TECHNOLOGY & BUSINESS REVIEW

Mechanical-Biological-Treatment : A Guide for Decision Makers
Processes, Policies and Markets

Annexe A
Process Fundamentals

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Processes, Policies & Markets

Annexe A
Process Fundamentals

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We wish to place on record our gratitude to the many process developers, site operators and others who provided information for the preparation of this report. In particular we are grateful to the many individuals who facilitated our visits to reference plants to conduct site appraisals.

Copyright Statement

Important Note

The inclusion of a supplier or proprietary process in this report does not constitute a recommendation as to its performance or suitability. Equally, non-inclusion does not imply that that process is not suitable for certain applications.

We welcome information to assist with the preparation of any future editions of this report. The opinions contained herein are offered to the reader as one viewpoint in the continuing debate about how MBT can contribute to a modern integrated waste management system. They are based upon the information that was available to us at the time of publication – and may subsequently change.

A wide ranging study of this type may contain inaccuracies and non-current information - for which we apologise in advance. We are always pleased to receive updated information or corrections about any of the processes reviewed for possible inclusion in future editions of the report.

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SITA Environmental Trust

ABOUT SITA Environmental Trust

SITA Environmental Trust commissioned this report in 2004 to provide answers to the many outstanding questions about the future for MBT in the UK.

SITA Environmental Trust distributes funding through the Government's Landfill Tax Credit Scheme (LTCS). All the Trust's funding is donated by the waste management company, SITA UK.

SITA Environmental Trust:

- Is one of the largest distributors within the LTCS handling circa 10% of all funds in the Scheme
- Has allocated over £40M to more than 900 projects since 1997
- Has been a strong and focused investor in sustainable waste management projects
- Is planning to invest circa £30M over the next five years in community and environmental improvement projects across the UK

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ASSURRE

ABOUT ASSURRE

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ASSURRE's approach is to:

- Raise the level of informed debate as regards the key issues of sustainable resource management and feed expertise into the EU institutions
- Uphold the vital link between EU policy formulation and implementation and ensure that experiences on the ground are fed back into the decision-making system.
- Commission Best Practice case studies and share lessons learned
- Track key issues and developments in technology and policy

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Separate Tables of Contents are also included at the start of each Annex and a Guide to the various sections is included on page A-5

Format of the Report : electronic, downloadable pdf

This report consists of a **Summary Report**, **4 Annexes** and an **Executive Summary**.

All parts of the report can be downloaded free of charge from the SITA Environmental Trust (www.sitaenvtrust.org.uk), ASSURRE (www.assurre.org) or Juniper (www.juniper.co.uk) websites (please bear in mind the file size when downloading!). Alternatively a CD-ROM containing a complete set of files is available to order from Juniper at a nominal charge.

Section	Scope
The Summary Report	Contains key findings about the role that MBT can play, assesses recycling and diversion performance, and reports on the issues and challenges that will affect its wider adoption
Annexe A: Process Fundamentals	Details the types of MBT system, related technologies and their key differences
Annexe B: Issues arising out of the Regulatory & Policy Framework	Identifies and discusses the key EU and UK policy initiatives and regulations and assesses their impact on the uptake of MBT
Annexe C: An Assessment of the Viability of Markets for the Outputs	Examines market constraints, technical obstacles and considers supply and demand issues related to fuel and soil improver applications
Annexe D: Process Reviews	Provides independent reviews of 27 commercial MBT processes and comparative analysis of these
Executive Summary	Summarises key conclusions

A1 Introduction

A 1.1. The purpose of this Annexe is to provide the reader with an overview of the fundamentals of the various technologies and systems that are used in MBT plants.

A 1.2. Although this Annexe touches on aspects of the underlying science and operation of some of the technologies, we have not attempted to provide exhaustive information about any one type of technology. For example, much more in depth information about phenomena such as anaerobic digestion can be found in the literature, where detailed design and operational aspects are covered and where the pro's and con's of the various industrial AD designs are presented for different applications.

A 1.3. In this Annexe we have;

- explained the array of acronyms used to refer to different types of MBT;
- assessed the roles of each element - **Mechanical** and **Biological** - within an integrated MBT process;
- provided an overview of the key mechanical systems used in MBT designs and assess how these can: **boost recycling**; **prepare the waste for the biological stage**; **remove contamination from MBT outputs and prepare the MBT outputs for market;**
- discussed the **core biological technologies** used in MBT plants and described the various ways in which these technologies can be configured and optimised to produce certain types of outputs; and
- outlined the potential for environmental and other impacts from MBT facilities.

A 1.4. We have also assessed and compared the eight process concepts introduced in the **Summary Report** in the context of:

- the level of biodegradation of the input waste that could be achieved;
- the type and quality of fuel that could be produced;
- the potential environmental and health impacts

A 1.5. This Annexe is one section of a report on MBT processes and their suitability for managing the residual fraction of MSW, which seeks to provide a comprehensive, objective review of the capabilities and limitations of MBT technologies in the context of evolving waste management requirements. Details of the other parts of this report, and how to obtain them, are on the previous page.

A 1.6. This study was funded by UK landfill tax credits disbursed by the SITA Environmental Trust (SET) and co-funded by ASSURRE (The Association for the Sustainable Use and Recovery of Resources in Europe). We are grateful to both organisations for their support.

A2 The MBT concept

A 2.1. The MBT (**M**echanical **B**iological **T**reatment) concept for waste processing evolved in Germany as a response to a strong desire to reduce the quantity of biodegradable waste sent to landfill and to increase the potential recovery of resources from it.

A 2.2. While MBT inherently incorporates two core stages: **mechanical** treatment and **biological** treatment, the different elements can be configured in various ways to meet a wide range of specific objectives:

- to maximise resource recovery;
- to produce a 'compost';
- to produce a soil improver;
- to produce a bio-stabilised material for landfilling;
- to produce a biogas for heat and/or power generation;
- to produce a 'good quality' solid fuel (SRF[1]).

A 2.3. The relative attractiveness of these objectives is influenced by the market and regulatory context, which is specific to the geography in which the process is to be operated. Hence, for example, a process designed to make a **bio-stabilised output suitable for landfilling in Germany** might be markedly different from one designed for the same objective in another EU Member State.

A 2.4. A large number of permutations are therefore possible for MBT because of the wide range of mechanical and biological elements that can be implemented (see **Figure A1**). These process operations will be described in more detail later in this Annexe.

Figure A1: Typical mechanical and biological process elements used in MBT processes

Process Stage	Possible Process Elements						
Mechanical	Trommel	Screen (static or vibrating)	Magnet	Eddy current	Hand picking	Air classification	NIR
Biological	Open windrow composting	In-Hall composting	Tunnel Composting	In-Vessel Composting (IVC)	Anaerobic digestion	Percolation	Bio-drying
NIR = Near Infrared detection – devices that make use of the absorbance of certain unique light wavelengths by materials to separate, for example, different types of plastics.							

A 2.5. The purpose of the mechanical stage is three-fold:

- to maximise resource recovery;
- to prepare materials for the core biological stage; and,

[1] SRF = Solid Recovered Fuel

- to refine outputs.

A 2.6. Which of the different core biological processes is chosen depends on a number of factors including:

- the type of output materials required (fully bio-stabilised solids, partially bio-stabilised solids, SRF or biogas);
- the quantity of waste to be treated;
- the prevailing regulatory requirements (on process and outputs); and,
- a number of other economic, technical and commercial factors.

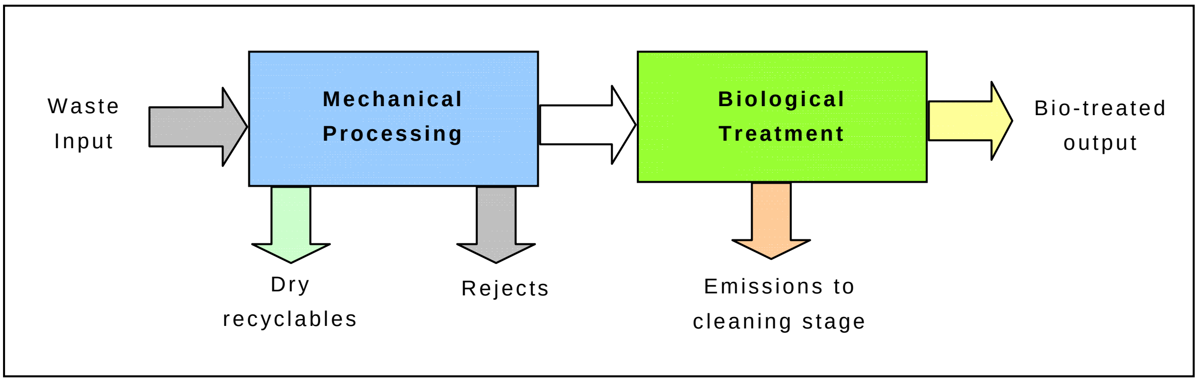
A 2.7. These factors are discussed in more detail in the section on *'Core components of MBT systems'.*

MBT and its various pseudonyms

A 2.8. There are a bewildering array of acronyms and terms, including MBT, BMT, MBS, MBP, MBV, MBA, MBR, bio-drying, waste splitting and stabilisation, used to describe processes that mechanically and biologically treat waste.

A 2.9. Most processes employ '**M**echanical' sorting, size classification or pre-treatment activities ahead of the '**B**iological' stage within the overall **T**reatment process, hence the acronym **MBT**.

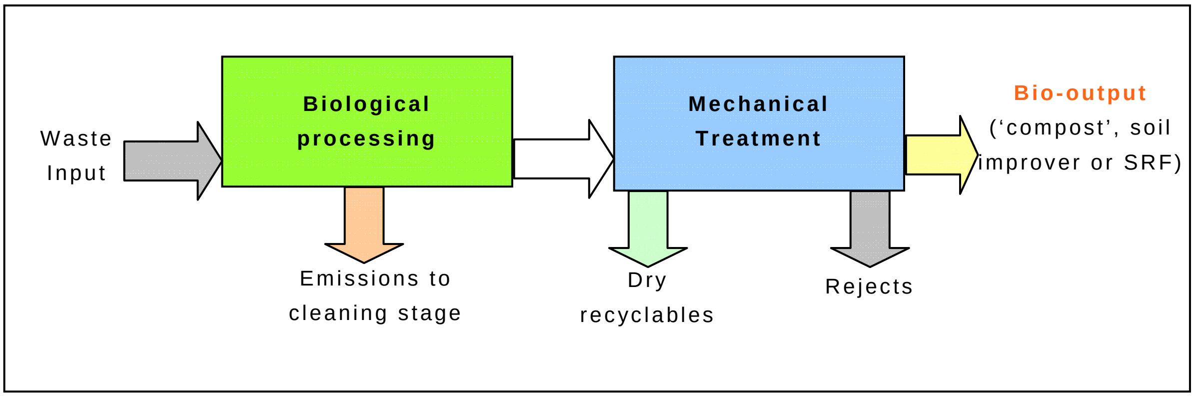
Figure A2 MBT: Mechanical Biological Treatment



A 2.10. In this process configuration only part of the waste input proceeds to the biological stage, so it is sometimes referred to as a **'waste splitting'** process.

A 2.11. In some types of process, the entire raw waste input is first processed in the **B**iological stage first followed by **M**echanical separation systems to provide an overall **T**reatment process. This configuration gave rise to the acronym **BMT** (**B**iological **M**echanical **T**reatment).

Figure A3 BMT: Biological Mechanical Treatment

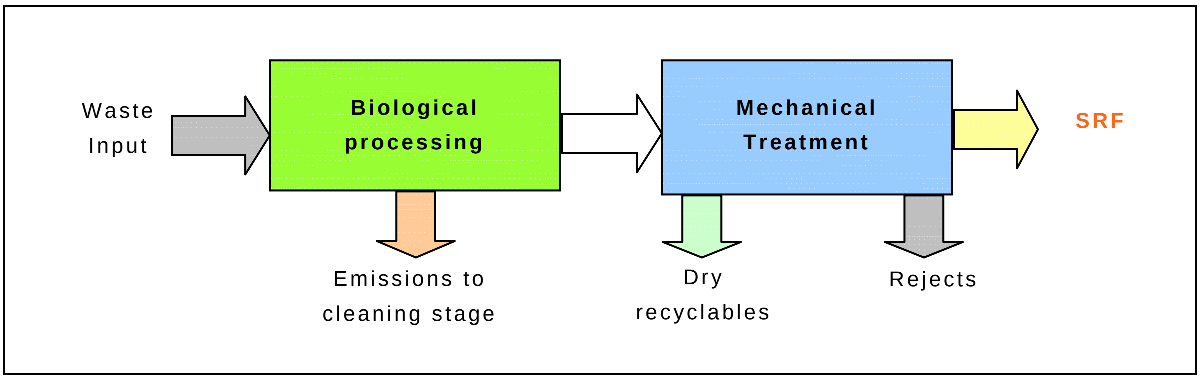


A 2.12. The acronym BMT is often used to describe those processes that biologically treat the waste, preserving its biogenous content, to give a relatively high CV solid output that could be used as a fuel (SRF).

A 2.13. There are two primary variants of this type of process:

- Stabilisation; and
- Bio-drying.

Figure A4: Stabilisation, 'bio-drying' or MBS



A 2.14. **'Stabilisation':** the acronym **MBS** (**M**echanical **B**iological **S**tabilisation) is also used to describe processes that **bio-stabilise the entire waste fraction**, preserving its biogenous content (i.e. 'bio-drying' processes).

A 2.15. **Bio-drying:** processes which preserve the biogenous content of the waste in this way utilise the biological activity of the waste to drive off moisture; and in the process of doing so, the putrescible content of the waste is also reduced, but the biological activity is insufficient to fully bio-stabilise the output.

A 2.16. So, the terms **'bio-drying'**, **'stabilisation'** and the acronyms **BMT** and **MBS** can be used interchangeably to describe processes in which the objective is to make a **fuel**.

A 2.17. However, this interchangeability is not total, because some processes that are arranged in a BMT configuration do not 'bio-dry' the waste but, instead, produce a fully bio-stabilised output, with a significantly reduce biogenous content. This is important to understand that BMT configurations are not only associated with 'bio-drying' processes.

A 2.18. Because of this potential for confusion in the use of terminology, we have concluded that the distinction between processes in which the core elements are configured as MBT and those in which the core elements are configured as BMT (the two most widely used terms in the UK) is unhelpful and often misleading. In spite of this, the various terminologies still appear in company literature and published papers from the Continent and, therefore, the differences, advantages and disadvantages need to be fully understood.

A 2.19. In fact, most processes that seek to produce a **'marketable' bio-output**, whether fully bio-stabilised or not, utilise some degree of post-biological mechanical processing to remove contaminants from the output or to change the output materials into a suitable form for their 'end-use' applications (e.g. for reducing the particle size, baling or pelletising).

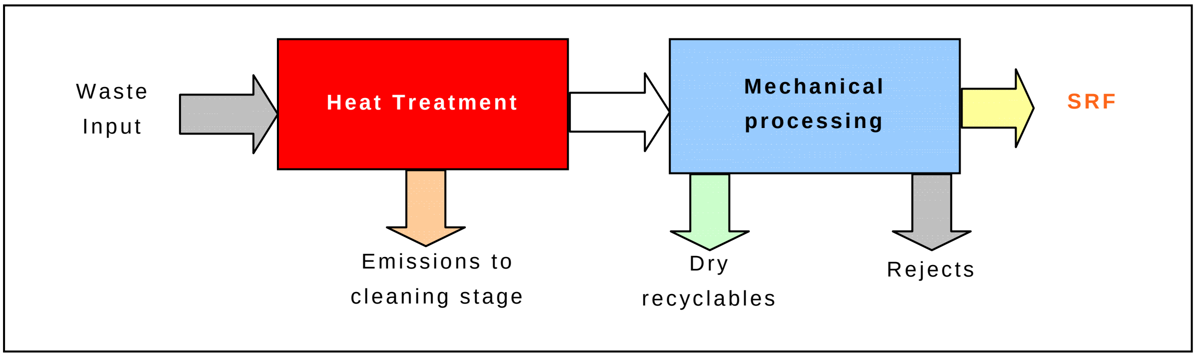
A 2.20. Naming the process by the order in which the core elements are configured leads to further confusion as many process suppliers have developed their own acronyms. Acronyms have also been derived from particular process objectives in different countries and are therefore influenced by language. For example, the acronym **MBP** (**M**echanical **B**iological **P**re-treatment) is the English translation for the German acronym **MBV** (**M**echanisch **B**iologische **V**orbehandlungs-anlage). In Germany, MBV is used to describe a process that pre-treats the waste by reducing its biological activity sufficiently so that the bio-stabilised residue can be landfilled in compliance with the requirements of the EU Landfill Directive.

A 2.21. The acronym **MBA** - **M**echanisch **B**iologische **A**bfallbehandlung (Abfallbehandlung being the German word for waste treatment) is also used in Germany and Austria and is equivalent to the acronym MBT.

A 2.22. **MBR** is the acronym for the German words **M**echanisch **B**iologische **R**estmüllbehandlung (referring to the treatment of residual waste).

A 2.23. Another more recent addition to this battery of acronyms is **MHT** (**M**echanical **H**eat **T**reatment) – developed in the UK to describe processes that utilise **M**echanical and externally derived **H**eat to achieve the overall **T**reatment of waste: thereby reducing its moisture content and sanitising the material by destroying its active bacterial content.

Figure A5 MHT: Mechanical Heat Treatment



A 2.24. **MHT** includes:

- waste drying **processes that use heat** to dry the raw waste followed by the mechanical sorting and separation of the dried and stabilised waste; and
- **autoclave processes which stabilise** the raw waste using steam at pressure followed by mechanical sorting and separation of the sterilised waste.

A 2.25. **MHT processes do not contain a biological element**, and in fact depend on the use of high enough temperatures (usually about 120^{0}C to 150^{0}C) to sanitise the waste in order to obtain an output that does not degrade biologically (ferment), which would otherwise cause storage problems, potential public health issues and odour prblems.

A 2.26. Although MHT systems are different from MBT from a process engineering perspective, functionally they are similar – i.e. they can frequently be considered for the same objectives. **But, because MHT has no 'B' element we do not review proprietary MHT processes in this report**.

A 2.27. Nevertheless, MHT processes can treat MSW, preserving the biogenous fraction of the waste to produce a relatively high CV output that can be used as a fuel.

A 2.28. MHT processes have been developed specifically to achieve the same objectives of some 'bio-drying' systems, namely to dry waste, reduce its volume and maximise recovery of recyclables. In contrast to 'bio-drying' systems, the resulting solids from MHT processes are sanitised making them easier to handle, transport and store. This and other advantages and disadvantages of MHT vs MBT are discussed later on in this Annexe.

Figure A6: List of some MHT processes suppliers in the UK

MHT process	Type of processing
Comex	Autoclave
Estech	Autoclave
Fairport	Thermal drying
Fernwood	Autoclave
Fibercycle	Autoclave
Slane/Remtech	Autoclave
Sterecycle	Autoclave
Thermsave	Autoclave

Source: Juniper database

A 2.29. The issues of SRF utilisation are discussed in **Annexe C**.

A 2.30. In the following sections we will examine the various objectives of the **Mechanical (A3)** and **Biological (A4)** stages in an MBT process. In general terms the mechanical parts of the process are included to prepare the waste, to recover recyclable fractions from the input waste and to remove inappropriate constituents of the input, whilst the biological process is employed to stabilise the organic constituents.

A3 Mechanical treatment

A 3.1. To recap, the objectives of the **Mechanical** element of MBT are:

- ⇨ to maximise resource recovery;
- ⇨ to prepare the waste for the core biological stage;
- ⇨ to refine the process outputs; and,
- ⇨ to remove inappropriate constituents within the input waste.

