relatively low levels. In many MBT plants, costs would be expected to be broadly constant down to scales of around 30,000 tonnes. Because, in this plant design, there are more capital items in which investment is made, we would expect similar costs to apply down to the 40-50,000 tonnes level. No significant economies of scale would be expected for larger sized plants.

Table 13: Itemised Capital Costs (1)

Component	('000 £)
Plant Site Development	500
Receival & Separation Building	4,000
Separation	4,000
Percolation/AD Building	2,500
Percolation/AD	4,000
Electricity Generation	700
Conveyors (w/o sorting)	700
Composting Hall	3,100
Composting Equip	2,000
Maturation	1,200
Refining	500
Air Handling/Ductwork	1,000
Biofilters	500
RTO	1,500
Mobile Equipment	800
Infrastructure, Miscellaneous and Spares	1,500
Total	**28,400**

(1) Without engineering, planning or commissioning

Table 14: Cost Assessment for MBT

Capital costs			**Depreciation**		
	Capital Cost		**Period (years)**	**Costs (£/a)**	**Costs (£/t)**
Structural & Civil works	10,500,000		20	991,126	9.91
Plant & Equipment	17,200,000		15	1,888,468	18.88
Vehicles & Mobile Equipment	800,000		6	167,837	1.68
Engineering, Planning & Commissioning	1,425,00		20	134,510	1.35
Subtotal	**29,925,00**			**3,181,940**	**31.82**
Maintenance and Repair Costs	**% of C/C**			**Costs (£/a)**	**Costs (£/t)**
Buildings	1.5%			157,500	1.58
Plant Equipment	3.5%			602,000	6.02
Vehicles, mobile equipment	5.0%			40,000	0.40
Subtotal				**799,500**	**8.00**
Ongoing Costs	**No.**	**Unit**	**Rate**	**Costs (£/a)**	**Costs (£/t)**
Staff: Operations Manager	2	persons	33,000	66,000	0.66
Office	1	persons	22,000	22,000	0.22
Operator Assistants	3	persons	25,000	75,000	0.75
Tipping Floor	2	persons	12,000	24,000	0.24
Loader	3	persons	19,000	57,000	0.57
Electricians	2	persons	22,000	44,000	0.44
Maintenance	3	persons	22,000	66,000	0.66
Truck	2	persons	20,000	30,000	0.30
Total salaries	**18**	**persons**		**384,000**	**3.84**
	No.	**Unit**	**Rate**	**Costs (£/a)**	**Costs (£/t)**
Fuel		lumpsum	30,000	30,000	0.30
RTO op. costs		lumpsum	50,000	50,000	0.50
Water	0	m3/yr		0	0.00
Sewerage	0	m3/yr		0	0.00
Electricity		lumpsum	0	0	0.00
Utilities		lumpsum	100,000	100,000	1.00
Consumables		lumpsum	120,000	120,000	1.20
Insurance		lumpsum	150,000	500,000	5.00
Management fees		lumpsum	80,000	80,000	0.80
Corporate costs (Accounting etc.)		lumpsum	50,000	50,000	0.05
Quality assurance		lumpsum	150,000	150,000	1.50
Disposal to landfill (incl. transport)	24,000	t/yr	30	720,000	7.20
Subtotal				**1,800,000**	**18.00**
Revenue	**No.**	**Unit**	**Rate**	**Costs (£/a)**	**Costs (£/t)**
Sale of FE metals	1,500	t/yr	25	37,500	0.38
Sale of Nfe metals	2,000	t/yr	450	900,000	9.00
Sale of Glass	1,500	t/yr	20	30,000	0.30
Sale of paper	10,300	t/yr	-10	-103,000	-1.03
Sale of Dense Plastics/Bottles	4,500	t/yr	70	315,000	3.15
Sale of Plastic Film	5,700		-30	-171,000	-1.71
Sale of Compost	6,200		-5	-31,000	-0.31
Subtotal				**977,500**	**9.78**
Total annual costs (revenue excluded)				**6,165,440**	**61.65**
Total annual costs (revenue included)				**5,187,940**	**51.88**
Total annual costs (revenue included, taking advantage of Renewables Obligation)					**49.18**

6.0 Environmental performance assessment

The mechanical biological treatment facility presented in this study is a new design. Although the various components of the facility are in operation in other plants, the combination of components is unique. In addition, the materials passing through these components are partially different from those materials going through such components in other plants. In other words, no such facility is presently operating anywhere in the world. There is a high degree of certainty that this plant will work reliably.

However, it is beyond the scope of this study to undertake a full LCA (Life Cycle Assessment) which would be necessary to quantify all substance flows through the system, and to quantify the credits from recycled products. Therefore, a life cycle review has been undertaken which compares the facility and its mass and substance flows with other residual waste treatment options.

6.1 Substance Flow Analysis for Organic Media

In addition to the mass flow balance, TBU has carried out a SFA (Substance Flow Analysis) for selected elements to derive the expected quality of the organic media (compost) which are separated from the stabilised material. The procedure is described below.

The *material* composition of the input is known. The *elemental* composition for each material was taken from Öko-Institut.[29] This composition was then applied to the mass balance calculations. The results for the output of the biological processing are shown in the third column of Table 15. The fourth column is an estimate of heavy metal concentrations in the compost assuming a 20% reduction compared to the total output. The last column indicates the standards applied in the Publicly Available Specification for Composted Materials.[30] This shows why the material is unsuited for unrestricted application to land (though nothing in UK law prevents this as such).

Table 15 shows that the heavy metal concentrations in compost from this plant are approximately 50% lower than those of conventional MBTs. The selected elements are also indicators for some other pollutants in the compost. These are below the threshold triggers for allotments and domestic gardens listed in ICRCL 53/83 except for Nickel which is slightly above.

Again, it is noted that the compost produced in this plant is not intended and must not be seen as an alternative to composting of source separated garden and food material. However, it can potentially be used in a range of subordinate applications. These applications could include:

- Landfill cover
- Surface layer of landfill capping
- Road (and railroad) embankment cover
- Erosion control
- Sites remediation
- Soil conditioner for other non-food sites

6.2 Air Treatment

The control of air emissions from MBT systems is defined by the MBA-Richtlinie (Directive for MBT) in Austria and by the 30. BImschV[32] in Germany. To minimise the costs of air treatment systems, the cleaning should be dependent on the load and the duration of waste air generation. Generally one can distinguish between:

- *Exhaust air from the reception hall and pre-treatment,* which is lightly loaded and occurs during working hours only, and
- *Exhaust air from the biological treatment (aerobic and anaerobic)* with a high continuous load.

Table 15: SFA Results Compared

Element	Literature[31]	Stabilized Material	Compost	PAS 100
Pb	695	405	324	200
Cd	7.4	2.9	2.3	1.5
Ni	87	120	96	50
Hg	3.0	0.8	0.6	1

Figure 2 shows the principle of the proposed treatment system. Exhaust air from the reception hall and the pre-treatment (sorting etc.) can be biologically treated through biofilters. Heavily loaded air from the biological treatment (aerobic and anaerobic) requires thermal air cleaning, also called RTO (Regenerative Thermal Oxidisation). Both RTO and biofilters are supported by acid scrubbers to reduce raw gas loads.

In the RTO, hydrocarbons are oxidised to carbon dioxide and steam in a combustion chamber. Heat recovery is achieved using ceramic heat exchangers. Following successful completion of oxidation a second chamber is reheated by the hot waste air. Cyclical changeover of the direction of flow ensures permanent operation.

6.3 Air Emissions

6.3.1 Air Emissions from Plant

The air emissions were calculated based on the amount of material going into the biological processing stage. Emissions data has been obtained primarily from BZL[33] and Doedens et al.[34] The data was taken from RTO clean air monitoring results for the intensive rotting phase in the encapsulated hall (4 weeks) assuming that the biogas conversion unit will have similar emission characteristics to the RTO. Added to this are emissions data from MBA biofilter outputs adjusted for the period of maturation. Table 16 shows the results of the calculations.

Emissions of organic compounds are expected to be negligible as the majority of these emissions (in the untreated off air) occur during the first *two* weeks of rotting (see Figure 3)[35] and, over the first *four* weeks, the biological processing off air is treated in the RTO which oxidises the entire organic load). NOx emissions which can potentially occur from the biofilters will also be reduced to a non-detectable level through the use of acid scrubbers as a front-end device to RTO, and through use of biofilters.

6.3.2 Air Emissions from Landfill

As discussed in Appendix 1, a number of studies have been carried out calculating and measuring landfill gas emissions from MBT output material. All of them conclude that these emissions are reduced significantly. A recent study by Doedens et al[36] conducted long-term research on three MBTs and concluded that the overall landfill gas generation potential of MBT-material is reduced by 95% compared to untreated waste.

6.3.3 Air Emission Credits from Recovered Recyclables

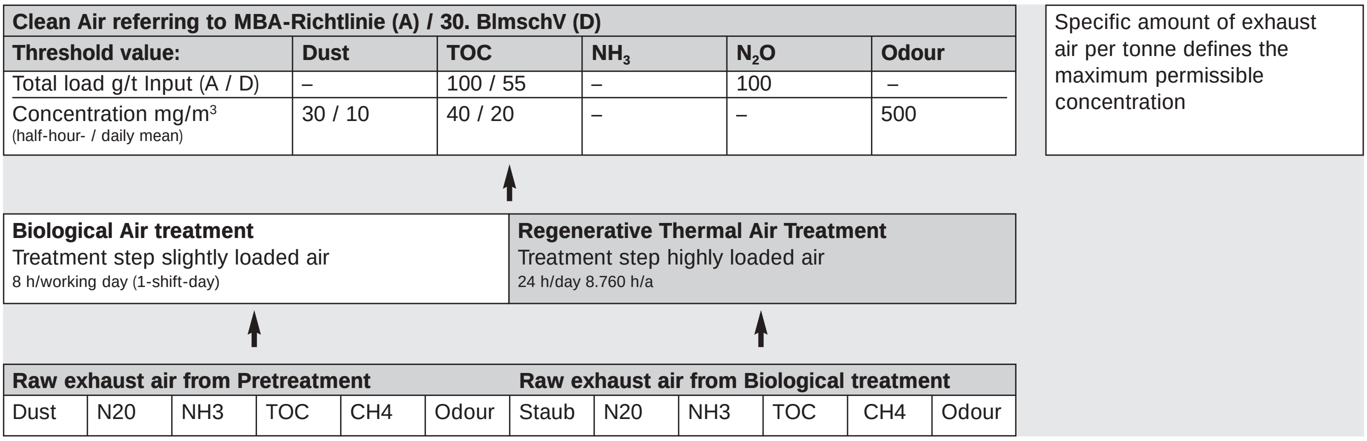
Air emissions credits are large particularly for metals. With additional metal recovery at 3,400t/a, the benefit over landfilling in comparison with the overall 100,000t/a waste stream is significant. Avoided release of greenhouse and toxic emissions during refining and manufacture is also significant. Benefits attributed to other dry recyclable streams are of the same order of magnitude. It is beyond the scope of this study to quantify these benefits.

