MINI BREF 2
INSTALLATIONS FOR THE BIOLOGICAL TREATMENT

[extract from *BREF for the Waste Treatments Industries* from August 2006]

<u>Note</u>: Text in blue corresponds to references also mentioned in MINI-BREF 1-Common techniques

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1. General information

Installations containing a biological treatment of waste

Refer to the Scope chapter of this document to see which biological treatments of waste are covered. However, note that the data contained in Table 1.1 refer to all biological treatments, including those not covered in the Scope. The reason for this is that available statistics typically refer to national data and it is difficult to separate information of only those installations covered in the Scope of this document.

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Country	Number of known installations		Known capacity (kt/yr)	
	Hazardous	Non-hazardous	Hazardous	Non-hazardous
Belgium	5	Y		
Denmark	1	0		0
Germany	57	200		
Greece	0	Y	0	
Spain	3	Y	140	
France	0	Y	0	
Ireland	1	Y		
Italy	74	3		180
Luxembourg	0	Y	0	
Netherlands	7	Y		
Austria	8	16 [1]	103	706 [1]
Portugal	1	9	88	514
Finland	20	41	98	305
Sweden		Y		
United Kingdom	0	173		
Iceland	0	0	0	0
Norway	0	Y	0	
TOTAL	**177**	**442**	**429**	**1705**

Y: exists but no data are available
[1] Data corresponds to MBT only
Data in this table correspond to all types of biological treatments and not only to those related with the ones inside the scope of this document. Therefore, the number of installations covered by this document will be less than the figures appearing in this table
Note: Numbers within this table may not reflect the real number of installations or capacity. The main reasons are that the market is so dynamic that numbers change rapidly and/or because no data have been provided by the TWG at all on certain topics. Cells without numbers mean that no information has been provided.

Table 1.1: Installations for the biological treatment of waste
[39, Militon, et al., 2000], [60, Azkona and Tsotsos, 2000], [61, Weibenbach, 2001], [86, TWG, 2003], [150, TWG, 2004]

In Finland there are 561 waste water treatment installations in which the septic tank sludges are also treated. There are 41 installations (aerobic 27 and anaerobic 14) for treating non-hazardous wastes. Besides the non-hazardous waste installations mentioned in Table 1.1, there are also 129 composting facilities, with a total capacity of 542 kt/yr.

In some countries (e.g. UK and Italy), biological treatment is mainly carried out by water companies, utilising existing capacity on waste water treatment works. It is estimated that there are potentially around 30 possible installations. The volumes of waste treated are small, typically less than 1 % of the input of the waste water treatment works, but in some cases this represents a significant COD load (in one case, 50 % of total COD input to the waste water treatment works). However, this type of treatment poses questions because there is a possibility of diluting contaminants as well as contaminating the sewage sludges coming from this kind of treatment.

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2. Applied processes and techniques

Biological treatments of waste

[31, Greenpeace, 2001], [32, DETR and DTI, 2001], [33, ETSU, 1998], [51, Inertec, et al., 2002] [53, LaGrega, et al., 1994], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [80, Petts and Eduljee, 1994], [81, VDI and Dechema, 2002], [86, TWG, 2003], [114, Hogg, 2001], [117, DG Env, 2001], [132, UBA, 2003], [138, Lanfranchi, 2003], [150, TWG, 2004].

Biological treatment uses living micro-organisms to decompose organic wastes into either water, CO_2 and simple inorganics or into simpler organics such as aldehydes and acids. There are several biological treatments used for the treatment of wastes, however, not all are included in the Scope of this document. Table 2.1, together with information included in the Scope section, tries to clarify which treatments are included in this document.

Biological treatment	Brief description	Included in this document?
Activated sludge	Decomposes organic wastes in water by exposing waste to biological growth. Water is recycled and aerated to facilitate biological action and a sludge is generated. Two commonly applied systems: suspended growth systems and attached growth systems	Included as a waste water treatment (see Section 2.6)
Aerated lagoons	Large lagoons containing high concentrations of micro-organisms. The lagoon is aerated to encourage bacterial growth and decomposition of waste	Included as a waste water treatment (see Section 2.6
Composting	'Engineered' mounds of waste are built to encourage the biological breakdown of organic solids, producing a humic substance valuable as a soil conditioner	Not included in this document
Aerobic digestion	Reduction of the organic content of waste. Applied to solid waste, non-continuous waste waters, bioremediation and to sludge and soil contaminated with oil	Mechanical biological treatment (see Section 2.2 and Section 2.3) Only ex-situ bioremediation covered in this document
Anaerobic digestion	Decomposes organic matter in closed vessels in the absence of air. Uses two forms of bacteria: acid-forming and methane- forming. Applied to solid-liquid wastes, highly contaminated waste waters (e.g. chlorinated compounds), bioremediation and in the production of biogas to be used as a fuel	See Section 2.1 and Section 2.3 Only covered the ex-situ bioremediation