A 3.2. The degree to which the input waste is mechanically sorted and separated depends on a number of project specific factors, including:

- ⇨ the type of waste input, (i.e. 'black bag' or 'grey bag' waste);
- ⇨ the level of potential recyclables in the waste input;
- ⇨ the output required and hence the amount of contamination in the waste that must be removed;
- ⇨ the quantity of recycling desirable;

A 3.3. Because of the different project goals, there are MBT plants that have been designed to have complex mechanical elements, while others have very basic systems.

A 3.4. It is therefore misleading to compare the recycling performance of different MBT process because the same process could be configured with different levels of mechanical treatment depending on the specific project requirements.

Maximising resource recovery

A 3.5. **Plastics:** The source separation and kerbside separation of plastics is becoming more prevalent throughout the EU but the waste input to an MBT facility could still contain high levels of plastics (see **Figure A7**).

A 3.6. **Metals:** The quantity of **metals** in the input waste to MBT processes in most EU countries is mainly dependent on the degree of source-separation of the raw waste. In Germany, where source separation schemes are well established, the metal content of the waste input to the MBT process will be lower than that for a plant treating 'black bag' MSW (see **Figure A8**).

A 3.7. **Glass:** The quantity of glass in the input waste to MBT processes in most EU countries is also dependent on the degree of source-separation of the raw waste. Most EU Members States have significant infrastructure of 'bottle banks' and the recovery of glass is high. There is not much scope for recovering large quantities of glass from the input waste to MBT plants.

A 3.8. Recovering glass in MBT processes is a challenge especially because many of these facilities treat residual waste in which most of the glass is finely divided and cannot be recovered by hand-picking methods. This is understandable because many of the more highly engineered MBT plants are in Germany and Austria where the recoverable glass is, to a great extent, removed, via bottle banks, from the residual waste stream going to the MBT plant. Further detailed description on how these various automated systems operate is outside the scope of this report.

A 3.9. Some MBT processes, mainly in Spain, rely on hand-picking to separate differently coloured glass bottles from the untreated waste stream. In the UK the labour costs associated with this option would be high.

A 3.10. MBT processes configured to produce a soil improver or 'compost' are designed to minimise the glass content of these outputs using sieves, trommels or devices that facilitate the separation of the components of the waste by making use of their density differences. In all of these cases, the glass fraction is mixed with other 'inert' materials and more often than not, it is deemed as uneconomic to recover the glass. The 'inert' stream is usually sent to landfill.

Preparing the waste for the core biological stage

A 3.11. Biological processing of waste make use of the action of bacteria to break down the biodegradable fraction of the waste. **Maximising the percentage of biodegradable material in the input to the biological stage is one reason for waste preparation.**

A 3.12. The use of mechanical separation techniques to pre-condition the heterogeneous input waste prior to the biological processing stage is critical to the successful operation of any MBT process.

A 3.13. In the proprietary processes we have reviewed during the course of this study, three main pre-conditioning methods are used to maximise the percentage of biodegradables in the input to the biological stage of MBT:

- **'Splitting'** the incoming waste, into a coarse fraction and a fine fraction;
- Separating waste fractions by making use of the differences in density and buoyancy of its components (**Densimetric separation**);
- Using water to wash the readily dissoluble organics from the bulk waste, as in **Percolation** processes.

A 3.14. **'Splitting' the waste'** into coarse and fine fractions is normally carried out using **trommels**. The fine fraction contains most of the organic material and this is then sent to the biological stage of the process, usually after additional mechanical stages to recover recyclables and reduce contaminants such as glass and plastics.

Figure A7: Issues concerning the recovery of plastics from waste via MBT processes

Issue	Comments
Plastic types	PE (polyethylene), HDPE (high density polyethylene), LDPE (low density polyethylene), PET (polyethylene terephthalate), PVC (polyvinyl chloride), PS (polystyrene)
Techniques	At a few of the MBT plants we visited during the course of this study, PET, HDPE and other 'dense' plastic bottles and containers were being recovered by hand-picking. Only one MBT plant (Münster, Germany) incorporated automated recovery systems for recovering 'dense' plastics using NIR (Near Infrared) equipment (see the Horstmann review in **Annexe D**). Practically all of the MBT processes recover plastic film. This is carried out using air separators to entrain light materials out of the waste stream.
Drivers	**The main drivers** for recovering plastics from waste in the UK are: • the **recycling targets** set by Government for each UK local authority; • **mandatory industry targets** set by the EU in the Packaging and Packaging Waste Directive (1994), which require that Member States achieve **22.5% plastics recovery** from these materials by **2008**;
Challenges	Plastics have posed technical challenges to the anaerobic digestion component of some MBT processes. These materials float in the digester forming 'floating layers'[1], which affects the performance of the digester and hence the biogas yield and also increases maintenance requirements. In many wet digesters, the light materials are separated before the digester and sent to landfill. In some processes this material is added to the recovered solid fuel fraction (SRF) (see the SBI review in **Annexe D**).
Incentives	**There are uses** for various types of plastics contained in MSW. For example, PET and HDPE bottles are commonly recycled because the process for making new materials is energy intensive, ultimately requires a fossil fuel derived feedstock and the plastics are non-biodegradable and pose a disposal problem in many countries. Plastic film is usually recovered from the waste for use as a fuel because of the relatively high energy content (CV) (17-18 MJ/kg) normally associated with this fraction.
Advantages	• reduces contamination of outputs • helps to meet the recycling objectives of the Packaging Directive • adds energy content to an SRF product
Disadvantages	• produces a potential residue stream that will require disposal • high technology solutions will add significant costs • minimal contribution to landfill diversion targets
Impact of MBT process configuration	The quantity of plastics recovered from an MBT process will depend on the outputs the MBT process is designed to produce and the degree of contamination that those outputs can accommodate. The level of plastic materials found in the CLO from an MBT process will depend on the degree of separation and recovery upstream of the biological process or in the post-digestion refining stage (see **A 4.24**). For processes producing a fuel fraction the majority of plastics will be left in the SRF to add energy content but the process would strive to remove PVC.

1 Light materials that include corks, plastic tubes and polystyrene that float to the top of the digester. This is a problem that has been experienced in a number of wet digestion plants

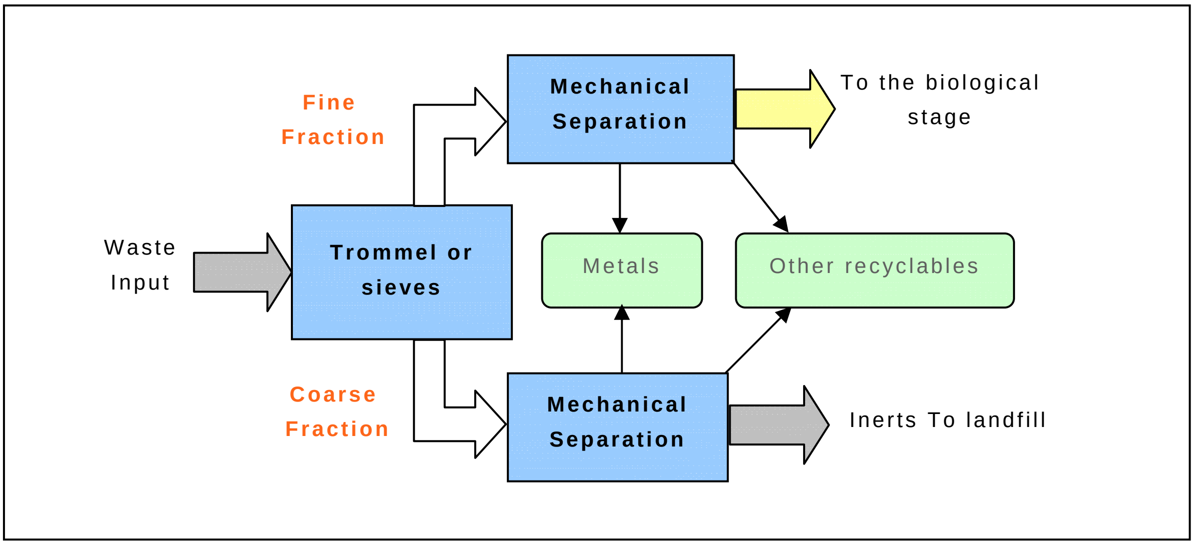
Source: Juniper analysis

Figure A8: Issues concerning the recovery of metals from waste via MBT processes

Issue	Ferrous metals	Non-ferrous metals
Metal types	Cast iron, steel and stainless steel.	Aluminium, copper, zinc, brass.
Techniques	Most ferrous metals can be recovered by using magnetic separation methods. Magnetic separation of the waste is normally conducted before eddy current separation to minimise the quantity of ferrous metals collected in the non-ferrous stream.	Non-ferrous metals can be recovered using eddy current techniques (a magnetic field is induced into the non-ferrous metals, propelling them out of the waste stream).
Drivers	**The main drivers** for recovering metals from waste in the UK are: • the **recycling targets** set by Government for each UK local authority; • **mandatory industry targets** set by the EU in the Packaging and Packaging Waste Directive (1994), which require that Member States achieve **50% metals recovery** from these materials by **2008**; • the **revenues** that can be obtained from the sale of recovered metals.	
Challenges	Whilst **most metals recovered from MSW are 'sent for recycling'**, and so count towards Local Authority recycling rates, the revenues that can be obtained by process operators for recovered metals vary widely and are often linked to their 'quality'. **The challenge** therefore for MBT processes is to recover metals with minimal levels of contamination. (Putrescible contaminants make it difficult to handle and store the metals and do cause significant odour and vermin issues. Inerts can be detrimental to the final mechanical). Some MBT processes are designed to **'split'** the incoming waste stream into 'fine' and 'coarse' fractions. The fine fraction usually contains most of the inerts and putrescibles whilst the coarse fraction contains mainly bulkier items. Metals are recovered from each fraction separately and in so doing those recovered from the coarse fraction have a lower level of contamination.	
Incentives	The UK government has set statutory targets for the various industry sectors. Because of the pressures of meeting these targets, all metals recovered from an MBT plant are desirable, but the highest prices are paid for the **best quality materials - free from external contamination**.	
	Recovery is a sustainable practice but revenue generation is potentially low	While all of the various non-ferrous metals recovered in an MBT process can be recycled, aluminium can command a high price - currently up to **£700/Tonne** in the UK market.
Advantages	• easy to recover • provides opportunity to recover a significant weight of material • increases landfill diversion • helps to meet recycling targets • removes ferrous metal from combustible SRF and CLO product	• relatively easy to recover • removal from SRF is beneficial to co-combustion application • potential high revenue product • removes aluminium from combustible SRF and CLO product
Disadvantages	• contaminated and dirty ferrous metal of less value • maximised recovery incurs greater costs • increased recovery requires more traffic movements	• low weight, high volume stream • uneconomic when input waste has been source-separated • aluminium stream can be contaminated because eddy current techniques will collect other non-ferrous metals and ferrous residuals
Impact of MBT process configuration	**The quantity and quality of metal recovery** is affected by the configuration of the MBT process implemented. Some MBT configurations in which the **metals separation takes place after the biological stabilisation** of the waste will have **less putrescible contamination** than in processes where the mechanical separation is done upfront. An advantage in recovering metals after the biological stage is that the waste is less voluminous and therefore it is easier to convey in reasonably uniform, shallow layers through the metals separation stages, which increases the recovery efficiency.	

Source: Juniper analysis

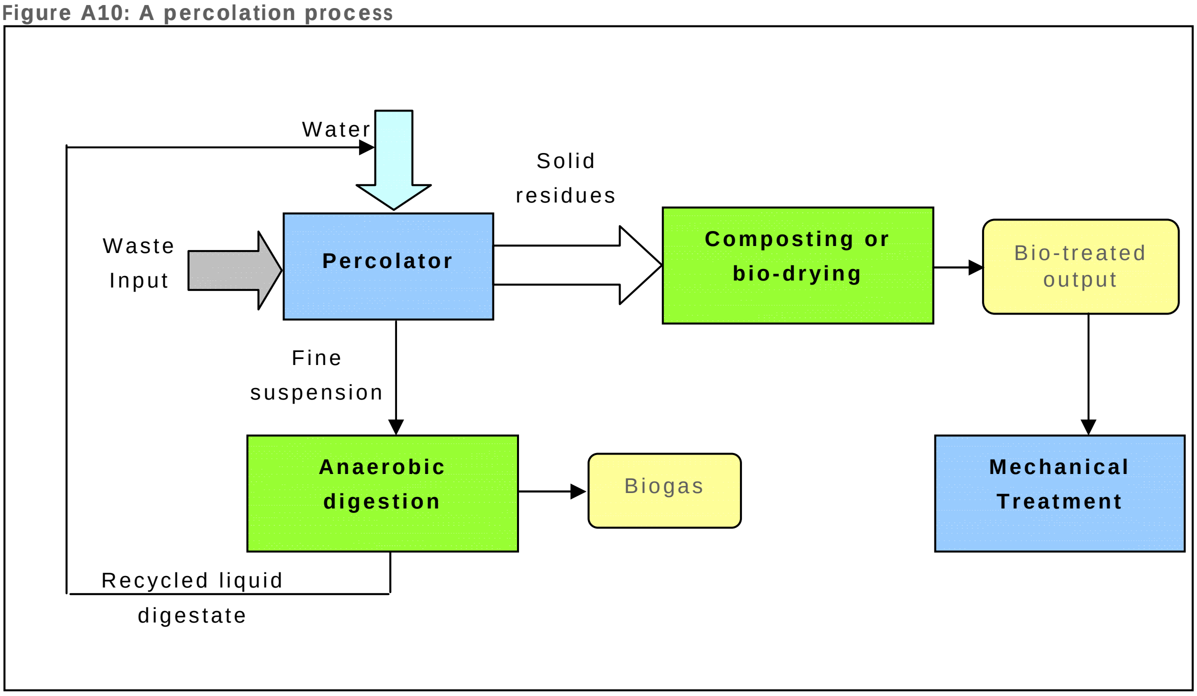
Figure A9: The waste splitting process concept



A 3.15. **Densimetric separation** of the waste is achieved by using water-based processes to separate recyclables and contaminants from the biodegradable materials. Various types of flotation and sedimentation units are used to achieve separation (e.g. see the **ArrowBio** process review and processes containing **wet AD systems** in **Annexe D**).

A 3.16. A portion of the biodegradable organic content of the waste can be washed out using water via **percolation**. Percolation is the term used by the suppliers of this type of MBT process.

Figure A10: A percolation process



A 3.17. A key aspect of percolation is that the readily soluble biodegradable organics and inorganics and the finer materials will be washed out from the waste to form a liquid stream containing dissolved and suspended solids which is then sent to the anaerobic digester. The soluble materials are more likely to be from food wastes, which usually contain a relatively high degree of biodegradable volatile solids (mainly starches), and less likely to be from wood, paper and garden waste. The latter materials are richer in cellulose and therefore less soluble in water, less easily hydrolysed than starches and they usually have lower biodegradable volatile solids content. However, this means that the percolation residues will still contain a significant biodegradable component.

A 3.18. The residual solids after percolation can be further stabilised for landfilling or bio-dried to produce SRF (see section on *'More complex MBT process designs'* below).

A 3.19. These techniques are at different stages of provenness with the trommel (waste 'splitting') and shredding methods the most commonly used (see Annexe D).

Controlling particle size of the waste in the biological stage

A 3.20. In MBT processes based on aerobic and anaerobic digestion, **the size of the waste particles processed in the biological stage is important**: the smaller the size of the particles, the more effective the temperature control, moisture distribution and mixing.

A 3.21. In order for **aerobic processes (composting)** to operate efficiently, the temperature, aeration and moisture content of the waste needs to be as uniform as possible. The smaller the particle size of the waste then the more efficient the process will be because of enhanced heat and mass transfer.

A 3.22. For **anaerobic digestion** processes, the temperature, the extent of mixing and levels of inoculum (active bacterial content), needs to be controlled. Again, small particle size is a pre-requisite for good performance.

A 3.23. The mean particle size of the input waste is controlled in various ways:

- using trommels (the most common technique) to 'split' the waste into different size 'cuts';
- shredding the waste to reduce the particle size;
- pulverising the waste in, for example, a ball mill (see **Hese** review in **Annexe D**); and,
- using combinations of these process elements.

A 3.24. In some MBT plants, the entire waste input is shredded or pulverised. The size reduced materials can be sent directly to the biological stage of the process (as in most **'bio-drying'** systems) or further processed using **trommels** to obtain a certain mean particle size to improve the efficiency of the biological stage.

A 3.25. A significant disadvantage of up-front **shredding** or **pulverisation** is that the **heavy metal contaminants** present in the input waste will be dispersed throughout the bio-fraction, and hence will contaminate the bio-treated output from the MBT process. The extent of the dispersion is a function of the input waste composition (i.e. the quantities of batteries, metal containing paints, glass and plastics) and the degree to which the waste is broken down by the shredding or pulverising pre-treatment process.

A 3.26. Although some suppliers explain that their process does not shred aggressively enough to break down batteries, the likelihood of a small, but significant, amount of metal (mercury, cadmium or nickel) contamination being dispersed through the bio-fraction is high.

A 3.27. Therefore, the way in which the waste is mechanically pre-treated could have a negative impact on the quality of the solid output from an MBT process and, as a consequence, its acceptability for many end-uses, impacting upon the economic viability of the process.

A 3.28. Size reduction methods also produce environmental impacts from **dust** and **bio-aerosols**. The smaller the particle size produced, the greater are the risks of dust and bio-aerosol generation. In addition, particles below a critical mean size can cause poor air distribution and high pressure drop in some composting tunnel designs, which can translate into relatively high energy costs.

A 3.29. **The level of heavy metals in the bio-treated outputs and the need for adequate dust control methods (to protect the health of workers) are important environmental parameters during the process design work for an MBT facility.**

Post-refining the outputs from MBT processes

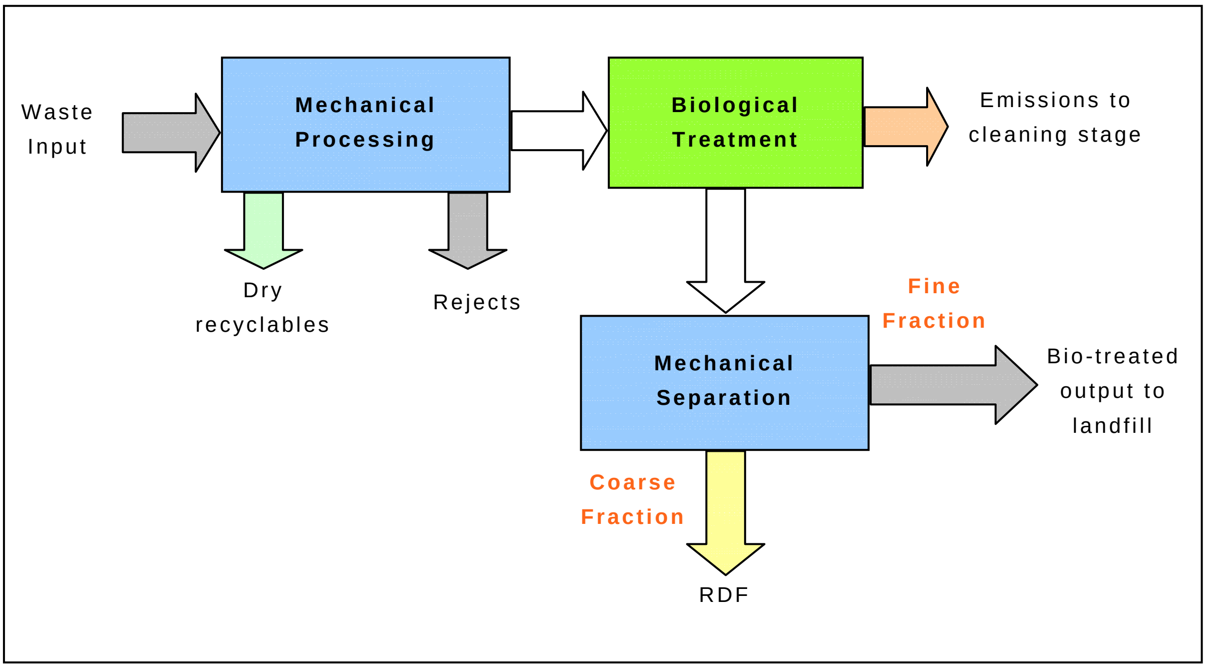
A 3.30. In order to ensure as high a quality product as possible from an MBT process the outputs must be further screened to remove undesirable materials. For MBT systems with **up-front mechanical separation** further screening is **desirable**. For **'bio-drying'** systems where the biological stage is placed first, mechanical **post-refining is essential**.