6.3.4 Comparison

For the purposes of comparison, the emissions to air of waste treatment technologies are shown in the Figures below.[37] These confirm that, in most instances, the MBT technology has the lower amount of air emissions. It should be noted that these are only the direct emissions and do not include credits for either energy or materials recovery.

In the event that avoided burdens are calculated, one has to understand the following. Firstly, the energy recovery technologies – incineration, and to a lesser degree, landfills (where collected gas is combusted for energy recovery) can be considered to lead to the avoidance of emissions which might otherwise have occurred through alternative energy generation techniques. For reasons considered elsewhere, we consider the most appropriate assumption in the UK is that new facilities generating electricity should be considered to ‘displace’ a mixture of gas fired generation and renewables, though here we use the assumption that gas fired generation is displaced.[38]

Figure 2: Proposed Air Treatment Principle



Clean Air referring to MBA-Richtlinie (A) / 30. BImschV (D)					
Threshold value:	**Dust**	**TOC**	**NH_3**	**N_2O**	**Odour**
Total load g/t Input (A / D)	–	100 / 55	–	100	–
Concentration mg/m^3 (half-hour- / daily mean)	30 / 10	40 / 20	–	–	500

Specific amount of exhaust air per tonne defines the maximum permissible concentration

Biological Air treatment	**Regenerative Thermal Air Treatment**
Treatment step slightly loaded air 8 h/working day (1-shift-day)	Treatment step highly loaded air 24 h/day 8.760 h/a

Raw exhaust air from Pretreatment						**Raw exhaust air from Biological treatment**					
Dust	N20	NH3	TOC	CH4	Odour	Staub	N20	NH3	TOC	CH4	Odour

Table 16: Indicative Air Emissions of Plant

	g/t Input
Mercury	2.50E-03
Other heavy metals	0.00E+00
TOC	1.62E+01
NH3	6.54E+01
Dioxins I-TEQ	1.35E-08
Dust	4.72E+00
TOC cont.	1.89E+01
CH4	5.34E+01
NO	2.64E+02
NOx	2.07E-04
CO	5.67E-05
CO2	1.22E+05
SO2	8.77E-08

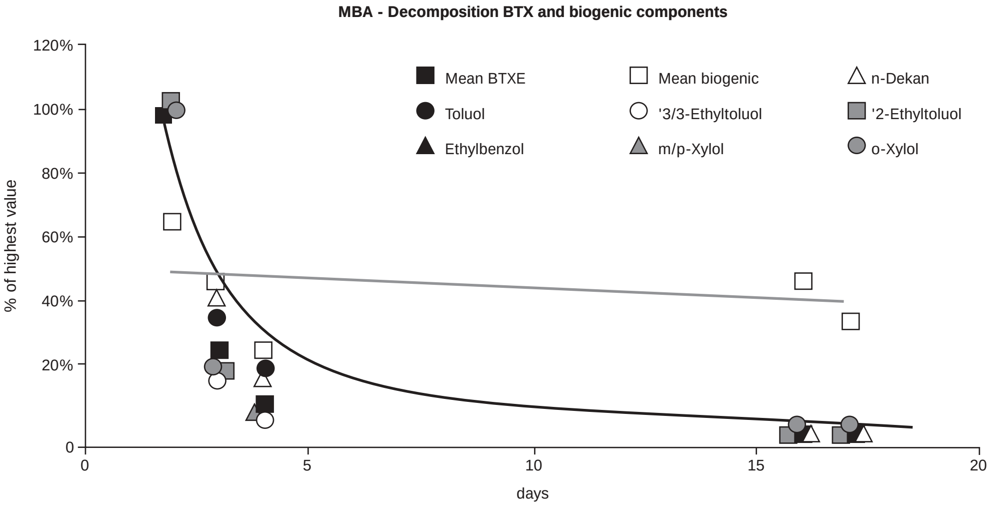


Figure 3: Decomposition of biogenic components over time

Figure 4: Quantitative Analysis of Direct Emissions of Carbon Dioxide

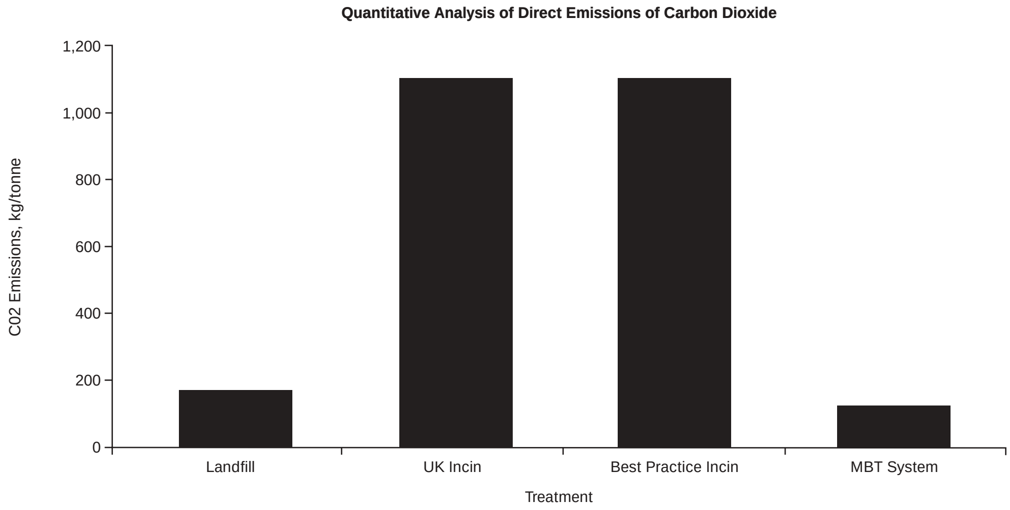


Figure 5: Quantitative Analysis of Direct Emissions of Methane

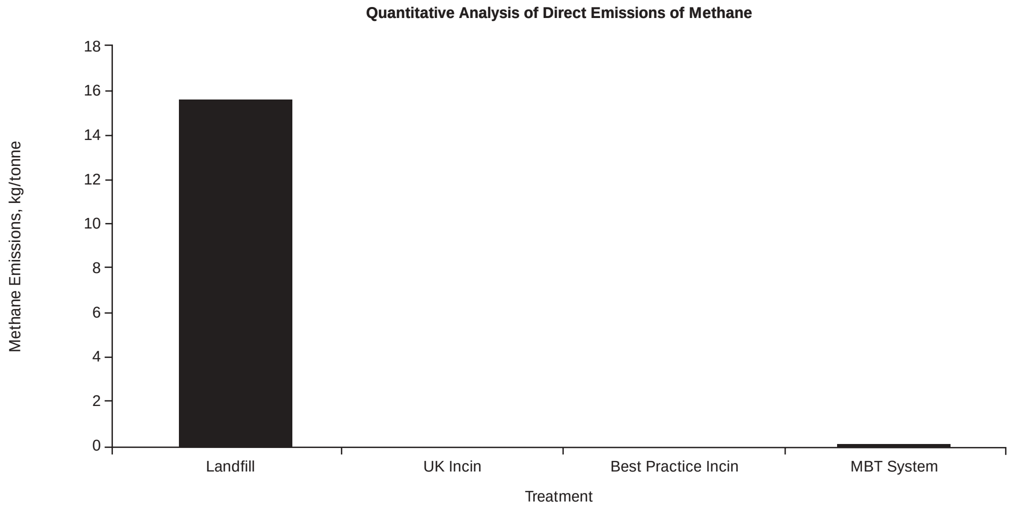
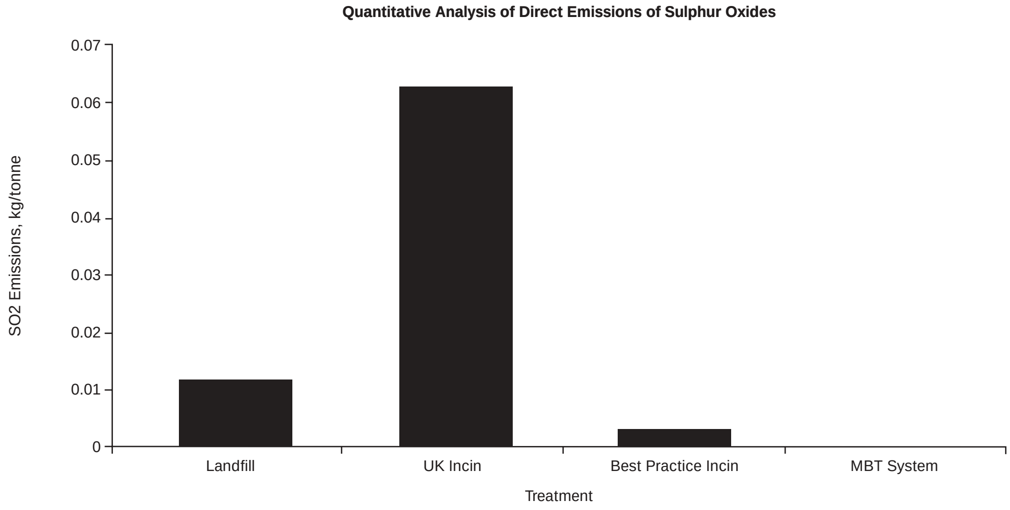