Table 2.1: Biological waste treatments

2.1. Anaerobic digestion

Purpose
Anaerobic digestion is used in industry to handle very high COD wastes and as a treatment process for sewage sludge after an aerobic treatment of the waste waters. The production of biogas from controlled anaerobic digestion is one of the principal advantages of the process.

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Principle of operation
Anaerobic digestion involves the bacterial decomposition of organic material in the (relative) absence of oxygen. One of the main limits on the anaerobic digestion process is its inability to degrade lignin (a major component of wood). This is in contrast with the process of aerobic biodegradation.

Feed and output streams
Anaerobic processes may be used to directly treat liquid wastes, the biological sludge generated by an earlier aerobic stage, organic solids and sludges. The inclusion of other feedstocks, such as sewage sludge, alters the resulting digestate. However, it is important to note that the mixing of household waste with these feedstocks can improve both the environmental and economic aspects of the process and has already been adopted in a number of plants (particularly, co-digestion with slurries and manure at small scale farm-based plants).

In the process, carbon from incoming organics is mostly converted to methane and carbon dioxide, and then released as biogas, which is capable of being combusted to generate energy or be used as a fuel to abate VOC emissions for example. The proportion of methane to carbon dioxide will vary with the waste stream and the temperature of the system. The system needs to have a balanced feed to maximise methane production. Installations usually target carbon rich wastes, that will make use of the available nitrogen (and probably the extra required through bioaugmentation).

The anaerobic digestion process leads to a production of methane, with a theoretical methane production of 348 Nm^3/tonne of COD. In general, anaerobic digestion produces 100 – 200 Nm^3 of COD per tonne of biological municipal waste processed. Biogas generation is very sensitive to the feedstock, one plant found volumes ranging from 80 to 120 Nm^3 per tonne depending on the waste input. Biogas can be used to produce electricity (for internal consumption and/or for export) it can be burned in boilers to produce hot water and steam for industrial purposes, and it can also be used as an alternative fuel in light and heavy duty vehicles. Biogas has a typical composition of 55 – 70 % methane, 30 – 45 % carbon dioxide and 200 – 4000 ppm hydrogen sulphide.

The semi-solid residue, referred to as a digestate, is further treated normally through aerobic digestion. Some countries allow direct application of the digestate onto farmlands in certain circumstances (e.g. Sweden, Denmark). The risk of digestate application onto soil, mainly due to the heavy metals is typically controlled by national legislation in the different EU countries. As well as the main product from the process, i.e. a solid digestate, small quantities of surplus liquor are also available which can be dewatered to provide liquid fertiliser or sent to a waste water treatment plant (often following some separation of the solids).

Process description
The primary process variables are the methods of contacting the waste with the biomass (microbes), the moisture content of the waste (e.g. liquid, slurry or solid), and the method and degree of aeration. Anaerobic digestion generally involves the following stages:

<u>Mechanical pretreatment</u>
In order to improve the digestion process, materials, such as plastics, metals and oversized components are removed from the waste to be treated. Separation can be carried out under wet or dry conditions. Following this, a further process of size reduction is used to create a more homogenous material, which aids fermentation and facilitates processing. The size reduction could be brought about by screw-cutting, milling, drumming, pulping or shredding machines.

<u>Digestion</u>
There are a number of different techniques used to effect digestion. They are usually distinguished on the basis of the operating temperature (thermophilic plants operate at around 55 °C (50 – 65 °C), and mesophilic ones at around 35 °C (20 – 45 °C)) and the percentage of dry matter in the feedstock (e.g. dry systems with 30 – 40 % dry matter, wet systems with 10 - 25 % dry matter). Generally speaking, the higher the temperature, the faster the process, but the thermophilic process may be harder to control and will need more biogas for heating to keep them at the required temperature. Some common technologies currently available are listed in Table 2.2.