A 3.31. As we have discussed MBT processes can be configured to produce **CLO**, **SRF** or a **bio-stabilised material**. The post-refining stage can be used to:

- remove contaminants (e.g. glass, plastics, etc.);
- change the output into a suitable form for its end-use application (e.g. particle size reduction, baling and pelletising).

A 3.32. **The extent of post-refining depends on the end-use application for the material:** 'compost', soil improver, solid recovered fuel or landfill.

Figure A11: MBT with post-refining



A 3.33. The equipment typically used to remove contamination from the various MBT outputs and their respective functions are summarised in **Figure A12** and **Figure A13**.

Figure A12: Mechanical elements for post-refining of CLO

Refining CLO (soil improver or 'compost')				
Function	Removing oversized contaminants from the bio-output	Removing light plastics	Reduce heavy metal contamination	Separation and sizing organic material, which has high moisture content
Typical Equipment	Trommel or Vibrating screen	Air Separator	Screening	Star screen

Figure A13: Mechanical elements for refining SRF

Refining SRF				
Function	Removing oversized contaminants such as glass, inerts and batteries	Removing small quantities of ferrous and non-ferrous metals not picked up in the primary metals recovery stages	Reducing the size of the SRF output	Improving the ease and safety of handling, transportation and feeding
Equipment	Air separator	Magnetic & Eddy current separators	Shredder	Pelletiser

A 3.34. Heavy metals in the original input waste will be well mixed by the action of the MBT process and the solid products, SRF and 'compost'/soil improver will contain the majority of the heavy metals entering the process. The digestate from an AD plant would normally be dewatered but this would concentrate heavy metal compounds such as metal sulphides and some non-soluble organic compounds.

A 3.35. **Figure A14** lists where heavy metal contamination can be found in materials commonly found in MSW. These heavy metals can find their way into the SRF, RDF and CLO outputs from MBT plants and subsequently can be dispersed into the environment by utilisation of the MBT outputs in co-combustion and land spreading applications.

Figure A14: Possible sources of trace heavy metals in materials found in MSW

Trace element (heavy metal)	Potential source
Mercury (Hg)	batteries, plastics (PVC), fungicides, medicines, lamps, herbicides, pigments, paints, electronics, fluorescent tubes, alloys, galvanized items, fish remains
Cadmium (Cd)	plastic stabilisers, papers, paints, pigments, batteries, printing inks, galvanized items, alloys, solders, surface metal coatings, textiles, semiconductors, glazed ceramics
Thallium (Tl)	electronics, semiconductors, optics, certain types of glass, fuels, lamps, alloys, plant materials, biological tissues
Arsenic (As)	clay materials, paints, medicines, pesticides, electronics, semiconductors, cosmetics, certain glass types, alloys, lamps, leather, orchard leaves
Antimony (Sb)	plastics, alloys, electronics, semiconductors, batteries, rubber, pigments, textiles, cables, surface metal coatings, certain types of glass, medicines
Copper (Cu)	alloys, steels, electronics, papers, printing materials, paints, plastics, galvanized items, building materials, fungicides, plant matter, chicken plasma
Cobalt (Co)	alloys, steels, inks, magnets, fuels, pigments, ceramics, certain types of glass, fertilisers
Chromium (Cr)	cardboards, papers, certain types of glass, paints, pigments, leather, alloys, steels, electronics, surface metal coatings, galvanized items, fireproofing, plastics
Nickel (Ni)	alloys, steels, batteries, plastics, pigments, certain types of glass, coins, electronics, surface metal coatings, magnets, vegetable oils
Molybdenum (Mo)	alloys, steels, batteries, electronics, lamps, papers
Zinc (Zn)	alloys, printing inks, papers, rubber, plastics, batteries, surface metal coatings, galvanized items, pigments, semiconductors, pesticides, medicines, food remains
Tin (Sn)	plastic stabilisers, tins, solders, surface metal coatings, alloys, semiconductors, certain types of glass, pesticides, pigments, lubricating oils
Lead (Pb)	plastics, pipes, paints, pigments, alloys, papers, cardboards, rubber, batteries, printing inks, glazed ceramics, electronics, cables, solders, surface metal coatings, galvanized items, certain types of glass, fuels, food remains, blood
Manganese (Mn)	steels, alloys, batteries, certain types of glass, resins, pigments, galvanized items, fuels, textiles, pesticides, fungicides, fertilisers, fatty acids
Vanadium (V)	steels, alloys, electronics, textiles, varnishes, rubber, ceramics, certain types of glass, medicines

Source: Vassilev & Braekman-Danheux, Fuel Processing Technology, 59 (1999), 135-161

A 3.36. The issues concerning the possible uses of 'compost'/soil improver produced by an MBT process and their subsequent impact on land is discussed in detail in **Annex C6**.

Figure A15: Overview of post-refining operations in MBT processes

	CLO	SRF	Bio-stabilised output
Objectives	To produce a soil improver product that can be used for landscaping, agricultural and remediation projects.	To produce a solid recovered fuel with a quality and composition that would meet current and future industry, national and EU specifications for co-combustion applications.	To produce a fully bio-stabilised material that can be used for landfill daily cover and landfill top cover.
Technical challenges	If the MBT output is to be used on soil, the level; of visible contamination from plastic film need to be < 0.25% by weight, otherwise the marketability is affected (see **Annexe C6)**. Plastics recovered in the refining of the bio-stabilised output for soil applications is usually landfilled, rather than recycled, because it is contaminated with other similarly size inert materials. It is also desirable to reduce the amount of glass in the bio-output, as this is detrimental to machinery and animals when used on crops and pastureland respectively. The heavy metal contamination must be controlled and kept to a minimum. The removal of heavy metal containing waste fractions (see Figure A14) must be achieved by the upstream process.	When the MBT output (SRF) is to be used as a fuel or co-fuel, contamination from certain types of plastics such as **PVC**[1], **aluminium** and heavy metals are problematic. The end-users will usually specify limits on the level of contamination and particle size of the fuel. Aluminium melts at relatively low temperatures, which can result in slag build-up on the cooler parts of the boiler furnace. This can cause a reduction in the operational efficiency of the boiler and increase maintenance costs (see further discussion in **Annexe C4**). The size and form (pelletised, baled, etc.) of the SRF is also important for co-combustion applications. Smaller particles burn more readily and are easier to blend with other co-fuels in boilers and cement kilns, but will be a fire hazard when stored or transported. Pellets are easier to feed but expensive to produce, whilst baled materials allow more economical transportation of the SRF. The issues in blending SRF with coal in utility power plants are discussed in **Annexe C4**.	Little or no post-refining of the MBT output is performed to remove contaminants when the bio-stabilised materials are to be landfilled. However, some MBT processes (mainly in Germany) use mechanical separation systems to recover a coarse fraction, as RDF, from the bio-stabilised output destined for landfill. The length of biological processing will determine the degree of bio-stabilisation. However, if contamination of the output includes organic materials, leaving it in might result in too high a level of residual bio-degradability.

1 PVC – Poly Vinyl Chloride – generates chlorine and chlorine based compounds when burnt, which can cause corrosion problems when treated in boilers (See Annexe C for further discussion).

Source: Juniper analysis

A4 Biological treatment

A 4.1. **The choice of the biological element is intrinsically linked to the desired output from the MBT process.**

A 4.2. As discussed earlier in this Annexe, MBT processes can be designed to:

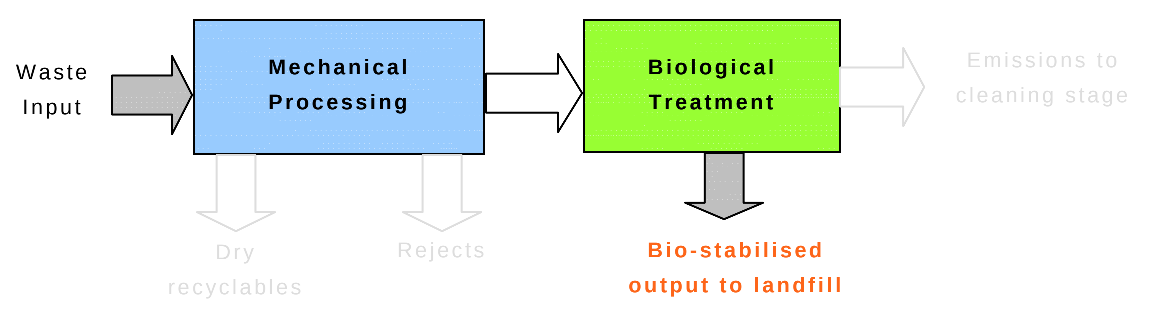
- produce a bio-stabilised material for use in landfill;
- produce a 'Compost-Like-Output' (CLO);
- produce a biogas for heat and/or power generation;
- produce a 'good quality' solid fuel (SRF) for co-combustion applications.

A 4.3. Often, it is desirable to produce more than one of the above outputs. In such cases, the MBT process design may have more than one biological element.

Producing a bio-stabilised output for use in landfill

A 4.4. MBT processes were originally developed in Germany to bio-stabilise MSW to the degree necessary to enable deposition in a landfill and meet the requirements of the EU Landfill Directive. The bio-stabilisation reduces the biological activity of the landfill and causes less methane[1] gas generation.

Figure A16: Bio-stabilised output to landfill



A 4.5. This objective is central to many of MBT processes being operated in Germany and as a consequence, much of the research on the bio-stabilisation of MSW has taken place

[1] The emission of methane from waste landfill is a contributor to 'greenhouse' gases emitted to the atmosphere.

there. This management route for the bio-stabilised output is also common in Italy and to a lesser extent Austria.

A 4.6. Currently, **only MBT processes that utilise composting**[1] **(aerobic digestion) can sufficiently bio-stabilised the MSW input** to meet the landfill requirements in Germany, Italy and Austria.

A 4.7. The requirements of the UK ABPR (as discussed in **Annexe B4**) mean that **in-vessel composting is the only relevant composting technology that can be implemented in the UK for treating MSW, if the bio-output is to be used on soil**. It is possible that other composting technologies[2] could be incorporated in MBT designs if the bio-stabilised output is to be used in landfill applications.

A 4.8. Nevertheless, it is unlikely that an MBT process based on 'open-air' composting of MSW would obtain the necessary waste management licence and IPPC certification to operate in the UK.

A 4.9. Because tunnels[3] are often used for in-vessel composting, the term **'tunnel-composting'** is sometimes used to describe the technology. In other instances the composting process is carried out in large enclosed buildings, referred to as 'halls' and the terms **'in-hall composting'** or **'in-building composting'** have been used as descriptions.

A 4.10. In aerobic composting processes, the degradation of biodegradable materials occurs, as the name implies, in the presence of oxygen (i.e. in contact with air).

A 4.11. The waste passes through a wide range of temperatures over the course of the active aerobic composting period. As the temperature varies, conditions become unsuitable for some micro-organisms while at the same time becoming ideal for others.

A 4.12. The material being composted requires water and a controlled flow of air to support bacterial growth. The degradation process releases heat and waste gases (mainly CO_2 and water vapour), which are also controlled to optimise the temperature of the composting process and thereby the bacterial activity in the waste.

A 4.13. Proprietary systems differ in the ways in which:

- the process parameters are controlled;
- the various inputs (air and water) are administered;
- the outputs (waste gases and leachate are managed);
- the waste is handled before, during and after composting.

[1] Aerobic digestion processes were traditionally used to produce compost from green waste, hence the term 'composting'. It is important to realise that not all processes that are called 'composting' produce a compost that can be used on soil.

[2] Composting technologies range from rudimentary approaches, such as open air compost heaps and windrows for green waste, to complex heated in-vessel systems, which can be used to either dry or fully digest putrescible wastes (such as, kitchen food waste).

[3] Rectangular reactors made from concrete or steel

A 4.14. For instance, some proprietary systems use **recycled process air** to control the temperature and humidity of the process while others do not.

A 4.15. In some systems air is supplied under slight pressure **through in-floor vents**, while others utilise an **air suction** configuration that draws the air through the waste, or both.

A 4.16. Some processes use manual feeding of materials using mechanical loaders, while others feed and discharge the waste from the composting process using automated systems.

A 4.17. Some of the suppliers of proprietary MBT processes that we have reviewed in Annexe D, have operating reference plants producing a bio-stabilised output from MSW for landfill applications. A list of these suppliers can be found in **Annexe D2.**

A 4.18. The advantages and disadvantages of the process variants described in **A 4.14** to **A 4.16** are summarised **Figure A17**, along with the various unit operations and operational parameters used in MBT plants that incorporate aerobic composting. The information in **Figure A17** is not specific to producing a bio-stabilised material suitable for use in landfill, but it is helpful in summarising how some of the process design choices can influence the operation of the plant and the quality of the bio-stabilised output from the MBT process.

A 4.19. In **Germany and Austria**, a minimum of about **8 weeks** of composting is required to reduce the respiration activity (see **Annexe B**) of the waste to a level suitable for landfilling, while in Italy about 4-6 weeks is required (as discussed in **Annexe B3**).

Producing a compost-like output (CLO)

A 4.20. **Aerobic composting process can also be configured to produce a CLO to be used on soil.**

A 4.21. The three key stages in the MBT process that determines the quality of the CLO are:

- the residence time and control of the composting process;
- the length of time for maturation; and
- the degree of post-refining.

A 4.22. **To use CLO on soil in the UK, the MBT process has to be UK ABPR compliant (see Annexe B).**

A 4.23. Currently, most of the Continental MBT systems do not fulfil the requirements of the UK ABPR regulations and therefore would need to be modified, to various degrees, to produce CLO that could be used on soil in the UK.

A 4.24. Some MBT processes, which produce a CLO, are designed to shorten the time period for the composting phase, in some cases to as low as seven days.

A 4.25. If the CLO does not undergo sufficient maturation after the intensive composting stage, then it is likely to be of a poorer quality than CLO obtained from well designed processes that compost waste and mature the output for longer periods of time.

A 4.26. The maturation stage is important if the materials are to be used on soil as it balances the C:N[1] ratio and reduces the levels of some organic acids, which could be damaging to soil. In addition, the formation of humic acids, which stabilise the CLO, is completed during the maturation stage.

A 4.27. Use as a soil improver on crops and pastureland requires high levels of maturation, but there are significant issues associated with using MBT-derived composts in such applications, which we discussed in **Annexe C6**.

A 4.28. CLO that has lower levels of maturation might be limited to applications like landfill daily cover and landfill final cap.

A 4.29. The post-refining stage is important in removing contamination from the CLO. Essentially, processes designed to significantly reduce the levels of heavy metals and visual contamination in the CLO will produce a more acceptable product that could be more attractive to end-users in the UK.

Producing a biogas

A 4.30. **Biogas** is a mixture of **methane (CH_4)** and **carbon dioxide (CO_2)**. **Only anaerobic digestion (AD) processes can produce biogas**.

A 4.31. **AD** differs from **aerobic composting** in that the degradation of biodegradable materials occurs in the **absence of oxygen**. The process also produces a digestate (undigested materials, typically inorganic mineral matter).

A 4.32. Usually, the biogas is cleaned to reduce its moisture content and remove H_2S (hydrogen sulphide) before it is pressurised and injected into gas engines. The gas engines generate electricity. Heat can also be recovered from the cooling system for the gas engines and this has been designed into some operating MBT plants.

A 4.33. The different configurations for managing the digestate fraction from AD are discussed later in this section.

A 4.34. In commercial systems the waste digestion is carried out in one vessel **(single- stage AD)**, or two vessels **(two-stage AD).**

A 4.35. Digesters have been implemented in MBT configurations to operate with minimal water addition (called **'Dry' AD**) and to treat suspensions or slurries (called **'Wet' AD**).

[1] C:N ratio refers to the carbon to nitrogen content of the 'compost'. If the C:N ratio is too high the compost will contain insufficient nitrogen to support the growth of micro-organisms.

Figure A17: Assessment of various systems and parameters used in composting-based MBT processes

SYSTEMS	ADVANTAGES	DISADVANTAGES
Air suction systems	Down-flow air suction is said to reduce dust and bio-aerosol emissions Reduces 'mist' and dust in 'in-hall composting' systems	Fine materials can be sucked through in-floor vents causing blockages
Positive pressure air supply	Enhances aeration and therefore the control of the composting process	Can cause high levels of dust especially in 'in-hall' composting systems, which could lead to a higher risk of bio-aerosols
Automated feeding and discharge systems	Less exposure of workers to waste, dust and bio-aerosols Less cross-contamination issues, which could be beneficial for meeting the requirements of the UK ABPR	Relatively high maintenance Relatively high capital and operating costs
'Manual' feeding and discharge	Relatively inexpensive and reliable	Exposure of workers to waste, dust and bio-aerosols Potential cross-contamination issues
Compost Turning	Improves homogeneity ensuring that oxygen (air) gets to all parts of the waste, thus ensuring that part of the waste does not start to degrade anaerobically (which will increase odours and reduce degradation rates) Prevents channelling, caking and drying Enhances biodegradation	Dust and other bio-aerosol risks Capital intensive machinery required
DESIGN PARAMETERS	**ADVANTAGES**	**DISADVANTAGES**
Water & moisture addition	Water levels are usually maintained to between 40 and 65% for the composting process to take place	Below 40% moisture - the composting process becomes inhibited Greater than 65% moisture - water replaces air in the pore spaces of the waste and process can become anaerobic
Air recirculation	Reduces fresh air requirements Reduces loading on off-gas cleanup systems such as biofilters and RTO's	Complex air mixing and control system Could, in some cases, introduce cross-contamination issues
Use of RTO's	Good abatement of all emissions from composting processes including TOC (total organic carbon)	High capital and operating costs as a result of the need for fossil fuel usage Potentially significant visual impact because of the need for a fluegas stack
Co-composting	Co-composting MSW with sludges provides additional nutrients (mainly nitrogen) for the bacteria to grow; enhancing bio-degradation	Odour issues in handling, storing and using materials such as sewage sludge
'Structure' materials	Cellulose based materials are added to lower the bulk density of the waste thereby improving aeration	Potentially increased cost and storage requirements
Thermophilic or mesophilic	Pathogen kill better with thermophilic Mesophilic systems are less energy intensive	Environment Agency may require thermophilic because of ABPR related concerns.
Particle size	Small particles enhance the bio-degradation rate. Optimum sizes are usually between 5-50mm	Very fine particles increase the pressure drop across the materials being composted and therefore reduces the aeration and thus the rate of bio-degradation

Source: Juniper analysis

A 4.36. Some digestion systems are designed to operate at temperatures of about 35°C, where mesophilic[1] bacteria thrive, while others are designed to operate at higher temperatures of about 55°C, where thermophilic[2] bacteria predominate. The former is referred to as **'mesophilic AD'** and the latter as **'thermophilic AD'**.