Figure 6: Quantitative Analysis of Direct Emissions of Sulphur Oxides



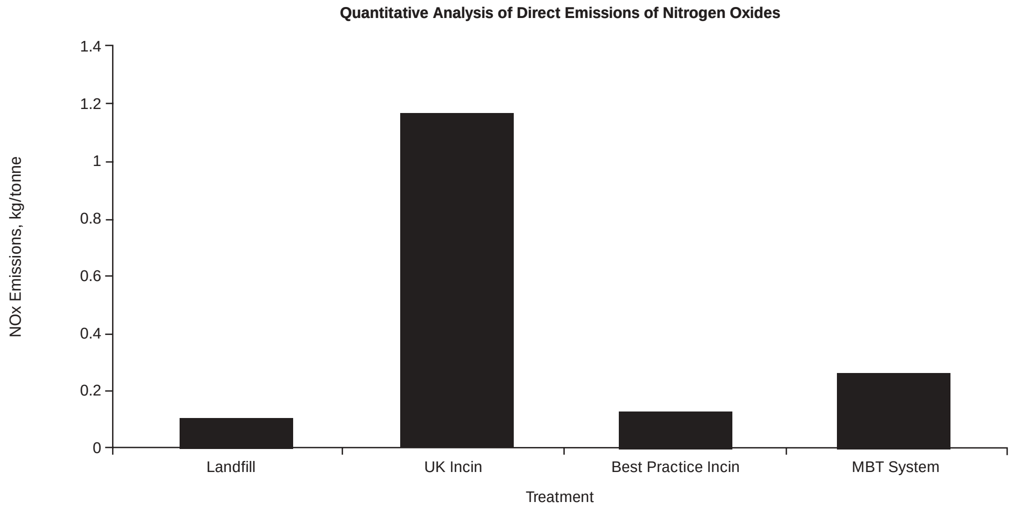


Figure 7: Quantitative Analysis of Direct Emissions of Nitrogen Oxides

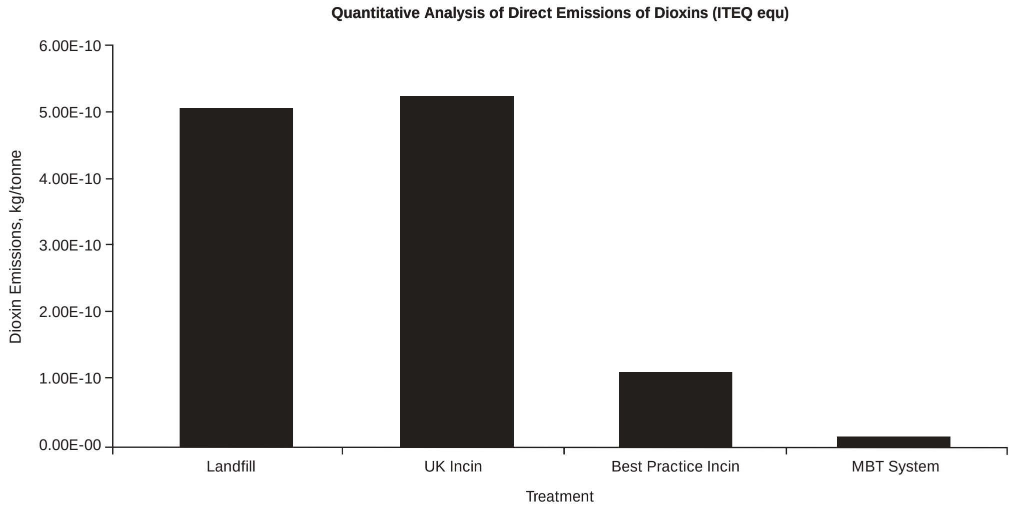


Figure 8: Quantitative Analysis of Direct Emissions of Dioxins (ITEQ equ) to Air

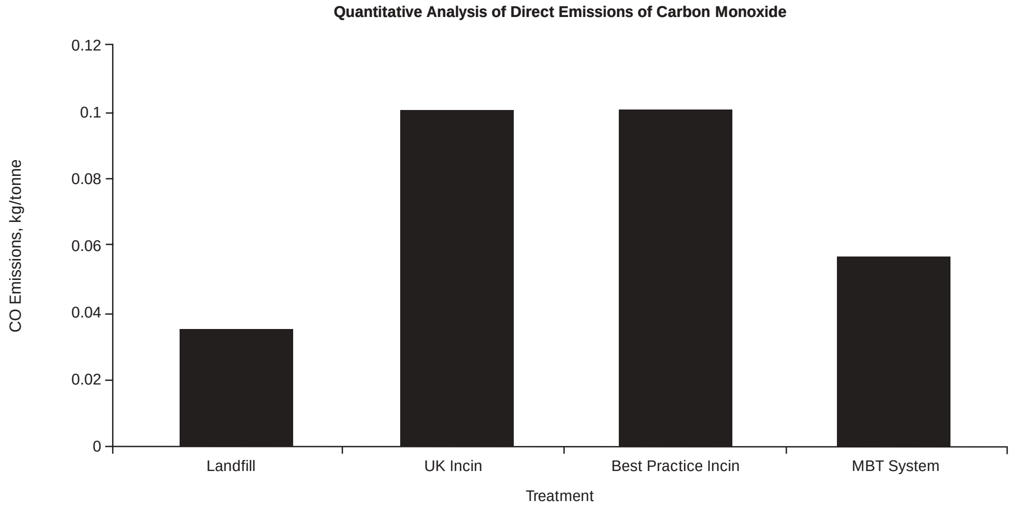


Figure 9: Quantitative Analysis of Direct Emissions of Carbon Monoxide

Figure 10: Quantitative Analysis of Direct Emissions of Volatile Organic Carbons

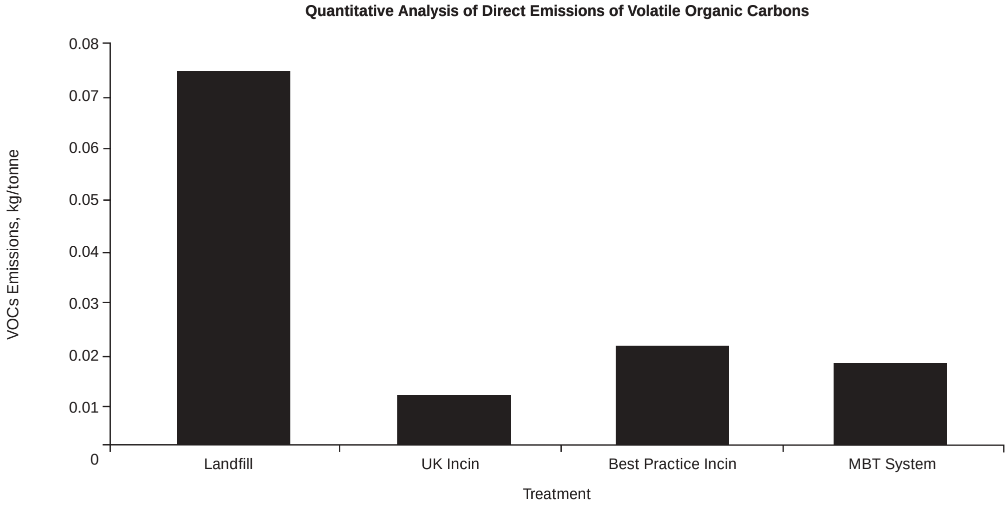


Figure 11: Quantitative Analysis of Direct Emissions of Particulate Matter to Air

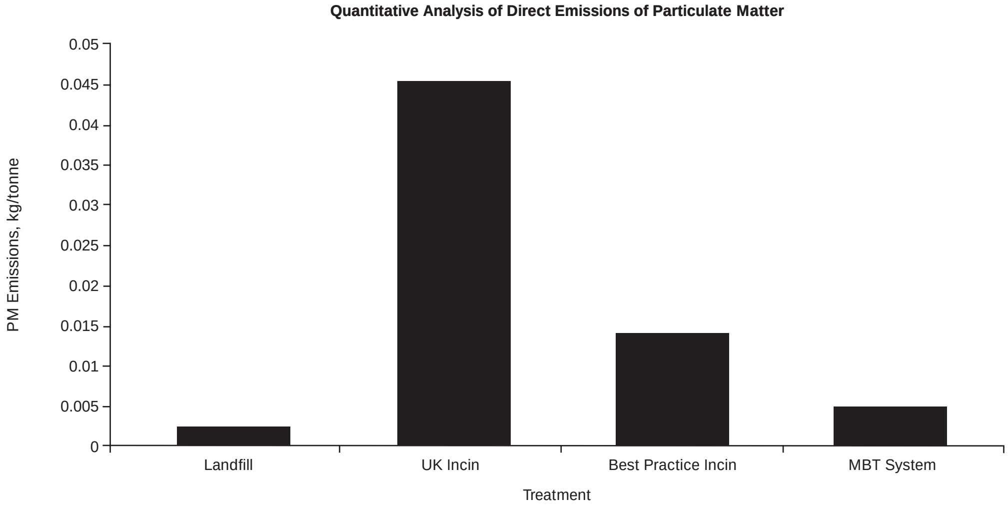
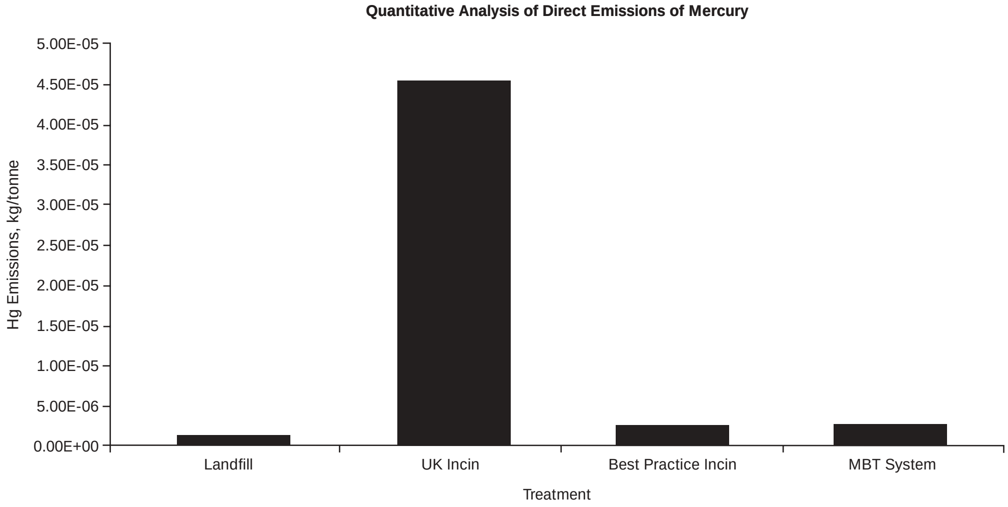


Figure 12: Quantitative Analysis of Direct Emissions of Mercury to Air



When one considers these ‘displaced’ emissions, the picture is altered. Yet one must also consider the avoided emissions associated with the use of secondary materials rather than primary ones. For the MBT facility as we have designed it, these are much greater than for the other facilities. The following are worthy of consideration:

- Recycling a tonne of aluminium may save the equivalent of 53,000 kWh;
- Recycling a tonne of textiles may save the equivalent of 15,000 kWh;
- Recycling a tonne of steel may save the equivalent of 4,700 kWh;
- Recycling a tonne of lead may save the equivalent of 7,500 kWh;
- Recycling a tonne of glass may save the equivalent of 900 kWh.[39]

In terms of greenhouse gas emissions, recent work by AEA Technology gives the following estimates:[40]

- Recycling a tonne of aluminium may save the equivalent of 9.074 tonnes CO_2 equivalent;
- Recycling a tonne of textiles may save the equivalent of 3.169 tonnes CO_2 equivalent;
- Recycling a tonne of steel may save the equivalent of 1.487 tonnes CO_2 equivalent;
- Recycling a tonne of PET plastic may save the equivalent of 1.761 tonnes CO_2 equivalent;
- Recycling a tonne of paper may save the equivalent of 0.600 tonnes CO_2 equivalent;
- Recycling a tonne of HDPE may save the equivalent of 0.491 tonnes CO_2 equivalent;
- Recycling a tonne of glass may save the equivalent of 0.253 tonnes CO_2 equivalent.

Hence, recycling can generate significant benefits in terms of savings in energy use and climate change emissions, larger than can be achieved through energy from waste incineration. This is part of the logic of the argument for the prior claim to recycle rather than send materials for disposal.

Table 17 shows the net balance of greenhouse gas emissions for the MBT facility and an incinerator. They show the situation where the avoided electricity source is gas. The result is that for each tonne treated in the MBT facility, savings of the order 940kg per tonne CO_2 equivalent can be realised. On the one hand, these estimates are conservative in that they only attribute CO_2 savings to materials where markets seem assured. They also attribute the same material recovery rates at the incinerator for steel as for the MBT plant. Lastly, they assume no net delivery of energy from the MBT plant. Under these assumptions, and assuming a displacement of 500g CO_2 equivalent per kWh, the net avoided emissions are broadly similar for the two plants and direct emissions dominate.