Technique	Description	Input

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Wet single-step	Solid waste is slurried with the process water to provide a diluted feedstock for feeding into a mixing tank digester	The process can be used for MSW on its own, but the wet process lends itself to co-digestion with diluted feedstocks, such as animal manure and organic industrial wastes
Wet multi-step	Solid waste is slurried and fermented by hydrolytic and fermentative bacteria to release volatile fatty acids which are then converted to biogas in a high rate industrial waste water anaerobic digester	The system lends itself to the digestion of MSW and to the wet organic waste from food processors
Dry continuous	The digestion vessel is continuously fed with a material with 20 – 40 % dry matter through batch loading. In both mixed and plug flow variants, the heat balance is favourable for thermophilic digestion	
Dry batch	A batch is inoculated with digestate from another reactor and left to digest naturally. Leachate is recirculated to maintain moisture content and to redistribute methane bacteria throughout the vessel	
Sequencing batch	Essentially a variant of the dry batch process, in which leachate is exchanged between established and new batches to facilitate start up, inoculation and removal of the volatile materials from the active reactor. After digestion becomes established, the digester is uncoupled from the established batch and coupled to a new batch in another vessel	
Heap bioreactor		

Table 2.2: Anaerobic digestion technologies
[53, LaGrega, et al., 1994], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002]

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Users
Anaerobic digesters are currently used for municipal waste (specifically biowaste separated at source) but have been tested for hazardous waste disposal as well. In some anaerobic digesters at sewage treatment works, spare capacity is being used for a range of industrial non-hazardous organic wastes. The anaerobic digestion of MSW has been commercially available for approximately 10 years and is utilised in Germany, the Netherlands and Denmark. There are developments in Spain, Portugal and Belgium, and it is used to a limited extent in other countries such as Sweden, the UK and France.

2.2. Mechanical biological treatments

Purpose
Mechanical biological treatment (MBT) is usually designed to recover materials for one or more purposes and to stabilise the organic fraction of the residual waste. The practical advantages of MBT plants are, above all, the reduction of:

- the volumes of waste
- the organic matter content of the waste, which are sent to final disposal (landfill or incineration).

Another purpose of MBT is material splitting for further processing (e.g. preparation of solid waste fuels). Biological digestion is intended to reduce the weight, and to render inert any biologically active organic materials (typically called ‘stabilised residue’).Typical values for the combined loss of water and biodegradable materials may be in the range of between 20 and 35 %, mainly depending on time the treatment occurs. Further reductions of the waste volume going to landfill may be achieved due to mechanical separation of the output and can then be finally even higher at 60 %.

Principle of operation

MBT plants significantly reduce humidity by extracting, reducing and stabilising the organic content in the waste. These treatments involve a mechanical separation of the waste, biological treatment (anaerobic and/or aerobic digestion) of the organic fraction, and a further mechanical separation if required.

MBT has to lead to a reduction of the contents of biodegradable organic substances, volume, water content, gas formation potential and respiration activity of the waste, as well as having a significant improvement in leaching and settlement behaviour.

Feed and output streams

In principle, many types of waste materials can be accepted at a MBT plant. The materials broken down and digested in the biological stage include paper and board, green/kitchen organics, and the organic content contained within nappies, packaging, textiles, some types of sewage sludge, etc. Generally, only mixed, unsorted waste enters the plant. However, some EC legislation and alterations in the treatment processes exclude or restrict some types of waste. Some examples are hazardous waste, waste for which a special treatment is obligatory because of EC legislation (e.g. Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption), waste for which a biological treatment is not appropriate and waste causing inhibition of the biological activity.

The output from MBT plants is greatly reduced in weight and stabilised (emission releases from the product compared with the non treated material could be reduced approximately 90 – 98 % under landfill conditions). Such figures are very variable and strongly depend on how reduction of emissions are calculated (e.g. gas generation and respiration activity) and typically can have significant variations in quality. In some countries, the waste OUT may be used as landfill cover if contamination is low enough (low grade compost, grey compost or stabilised biodegradable waste), or it may be landfilled. The quality of the waste OUT produced is generally not acceptable for widespread use because of the contaminants within related to both the inert content (glass, plastic, etc.) and also to the heavy metals content arising from other wastes entering the stream (batteries, etc). Other outputs are combustable fractions and recyclable materials (e.g. metals, plastic)

Process description

MBT plants are very flexible and they can be built on a modular basis. The mechanical treatment phase involves segregating and conditioning the wastes. The processes that may be involved are:

- open waste bags (where necessary) (e.g. shredders)
- extraction of undesirable components that might obstruct the subsequent processing (e.g. metal separators)
- optimising the particle size for subsequent processing (e.g. by sieves, or shredders)
- segregation of biodegradable materials in the underflows of primary screening, so that they can be sent to the biological treatment process (e.g. by sieves)
- segregation of materials with a high calorific value, such as textiles, paper and plastics, in the overflows of primary screening, so that they can be sent for use in the production of fuel. Also, segregation of those materials suitable for further material recovery (e.g. by air separation)
- homogenise materials destined for biological treatment.