A 4.37. Process suppliers implement differing strategies in:

- pre-treating the waste before the anaerobic digestion process;
- the design of the digester to optimise biogas yield and to minimise downtime; and,
- biogas cleaning.

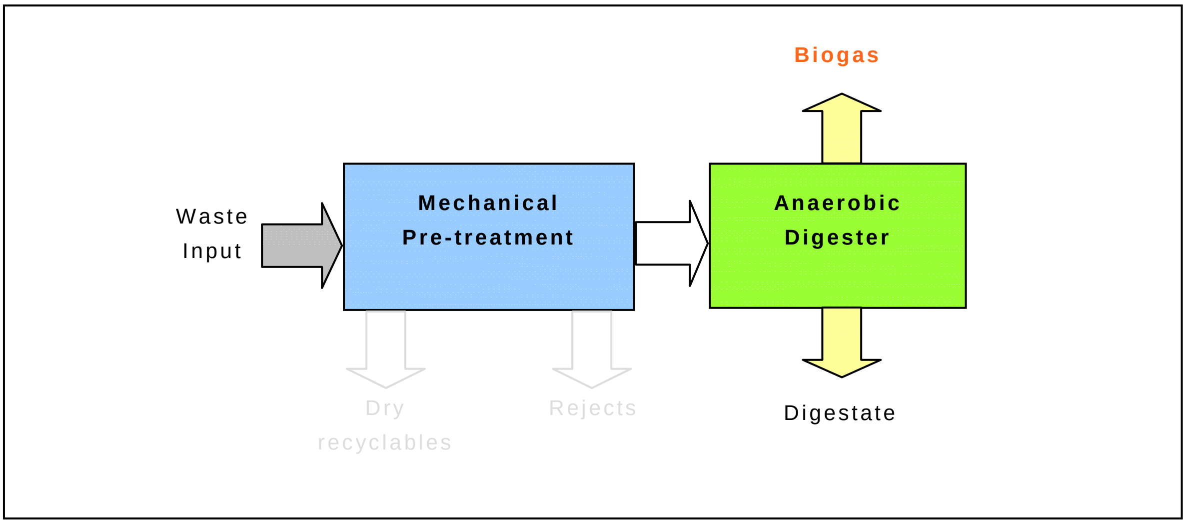
A 4.38. Consequently, there are a host of proprietary AD processes that have been incorporated into MBT configurations.

Single-stage vs two-stage AD

A 4.39. Essentially, the mechanism of waste digestion involves two main steps:

- **Hydrolysis** and **acetogenesis** processes, which convert the bio-degradable waste to glucose and amino acids, and then to fatty acids, hydrogen and acetic acid[3]
- Conversion of the products of hydrolysis and acetogenesis to a gas rich in methane (biogas). This process is called **methanogenesis**.

Figure A18: MBT with single-stage AD



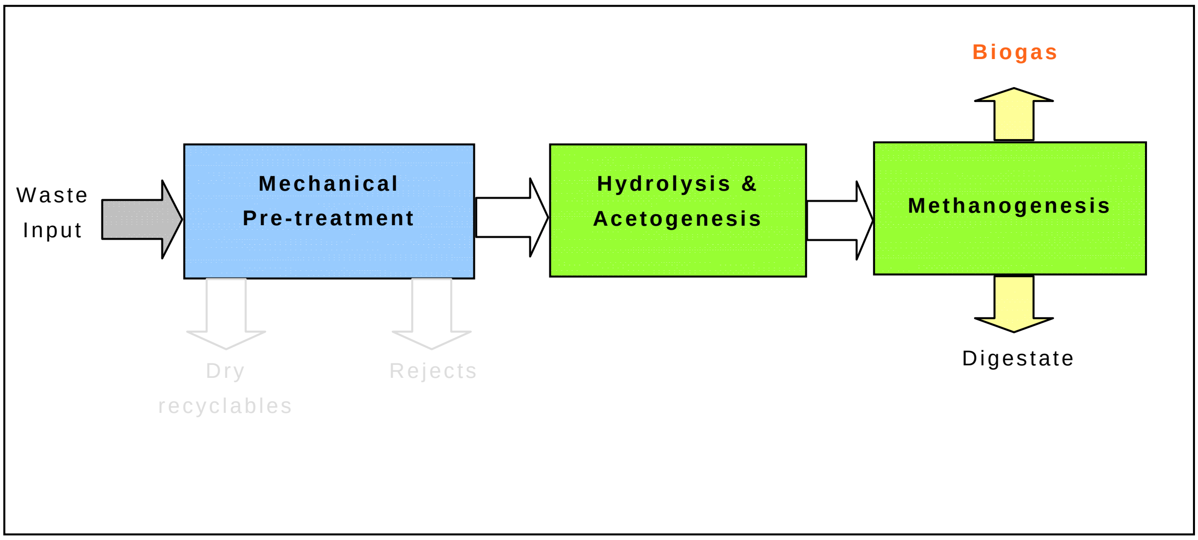
[1] Mesophilic - from the Greek word mesos - (middle) describes the growth of micro organisms in the moderate temperature range, from about 20°C (or lower) to about 45°C.
[2] Term used to describe 'heat-loving' bacteria with an optimum growth temperature of 50°C or more, a maximum of up to 70°C or more, and a minimum of about 20°C
[3] The process of converting the glucose and amino acids to acetic acid is sometimes referred to as 'acetogenesis'.

A 4.40. In single-stage AD processes, hydrolysis, acetogenesis and methanogenesis take place in a single reactor.

A 4.41. Methanogenesis requires different optimum conditions, such as pH, from hydrolysis and acetogenesis and it takes place much more slowly[1].

A 4.42. By separating the two processes, the conditions for the two key steps can be optimised separately.

Figure A19: MBT with two-stage AD



A 4.43. While it has been reported in the literature that this could increase the rate of biogas generation, and therefore the overall performance of the AD process, the often-cited disadvantages of using two-stage anaerobic digestion are:

- Higher capital costs because of the greater number of reactors and auxiliaries that will be required;
- More complex process control.

Wet vs Dry AD

A 4.44. Anaerobic digestion was initially adopted for low solids applications, predominantly in the sewage treatment sector. Thus it has been seen as a useful technology for dealing with high moisture feeds.

[1] The slow methanogenesis step is the primary reason why AD processes take longer than aerobic digestion to achieve similar levels of bio-degradation. The longer retention time translates to larger, or more, reactors and potentially higher capital costs.

A 4.45. However, there has been a noticeable trend over the past decade towards the use of AD for waste streams that have higher solids content than sewage sludge and wastewater, opening up a range of new applications treating **commercial, industrial and municipal solid wastes**.

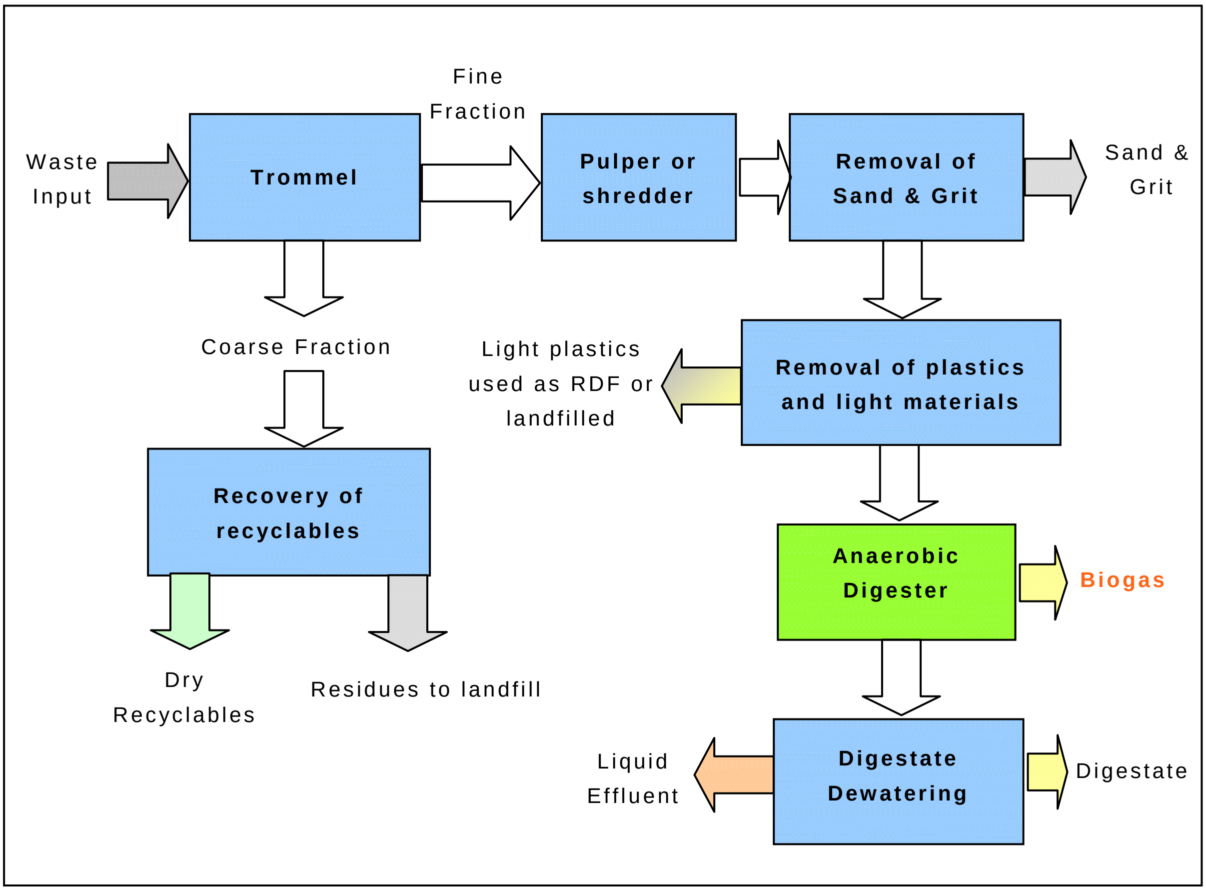
A 4.46. Some companies have chosen to pre-treat the MSW input to obtain a suspension or slurry similar to wastewater or sludge. This is done so that AD systems proven in sludge digestion, wastewater treatment and in the digestion of various organic wastes, such as manure, can be utilised without significant modifications.

A 4.47. Other companies have designed MBT systems that have minimal pre-treatment, and therefore the input to the digester has relatively high solids content.

A 4.48. A distinction is made between processes that treat low solid content wastes (usually <15% DM[1]) - **'Wet' AD** - and those that are designed to treat higher solids content waste (15-40% DM) - **'Dry' AD**.

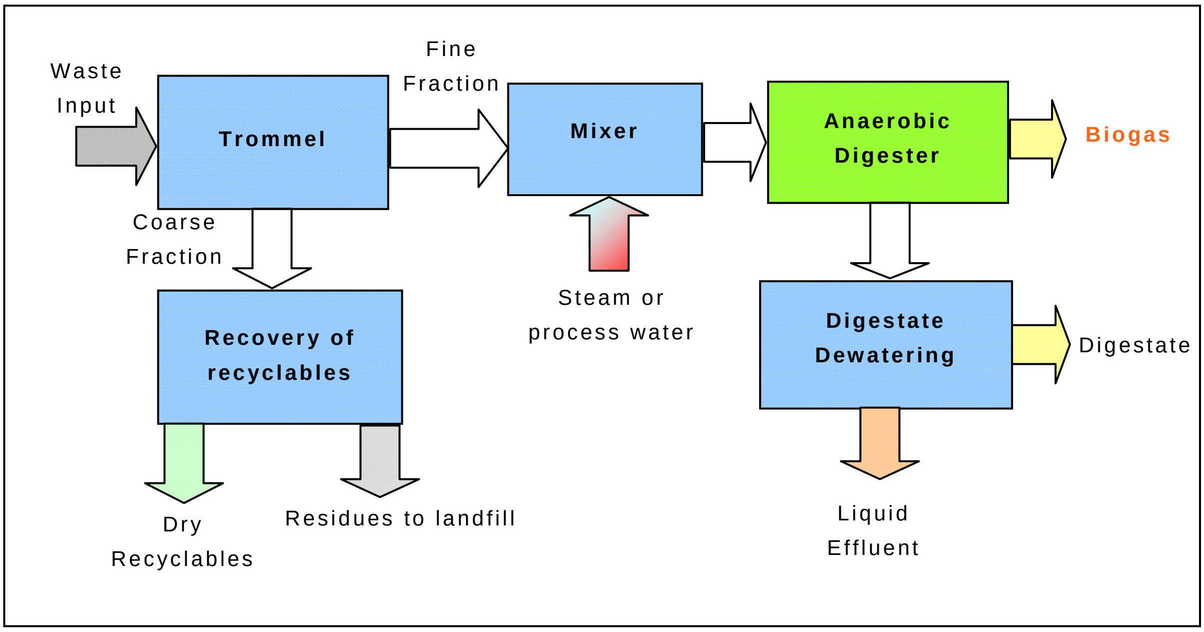
A 4.49. This distinction gives an initial indication of the extent of waste pre-treatment and post-treatment that will be required to provide a suitable input for the AD stage. This is shown schematically below.

Figure A20: A typical MBT process using Wet AD



[1] DM = Dry Matter

Figure A21: A typical MBT process using dry AD



A 4.50. As can be seen, MBT processes based on dry digestion require fewer pre-treatment stages than processes based on wet digestion. Therefore, **dry digestion processes can have lower capital and operational costs**.

A 4.51. In addition, dry processes produce less wastewater than wet digestion systems and therefore require less equipment for managing this effluent stream.

A 4.52. Another advantage of MBT based on dry AD is that problems such as 'settling'[1] 'foaming'[2] and 'flotation'[3] that have occurred with some wet AD plants we have reviewed are avoided (see the review of the SBI and Linde processes in **Annexe D3**).

A 4.53. However, the contents of the digester in dry AD processes are essentially in plug flow and as a result these systems depend on external mixing of the feed for homogeneity. If this is inefficient, the digestion process is adversely affected.

A 4.54. Conversely, because no mechanical equipment is used inside the digester, downtime as a result of mechanical failure in the digester (see the review of the SBI process in **Annexe D3**) is avoided.

A 4.55. A list of the companies that supply AD technologies that have been incorporated into MBT plants designed to treat MSW is provided in **Annexe D2**.

[1] **'Settling'** is the sedimentation of biodegradable solids attached to heavy inerts in the waste.

[2] **'Foaming'** is the entrainment of biodegradable solids with light plastics (such as polystyrene) resulting in poor mixing and low biogas yield.

[3] **'Flotation'** - layers of light materials that include corks, plastic tubes and polystyrene that float to the top of the digester. The layer can dry out and form a hard layer on top of the digester contents, which affects biogas yield and can damage internal mixing units.

Mesophilic vs. Thermophilic AD

A 4.56. Biochemical reaction rates increase with temperature, until a limiting temperature is reached. Thermophilic digestion is therefore much faster than mesophilic digestion. This translates to shorter retention times to achieve a certain biogas yield as compared with mesophilic systems.

A 4.57. The interest in thermophilic processing has increased significantly because of its sterilising properties that can reduce health concerns associated with the possible presence of pathogens. The requirements of the UK ABPR for biogas producing processes (see **Figure B5** in **Annexe B**) is that the process holds the waste at a temperature of 57^{0}C for at least 5 hours or for at least 1 hour at 70^{0}C.

A 4.58. **Therefore some MBT processes, which utilise thermophilic conditions, are capable of meeting the operating conditions set out in the UK ABPR.**

A 4.59. The main disadvantages of thermophilic systems are:

- the high energy requirements to maintain the operating temperature;
- the additional infrastructure to provide in-situ heating of the contents of the digester or the heating and circulation of these materials to and from external heat exchangers.

A 4.60. Thermophilic systems are therefore usually viable where the process requires the lowest amount of energy. Therefore it is not surprising that most of the wet AD processes use mesophilic digestion (larger quantities of material to heat), while most of the dry AD systems operate under thermophilic conditions.

Utilising the digestate fraction from AD

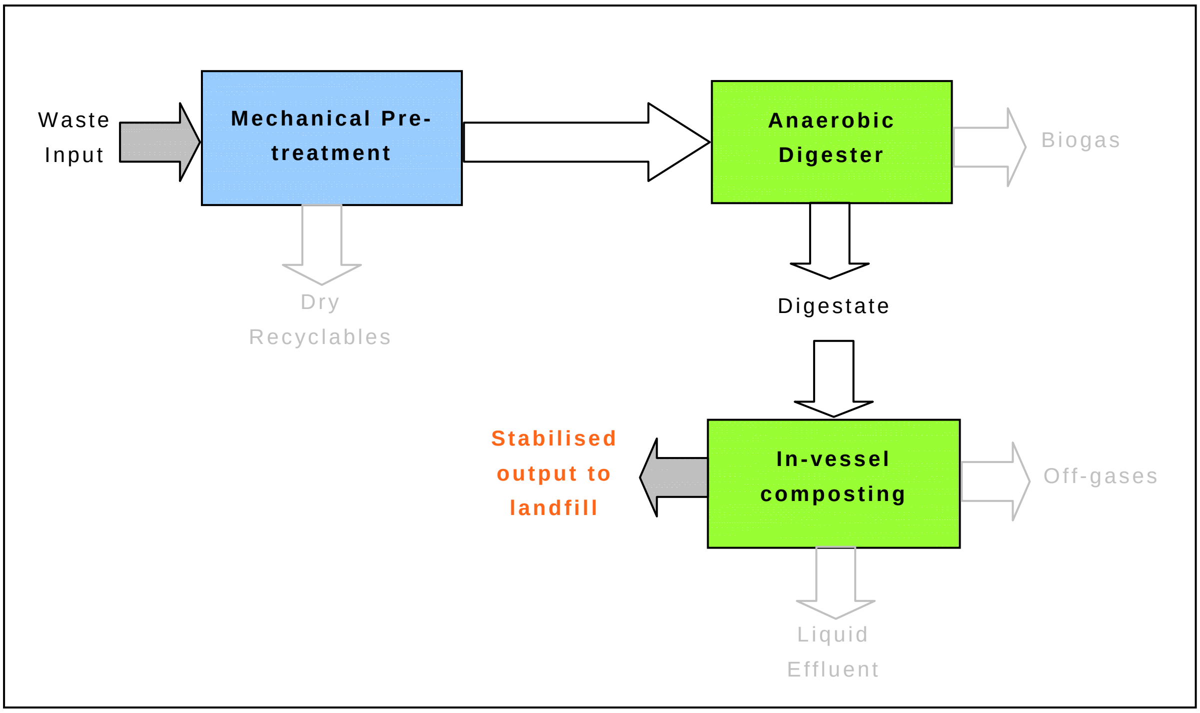
A 4.61. The digestate from AD processes incorporated into MBT configurations, have so far been used in a number of different ways. The most important are:

- Composted and sent to landfill;
- Composted and used as Compost-Like-Output (CLO)[1];
- Dewatered and used without further treatment as a 'fertiliser';
- Dewatered and combusted.

A 4.62. In Germany the MBT plants utilising AD to treat MSW, further bio-stabilise the digestate to a quality suitable for use in landfill applications. A typical process configuration is shown below.