If one posits that the avoided electricity source is coal rather than gas, then the avoided emissions are of the order 1kg CO_2 equivalent per kWh. In this scenario, the differential falls, but is still 674kg CO_2 equivalent per tonne of waste throughput in favour of the MBT plant. Even if direct (process) emissions from the plant were trebled, the net balance would still be in favour of MBT by 427kg CO_2 equivalent per tonne of waste throughput. Such a trebling more than accounts for the fact that our analysis has not considered emissions of greenhouse gases over the very long term, including those which arise following the application of landscaping material to land.

Table 17: Greenhouse Gas Balance for MBT Facility and Incineration

	MBT	**Incinerator**	**MBT Avoided CO2**	**Incinerator Avoided CO2**
Materials	**Tonnes**	**Tonnes**	**Tonnes**	**Tonnes**
Steel	1,500	1,500	2,230	2,230
Aluminium	2,000		18,148	
Glass	1,500		380	
Paper	10,300			
Dense Plastics	4,500		5,067	
Plastic Film	5,700			
Landscaping material	6,200			
Electricity (net, gas displaced)		539		26,950
Total Avoided CO2 (tonnes)			25,825	29,180
Avoided CO2 (kg CO2/tonne waste)			258	292
			Direct Emissions	**Direct Emissions**
CO2			122	1,101
CH4			0.05	0.00
Total Direct Emissions (CO2 equ.)			124	1,101
BALANCE (CO2 equ.)			**-135**	**809**
DIFFERENTIAL (CO2 equ.)			**943**	

6.4 Water Emissions

6.4.1 Water Emissions from Plant

The facility would be operated without any waste water discharge. The 18,000 t/a of process water from the anaerobic digestion is partially recirculated in the percolators (after nitrification/denitrification) and partially used for maintaining appropriate moisture levels in the stabilisation stage where substantial quantities of water are required to maintain moisture levels as the aeration tends to dry out the material. There are a number of other new MBT plants combining aerobic and anaerobic technologies which operate waste water free.[41,42]

6.4.2 Water Emissions from Landfills

Ehrig and Witz[43] state that both quantity and composition of leachate from landfills with MBT-output is not significantly different from that of landfills containing untreated waste. However, this does not consider the reduced quantity of MBT-output as compared with untreated residual waste. Other studies such as Binner[44] conclude that both the amount and the quality of the leachate from landfilled MBT-material is markedly different to leachate from untreated waste. Binner shows that the differences are also significantly dependent upon the time and intensity of the treatment. On the balance of evidence available from a range of studies, it can be concluded that

- The leachate generated from MBT-landfills contains about 50% less pollutants than leachate from untreated waste landfills;
- The quantity of leachate generated from one tonne of MBT-output is lower than from one tonne of untreated waste. Even if this reduction cannot be precisely quantified at this stage, there is at most no more than one quarter of leachate generated per tonne of residual waste if it is treated in the MBT facility presented here (only 24% of residual waste requiring disposal).

Water emissions from other treatments have not been considered. The issue of long term emissions from landfilled waste is currently a major theme in life-cycle modelling, yet the analysis is fraught with difficulties and uncertainties. Results thus far do suggest, however, that emissions from landfilled waste following MBT pre-treatments are much reduced than those from untreated waste.

6.4.3 Water Emission Credits from Recovered Recyclables

As with the case of air emissions in the previous section, the net benefit is significant. The full extent of the credits would need to be determined in a larger scale study.

6.5 Energy Use and Balance

Approximately 40-50m^3 of biogas can be generated per tonne of waste input. Assuming an energy content of 6 kWh per m^3 of biogas and a 30% efficiency for electricity generation, around 80 kWh[45] of electricity can be generated per tonne of input material. The internal use of electricity for residual waste treatment plants is in the order of 50-80 kWh/t input,[46] hence the plant is likely to be self sufficient in term of electricity use. Some additional energy is required in the form of diesel fuel to run mobile equipment. There may be some scope to utilise the off-heat (steam) generated from the electricity generation, however this is very much dependent on whether there is demand for the steam in close proximity of the plant.

7.0 Conclusions

Perhaps the key conclusion of this report is that there are ways of designing treatment facilities which can provide solutions for specific purposes. The range of technologies available for screening, sorting and treating materials lends itself to increasingly careful design of facilities through integration of complementary elements.

The facility which we have designed makes contributions to materials and energy recovery. The total contribution to materials recovery depends somewhat upon the markets for the materials. The input composition assumed a rate of source separation in excess of 60%. An additional contribution to the recycling/composting rate of between 3-8% would be likely.

Of the input waste, between 25 - 30% of the input material by weight would still require landfilling. Of this, however, between 63-74% of the material would be stabilised material with much reduced environmental impact once landfilled. Another 16-20% of the material would be sand from the digester. Hence, both the quantity of the material to be landfilled and its potential for environmental harm would be much reduced.

Relative to both an incinerator or a landfill, the direct emissions to the atmosphere are low. Once one accounts for the avoided emissions associated with materials and energy recovery, the net benefits relative to incineration in respect of, for example, CO_2 emissions appear significant irrespective of the source of energy which one assumes is displaced by energy from waste technologies. Further analysis would need to be undertaken to ascertain the full impacts (in absolute and comparative terms) of the plant as designed here. However, we believe that this plant exhibits considerable potential in that it offers to local authorities a treatment which is:

- A high performer in environmental terms;
- Shows limited visual disamenity;
- Able to function at relatively small-scales without significant diseconomies of small scale; and
- Competitively costed given the low atmospheric emissions and positive environmental features.

This type of treatment should be of significant interest to authorities who recognise the potential for public disquiet arising from conventional incineration and other thermal treatment technologies and who are concerned to ensure that technologies used are environmentally sound and relatively flexible in terms of their ability to operate using different waste mixes.

An interesting aspect of the facility is that it is compatible for use with other waste inputs such as sewage sludge and other commercial and industrial wastes. As such, changes in throughput and composition could also be made through changing the mix of input materials, though always with the prior aim of ensuring that materials do not need to be sent to the facility in the first place.

There are a number of policy instruments which might help the development of this type of plant. Most pertinent, given the pre-Budget Report, would be a landfill tax designed to encourage pre-treatment rather than the landfilling of untreated waste. This would, in turn, require a system of standards designed to specify the criteria (in terms of stability) which waste would have to conform to in order to qualify for a lower rate of landfill tax. The differential (between treated and untreated) would help drive forward pre-treatment and reduce the problems associated with landfilling. It ought also to be the case that standards for compost are given some statutory basis so that residues from plants such as these are not used as ‘compost’, with all that this might imply for the long-term build up of potentially toxic elements in soil. In this context, the European Commission’s Communication to the Council and the Parliament

‘Towards a Thematic Strategy for Soil Protection’, issued in 2002, states:

> *By the end of 2004 a directive on compost and other biowaste will be prepared with the aim to control potential contamination and to encourage the use of certified compost.*

The plant offered here is not a ‘treatment plant of the future’. It is very much of its day. The plant and the principles behind it, give some insight as to how (and why) it makes sense to consider options beyond the ‘off-the-shelf’ techniques such as mass-burn incineration. We ought to be entering a period of ‘post-Fordist’ residual waste management. In this period, residual waste technologies would not be selected for mass treatment of all waste in one process, but increasingly residual waste will be split into constituent parts for more tailor made treatments. Such treatments will not supplant source separation approaches. Source separation will ensure quality of materials recovered (especially the major fractions, biowaste and paper), and enable the introduction of incentive measures, such as charging, which encourage both minimisation and source separation. Residual waste management technologies like MBT should complement source separation approaches and, in doing so, reduce the environmental impact of residual waste treatments, and the demand for primary resources.

In support of intensive source separation activities, the front end recycling and moisture loss from this type of plant could ensure that from 200,000 tonnes of waste in a given area, something of the order of only 25,000-30,000 tonnes would require landfilling. This illustrates the potential for non-thermal treatment systems to deliver enormous reductions in the quantity of landfilled waste, with that waste which is to be landfilled being significantly less likely to generate major concerns.

Appendix 1: Landfilling of MBT residues

If the management of waste is to be environmentally responsible over the long-term, landfill sites should be safe on a long-term basis.

Both Austria and Germany have given this objective a key role in the development of their legislation. The same type of legislation is emerging in Italy (and is already in place in the Veneto District).

Germany

In Germany, the TASI (*TA Siedlungsabfall*, or Technical Data Sheet for Urban Waste) limits the volatile organic solids content of waste for landfilling to 5% (assessed by loss on ignition) as of 2005. So residual waste has to be treated and the organic fraction has to be collected (the TASI also lays down that biowaste should be collected separately). From a technical standpoint, this 5% limit would only have been achieveable by incineration. However, since 2001, mechanical-biological treatment has been officially accepted as an adequate treatment procedure (in comparison to incineration) to reach the target of a stable landfilling material via a so-called 'law of equivalence'. In 2001 over 20 pre-treatment plants were processing more than 1 million tonnes of residual waste and several more are presently under construction.

Austria

MSW-compost may not be mixed up with the generation of mechanical biologically stabilised waste. MSW-compost serves as amelioration for the construction of the final reclamation layer on landfill sites. Mechanical biologically stabilised waste is dedicated as stabilised waste material allowed for regular disposal or parts of it for incineration. Both processes must be conducted in MBT plants.

Following the targets laid down in the *EC Landfill Directive, the Austrian Landfill Ordinance*[47] lays down the restriction for the disposal of waste:

> '*with an organic carbon content greater than 5% /m/m'* with the exemption for waste *'originating from mechanical-biological pre-treatment, that is disposed in separated areas within a mass waste landfill site, if the upper calorific value gained by combustion of the dry matter is below 6,000kJ/kg. The mixing of waste originating from mechanical-biological pre-treatment with materials or waste of low calorific value in order not to exceed the limit value, is not admissible.'*

In order to determine criteria for an environmentally sound process design and the suitability of MBT material in accordance with the requirements of the *Austrian Landfill Ordinance,* a working group chaired by the Ministry for Agriculture and Forestry, Environment and Water Management has outlined *a Guideline for the Mechanical Biological Treatment of Waste* (Federal Ministry for Agriculture and Forestry, Environment and Water Management, 2001). The main tasks and provisions of this guideline are listed in Table 18.