Apart from these elements, the plant may include equipment for recovery of metals and for extraction of mineral fractions. The permutations regarding the design of an MBT plant are many and varied. Some plants are designed to separate and biologically treat the residual waste from MSW prior to landfill. A scheme of a MBT process is shown in Figure 2.1.

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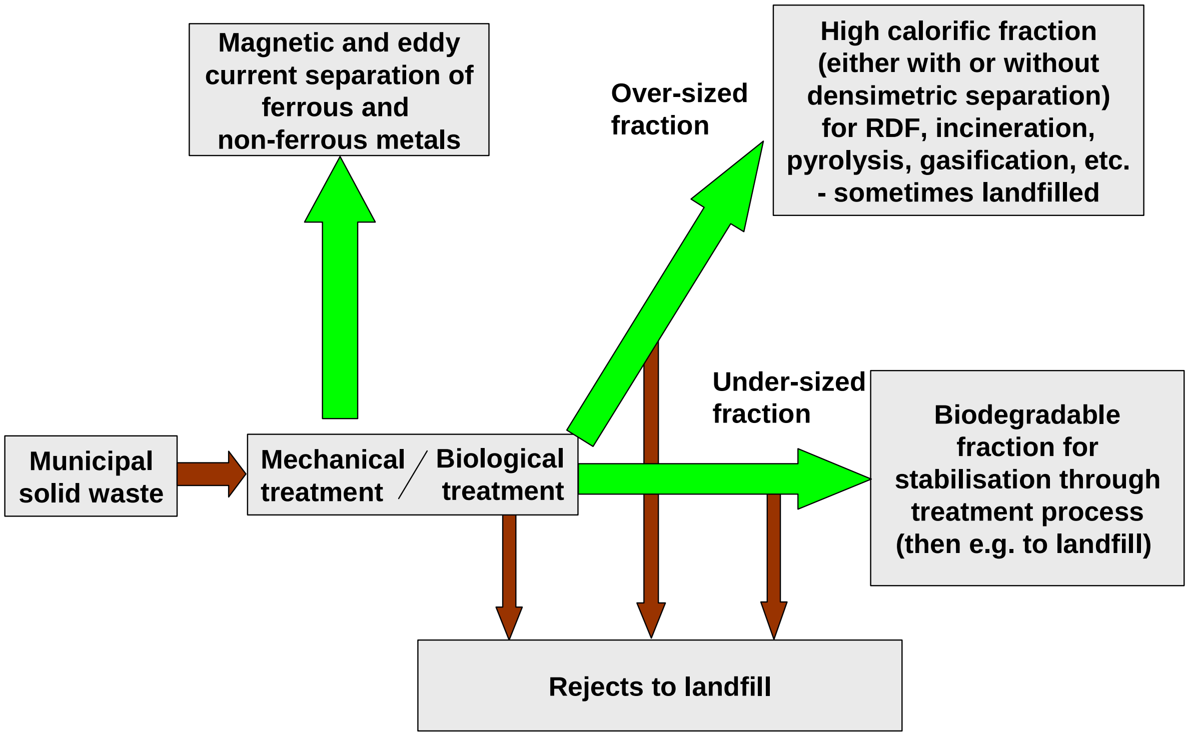

Figure 2.1: Schematic representation of mechanical/biological treatment inputs and outputs
Note: Brown arrows represent residual materials
Green arrows represent processed outputs
Mechanical treatment may be carried out before or after the biological treatment
[17, Eunomia Research & Consulting, 2002], [150, TWG, 2004]

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Two types of systems exist: encapsulated and housed. *Encapsulated systems* (container, tunnel) are usually operated only under pressure with circulating air. Control is exercised through the parameters of temperature and oxygen content in the circulating air. The heat has to be led off from the system by cooling the circulating air. The condensate that is created may be used for watering the heaps or has to be disposed of as waste water.