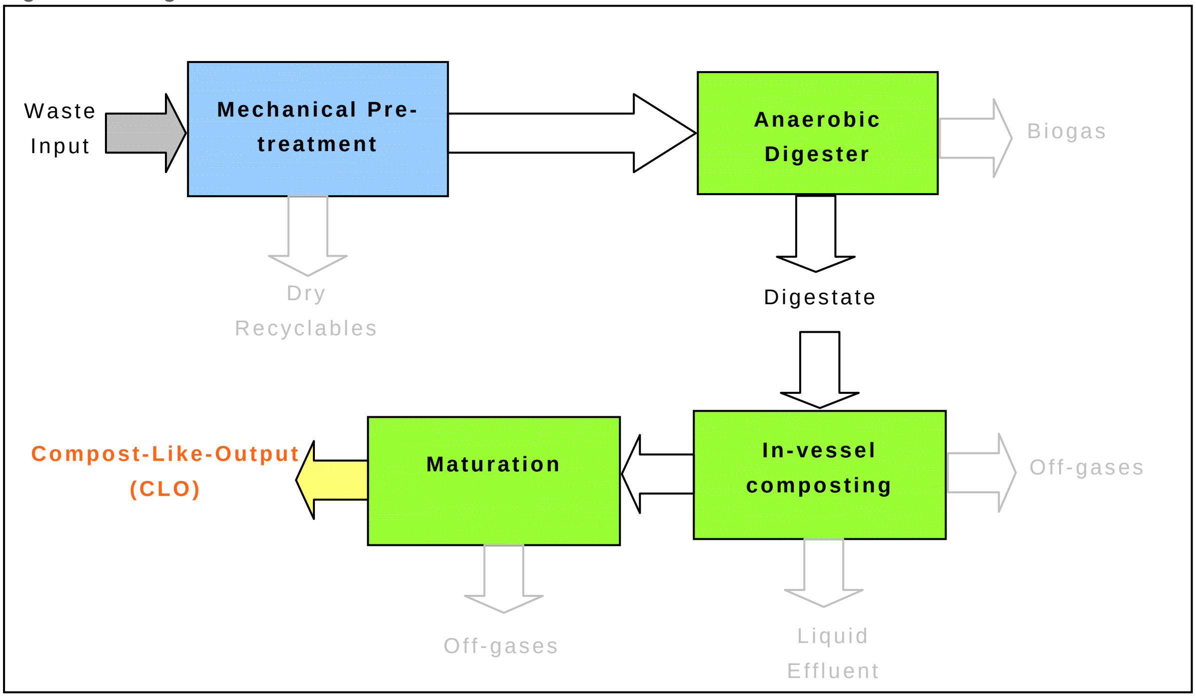
[1] The reader is referred to **Annexe C6** for discussion about the viability of markets for compost-like outputs from MBT.

Figure A22: Digestate bio-stabilised for use in landfill



A 4.63. In some MBT plants the digestate is composted and further matured (usually for over 6-8 weeks) so that it can be utilised on soil. This longer maturation step is essential to balance the C:N ratio, via assimilation of ammonia to organic nitrogen (see **A 4.26**) and complete the formation of humic acids, which stabilise the CLO.

Figure A23: Digestate stabilised for use on soil



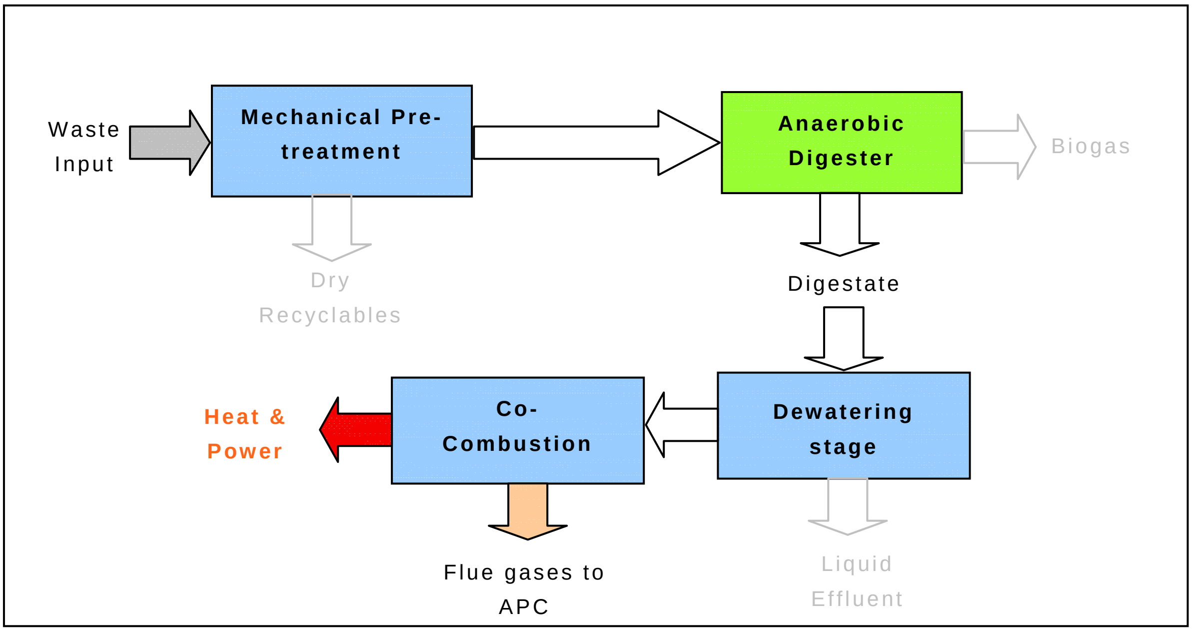
A 4.64. In at least one MBT plant (in Israel), the digestate is dewatered and sent directly for use as a 'fertiliser'. The proponents of this process state that the digestate would be further processed if their technology were to be implemented in the UK, in order to meet the UK ABPR criteria (see the **ArrowBio** process review in **Annexe D3**).

A 4.65. In one plant in Verona, Italy (see the **BTA** review in **Annexe D3**), the digestate is being dewatered and combusted along with RDF from the same plant in an on-site boiler.

A 4.66. The CV of AD digestate is likely to be relatively low, but this will depend on the extent of dewatering, which itself would be machinery and energy intensive. It will also contain all the heavy metals contaminants and undigested plastics that have not been removed in the mechanical pre-treatment stage.

A 4.67. The low CV of the digestate, and the potentially high cost of increasing its CV via dewatering, means that it is a relatively unattractive co-fuel.

Figure A24: Digestate dewatered and co-combusted



More complex MBT process designs

A 4.68. **Many MBT plants have more than one core[1] biological element.**

A 4.69. We have already summarised (from **A 4.61** to **A 4.63**) the MBT processes that contain both AD and a composting element to further stabilise the digestate from the AD part of the process.

[1] Maturation can be considered as a separate biological element from the composting processes. However, because a number of processes carry out maturation using rudimentary techniques, such as static piles, we have not considered maturation as a 'core' biological element of the MBT process design.

A 4.70. A number of different designs have been implemented at the various MBT reference sites that we have listed in **Annexe D3**. These designs are summarised in four process schematics below. A list of MBT suppliers with operating reference sites using these various designs have been provided in **Annexe D2**.

Figure A25: MBT using AD and In-Vessel Composting (IVC)

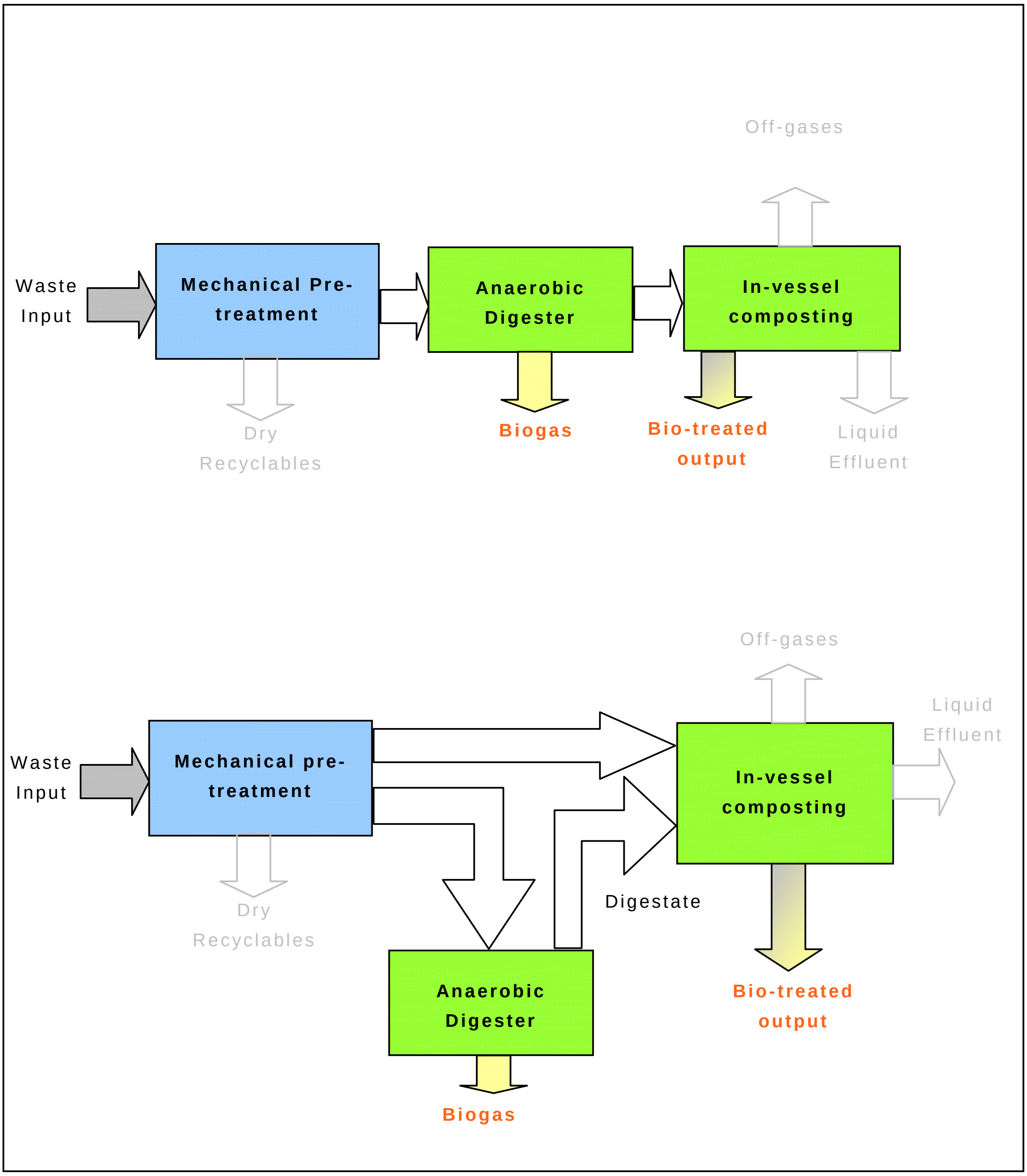


Figure A26: MBT using Percolation, AD and IVC

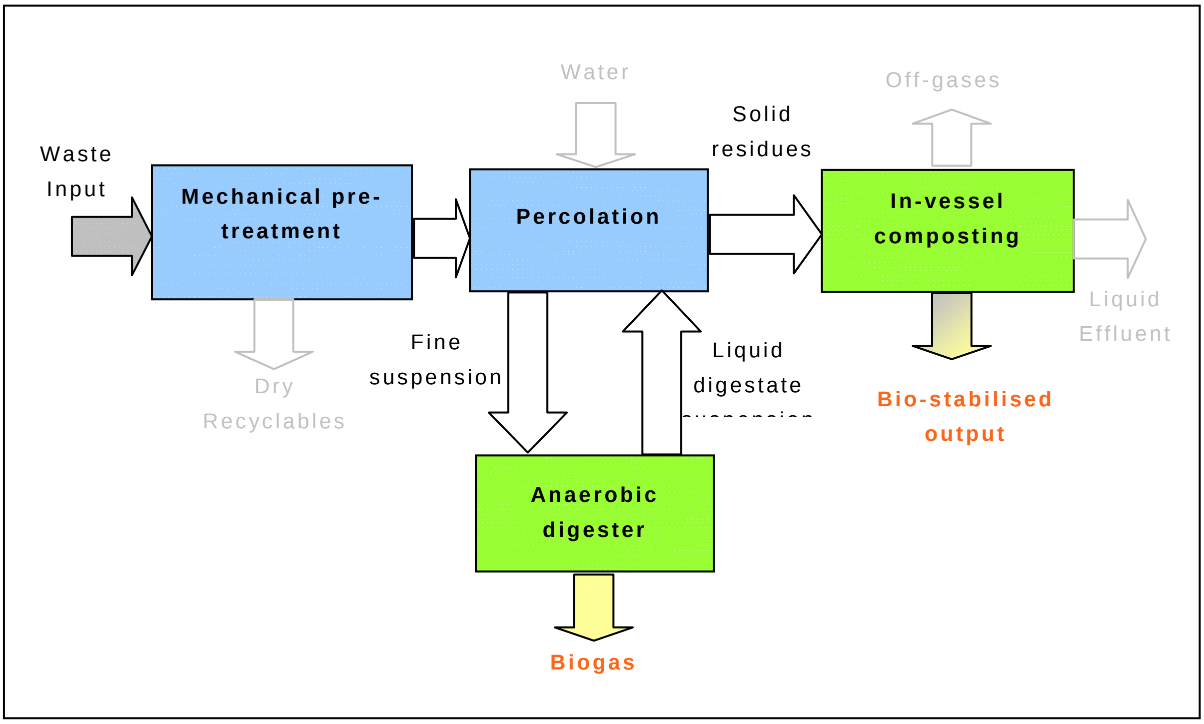
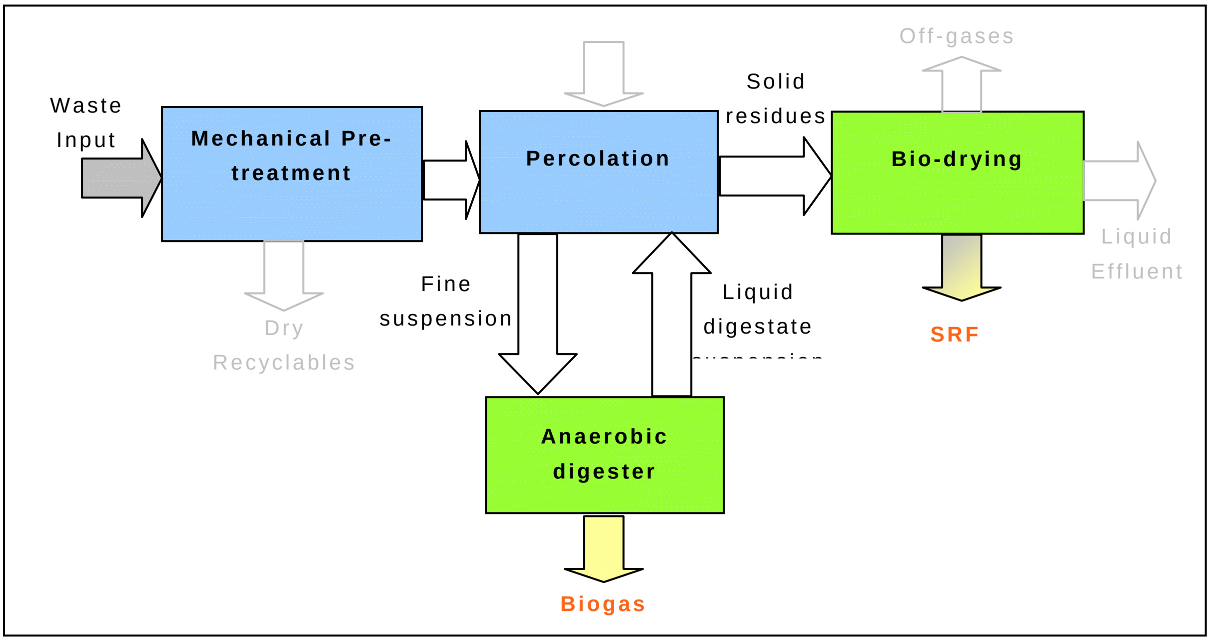


Figure A27: MBT suppliers marketing processes with Percolation, AD and bio-drying



A5 Comparing process designs

A 5.1. In the **Summary Report** we introduced **eight generic MBT process designs** that encapsulate the ways in which MBT systems can be employed to meet specific requirements.

A 5.2. Many of these designs have already been implemented in commercial plants, and others are under consideration for future projects.

A 5.3. There are a number of objectives which influence MBT process design, including:

- minimising the biodegradability of the output;
- matching outputs to market requirements;
- maximising the quantity of materials recovered for recycling;
- minimising the environmental impact of waste treatment;
- minimising the visual profile of the facility.

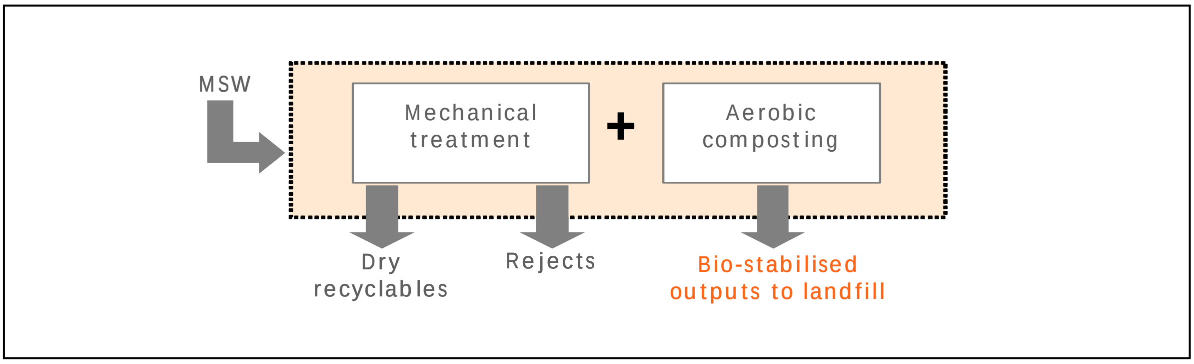
A 5.4. In this section we will assess the degree to which each process design meets these different objectives by focussing on three of these:

- minimising biodegradability;
- producing a fuel; and
- environmental and health impacts.

Minimising biodegradability

A 5.5. All of the generic process designs listed in **Section 5** of the **Summary Report** will reduce the biodegradable content on the input waste. However, the extent to which it is reduced is inextricably linked to the type of output that the process is designed to produce.

Stabilisation of waste for landfilling



A 5.6. **The primary objective of this process concept is to reduce the biodegradability of the output** so significantly that when it is landfilled its ability to generate methane gas is considered to be negligible. This is achieved by removing as much organic carbon as is possible through the bio-degradation processes that occur during aerobic composting.

A 5.7. Experience in Germany, where this design is widely implemented, has shown that to achieve a **high degree of bio-stabilisation** in a relatively quick time, the waste has to be aerobically treated for periods of time ranging from **6 to 8 weeks**. The actual composting time required is known to be technology dependent[1] and is also linked to the degree to which the waste has been treated before the composting stage.

A 5.8. In processes that are designed to bio-stabilise the waste for landfilling, the operating conditions are closely controlled to optimise pH, temperature, moisture and the supply of oxygen to the waste in the first 3 to 4 weeks. This initial period is often referred to as **'intensive composting'**. After this period a further 3 to 4 weeks of compost stabilisation (or **maturation**) is conducted that has comparatively little or no process controls.