Table 18: Provisions of the ‘Guideline for the Mechanical Biological Treatment of Waste’

Area/provision	Scope/task/objectives
Receipt control	• Visual receipt control before any treatment. • Removal and separation of eventually hazardous fractions. • For sludge and industrial waste: approval of origin and identity.
Input materials	• Non-hazardous waste only. • No waste from source-separation systems that could be recycled. • Detailed list of admissible waste and input materials. • List A: suitable waste without restrictions. • List B: suitable waste with certain restrictions and additional requirements. • Exclusion of specified waste which may not be treated in a MBT plant.
Requirements for construction, equipment and processing	• Licensing of MBT plants. • Waste transport within the facility. • Requirements for the limitation of emissions in physical and mechanical treatment processes. • Requirements for the limitation of emissions in biological treatment processes. (a) Closed-in vessel system and cleaning of the entire waste air at least for the first 4 weeks of aerobic treatment; after that period an open rotting technique may be authorised by individual authorisation if the respiration activity (AT_4) of the pre-treated material is below 20 mg of oxygen/g dm. (b) After anaerobic pre-treatment the same requirements for the aerobic rotting and stabilisation phase apply.
Limitation of waste air emissions	• Total organic compounds: half-day mean value: 40 mg/m^3; day mean value: 20 mg/m^3; relative mass: 100 g/t_{waste}). • Nitrous oxides (NO_x): calculated as NO_2: half-day mean value: 150 mg/m^3; day mean value: 100 mg/m^3. • Ammonia (NH_3): 20 mg/m^3. • Dioxin/Furans: for 2, 3, 7, 8-TCDD equivalent (I-TEQ) ≤ 0.1ng/m^3. • Dust: ≤ 10 mg/m^3. • Odour emissions: ≤ 500 odour units /m^3.
Waste water capture and treatment	• Detailed requirements for the collection, storage and treatment of wastewater.
Determination and control of waste air emissions	• Definition of continuous and single measurements. • Requirements for continuous measurements for the determination of half-day and day-mean values (see above). • Requirements for discontinuous measurements for dust, NH_3, PCDD/PCDF and odour-emissions depending on throughput of the plant.
Requirements for the disposal residual waste	• In addition to the provisions of the waste-management-act of (organic carbon ≤5% m/m; upper calorific value ≤6,000 kJ/kg). • The following parameter stability criteria apply: (a) Respiration activity after 4 days (AT_4): ≤7 mg O_2/g dm. (b) Gas generation or fermentation test (incubation 21 days): ≤20 Nl/kg dm. • Provisions for self-controlling, external monitoring and analytical methods.
Protection of labour	
Protection against fire and explosion	
Documentation and compulsory records	
External monitoring and control measures by the responsible authority	
Analytical methods	

Italy - Draft Decree on Bio-stabilised Materials

In Decree n.22/97, (the current National Waste Management Act) new regulations on the application of materials from MBT are foreseen, and have actually been drafted, but have not yet been enforced. Therefore, as mentioned above, the law in force regarding the application of stabilised materials from mechanical-biological treatment of mixed MSW – including land reclamation and final restoration of former landfilling sites – is the old technical regulation, DCI 27/07/84, which defined:

- features of composted materials;
- possible applications and restrictions;
- a maximum rate of application;
- a maximum allowable concentration of heavy metals in soil and a maximum annual load of heavy metals by means of compost application; and
- a maximum concentration of heavy metal and inert materials in compost.

The main goal of such provisions is the protection of the environment and of human health. Some provisions actually deal with agronomic features (e.g. humification and content of nutrients), although they were mainly aimed at justifying a minimum agronomic benefit of compost application, and do not constitute the main body of regulations. Table 20 and Table 22 below show the relevant limit values.

It is commonly thought that the new regulations to be issued on stabilised organic fractions will keep the main structure of DCI 27/7/84, namely in the case of health and safety issues, whilst the most important changes are likely to cover:

- possible applications (with restrictions to non-food and fodder crops; the only applications allowed would be in land reclamation, restoration of landfilling sites, etc.);
- humification (not likely to be included any more, due to its low reliability; it will probably be substituted by parameters on stability);
- nutrients (minimum amounts are unlikely to be included any more due to their relative lack of importance for a soil improver; moreover nitrogen actually constitutes a constraint to loads of compost due to its potential release into the groundwater);
- heavy metals (maximum allowable concentration in compost likely to be diminished); and
- loads (to be increased for one-off applications in land reclamation projects, see later).

Some regions and provinces have already issued guidelines and/or technical regulations to allow the use of MSW compost for land reclamation. Their principles have also been taken up by the draft national regulation which is expected to be issued in the near future. Such regulations rely upon the hypothesis of one-off applications with high loads in order to promote biological activities in surface soil layers on exploited mines and finished landfill sites, slopes to be consolidated, anti-noise barriers, etc.

As for the technical requirements of such applications, regulations address above all the need to check both:

- heavy metal loads; and
- nitrogen load.

Loads have to be calculated in order to stay within the maximum desirable concentrations of heavy metals in the soil and to prevent large releases of nitrogen to the groundwater.

A brief description of main features of such regulations follows.

Key Aspects of the Draft Decree

The decree is to be issued according to Article 18 of Decree 22/97, which requires the government to set technical regulations for waste management activities. The Draft Decree has already been endorsed by the Ministry of Environment and has been discussed among all the relevant Ministries (Health, Agriculture, Industry, Environment) during the past legislative period in order to finalise its shape. In the last draft (April 2000) two types of *'Biostabilizzato',* or SOF, were defined:

1st quality SOF, to be used *as an amendment* in Land Reclamation projects (therefore, an *agronomic* use);

2nd quality SOF, to be *landfilled* or to be used *as a daily cover material* (according to the expected need to 'treat' waste before landfilling).

The basic qualifying parameters for the two types are listed below.

In addition, some microbial limit values are listed but these are still hotly debated, due to the lack of reliable reference test methods. Therefore, limit values are focusing especially on the fermentability issue.

Table 19: Limits for concentration in compost and soil for heavy metals and maximum annual load, according to DCI 27/7/1984

Element	Maximum permitted concentration		Maximum load
	In compost	in soil	
	mg/kg dm	mg/kg dm	g/ha per year
Arsenic	10	10	100
Cadmium	10	3	15
Chrome III	500	50	2,000
Chrome VI	10	3	15
Mercury	10	2	15
Nickel	200	50	1,000
Lead	500	100	500
Copper	600	100	3,000
Zinc	2,500	300	10,000

Table 20: Physical, chemical and microbial features of compost (DCI 27/7/1984)

Parameter	Limit	Parameter	Limit
Inert material	≤3% dm	Relation C/N	<30
Glass (size)	≤3 mm	Total N	<1% dm
Glass (quantity)	≤3% dm	P_2O_5	>0.5% dm
Plastics	≤1% dm	K_2O	>0.4% dm
Metals	≤0.5% dm	Particle size	0.5– 25 mm
Moisture	<45% fm	*Salmonella*	absent in 50 g
Organic matter	>40% dm	Weed seeds	absent in 50 g
Humified OM	>20% dm	pH	6–8.5

dm: dry matter, fm: fresh material

Table 21: Limit values for 1st quality SOF:

Parameter	Limit value[1]
Cadmium	3 ppm dm
Chromium VI[2]	3 ppm dm
Mercury	3 ppm dm
Nickel	100 ppm dm
Lead	280 ppm dm
Copper	300 ppm dm
Zinc	1,000 ppm dm
Plastics	0.5% w/w
Inert materials (including plastics)	1% w/w

[1] Many people from research centres and institutions are asking that the limit values for heavy metals be increased by at least 1.5 (e.g.zinc: 1500 ppm; copper 500 ppm), which would be much more consistent with limit values to allow sludge application on croplands (zinc: 2,500 ppm; copper: 1,000 ppm; nickel: 300 – see also later concerning the regulations issued by Region Veneto).

[2] Many technicians and institutions are proposing that the total chromium be considered as a more prudential approach and the final regulation seems likely to reflect this.

Table 22: Limit values for 2nd quality SOF

Parameter	Limit value
Moisture	less than 65%
Respiration index (UNI method)	less than 400 mg O2/kg Volatile Solids / hour

Use of SOFs

First quality SOF can be used, *under permitting procedures,* in one-off applications in landscaping and land reclamation projects. The maximum load stated in the Draft Decree is 100 t/ha of dry matter. Many technicians and institutions are asking for a higher maximum load, based on scientific assessment. Proposals include:

- a maximum load of 100 tonnes dry matter per hectare with the sole requirement that the landscaping project be subject to permitting procedures;
- higher loads, up to 300 t/ha of dry matter (some say 500 t/ha), have to be supported by 'risk assessment', evaluating the release of nitrogen, its transportation to groundwater, and its dilution, according to geological site-specific conditions. A further calculation has to be made to assess final concentration of heavy metals in the soil, though the nitrogen related risk is in general much higher and therefore more usually defines the actual restriction for the admissible load.

This latter proposal is supported by many sound scientific surveys and insights into the potential effects. Second quality SOF can be used, under permitting procedures, as a partial or total substitute for inert materials used as a daily cover, according to 'good practice' in management of landfilling sites.

Ordinance Region Veneto, 766/2000

The approach of the Draft Decree can already be found in the DGR (Ordinance of the Regional Government) #766, 10 March 2000, issued by Region Veneto. Maximum loads for the *agronomic* use of SOF are defined at 200 tonnes/ha (fresh matter) with no further procedure other than permitting the project, and up to 2,000 tonnes/ha (fresh matter) where this is accompanied by a risk assessment. Limit values for the so-called *'Biostabilizzato Maturo'* ('Mature SOF', corresponding to 1st class SOF) are shown in Table 23.

The table shows that the same limit values for heavy metals apply here as they do for sludge and the same limit values for inert materials are used as in the previous legislation on 'controlled' use of mixed MSW compost.

A *'Biostabilizzato da discarica'* ('SOF for landfilling sites', corresponding to 2nd quality SOF) is defined through reference to limit values shown in Table 26.

Table 23: Limit values for 'Biostabilizzato Maturo' ('Mature SOF', corresponding to 1st class SOF)

Parameter	Limit value[1]
Cadmium	10 ppm dm
total Chromium	500 ppm dm
Mercury	10 ppm dm
Nickel	200 ppm dm
Lead	500 ppm dm
Copper	600 ppm dm
Zinc	2500 ppm dm
Plastics	0.5% w/w
Inert materials (including plastics)	3% w/w

Table 24: Limit values for 'Biostabilizzato da Discarica'
('SOF for landfilling', corresponding to 2nd class SOF)

Parameter	Limit value
Moisture	between 30[1] and 65%
Respiration index (UNI method)	less than 600 mg O2/kg Volatile Solids / hour

[1] Below such moisture content the material gets too dusty, hence off-site transportation becomes more problematic.

European Commission

The Second Draft of the Biowaste Directive also contains within it specific provisions regarding materials treated through MBT. The document states, regarding 'Residual municipal waste':

> *The amount and contamination of residual municipal waste should be reduced to the minimum extent possible via the separate collection of municipal waste fractions such as biowaste, packaging, paper and cardboard, glass, metals and hazardous waste.*
>
> *If residual municipal waste undergoes a mechanical/biological treatment prior to landfilling, the achievement of either a Respiration Activity after four days (AT_4) below 10 mg O2/g dm or a Dynamic Respiration Index below 1,000 mg O_2/kg VS/h shall deem that the treated residual municipal waste is not any more biodegradable waste in the meaning of Article 2 (m) of Directive 1999/31/EC.*
>
> *If residual municipal waste is incinerated prior to landfilling, the achievement of a Total Organic Carbon value of less than 5% shall deem that the incinerated residual municipal waste is not any more biodegradable waste in the meaning of Article 2 (m) of Directive 1999/31/EC.*

Gaseous Emissions from Landfill and Links to Stability

After mechanical-biological pre-treatment, in addition to mineral or biological inert material, there still remains a certain proportion of organic substances which can be broken down biologically. Gas emissions and temperature increases are therefore still possible once the material is landfilled, albeit at a much reduced rate.