Housed systems (wandering heap process) are operated both with pressure and with suction, in some plants both aeration methods are used alternatively. Circulating air systems are only possible to a limited extent in housed systems. In the suction operation, at least repeated re-use of the heap exhaust air is feasible. The heat generated can only be led off through water evaporation and exhaust air. In addition to specific aeration control, the periodic turnover of the biologically degraded material is of decisive importance for the progress of biological treatment. It serves the purpose of:

- mixing the material and making new surfaces accessible for the micro-organisms
- activating the biological degradation
- minimising the biological degradation times
- watering the heap evenly and compensating evaporation losses
- compensating for the volume loss of the biological degradation
- leading off heat from the heap.

So the biological process is optimised and the existing biological treatment capacities are cost-effectively utilised. In MBT plants with quasi-dynamical biological treatments according to the moving heaps process or the tunnel process, turnover usually occurs in weekly intervals. Some biological processes require two turnover cycles per week during the first three weeks. After this period, the material is turned over every five to seven days.

Users
Mechanical biological treatment is a tool for pretreating wastes prior to landfilling or for preparing solid waste (typically municipal solid waste) to be used as fuels. Although the popularity of mixed waste composting is declining, it is currently still carried out in Greece, Spain, and Portugal, whilst in Italy, Germany and Austria, it is being progressively or totally 'converted' to MBT of residual waste. These types of treatments are also emerging in the Netherlands and Belgium. There is currently a lot of interest in this technology in the UK with some plants currently being constructed and the UK Government sponsoring trials of such new technologies.

These plants tend to have large capacities because they treat large volumes of mixed waste. An average capacity of 50 – 100 kt/yr is quite normal, but they can be as large as 700 kt/yr, as is one in Milan in Italy and can be as small as 7 kt/yr. At least four examples exist in Europe with the purpose of achieving complete recovery of MSW in the form of recycling materials and energy recovery.

2.3. Biological treatments applied to contaminated soil

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Purpose
To reduce the contamination of soil.

Principle of operation
Aerobic and anaerobic degradation of pollutants in the excavated soil.

Feed and output streams
The types of contamination to be treated are biodegradable pollutants, fuels (gasoline, kerosene, gasoil, heating oils, heavy fuels), mineral oil, waste oils and heavy organic oils. The main products of this type of treatment are decontaminated excavated soils.

Process description
The lack of oxygen is the most limiting factor of pollutant biodegradation in soil and lots of different processes have been developed to optimise soil oxygenation. The various biological treatments differ with the aeration techniques used. Two types of processes exist. *In-situ* and *ex-situ*.

In-situ biodegradation
In situ biodegradation is the term for biological treatment processes that are performed in the original place where the contaminated soil is. Such processes are not covered in this document.

Ex-situ biodegradation
Ex-situ biodegradation is the general term for treatment processes in which the contaminated soil or sludge is excavated and remediated through biological processes. Ex-situ bioremediation technology most often involves slurry-phase bioremediation where an aqueous slurry is created by combining contaminated soil or sludge with water and then the contaminants are biodegraded in a self-contained reactor or in a lined lagoon. Ex-situ biodegradation also encompasses solid-phase bioremediation, such as landfarming, composting, and biopiles. In these processes, the contaminated soil is excavated, and oxygen, nutrients, water, or micro-organisms are added to enhance the natural biodegradation of the contaminants.

Slurry-phase bioremediation
There are two main objectives behind using slurry-phase bioremediation: (1) to destroy the organic contaminants in the soil or sludge, and, equally important, (2) to reduce the volume of contaminated material. Slurry biodegradation has been shown to be effective in treating highly contaminated soils that have fuel or

other organic contaminant concentrations ranging from 2500 to 250000 mg/kg. The slurry process has also shown some potential for treating a wide range of contaminants, including pesticides, creosote, pentachlorophenol, PCBs, and other halogenated organics.
Waste preparation is required before applying slurry biodegradation. The preparation may include excavation and handling of the waste material, as well as screening to remove debris and large objects. Particle size reduction, water addition, and pH and temperature adjustment may also be required to meet feed specifications.

Once biodegradation of the contaminants is completed, the treated slurry is sent to a separation/dewatering system. A clarifier for gravity separation can be used to remove the water from the soil.

Solid phase bioremediation
Solid-phase bioremediation involves the excavation and preparation of contaminated soil to enhance the bioremediation of contaminants in the soil. The techniques typically used for preparation of the soil to be bioremediated are sifting/riddling, homogeneisation, nutrient improvement and compost addition. The bioremediation is carried out in biopiles (soil turning or air injection).