A 5.9. Though there is no UK standard to determine when an output has had its biodegradability sufficiently reduced to be deemed as 'bio-stabilised', standards exist in some other EU states including Germany, Austria and Italy. In these countries, bio-stability is determined by the respiration activity of the output from the process (see **Annexe B3**). The limits in each of these countries are summarised in **Figure A28**.

A 5.10. The amount of biodegradation achieved is usually between 40-60%DM[2] depending on the technology used.

Figure A28: Summary of methods used to determine a 'stabilised biowaste' in EU Member States

Country	Testing protocol	Limit value
Germany	Respiration Activity after 4 days (AT4) using Static Respiration Index (SRI) method	5mg 0_2/g dm
Austria	As above	7mg 0_2/g dm
Italy	Dynamic Respiration Index (DRI)	1g O_2/kg VS / h

Source: footnote 2

Make a compost from MSW

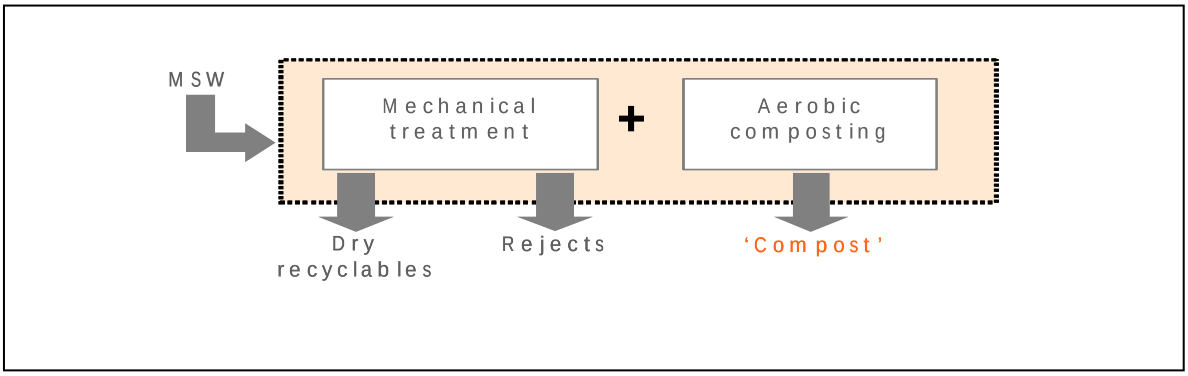
A 5.11. In the UK, good quality compost is assessed by its compliance with the voluntary BSI **PAS 100**[3] standard (discussed in **Annexe B2**). Although compost produced from a mixed waste input cannot be certified under PAS 100, this standard is often used as a benchmark.

[1] Lower grade technologies such as stationary pile composting require longer composting times than in-vessel intensive composting systems.

[2] Muller, W., Bulson, H., Poller, A., 'Modelling the performance of Mechanical and Biological Treatment in terms of UK and EU targets - case study for a UK waste disposal authority': Biodegradable and Residual Waste Management Conference Harrogate, UK, February 2004.

[3] BSI PAS 100 = British Standards Institution's Publicly Available Specification

A 5.12. PAS 100 requires that the respiration activity of the compost output is assessed in addition to the levels of phytotoxins[1], the C:N ratio, pathogens, the levels of contamination and a number of other parameters.



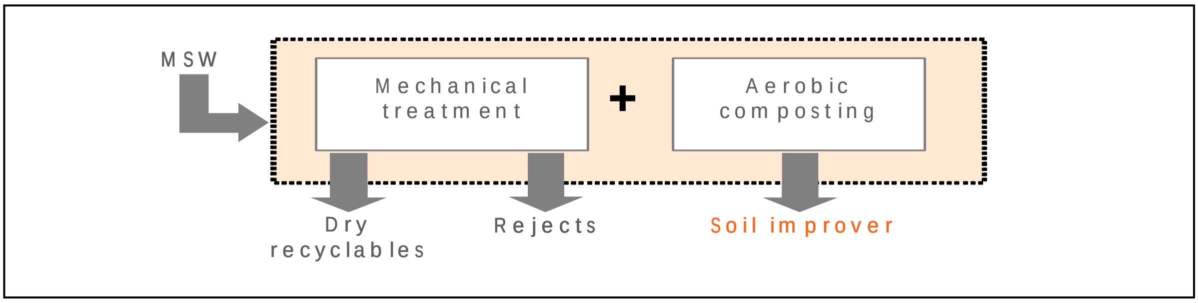
A 5.13. **To produce good quality compost**, this process design usually requires compost maturation times of up to three months, significantly more compost decontamination equipment and more careful control of the composting conditions to ensure the destruction of pathogens. **The implications of this are higher land-take, lower plant throughput, increased levels of rejects which would need to be landfilled and higher investment costs**.

A 5.14. Though composting processes generally take longer to produce a usable output, they can also significantly reduce the level of readily degradable materials in the waste.

A 5.15. Because compost standards in many countries are voluntary, (unlike the statutory requirement of stabilisation for landfill required in Germany, Austria and Italy) a **bio-treated output that is stabilised to a reasonable degree is often referred to by some MBT suppliers as 'compost'.**

A 5.16. But the analysis we have conducted for this review has led us to conclude that the majority of these processes would **not produce a material that would meet the PAS 100 requirements**.

Make a lower grade soil improver from MSW



[1] Phytotoxins = Substance(s) or condition(s) that are toxic to plants and cause(s) symptoms such as delayed/reduced seed germination, root death, restricted root growth or stunting, distortion, necrosis or chlorosis etc. of aerial portions (WRAP definition)

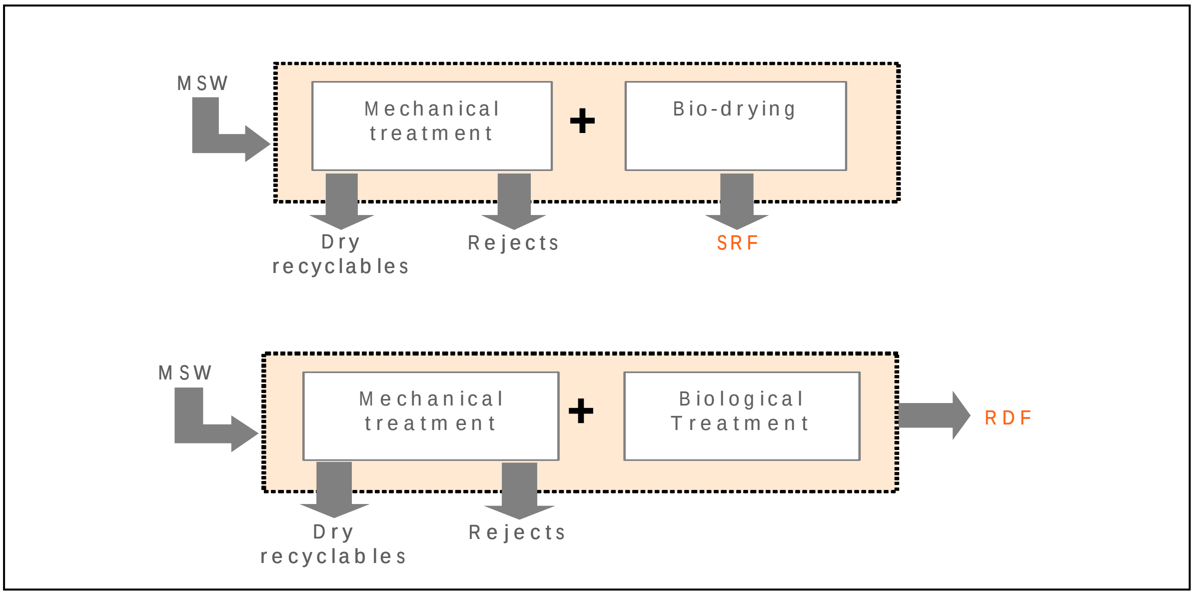
A 5.17. Some MBT suppliers design their process to **produce a compost-like output (CLO)**, as in the generic design above.

A 5.18. Because there is **no clear bio-stability measure** of what constitutes a **CLO**, most processes that bio-treat the waste to some degree are said, by the process supplier, to produce an output that can be used as CLO (see **Annexe C6**).

A 5.19. The level of biodegradation achieved in such processes varies widely. Some of the processes that we have reviewed are designed to complete the bio-treatment of the waste in less than one week (such as the **Civic** and **Wastec** processes), while others bio-treat the waste for much longer periods of time. As a result, the BMW diversion associated with this design will vary widely (this is discussed in **Section 11** of the **Summary Report**).

A 5.20. Published data[1] indicates that processes which bio-treat the waste for periods of less than about three weeks, will achieve a biodegradation of less than 50% of that achieved by Continental facilities that are configured to bio-stabilised the waste for landfilling.

Make and RDF; Produce a fuel using 'bio-drying



A 5.21. **The process designs that produce a solid fuel output**[2] are different because they are not concerned about the level of reduction in biodegradability since this is irrelevant if fuel is combusted.

A 5.22. RDF is usually recovered from the coarse fraction removed from the materials going to the biological process stage. Therefore, this fraction is not bio-stabilised to any degree and if it has to be landfilled it would contain a significant level of BMW.

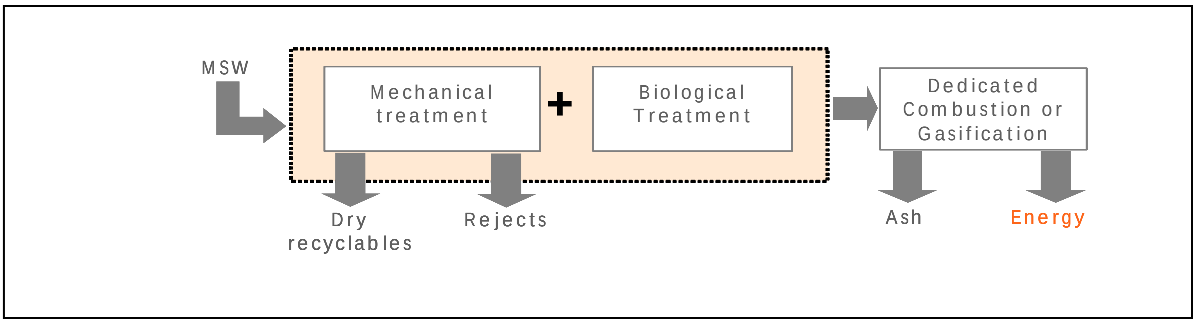
[1] BSI PAS 100, *op. cit.*
[2] The reader is referred to **Annexe C** for further discussion on fuel outputs from MBT.

A 5.23. In a few cases, RDF is recovered after the waste has been partially bio-treated. In such cases the RDF comprises mainly plastics and 'fluff' that are removed from the bio-treated output as contamination. It will have significantly lower BMW content than the material recovered before the biological stage.

A 5.24. Because of its varying and relatively low fuel quality, RDF recovered from MBT plants is usually incinerated. The current shortage of incineration capacity in the UK would mean that different outlets would have to be found for the utilisation of this material.

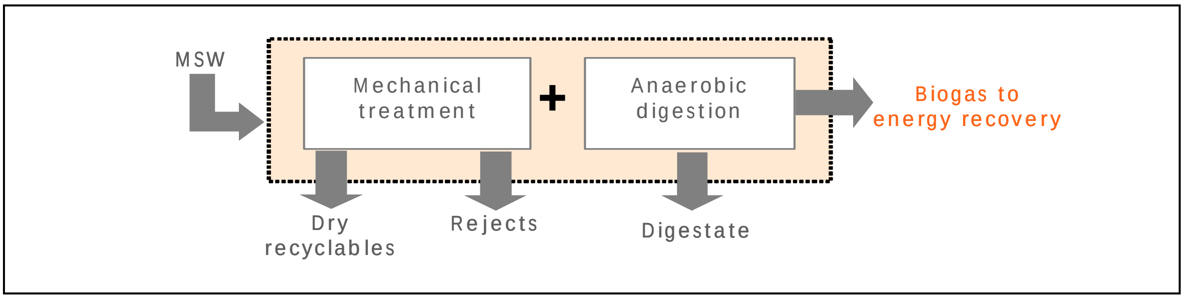
A 5.25. To produce SRF suitable for use as a co-fuel, the biogenous content of the waste is preserved so that the fuel output from the MBT plant has a sufficiently high calorific value. As a result, these designs only reduce the biodegradability of the input waste by a relatively small amount (usually <10%DM[1]).

MBT to reduce the need for thermal treatment



A 5.26. Processes have been promoted where the **solid fuel output is converted to energy in an integrated system**. Processes configured in this way are likely to have a very high BMW diversion because all of the BMW is converted to CO_2 and water vapour in the combustion process, but because this type of process will still have a small reject stream (which will contain some BMW), the BMW diversion would not be 100%.

Produce biogas



A 5.27. **A number of MBT process designs incorporate anaerobic digestion (AD) and produce a biogas**. The reduction in the biodegradability of the input in this design is technology dependent. For instance, some AD processes are designed to have an

[1] DM = dry matter

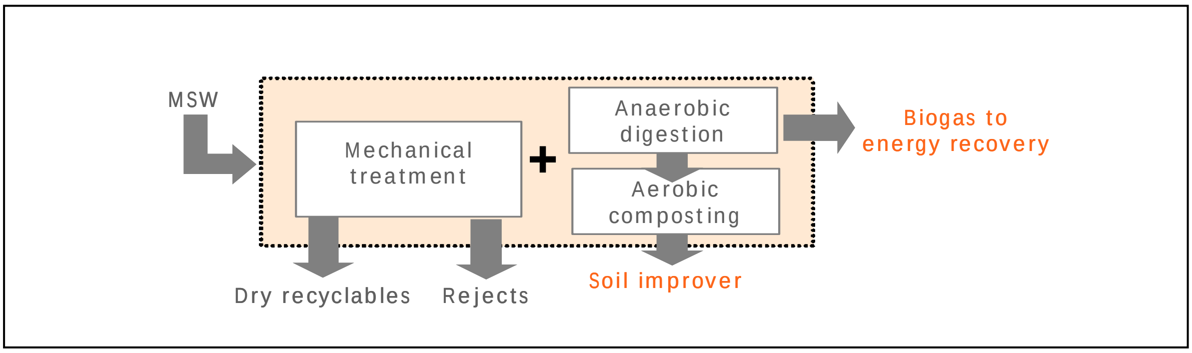
average SRT[1] of about 3 to 4 weeks (**OWS-Dranco, BTA, Ros Roca, Linde**), while one process (**ArrowBio**) is designed to digest the waste for up to three months (see **Annexe D3**).

A 5.28. Each approach has its own advantages and disadvantages, which are discussed in the individual process reviews in **Annexe D3**. However, the extent of biodegradation of the waste is likely to be greater in a process that digests for three months than in those that digest for one month.

A 5.29. In general, **if the digestate from this MBT design has to be landfilled, its BMW content could still be high**, because it is well known that some BMW compounds, such as cellulose-based materials, are difficult to breakdown in AD processes but its residual 'bio-degradability' is likely to be low.

A 5.30. Thus, depending upon whether diversion is measured in terms of reduction in biodegradability or in terms of the reduction in the amount of bio-carbon, the performance of such systems can vary. (a full discussion of BMW diversion for all of the eight generic process designs can be found in **Section 11** of the **Summary Report** and **Annexe B3**).

Produce biogas and soil improver



A 5.31. Some **AD processes are designed to combine short digestion periods with a post-digestion aerobic treatment stage** as in the concept shown above. The aerobic stage degrades the waste further thus producing a solid output, which could have a relatively low BMW content.

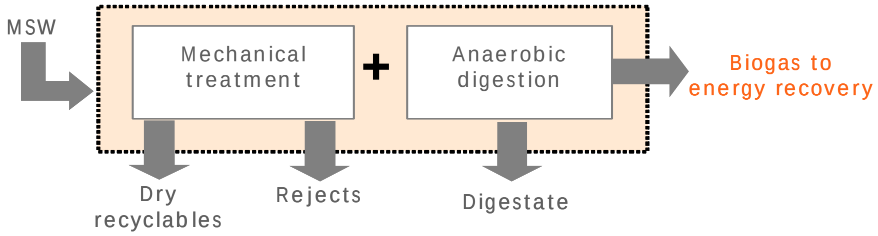
Producing a fuel

A 5.32. Five of the generic MBT process concepts will produce a fuel. In three of these the output from the MBT process will be a solid fuel, while two produce biogas.

[1] SRT= solids residence time

Producing biogas

A 5.33. In all of the MBT plants we visited, the biogas produced in the AD processes is being used in on-site gas engines to generate electricity. There are no marketing issues with the biogas output and it is classed as a renewable fuel. Further discussion about renewable income that could be obtained from the utilisation of biogas to generate electricity can be found in **Annexe B7**.



A 5.34. The amount of electricity generated is directly determined by the quantity of biogas produced. This, in turn, is dependent upon the specific operating conditions (dry or wet, mesophilic or thermophilic, and the residence time) used in the AD process and the way in which the process is configured (single stage or two stage). Therefore, processes using AD produce varying levels of biogas, and, hence, also income.

A 5.35. The combustion of biogas in gas engines, also releases heat, which has to be dissipated to keep the gas engine functioning properly. Most AD-based MBT processes utilise this heat, via heat exchanging systems, to provide some or all of the energy that is needed to maintain the operating temperature of the digestion reactor.

A 5.36. In MBT plants where sufficient heat for process operation cannot be obtained from the heat recovered from the gas engines alone (mainly in thermophilic AD plants), a portion of the biogas is separately combusted to generate the additional heat.

Upgrading of Biogas

A 5.37. Although there is no general quality specification for biogas produced in MBT plants, gas engine manufacturers will require that the biogas delivered to their supply is of a certain quality in order to provide the relevant performance guarantees.

A 5.38. The constituents in the biogas that have to be controlled to certain specifications are:

- methane;
- sulphur compounds, primarily hydrogen sulphide;
- halogenated compounds (chlorine and fluorine);
- siloxanes;
- dust; and,
- moisture.

A 5.39. A discussion of the technical challenges associated with these contaminants is given in **Figure A29**.