Furthermore, the pre-treated waste still contains a series of organic and inorganic pollutants which could be emitted via the gaseous and aqueous pathways. For this reason, for the planning, operating and after-care of pre-treated waste landfill sites, information is needed concerning the pollutant loads which are to be expected long-term (emissions potential) and their speed of release (emissions kinetics), depending on the environmental and boundary conditions.

Amongst the biological parameters, the measure of the compost respiration activity is undoubtedly an important parameter for the evaluation of stability. The aerobic micro-organisms, by using the substratum's organic substance as a source of energy and nourishment, use oxygen and emit carbon dioxide. The metabolism is more intense when the organic compounds are more easily biodegradable, while it is slow in presence of organic substances with higher molecular and structural complexity, such as the humic substances present in the mature compost. Therefore the measure of the biodegradability of organic substances present in the material is an index of the degree of evolution of the product or of its stability.

The respirometric test evaluates the stability of the organic content through the determination of its most easily degradable fraction. Compared to other methods this enables one to calculate the speed of the transformation, otherwise possibly determined only through a continuous control of the oxygen consumption, which enables one to evaluate the period in which the degradation speed is at the maximum.

In this way the test enables one to make a judgement not only on the quantity of organic substances, but also on the biological capacity of the material, as indicated by micro-organisms' presence and activity.

As indicated in Section 2, the duration of the composting process until the alternative maturation criteria are reached (RS_4, GF_{21}, TOC) is dependent on the operating management and the system selected. As a rule the following applies:

- the more dynamic the process, the shorter the composting time to achieve a given level of stability;
- the shorter the time in the (quasi) dynamic system, the longer the secondary composting required in the static system to achieve the same level of stability;

Unfortunately, comparison of measurements from various plants and laboratories continues to be impeded due to an uncoordinated, unstandardized or differentially applied methodology for analysis. Furthermore, there remains some discussion as to what constitutes an adequate measure of stability.

It is quite clear from the previous section that different nations make use of different criteria for assessing the stability of biowaste in the context of MBT pre-treatments prior to landfilling. The Italians tend to use a dynamic index, the Dynamic Respiration Index. This was also considered in the EC Working Paper on Biological Treatment, alongside the German AT4 (Atmungsaktivitaet vier = respiratory activity on 4 days). Austria uses AT7.

Table 25 shows the potential reductions in key emission characteristics associated with biologically pre-treated waste. The actual level of reduction in gas generation potential and other factors is significantly affected by the time for which the material is treated and the nature of the treatment. It is important to understand, however, that the degree to which reductions in gas generation potential are achieved over time follows something akin to an exponential decay curve. This means that successive reductions in gas generation potential are achieved over progressively longer periods. This has implications for the costs of pre-treatment. Hence, there remains a debate concerning the appropriate standard to set for stability.

The crux of this debate is neatly encapsulated in the comparison between German and Italian standards shown in Table 26. From the Italian perspective, both the German and the Austrian threshold values are far too low (stringent), and both require very long maturation times (in exceptional cases, up to 8 months!). This has the effect of increasing the costs of MBT where the intention is to send some of the residual mass to landfill / landscaping etc. The Italian threshold value (DRI = 1000 mg O_2/kg VS/h) requires shorter time periods, depending on process optimisation. This delivers a reduction in gas production (as assessed through the Generation Sum test method) by 80% (this is on a reduced mass, hence the overall environmental benefit is even higher relative to direct landfilling).

The reasons for this are illustrated clearly with reference to graphical illustrations of the behaviour of landfilled MBT waste as observed in Austrian experiments. Figure 13 below shows how the gas generation varies with the length of time for the pre-treatment process at different plants. The reduction in gas generation potential with increasing treatment duration is notable. Note also, however, that the incremental reduction in gas generation potential falls with increasing time. This is also shown in Figure 14.

Table 25: The effects of biological pre-treatment

Feature	**Final outcome** [source]		**% reduction** (as compared to initial)
Respiration rate	5 mg O2/g d.m. (96 h) about 400 mg O2/kg VS.h	[1] [2]	80-90%
COD, Total N in leachate	< 100 mg/l < 200 mg/l	[1] [1]	about 90%
Gas production attitude	20-40 l/kg d.m	[1,2]	90%
Volume	final density (compacted): 1.2-1.4 t/m3 mass loss (due to mineralisation): 20-40%	[1] [1]	up to 60%

Source: Adani F. (2001) Personal communication with E. Favoino; Leikam K., Stegmann R.(1997). "Landfill behaviour of mechanical-biological pretreated waste". ISWA Times, Issue 3/97, pp.23-27; Wiemer K., Kern M.: Mechanical-biological treatment of residual waste based on the dry stabilate method, in Abfall-Wirtschaft: Neues aus Forschung und Praxis, Witzenhausen, Germany, 1995

Table 26: Comparison of German and Italian Standards for Stability of MBT Output

Standard for Stability	**Residual Biogas** (kg TS-1)	**Biogas Reduction** (%)	**Treatment Time**
Germany 5000 mg kg TS 96hr^{-1}	20	90-95	2-6 months
Italy (proposed) 1000 mg O2 kg VS^{-1}h^{-1}	60-80	95-85	15-40 days

Source: Adani et al (2002) Static and Dynamic Respiration Indexes – Italian Research and Studies, Paper to the European Commission Technical Workshop on Biowaste.

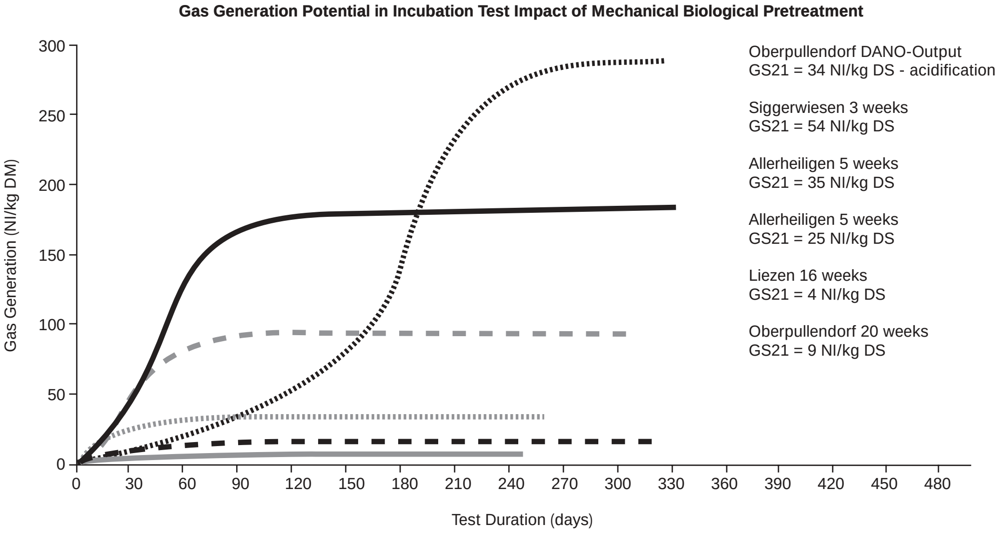


Figure 13: Impact of MBT on Gas Generation Potential as Measured in Incubation Tests
Source: Erwin Binner (2002) The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour, Paper Presented to the European Commission Biowaste Workshop, May 2002.

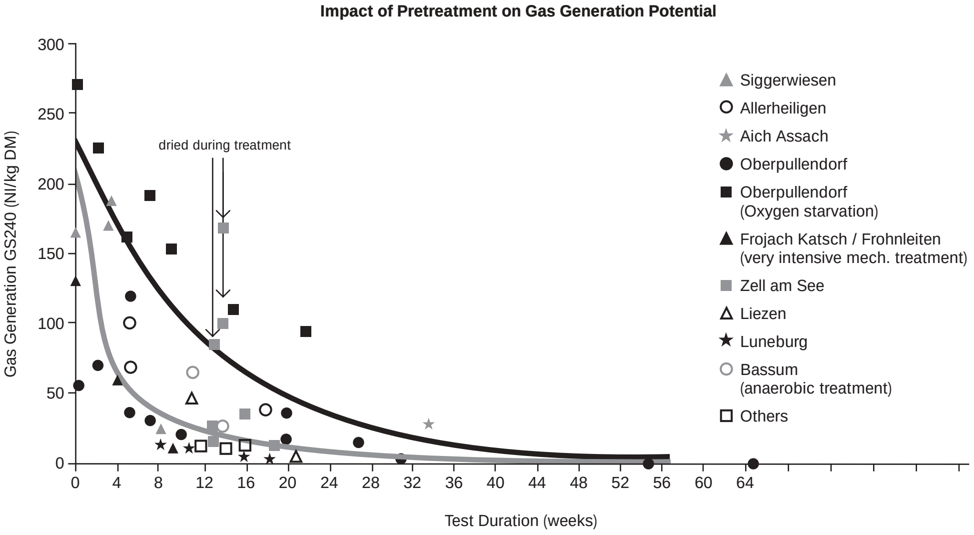


Figure 14: Illustration of Impact of Length of Pre-treatment on Gas Generation Potential
Source: Erwin Binner (2002) The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour, Paper Presented to the European Commission Biowaste Workshop, May 2002.

Recalling the discussion concerning stability limits, the cost implications of the setting of a standard at one or other level are made clearer. The longer the pre-treatment time, the higher the cost of the pre-treatment. Yet, as mentioned above, the incremental reduction in gas generation potential with increasing duration of pre-treatment falls over time. Effectively one reaches diminishing marginal returns where the incremental gain in terms of reduced gas generation potential exceeds the costs of those further reductions. This is the argument used by the Italians to support their standard – the costs of achieving such a standard are significantly lower than those required to meet German or Austrian standards for stability yet the environmental gain is not significantly less.

These results are broadly consistent with those from German studies, in which fermentation tests were carried to assess gas generation.[48] According to the regulations in Germany, gas formation (GF) should be observed for at least 21 days = GF_{21}. Importantly, because of the low level of fermentability of waste after MBT, no statement was considered possible concerning a gas potential during this period.

Interestingly, in these tests, the “extensively stabilized” sample of waste led to no more measurable production of gas after 8 weeks of the test. Up to this point in time, on average 2.69 Nl/kg DS gas was formed. By the end of the test, the methane content was at ~40 vol.%. In Figure 17 below, the volume of gas produced was expressed in relation to the organic dry matter (oDS), as only this can be potentially converted into landfill gas. In so doing, a better comparability of the test results can be achieved. The plots refer to outputs from plants achieving differing levels of stabilization. The shape of the curves is similar to Binner’s above.

Figure 15 demonstrates that the gas formation rates of the “less-well stabilized” waste, MB-QB2, MB-HP1 and MB-LF1 show similar orders of magnitude and are initially in the region of ~0.15-0.6 Nl/kg oDS x d.