Figure A29: Management issues associated with some constituents of biogas

Methane	The main combustible constituent of biogas, providing its relatively high calorific value (usually greater than 26 MJ/Nm^3). The reported methane concentration in the biogas from MBT facilities using AD ranges from about 60-80% by volume. The higher the concentration of methane, the higher its calorific value and the greater the quantity of electricity that can be generated.
Sulphur compounds (H_2S)	There are various types of sulphur compounds that are contaminants in biogas. These compounds are formed during the anaerobic digestion of the waste, many are highly odorous and will form corrosive mixtures in the presence of free water or the moisture found in gas engine oils. Of these sulphur contaminants, **hydrogen sulphide** is the most prevalent. It is produced by the action of the sulphur reducing bacteria that are involved in the breakdown of waste in the anaerobic conditions prevailing in the digester. Hydrogen sulphide poses a health and safety hazard in plant operations and is very odorous (giving an unpleasant bad-egg smell, which can still be detected even when it is present in extremely low concentrations). This contaminant causes further issues when it is combusted because it generates SO_2, which forms corrosive compounds when mixed with water. Because of the presence of SO_2 in the exhaust gases from gas engines firing biogas, it might be necessary to install suitable abatement measures. However, it is not yet clear how the emissions from gas engines firing biogas will be regulated in the UK, although limits have been proposed in the draft waste treatment BREF[1] (see **Annexe B5**).
Halogenated compounds (Cl, F)	**Halogenated compounds** contained in the waste may be volatilised at the digestion conditions and will partition to the biogas. Some halogenated compounds can also form in-situ as a result of the degradation processes. The extent to which halogenated compounds partition to the biogas, depends on their vapour pressure relationships. But at the relatively low digestion temperatures acting over a relatively short period of time (compared to similar compounds in a landfill), it is likely that only trace amounts of halogenated compounds will be present in the biogas. Of these, some will be broken down when the biogas is combusted in the presence of moisture to form hydrogen fluoride (HF) and hydrogen chloride (HCl). These are responsible for the corrosion of piping and engine components. Most engine suppliers stipulate a total chlorine and fluorine gas composition and consequently, in many MBT plants, the biogas is passed through alkaline scrubbers to abate halogenated contaminants prior to biogas combustion. None of the plants we visited utilised scrubbers after the gas engines to abate HCl and HF, indicating that the emissions of these contaminants have not been a major concern.
Siloxanes	**Siloxanes** are a subgroup of compounds containing Si-O with organic radicals bonded to the silicon, present in the biogas. Waste containing small amounts of silicone-containing products (such as sealants and cosmetics) which are responsible for the generation of siloxanes in biogas. The increasing usage of these compounds in consumer and commercial products suggests that levels in biogas are likely to increase. Because of the long-term performance and maintenance requirements of gas engines, some engine manufacturers specify the reduction of siloxanes before biogas utilisation, while in some cases direct monitoring of silicon build-up in the engine oil is recommended. Their experience has been gained by the extensive use of gas engines in landfill gas utilisation schemes.
Particulates (dust)	**Dust** in the gas engines arises from particulates contained in the biogas as well as particulates drawn into the gas engine with the combustion air. The latter could be high where the combustion air is taken from inside the process building in order to reduce the likelihood of fugitive emissions. Particulates can also cause accelerated engine wear and steps are usually taken, mainly using in line filters, to reduce the dust load in the air-intake to gas engines.
Moisture	**Moisture** is removed from the biogas, via condensers, before it is combusted. This is necessary because it reduces the calorific value of the biogas. It also adversely impacts on gas engine performance and causes control problems.

1 BREF is the non-binding Best Available Technology Reference documents (BREF), which are specific to each industry sector and are being developed by the European IPPC Bureau in Seville.

Source: Juniper analysis

A 5.40. There are several methods to abate hydrogen sulphide, ranging from adsorption on a solid to chemical conversion in the liquid phase. At many of the reference plants we visited during the course of this study, H_2S was removed in wet scrubbing systems using ferric chloride ($FeCl_3$) before the biogas was utilised. This chemical reacts with H_2S to form insoluble iron sulphide, but because it is highly corrosive it can cause damage in pipework and reactors.

A 5.41. Biological biogas cleaning systems have also been implemented in a few MBT reference plants, which utilise a sulphur oxidising bacterium which converts the hydrogen sulphide to sulphates or to elemental sulphur.

A 5.42. Other techniques, such as the suppression of H_2S in the digester by adding a controlled flow of air to the digester free space, have also been used.

A 5.43. None of the MBT plants we visited during the course of this study had implemented measures to abate siloxanes. From experience gained in combusting landfill gas, it has been proposed that activated carbon based systems be used to adsorb this contaminant from biogas. This type of treatment could significantly increase the capital and operating costs associated with biogas utilisation, which may impact upon the viability of MBT projects using anaerobic digestion.

Producing a solid fuel

A 5.44. MBT processes can be configured to produce RDF (Refuse Derived Fuel) or SRF (Solid Recovered Fuel). The SRF output from MBT is usually aimed at the co-fuel market and because of this, the fuel specifications are more tightly controlled than those for RDF.

A 5.45. To meet the stringent SRF specifications, a greater level of processing and refining of the output is required, which will have an impact on the investment and operating costs, may impact on the yield of fuel and the amounts of rejects sent to landfill. Market specifications for SRF and RDF are discussed in **Annexe C2**.

A 5.46. The quality of the solid fuel recovered from MBT depends on:

- its calorific value;
- its moisture content;
- its ash content; and
- its chemical content (including heavy metals).

A 5.47. This information about the solid fuel can be obtained from a **proximate analysis**[1] (as shown in **Figure A30**) and an **ultimate analysis**[2] (**Figure A31**).

[1] Laboratory test that determines the balance between the mass% of volatile matter, fixed carbon, ash and moisture in the fuel.

[2] Laboratory tests that determines the balance between the mass% for the elements that will undergo chemical reactions within the combustion process; e.g. C, H, O, S, F, Cl, Br, N

A 5.48. **Calorific value** (CV) is the heat per unit mass produced by the complete combustion of a fuel or waste material. CV may be determined on an 'as-received', dry or 'dry-ash-free' basis and the significance of these definitions is shown in **Figure A30**. The dry, ash-free CV will be a higher value than for the 'as received' fuel.

A 5.49. The higher (or gross) heating value [**HHV**], assumes the water vapour in the flue gases condenses and therefore includes the latent heat of vaporisation of the water, whilst the lower (or net) heating value [**LHV**] does not include the latent heat of vaporisation of the water vapour because the combustion gases are not cooled sufficiently for the water to condense within the energy recovery part of the plant. In practice the energy that can be recovered from the solid fuel in most modern combustion systems (which could incorporate condensing steam turbines), falls between these two limiting values.

Figure A30: Typical proximate analyses and CV of selected waste-derived fuels and coal

Fuel	Volatiles	Moisture	Fixed carbon	Ash	HHV
	wt %				MJ/kg
Coal [1]	30	5	45	20	26
Wood	85	6	8	1	19
MSW	33	40	7	20	10
RDF [2]	60	20	8	12	15
PDF [3]	73	1	3	13	21
SRF	see Ecodeco, Herhof and Nehlsen process reviews in Annexe D3				
1 bituminous coal ; 2 typical RDF (not from MBT plants); 3 plastic derived fuel					

Source: multiple sources

Figure A31: Typical ultimate analyses and CV of selected waste-derived fuels and coal

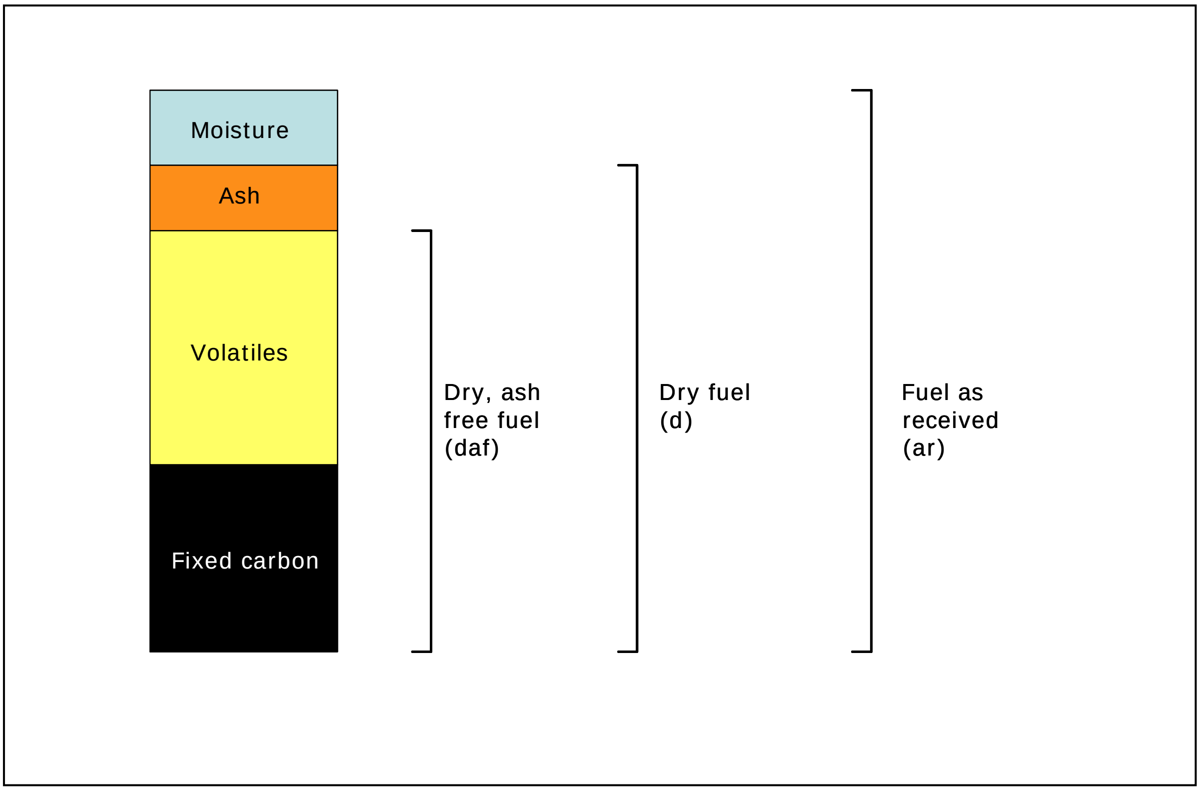
Fuel	C	H	N	O	S	Cl
	wt %					
Coal [1]	60 - 80	3 - 5	1 - 2	~10	1 - 5	0.01 – 0.1
Wood	40 - 50	~6	~0.2	~45	~0.1	~0.01
MSW	~25	~3	~0.5	~20	~0.2	~0.5
RDF [2]	~45	~5	~0.5	~35	~0.2	~0.5
PDF [3]	~50	~6	~1	~40	~0.2	~1
SRF	see Ecodeco, Herhof and Nehlsen process reviews in Annexe D3					
1 bituminous coal ; 2 typical RDF (not from MBT plants); 3 plastic derived fuel						

Source: multiple sources

A 5.50. **Moisture content:** In solid fuels moisture can exist in two forms – as free water and as bound water. The moisture content of the fuel directly affects the energy recovery potential of the thermal conversion process. Evaporation of the moisture requires an input of energy which may be supplied by additional fossil fuel usage or as a parasitic input which reduces the quantity of energy output. Typically the water evaporated from the fuel is not condensed downstream in the heat recovery part of the plant but exits the process as water vapour via the stack.

A 5.51. **Ash content:** Solid fuels such as coal, biomass and SRF/RDF contain inorganic compounds. Ash is the inorganic residue remaining after the fuel has been completely burned. The inorganic content of the fuel can include alkali metal compounds, e.g. sodium (Na) and potassium (K). Compounds of these metals can be molten at the temperatures prevailing in the thermal conversion process and they pass through the equipment until they condense on cooler metal surfaces causing fouling and slagging. This will lead to operational problems and unplanned downtime or shorter periods between planned maintenance activities. Whichever is the case it will result in increased operating costs.

Figure A32: Definition of fuel properties



A 5.52. In combustion and gasification processes the management of the ash is very important. The combination of different inorganic compounds in the ash phase can lead to sintering, agglomeration and eutectic formation. Careful control of the ash within the thermal process, particularly in fluidised beds, and removal of the ash from the thermal process is essential to maintain trouble free operation.

A 5.53. **Chemical content:** The levels of sulphur (S) and chlorine (Cl) are critical to the performance of a utility boiler with respect to corrosion of the heat transfer surface. **Figure A31** indicates that typically waste-derived fuels contain more chlorine than coal or biomass but that coal contains more sulphur.

A 5.54. The higher the nitrogen (N) content in the fuel or co-fuel mixture then the higher the NOx emissions will be. This will require either minimisation by the use of low-NOx burners or downstream abatement by SCR (selective catalytic reduction) or SNCR (selective non-catalytic reduction) techniques[1]. SNCR is the lower cost option.

A 5.55. Some of the **heavy metals** that can be found in the input waste to the MBT plant (see **Figure A14**), will partition to the solid fuel product. When SRF or RDF is combusted, some of the heavy metals will vaporise and would be potential pollutants in the flue gases from the combustion process.

A 5.56. Regulatory controls, such as the EU Waste Incineration Directive (WID), set prescriptive limits for heavy metal emissions to atmosphere. The metals of concern, grouped by volatility, are:

- Hg
- Cd + Tl
- As + Cr + Co + Cu + Mn + Ni + Pb + Sb + V + Zn

A 5.57. The more volatile metals vaporise in the high temperature environment within the thermal process and pass through the downstream equipment. Mercury (Hg) will pass completely through the plant and will require abatement technology, such as activated carbon adsorption or filtration to capture it.

A 5.58. Cadmium (Cd) and lead (Pb) will condense on the cooler parts of the equipment and will be associated with the fly ash from the gas cleaning plant. The other metals will distribute between the bottom ash and fly ash to differing degrees. It is essential that the fate of heavy metals is considered carefully because in co-combustion applications the existing ash fractions may be contaminated by increased levels of heavy metals causing the operator to create a waste disposal problem for a material that may currently be recycled into construction applications.

Making a good quality fuel (SRF)

A 5.59. **Of the many variants of MBT process, SRF (Solid Recovered Fuel) is mainly produced by those that employ 'bio-drying'**[2].

A 5.60. 'Bio-drying' technologies drive-off moisture from the waste using the biological activity in an aerobic in-vessel system but do not fully bio-stabilised the waste. **The SRF output is not normally sterilised by bio-drying and can continue to degrade if moisture is added.** This could give rise to odour problems and public health issues if the SRF is stored for long periods before it is utilised.

A 5.61. Bio-drying takes place under aerobic conditions (in the presence of air), but unlike in aerobic composting, water is not added to the waste and the moisture content is allowed

[1] discussion of SCR and SNCR is beyond the scope of this report
[2] SRF is also produced by some types of MHT, but these processes are outside the scope of this report.

to fall below the level (usually c. 40 wt%) which is necessary for the bio-degradation process. Consequently, the waste is not digested and its biogenous content is preserved.

A 5.62. As a result of water evaporation and the degradation of part of the more volatile biodegradable content of the waste (reported to be between 24-30% of the input mass of the waste), the output from 'bio-drying' processes usually has an appreciable calorific value (c. 15-18 MJ/kg).

A 5.63. The 'bio-drying' stage of the process is followed by mechanical processing, which is designed to reduce the levels of non-combustible materials in the SRF and to produce a 'fuel' that is compatible with the requirements of the end-user (see section on *'Post-refining the outputs from MBT'*). Issues concerning contamination limits and end-use specifications from the processes that could take the SRF are discussed in **Annexe C**.

A 5.64. Currently SRF from MBT plants is being used as a co-fuel in cement kilns, co-fired boilers and fluidised bed boilers. The SRF output could be deemed as renewable and therefore may be economically attractive to companies wishing to boost their generation of renewable energy. A detailed discussion about the technical challenges of using SRF in these various applications can be found in **Annexe C**.

A 5.65. Proprietary systems differ in terms of:

- the process control of the 'bio-drying' stage to maximise moisture removal;
- the retention time used (varies from 5 to 14 days at the various SRF plants);
- the extent of separation of contaminants from the SRF in the mechanical post-refining stage and how it is prepared for the end-user.

A 5.66. A list of MBT suppliers who have reference plants utilising the bio-drying technology, can be found in **Annexe D2**.

A 5.67. Only one company, Ecodeco, operates a dedicated on-site fluidised bed boiler to convert the produced SRF into heat and power. Information provided by the suppliers of 'bio-drying' systems, indicating the main outlets for the SRF from their respective MBT reference plants can be found in the individual process reviews. A summary of this information is also in **Annexe D2**.

Producing an RDF

A 5.68. Many MBT processes will recover non-biodegradable materials (such as light plastics) and the difficult-to-degrade bio-carbon containing materials, such as wood. This stream can be recovered before or after the biological stage of the process.

A 5.69. As we have discussed in **Annexe C** and in the process reviews in **Annexe D3**, the RDF output from MBT can have widely varying compositions and as a result it is usually sent for incineration. In some cases, where no suitable outlets can be found, this stream is landfilled.

A 5.70. To circumvent the issues of securing viable outlets for RDF, some process companies are developing fully integrated solutions to manage the RDF in a thermal conversion stage. This reduces the risks associated with obtaining markets for this output and generates revenues via power production.

A 5.71. Where the integrated process is designed to utilise gasification, a portion of the energy generated will qualify for Renewable Obligation Certificates (ROCs) (this is discussed in **Annexe B7**). Hence, substantial revenues can be obtained from the electricity exported to the grid from this configuration.

A 5.72. Where combustion of the RDF is integrated with the MBT process, qualification for ROCs is less straightforward. Electricity generated in this configuration does not automatically qualify for ROCs. Currently, if RDF can meet a limiting composition of 98% biomass, then a portion of the electricity generated will qualify for ROCs. We are not aware of any MBT plants that produce an RDF output that currently satisfy this limit.

A 5.73. There are, however, significant differences in the provenness of these two concepts: (MBT with integrated combustion and MBT with integrated gasification) as summarised in Figure A33.

A 5.74. **Combustion** is **proven** for MSW applications, whereas **gasification** is **relatively unproven** for this application in Europe.

A 5.75. In Japan, gasification technologies are proven for waste applications but they operate at high temperatures using oxygen to facilitate melting of the inorganic ash. Such designs are compatible with reducing the volume of material that is sent to landfill but the high energy needed to melt the inorganic compounds, means that energy production is usually a secondary objective.

A 5.76. In Europe, the market drivers are different and relate to maximising energy recovery, which is a key economic aspect in waste management plants throughout Europe. Thus, gasification technologies that have been successful in Japan are currently not being considered for European projects.

A 5.77. As a result, there could be significant technology risks in implementing a gasification solution and this may be viewed as commercially risky and consequently 'unbankable' from a financial perspective.

A 5.78. There are other benefits and dis-benefits of integrating combustion rather than gasification in the MBT plant. These relate to their relative:

- technology status;
- energy recovery efficiencies;
- flexibility;
- public perception profile;
- gas cleaning requirements.

A 5.79. **Figure A33** is a summary of the above factors for MBT integrated with combustion or gasification.

Figure A33: Some important considerations for MBT integrated with Combustion/Gasification

Parameter	Combustion	Gasification
Technology	▪ Development has been down the learning curve ▪ Proven at all scales ▪ Low risk, reliable, robust	▪ More flexible conversion technique ▪ Relevant processes are often small scale ▪ Not many systems commercially proven in Europe ▪ Significant development is still needed ▪ Scale-up risks
Energy recovery	▪ Proven methods for steam and electricity recovery	▪ High efficiency energy recovery routes (using gas engines or gas turbines) feasible. ▪ Integration with gas engines not yet fully proven ▪ Integration with gas turbine not yet demonstrated
Gas cleaning	▪ Gas cleaning methods for combustion flue gases well established	▪ Stringent gas cleaning required for high energy efficiency options ▪ Syngas cleaning can be complex and it is relatively undeveloped for waste applications ▪ The cleaning processes require significant investment and operating costs to produce a gas of suitable quality
Perception	▪ Bankable ▪ NIMBY issues	▪ Sometimes seen as unproven and risky so may not be easily bankable by external sources of finance
Economics	▪ ROC credits unlikely	▪ Automatic ROCs and emissions trading credits

Source: Juniper analysis

Environmental and health impacts

A 5.80. All waste treatment processes and facilities produce environmental impacts. We will consider the following impacts in this section:

- emissions to air;
- emissions to water;
- residues to land;
- Potential health impacts.

Emissions to air

From an aerobic digestion process

A 5.81. The process designs, that utilise **aerobic treatment (composting, maturation and bio-drying)** will produce off-gases, which mainly consists of:

- CO_2 and H_2O;
- organic contaminants (sometimes referred to as VOCs but are correctly known as TOCs[1]);
- ammonia (NH_3);
- bio-aerosols;[2]
- fine particulates.

A 5.82. The Waste Treatment BREF proposes that particulates (bio-aerosols) and hydrocarbons (VOCs) in the off-gases from MBT processes should be controlled to the levels indicated in **Figure B7** in **Annexe B5**.