The gas formation of the test materials was also measured under high compression in landfill simulation reactors (compression pressure = 250 kN/m^2). The tests were carried out under mesophilic conditions of 35˚C and with an average water content in the reactor of 30-35 wt. % (WS). The materials in this were mostly incorporated with their original water content and, due to the release of water within the framework of the infiltration tests, were saturated to the water content referred to above.

Figure 16 shows a comparison of the measurements with reference to the gas formation on the organic dry materials. The gas formation of the landfill tests with the “less-well stabilized” waste, MB-QB2-D-1, MB-LF1-D-1, and MB-WS1-D-1, was initially between 0.01 and 0.15 Nl/kg oDS x d. A comparison between the two figures shows that the results in the fermentation test at 35˚C and 90 wt. % (WS) water content, intended to mimic ‘real conditions’, reveal that the initial gas formation rates in the fermentation test are lower by a factor of 4-15 (the linear projections bounding the plots in the two Figures show much shallower gradients in Figure 15 than in Figure 16).

One of the measures of stability, the dynamic respiration index (DRI), aims to assess stability in a quick test of the material. DRIs for different materials are shown in Table 29. This clearly shows the effect, in Italian waste management systems, of source separation on the fermentability of the residual material. Furthermore, it shows that door-to-door source separation systems reduce the DRI of residual waste much more effectively than systems which are based upon road containers (effectively communal bring schemes). Conversely, the DRI of separated organic fractions from door-to-door systems is much greater than those where the collection approach is through road-containers. Hence, not only does the DRI Table illustrate the value of stabilization of the residual waste through MBT / BMT, but it also shows how source separation can, through reducing the biowaste content of residual waste, significantly alter the nature of residual waste.

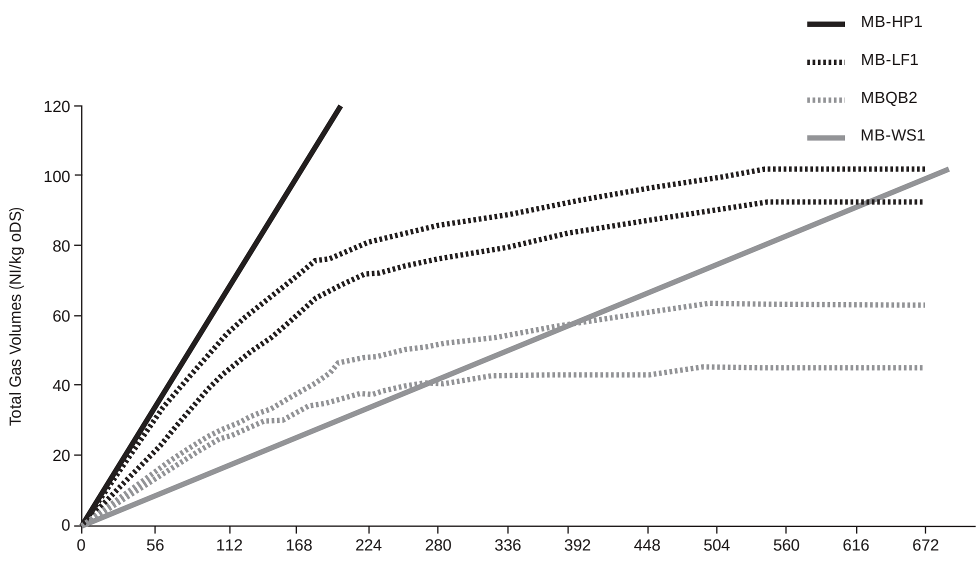


Figure 15: Comparison of the fermentation test with reference value oDS.

Source: Zeschmar-Lahl et al. (2000) Mechanisch-Biologische Abfallbehandlung in Europa, Berlin: Blackwell Wissenschafts-Verlag GmbH

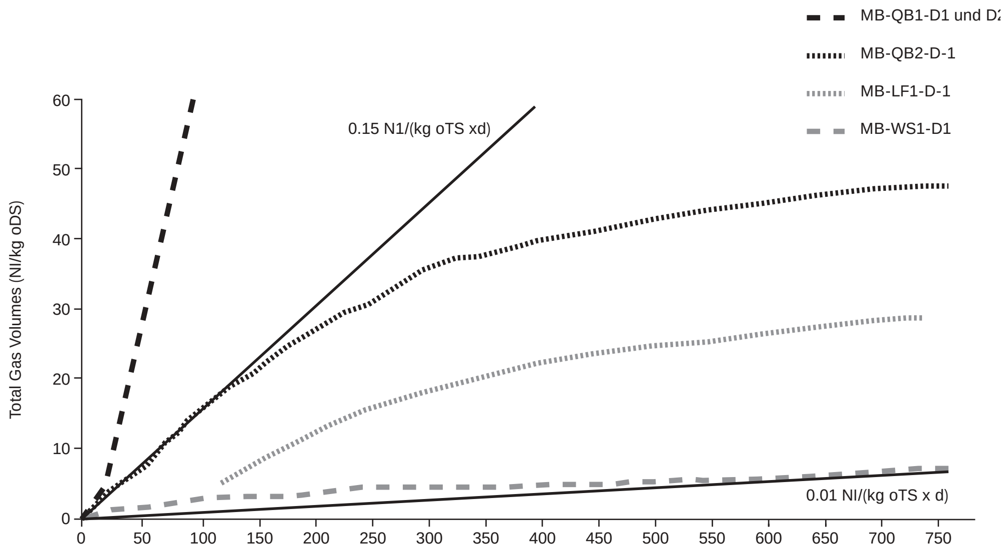


Figure 16: Comparison of the gas formation of the landfill tests with reference value oDS.

Source: Zeschmar-Lahl et al. (2000) Mechanisch-Biologische Abfallbehandlung in Europa, Berlin: Blackwell Wissenschafts-Verlag GmbH

Table 27: Dynamic Respiration Indices for Different Waste Fractions

DRI (mg O 2 kg VS -1 h -1)	**Typology**
70-150	MSW landfilled (age : 20 years)
200-500	Evolved compost (OMEI > 0.6)
300-400	Residual waste from door separate collection (dry fractions)
500-700	MSW Biodried/biostabilized (10-12 days)
800-1000	Residual waste from double road containers (dry fractions)
800-1200	Stabilized OM from mechanical separation (15-30 days)
1000-1300	Residual waste from road containers (dry + wet fractions= MSW)
2000-2800	Organic matter from mechanical separation of the MSW (Ø < 50-60 mm)
2500-3500	OM sep. collection/lignocellulosic (2:1 p/p)
4000-5000	Separate collection (OM= 80-85 % p/p)

Source: Adani et al (2002) Static and Dynamic Respiration Indexes – Italian Research and Studies, Paper to the European Commission Technical Workshop on Biowaste.

Leachate Emissions from Landfill

AEA Technology report that long-term behaviour of highly stabilised MBT residue has been predicted from a series of detailed experiments using landfill simulation reactors.[49] Consistent with the above discussion, the results showed that:

1. MBT reduces the landfill gas emission potential by 90% compared with untreated MSW. The remaining emission potential is characterised by half-lives of 15 – 30 years, about 10 times longer than for untreated MSW. The authors conclude that the slow rate of residual CH_4 emission means that methane oxidising organisms in the cover soil will, in all probability, oxidise all of the CH_4 released (as discussed above, this should be contextualised by knowledge of the duration of the pre-treatment process);
2. MBT residual waste can be compacted to very high density in landfills (ca 1.5 tonnes / m^3, which results in very low hydraulic conductivities (in the range 1 x 10 -10 to 5 x 10 -9 m/s). As a consequence of the low infiltration of water, leachate production is minimised and the total nitrogen and total carbon content of the leachate reduced by up to 95% and 80 - 90 % respectively.

The latter findings are confirmed by Binner who reports on the lower permeability of landfilled waste from mechanical biological pre-treatment.[50] This can however lead to problems of placement and the smaller particle size reduces the friction angle giving rise to problems of stability of large quantities of the material.

Some illustrations from Binner's report are given below. The first shows that mechanical biological pretreatment (MBP) reduces ammonia-nitrogen concentrations in leachate significantly relative to the situation in which no pre-treatment occurs. The age of the site also affects the concentrations.

Studies by the German Federal ministry of Education and Research (BMBF) and the state of Hessen, discussed earlier in the context of gas formation, also investigated leachate pollution in compacted bodies of waste of mechanically-biologically pretreated waste.[51] During tests in landfill simulation reactors, the heavy metal concentrations in the leachate decreased over the course of the tests, with all materials. However, with the organic substances contained in the leachate, the COD (chemical oxygen demand) level, the nitrogen parameters and the anionic salt components, relevant concentrations in the leachate are still detectable in later phases of the tests, in all cases.

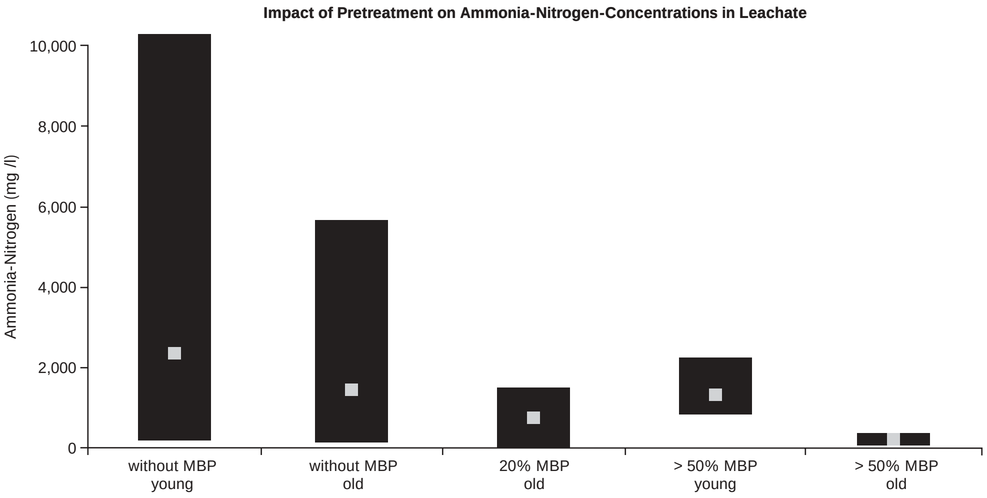


Figure 21: Impact of Mechanical Biological Pre-treatment on NH3-N Concentrations in Leachate
Source: Erwin Binner (2002) The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour, Paper Presented to the European Commission Biowaste Workshop, May 2002.