A 5.83. Bioaerosols from waste treatment facilities is a topic of increasing concern in relation to possible health impacts. Most MBT process companies could provide little information on the performance of their process in this respect.

From an anaerobic digestion process

A 5.84. In systems employing anaerobic digestion, all of the gaseous contaminants from the digestion of the waste are incorporated into the biogas.

A 5.85. When the biogas is combusted in a gas engine, exhaust gases will be emitted into the atmosphere and will contain pollutants such as **carbon monoxide** and **nitrogen oxides**. Heavy metals are unlikely to be a pollutant in gas engine exhausts because of the temperatures at which biogas is produced in AD systems. At these relatively low temperatures, heavy metals would not be volatilised to any appreciable degree.

A 5.86. When a bypass flare is used to combust the biogas the same types of contaminants would also be released to the atmosphere when this device was in operation.

A 5.87. It follows that processes that are designed to contain both aerobic and anaerobic digestion elements will generate emissions from the aerobic digestion stage as well as from the gas engines.

[1] TOCs = Total Organic Carbons
[2] Bio-aerosols are micro-organisms and other very small biological particles suspended in air. They are respirable and normally invisible.

From the mechanical stages of MBT

A 5.88. In addition to the emissions from the biological stage of the MBT process, pollutants are also produced from the mechanical parts of the process. These are usually:

- fine particulates (dust);
- bio-aerosols; and
- odour.

A 5.89. These emissions are often referred to as **'fugitive emissions'** and they are usually controlled by maintaining a negative pressure in the building that houses the mechanical separation equipment, in order to channel the air from this part of the process to the off-gas management system (usually a bio-filter or thermal oxidiser).

A 5.90. Air from process buildings has also been used as the air intake for gas engines burning biogas, but there are engine contamination issues that have to be addressed. These are discussed in the section on *'Upgrading of biogas'.*

From MBT configurations with an integrated thermal element

A 5.91. MBT designs that are promoted to include a dedicated thermal conversion stage, will produce different gaseous emissions from those we have already identified because of the much higher temperatures that are used in the thermal stage. The exact nature of the emissions depends on the thermal conversion technology employed: combustion, or gasification. The emissions could include:

- acidic gases (e.g. SO_2, HCl, HF, NO_x);[1]
- heavy metals (Hg and its compounds; Cd and its compounds, arsine, etc);[2]
- VOCs (Volatile Organic Compounds);
- dioxin/furans (generic name for the isomers of **P**oly **C**hlorinated **D**ibenzo-p-**D**ioxins and **P**oly **C**hlorinated –**D**ibenzo **F**urans);[3]
- particulates (dust).

A 5.92. In the UK, emissions from thermal processes[4] that treat waste or waste derived materials are controlled by the EU-WID (EU - Waste Incineration Directive, which provides the statutory limits on emissions to air) regulations. This means that processes that have integrated thermal treatment will require abatement systems to meet EU WID. The WID

[1] SO_2 = sulphur dioxide; HCl = Hydrogen chloride; HF = Hydrogen flouride; NO_x = generic formula use to refer to the oxides of nitrogen.

[2] Hg = Mercury; Cd = Cadmium; Arsine is the hydride of Arsenic (As) formed when arsenic present as a contaminant in waste streams is reduced by nascent hydrogen. Arsine is an extremely poisonous gas which decomposes to its elements As and H_2 when heated above 250-300^{0}C (therefore at gas engine temperatures) As is likely to be present in the engine exhaust gases.

[3] **PCDD** & **PCDF** are a range of chlorinated aromatic compounds that are of primary concern in emissions

[4] The regulatory status of gas engine is unclear

limits for the various types of combustion applications can be found in **Figure B10** in **Annexe B6**.

Figure A34: Potential emissions to air from MBT processes

<table>
<tr><th>Emission</th><th>Mechanical Processing</th><th>Aerobic Processing</th><th>Anaerobic Processing</th></tr>
<tr><td>Dust</td><td>All mechanical handling of input waste and product streams. Sieving, grinding and turning operations.</td><td>Aerobic composting operations are known to produce a range of fungi.
Wind blown dusts from open maturation areas.</td><td>Transfer of materials to and from the digestion plant, where this may be in open conveyor systems or by mechanical loaders.</td></tr>
<tr><td>Bio-aerosols</td><td>Fungi and spores produced by the biological processing stage can be made airborne by mechanical handling of solid materials. They could also be released by the action of equipment such as trommels and vibrating screens.</td><td>Produced by aerobic processes and surveys have specifically identified a fungus called Aspergillus fumigatus, which is found all over the world in soil and forest litter. It is associated with the degradation of cellulose and is capable of surviving temperatures up to 65°C.</td><td>As the AD reactor is closed bio-aerosol formation and dispersion would occur from waste or product storage.</td></tr>
<tr><td>Odours</td><td>Bad housekeeping allowing a build-up of putrescible material on mechanical equipment would produce odours</td><td colspan="2">Typically, odour emissions are caused by anaerobic conditions. Odours can be emitted from the surfaces of open piles, windrows, maturation piles and storage piles. The most problematic compounds creating odours include ammonia, hydrogen sulphide, mercaptans, alkyl sulphides and terpenes.
The anaerobic digestion process releases H_2S and because this gas can be odorous at concentrations in the ppm (parts per million) range, it can usually often be detected at many MBT installations and can reach nuisance levels at AD-based facilities.</td></tr>
<tr><td>Ammonia (NH_3)</td><td>Not Applicable</td><td colspan="2">Generally smaller for enclosed aerobic operations but higher from open windrow composting. Generally smaller for anaerobic systems.
Nitrogen in the waste can easily be converted to NH_3, which is more likely to occur if the C:N ratio is unbalanced because of an excess of nitrogen or the biomass becomes anoxic. High levels of NH_3 can have a detrimental effect on the biofilters. Acid gas scrubbers have been used to reduce the level of NH_3 to below 10 mg/m^3.</td></tr>
<tr><td>Methane (CH_4)</td><td>Not Applicable</td><td>Depending on temperature and moisture control, aerobic processes can become anaerobic with subsequent CH_4 emissions.
Since composting processes would not usually have abatement for methane, this potential green-house gas will be vented to the atmosphere.</td><td>Although emissions from an enclosed AD process operating at atmospheric pressure are unlikely, release of biogas is possible during transfer of materials to and from the digester and from emergency vent valves. This could pose safety risks from uncontrolled CH_4 releases.</td></tr>
<tr><td rowspan="2">VOCs</td><td rowspan="2">Open air heaps have TOC concentrations above 1000 mg/m3 because of the anaerobic conditions at the core of the heap.</td><td>VOCs in the input waste will be transferred to the gas phase by the action of heat and emitted to atmosphere. Gases from MBT plants contain a large number of single organic compounds with fluctuating concentrations.</td><td>VOCs released in the biological process (AD) will be incorporated into the biogas and be combusted in the gas engine.</td></tr>
<tr><td colspan="2">Low concentrations of CFCs, particularly di- and tri-chloromethane, have also been detected in the air emissions from MBT plants.</td></tr>
<tr><td>Gas engine exhausts</td><td>Not Applicable</td><td>Not Applicable</td><td>The gas engine exhausts will contain high levels of CO and NOx. Depending on local regulations it may be necessary to abate these emissions by the application of catalytic technology.</td></tr>
</table>

Source: multiple sources

Abatement of emissions to air from MBT plants

Mechanical and aerobic treatment stages

A 5.93. The off-gases from configurations incorporating these two stages are usually treated using bio-filters or thermal oxidisers.

A 5.94. **Bio-filters** are the traditional means of managing off-gases from MBT, mainly because they are a relatively low cost option. They consist mainly of a mass of humidified porous organic material (usually woody biomass) that is populated with microbes capable of **degrading odorous contaminants** present in the off-gases.

Figure A35: Bio-filter at VKW's reference plant in Tufino, Italy

Source: Photograph taken by Juniper during site visit

A 5.95. Adsorption, physio-chemical and microbiological processes take place between the process off-gases and the filter medium resulting in the breakdown of the contaminants in the off-gases.

A 5.96. Some processes humidify the gases before there are passed through the bio-filter as this is known to assist the uptake and breakdown of contaminants. But, pH, nutrient supply, off-gas flowrate, porosity and the dimensions of the biofilter can also affect the performance of the bio-filter.

A 5.97. The **abatement of bio-aerosols** in bio-filters, depends solely on the physical impact between the bio-aerosols and the bed particles. Hence, the main design parameters to maximise bio-aerosol capture are:

- the size of the bio-filter particles;
- the off-gas flowrate;
- and the size of the bio-filter bed

A 5.98. Bio-aerosol capture is said to be greatest with smaller bio-filter bed particles because there are smaller spaces between particles. But smaller bed particles can result in clogging of parts of the bed. This would cause the velocity of the off gases passing through other parts of the bed to increase, which could reduce the efficiency of odour control.

A 5.99. The suppliers of this type of off-gas cleaning technology employ various techniques to optimise both odour control and bio-aerosol capture, a discussion of which is outside the scope of this report.

A 5.100. **Regenerative Thermal Oxidation** systems (RTO) are now required in Germany, by the 30th BImSchV regulations, to treat off-gases from MBT plants. This requirement results from the stringent limits on the level of Total Organic Carbon (TOC) that can be emitted to the atmosphere, which is beyond the abatement performance of bio-filters.

A 5.101. This technology utilises fossil fuels to combust the off-gases from the process in specially designed burners, which recuperate the heat from the burner exhaust gases (i.e. the 'regenerative' component of the design). In a few cases biogas generated at the MBT plant is also being used to minimise fossil fuel use.

A 5.102. This requirement in Germany adds to both the investment and operating costs of an MBT plant, but the RTO effectively destroys odorous contaminants, bio-aerosols and organic contaminants. In some MBT plants the use of an RTO will avoid the need for a relative large land area that might be required to install a bio-filter.

A 5.103. The integration of an RTO within an MBT plant may also increase the overall plant profile, but the stack for the RTO is shorter and thinner than those found at large scale MSW incinerators (see **Figure A36**).

A 5.104. While most MBT suppliers indicated to us during this study that designs proposed for the UK will not have this element unless it is necessary, one supplier has incorporated RTO's as part of their submission for a UK MBT project (see Herhof process review in **Annexe D3**).

Figure A36: Horstmann reference plant at Münster, Germany

Chimney for RTO

Source: Photgraph taken by Juniper during site visit

Exhaust gases from gas engines

A 5.105. Gas engine exhaust could contain the following pollutants:

- nitrogen oxides (NO_x);
- sulphur dioxide (SO_2);
- hydrogen sulphide (H_2S);
- particulates;
- carbon monoxide (CO);
- Volatile Organic Compounds (VOCs).

A 5.106. Although it is not yet clear how the emissions from gas engines firing biogas will be regulated in the UK, limits have been proposed in the draft waste treatment BREF and are summarised in **Figure A37**. Discussion about this BREF as it pertains to gas engine emissions can be found in **Annexe B5**.

Figure A37: Proposed maxima for exhaust gas emissions for biogas combustion

Pollutant	Maximum concentration limit	Lowest achievable concentration limit
	mg/Nm^3 at 5 vol% O_2	
Particulate	50	10
NO_x	300	100
SO_2	500	?
CO	650	100
H_2S	5	?
Hydrocarbons (VOCs)	50	?
? no lower limit currently included. Consultation with industry ongoing		

Source: adapted from IPPC Draft Waste Treatment BREF, Jan 2004 (page 466)

A 5.107. Similar to the treatment of flue gases from combustion processes, gas cleaning technologies for dealing with the pollutants listed in **Figure A37** are well established and can be easily implemented, but at significant additional costs, which could affect the viability of the MBT project. None of the MBT reference plants we visited during the course of this study, which utilised anaerobic digestion, had gas cleaning systems for the gas engine exhausts.

Emissions to water

A 5.108. Aerobic processes evaporate water from the input waste. Below about 40% moisture, the composting process becomes inhibited and therefore water, usually recycled from some other part of the process, is added to sustain digestion. Some of the water passes through the waste pile extracting solids, either dissolved or suspended, from it. The resulting suspension is called **'leachate'**.

A 5.109. **Leachate can also be produced in processes that are designed to bio-dry the waste, even though no water is added to the process.** The quantity of leachate produced in such processes is lower than that from processes designed to fully digest the waste aerobically.

A 5.110. MBT processes that employ a final maturation stage will require storage of large volumes of 'compost' for several weeks. Leachate will be formed naturally or from rain water passing through the storage piles.

A 5.111. The leachate usually contains various easily bio-degradable compounds (which makes it odorous), nitrates and organic acids, which will need to be managed and treated before discharge to sewer.

A 5.112. Anaerobic digestion processes can produce liquid effluent. This liquid effluent can be in the form of a concentrated sludge or suspension leaving the AD reactor as the digestate. Typically, liquids are recovered from the digestate in a dewatering stage.

A 5.113. As the AD process is optimised to maximise the production of methane, then generally, the COD in the effluent tends to be high. Because many AD systems operate with low solids concentration and require wet pre-treatment systems to prepare the waste for the anaerobic digestion process, relatively large quantities of liquid effluent has to be managed. Such types of anaerobic digestion processes produce larger volumes of liquid effluent than their aerobic counterparts.

Residues to land

A 5.114. MBT processes producing a bio-stabilised output result in about 20-50% of the mass of the input waste being sent to landfill. As we have discussed elsewhere, the biodegradability of this output is significantly reduced. In Germany and Austria further reductions in the TOC levels in this output is necessary for it to be classified as sufficiently inert to be landfilled.

A 5.115. The ‘compost’ or soil improver produced by some MBT processes, which can amount to 50% by weight of the input waste, would need to be managed as a residue if long-term market outlets cannot be found and secured.

A 5.116. MBT processes configured to produce SRF can generate a significant quantity of solid residues. This can be as much as 20 wt% of the input waste. The relatively large residual stream, which is usually landfilled, is a consequence of the degree of refining that is required to produce a good quality fuel (see further discussion of SRF quality in **Annexe C**).

A 5.117. If a long-term outlet cannot be found for the SRF, it would have to be landfilled. Because of the way in which the process is optimised, the SRF would still have a significant biodegradable content, meaning that up to 70% of the input waste may end up in landfill.

A 5.118. If RDF is utilised in a dedicated on-site boiler, the process will generate ash. It will also produce gas cleaning residues as a result of flue gas abatement that will be necessary to comply with EU-WID. Both the ash and gas cleaning residues will need to be managed and disposed of in a landfill.

Potential health impacts

A 5.119. We have discussed the emissions to air, water and land produced by MBT processes. There is significant interest in how such emissions could impact on the health of workers and the population local to waste treatment plants. In this section we provide a brief overview of the possible health risks associated with MBT processes. **It should be stressed that no data exists from studies directly related to an MBT plant** but work has been carried out to explore the risks associated with composting plants. No extrapolations should be made from this information but specific research should be conducted on actual reference facilities.

A 5.120. The possible health risks associated with composting and AD processes have received far less attention than those associated with incineration. For example, the formation and release into the atmosphere of bio-aerosols, undestroyed pathogens in the CLO (digestate or 'compost') and heavy metal contamination of the MBT process solid outputs could lead to exposure for workers, the neighbouring community or those exposed to products related to the outputs. These health risks can be satisfactorily addressed in a modern professionally managed and operated facility, provided a detailed assessment of the issues is conducted.

A 5.121. Notwithstanding this, there remain some concerns in the UK about the possible health impacts of waste treatment facilities, including MBT plants. The House of Commons Environment, Food and Rural Affairs Committee Report – 'The Future of Waste Management' - made reference to scientific doubts about the impact of different waste treatment methods. Subsequently, DEFRA published a report[1] which reviewed the environmental and health impacts of the management and processing of MSW. This report contained some literature data and also referred to the Waste Management BREF[2] being developed in Seville (see **Annexe B**).

A 5.122. This report found that no studies concerning the potential health impacts from MBT plants have been carried out and that there is limited data from Mechanical Recovery Facilities (MRFs) and aerobic composting plants.

A 5.123. It is stated that plant operators will come into close contact with the MSW-derived waste and as such will be exposed to chemical hazards, vapours and suspended particulate matter. The latter will include bio-aerosols that pose the greatest health risk. The greatest exposure of workers is likely to occur in MBT plants that operate hand-picking lines.

A 5.124. It is also said that there are no epidemiological studies of populations living close to a MRF.

A 5.125. Several studies are reported in the DEFRA report[3] where data was obtained from workers exposed to mixed MSW in waste sorting plants but none are directly relevant to MBT plants. The general conclusion was that there was little evidence that MRFs posed a significant threat to public health or the environment but the most important emissions were bio-aerosols for which there are no adopted occupational exposure limits.

A 5.126. The DEFRA report pointed out that composting processes have been subjected to a greater degree of study. Again the primary pollutant of concern was bio-aerosols. The specific components which form bio-aerosols derived from composting processes are as follows:

- Fungi – proliferate during the composting process and are of concern since some are allergenic;

[1] DEFRA – Review of environmental and health effects of waste management: municipal solid waste and similar wastes, written by Enviros Consulting, University of Birmingham, the Open University and Maggie Thurgood.

[2] IPPC – Draft Reference Document on Best Available Techniques for the Waste Treatment Industries, January 2004

[3] DEFRA, op. cit.

- Bacteria – include a wide range of both gram-negative and gram-positive organisms, many of which arrive in the input MSW. These include faecal coliform organisms which should be destroyed by the elevated temperatures developed by the composting process unless they by-pass the high temperature zone;
- Actinomycetes – filamentous gram-positive bacteria some of which are thermophilic (can survive at high temperatures) and thrive in wet compost. They are recognised respiratory allergens;
- Endotoxin – a term given to fragments of the bacterial cell wall from gram-negative bacteria. Can cause illness by inhalation;
- Mycotoxins – non-volatile low molecular weight secondary metabolites produced by fungi. Can be ingested and are considered carcinogenic, neurotoxic and teratogenic and can cause occupational lung disease;
- Glucans – polymeric species of glucose found in the cell walls of fungi, bacteria and plants. A potent inflammatory agent known to cause adverse respiratory health effects.

A 5.127. According to Swan et al. (2002)[1] the effects of exposure to organic dusts (containing the bio-aerosol components listed above) on respiratory health may lead to the following identifiable conditions:

- Allergic rhinitis and asthma – inflammatory condition caused by exposure to allergens in organic dusts;
- Chronic bronchitis and chronic obstructive pulmonary disease – inflammatory diseases of the respiratory system causing obstruction of air exchange. There is evidence that airborne bacterial endotoxins may be one causative factor;
- Extrinsic allergic alveolitis and granulomatous pneumonitis – specific inflammatory reactions of the deep lung leading to chills, fever, dry cough and increasing breathlessness with the long term possibility of permanent lung damage;
- Toxic pneumonitis or organic dust toxic syndrome – an acute illness occurring during or after high exposures to airborne dust and leading to influenza-like symptoms.

A 5.128. Whilst many measurements of airborne concentrations of organisms and dust particles have been made in the vicinity of composting plants (e.g. Wheeler et al. (2001)[2]), which provide evidence of potential hazard to compost workers, there have been **very few studies of health effects from which any quantitative indication of risk can be derived**.

A 5.129. **The Defra Report[3] could not find any direct evidence that living close to a MSW-derived waste composting facility would pose a significant risk to human health but it cautioned that with the expected increase in the number of composting plants then the need to investigate the local health consequences of composting should be pursued**.

[1] Ibid, Swan et al (2002)
[2] Ibid, Wheeler et al (2001)
[3] Ibid

Specialist Support for the Waste Management Sector

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