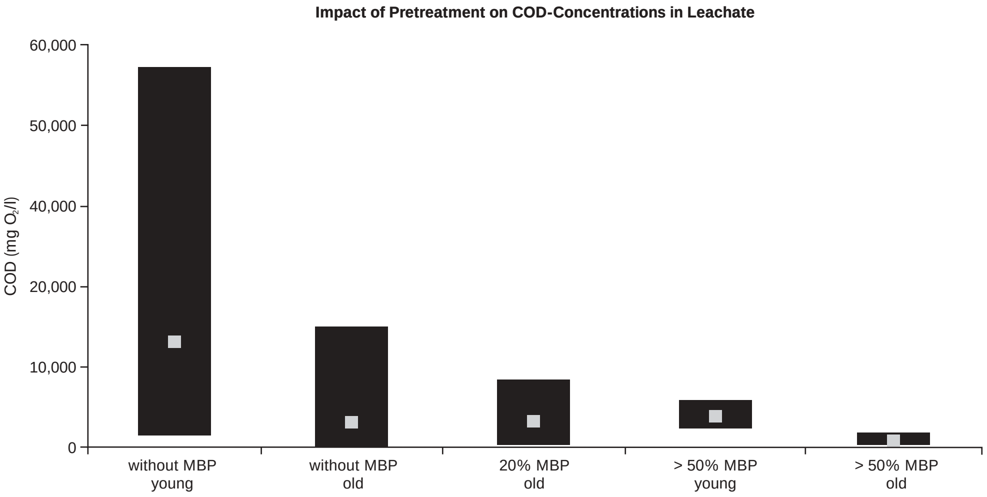


Figure 22: Impact of Mechanical Biological Pre-treatment on COD Concentrations in Leachate
Source: Erwin Binner (2002) The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour, Paper Presented to the European Commission Biowaste Workshop, May 2002.

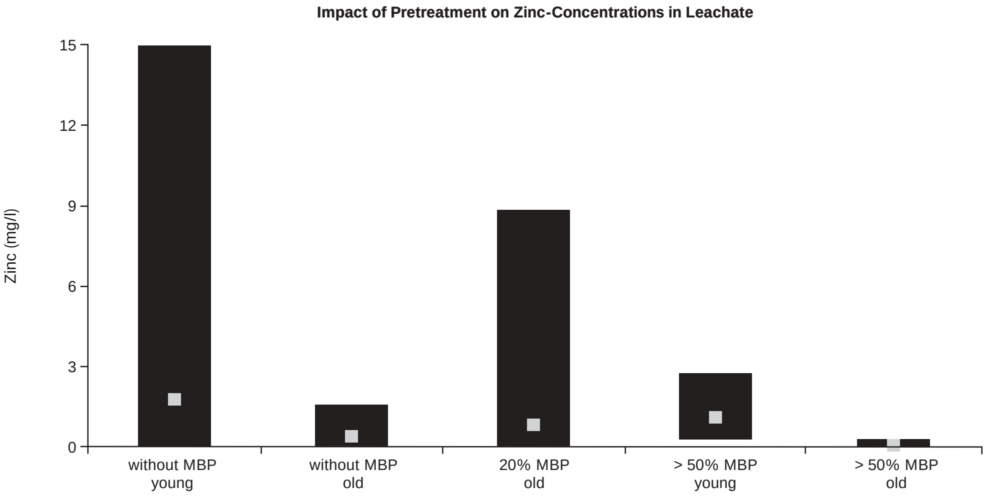


Figure 24: Impact of Mechanical Biological Pre-treatment on Zinc Concentrations in Leachate
Source: Erwin Binner (2002) The Impact of Mechanical-Biological Pre-treatment on Landfill Behaviour, Paper Presented to the European Commission Biowaste Workshop, May 2002.

Physical Characteristics

After MBT, in comparison with untreated municipal waste, waste becomes a relatively homogeneous mixture which is optically somewhat similar to composts derived from surce separated materials. Waste after MBT could only be differentiated from composts by an increased proportion of synthetics, textiles and composite materials. Even when this material strongly shapes the appearance of the waste, its proportion of the bulk of the waste is relatively low (0.5-3 wt. % of the DS or 3-10 wt. % of the oDS). A mathematical estimation of the synthetic fraction from the sort analysis before the pretreatment produced proportions of 5-8 wt. % of the DS or ~15-25 wt. % of the oDS. This leads to its own problems since clearly the 'invisible' contamination suggests that in terms of specific qualities of environmental and agronomic relevance for the application of such material, MBT residues are quite different from biowaste composts (and hence, residues ought to be restricted in the way in which they may be applied, as indeed they are in many countries with standards for quality compost).[52] A clear need for some form of standards exists.

Table 28 gives an overview of the incorporation characteristic values of reactor tests from the studies by the German Federal ministry of Education and Research (BMBF) and the state of Hessen,[53] Germany. Proportionally high permeabilities were measured in the bodies of the waste which had been incorporated in a relatively dry condition. Different columns relate to different pre-treatment concepts and durations.

With waste which was incorporated in a damp condition, generally very low permeability values for water became apparent, from 4.2 x 10^{-8} to 1.0 x 10^{-10} m/s (see Table 29). It is however to be assumed from it that the water permeability is likely to be greater under landfill conditions than the values measured under laboratory conditions.

With the waste which was incorporated in a damp condition, high water *saturations* were shown from the beginning onwards, of sometimes > 90 vol. %. With some of these tests, consolidation water came out during the compression. Mathematical estimations revealed that with the given incorporation densities, a complete saturation from around 35 wt % (WS) water content can occur. In exceptional cases such as MB-WS1 even from around 30 wt % (WS) (see water content with full saturation in Table 29). This means that with the incorporation and compaction of materials with a water content of around 30-35 wt % (WS), a compression water discharge must be reckoned on, which was also confirmed in the tests.

Model considerations further showed that with a low hydraulic conductivity of the body of the waste and with a very damp incorporation of the waste, there is a danger of consolidation settlements over a long period. From tests it was estimated that this danger can be clearly reduced by the reduction of the water content before the incorporation of the waste.

The incorporation conditions also have consequences for gas permeability. This is heavily dependent on the proportion of gas pores of the waste input to the landfill. Experimentally determined diffusion resistance factors for compressed bodies of waste are in the region of 30-50 with gas pore proportions of 30-40 vol. %. The gas pore proportion diminishes with increasing water content. With high water contents the diffusion resistance factor increases to values which lie one to two orders of magnitude above this value. In particular with high saturation (> ~80% total pore volume), an active degassing of the landfill body becomes awkward. Model calculations show that even in MBT landfill sites without surface insulation, and with very low respiration rates of 25 mg O_2/kg DS x d (RS_4 – value of 0.1 mg O_2/g DS), anaerobic conditions are to be expected in the body of the landfill.

On the basis of the very low gas formation rates in combination with the low gas permeability rates, the planning of a conventional active degassing is advised. It can be expected that an active degassing for an MBT landfill site with "well stabilized" waste is not practicable. For this reason, it seems more promising to implement a passive degassing by gas drainage at the landfill surface and base. With large landfill heights and very low permeability, flat degassing elements or trenches in the body of the waste should additionally be envisaged.

Binner reports that relative to untreated waste, waste pre-treated through MBT has:

- higher compactability (1.3 t/m 3, facilitating a reduction in volume)
- lower permeability (10^{-10} m/s, reduction of leachate)
- low particles size (< 15 - 35 mm, calorific value)
- problems in placement (rainfall)
- problems in structural stability (a reduction of friction angle is experienced related to the smaller particle size as follows)
  < 12 mm ➡ ø = 31°
  < 25 mm ➡ ø = 32°
  < 40 mm ➡ ø = 37°
  < 80 mm ➡ ø = 40°[54]

Hence, waste pre-treated using MBT experiences changes which are positive, as well as ones requiring new management approaches.

Table 28: Incorporation characteristic values of the bodies of compost at the beginning of the test.

Waste batch		**MB-MH1**		**MB-QB1**		**MB-QB2**	**MB-LF1**	**MB-WS1**
Test		**D-1**	**D-2**	**D-1**	**D-2**	**D-1**	**D-1**	**D-1**
Water content *w*		Dry	original	dry	original	original	original	original
Wet weight *ww*	wt %	7.4	34.0	16.9	30.1	27.7	35.6	27.8
Dry weight *wd*	wt %	8.0	51.5	20.3	43.0	38.3	55.3	38.5
Incorporation density								
Wet density *Qw*	kg/m^3	1,032	1,385	1,062	1,218	1,155	1,479	1,610
Dry density *Qd*	kg/m^3	956	914	883	852	835	952	1,163
Pore level								
Total pores ψ *tot*	vol %	52.4	54.5	50.4	52.1	55.4	52.9	49.0
Gas pores ψ *g* (absolute)	vol %	44.7	7.4	32.5	15.5	23.4	0.2	4.3
Avg. saturation S *w at full saturation*	vol %	14.6	86.5	35.6	70.3	57.7	99.5	91.3
Wet weight *w*w,max	wt. %	35.4	37.3	36.4	38.0	39.9	35.7	29.6
Dry weight *w*d,max	wt. %	54.8	59.6	57.1	61.2	66.3	55.6	42.1
Height of waste Δz	m	0.71	0.70	0.60	0.73	0.67	0.64	0.62
Discharge of consolid ation water on incorporation		no	yes	no	no	no	yes	Yes

Source: Zeschmar-Lahl et al. (2000) Mechanisch-Biologische Abfallbehandlung in Europa,
Berlin: Blackwell Wissenschafts-Verlag GmbH

Table 29: Permeability coefficient and permeability on addition of water.

Waste batch		**MB-MH1**		**MB-QB1**		**MB-QB2**	**MB-LF1**	**MB-WS1**
Test		**D-1**	**D-2**	**D-1**	**D-2**	**D-1**	**D-1**	**D-1**
Permeability Coefficient ko,w	m/s	2.0E-06	7.2E-09	8.0E-09	4.9E-10	4.0E-06	>1.0E-10	4.5E-08
Permeability ko	m^2	2.4E-13	8.6E-16	9.6E-16	5.9E-17	4.8E-13	<1.2E-17	5.4E-15
Hydraulic drop I		2.7	3.3	7.2	7.3	6.5	6.9	7.0

Source: Zeschmar-Lahl et al. (2000) Mechanisch-Biologische Abfallbehandlung in Europa,
Berlin: Blackwell Wissenschafts-Verlag GmbH

Summary of Appendix

MBT landfill fractions still show residual emission potential over a period of time (both to atmosphere and water), although at a much lower level than for untreated wastes. This needs to be taken into consideration in future landfill concepts and in the passing of legislation, particularly as it affects environmental issues. These facts also ought to influence the choice of residual waste management.

Research suggests that pre-treatment of waste through MBT prior to landfilling leads to:
- reduction and stabilization of organic solids;
- better input-control at landfills;
- reduction of gas generation;
- reduction of leachate (both the amount and concentrations);
- lower consumption of landfill volumes;
- lower settlement; and
- reduction of harmful substances.

The low gas and water permeability have relevant consequences for landfill practice. Some serious engineering problems have already arisen in isolated cases in Germany, where MBT output has been used for landfill. In Bavaria, for example, in the spring of 1998, approximately 100 m^2 of a steeply laid-out embankment constructed from MBT output slipped at the Bad Tölz/Wolfratshausen landfill site. The embankment was afterwards laid out less steeply, and there have been no further problems.

The above considerations highlight the fact that MBT should be considered as part of an altered landfill concept. Combinations of questions related to this new concept and highlighted by Zeschmar-Lahl et al include those of:
- Structural stability control,
- Incorporation with controlled water content
- New concepts of leachate containment, gas drainage and surface insulation,
- Toxicological and ecotoxicological assessment of the individual substances in the TOC of the leachate; and
- Reduction of the residual methane emissions (through management processes).[55]

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