Aerobic digestion involves the storage of biodegradable waste with a bulking agent to increase the porosity of the soil material. Bioremediation is similar to composting in that the contaminated soil is piled in large mounds. However, for these processes air is usually provided by pulling a vacuum through the pile.

Users
Contaminated soils

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3. Current consumption and emission levels

Emissions and consumptions from biological treatments

[33, ETSU, 1998], [51, Inertec, et al., 2002], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [76, EEA, 2003], [81, VDI and Dechema, 2002], [86, TWG, 2003], [113, COWI A/S, 2002], [138, Lanfranchi, 2003], [150, TWG, 2004]

This section discusses the emissions and consumptions of the biological treatments mentioned in Section 0. Each section of this Section 3.2 is structured in the same way as Section 0, namely the treatments follow the order of: emissions and consumptions of anaerobic digestion, mechanical biological treatments and lastly biological treatments applied to contaminated soil. Emissions associated with an ancillary treatment, e.g. transfer station operation, are covered in Section 3.1.

3.1. Waste IN in biological treatments

Generally successful biotreatment only occurs when the waste is non-toxic (although micro-organisms can acclimatise to some extent and to certain wastes), within the relatively narrow pH range of pH 4 – 8, and with a C:N:P ratio of around 100:5:1. Biological treatment is, if well prepared, able to be adapted to a great variety of organic compounds which can be found in wastes or contaminated ground.

Anaerobic digestion
Anaerobic digestion may be used to treat liquid or solid wastes directly (e.g. MSW), or to treat the biological sludge generated by an earlier aerobic stage. There are a number of possible feedstocks which can be used in anaerobic digestion. These include the following: source separated food waste, sludge (e.g. sewage sludge from municipal waste water treatment), agro-industrial by-products, manure, slurries, some fractions of the MSW, and yard waste.

Anaerobic digestion (AD) is better suited to waste with a higher moisture content than aerobic digestion. The process of AD can occur between 60 and 99 % moisture content. Moisture content is also important. A low value increases both the ammonium inhibition of the AD process and the salt toxicity. Therefore, kitchen waste and other putrescible wastes, which by themselves may be too wet and lacking in structure for aerobic digestion, can provide an excellent feedstock for AD. Liquids are often added to the AD processes (either water or recycled effluent) to maintain a high moisture content.

The characteristics of the feedstock have very important effects on the AD process. A high quality feedstock will increase the quality of the digestate. High heavy metal concentrations in the feedstock can be toxic to methanogenic bacteria, in the following order (of increasing severity): iron < cadmium < zinc < chromium < lead < copper < nickel. The volatile solids content will affect the extent to which the process needs to be monitored to avoid the damaging effect of overloading.

The type of waste accepted in this type of treatment is, principally, source separated biodegradable waste, since matter and nutrients are to be recovered with minimal contamination, composting of residual waste or separated fractions thereof is becoming increasingly uncommon. Therefore, the types of waste typically used are the wet organic fractions from kitchen waste and from hotels and restaurants. Garden and park waste and paper and board are not usually processed. Some waste fractions excluded are metals, plastic, glass, animal waste, which is undesirable at plants without hygienisation due to the degradation of lignin which requires post-digestion composting.

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There are two main alternatives for waste separation. The choice between them has an important bearing on the anaerobic digestion feedstock quality:

- source separation (not covered under the scope of this document) – this is actively encouraged in a number of Member States. It includes separation of the putrescible organic fraction (biowaste). It is generally accepted that source separation provides the best quality feedstock for both AD and composting, offering both a maximum organic content and a minimum contamination with heavy metals, glass and plastics. After digestion of this source separated waste in a reliable process, the end result will be the formation of a quality digestate and a high volume of biogas
- centralised separation – this is is the only route for obtaining a digestible fraction from residual waste. The techniques involved include mechanical processing, optical processing and hand-picking. The digestible fraction obtained tends to be more contaminated than source separated biowaste, with inevitable consequences for the digestate's ultimate utilisation (there is some evidence that where pulping is used as a pre-process sorting phase, liquid separation can lead to the removal of some more hazardous elements). There is also the risk of larger non-separated components of the waste being carried over and then causing physical damage to treatment plants further downstream (by abrasion, blockages or tangling).

Mechanical biological treatments
The types of waste that may be accepted by this treatment are non-source separated municipal waste, sludge (e.g. sewage sludge from municipal waste water treatment plants) and commercial solid waste. Technically speaking, there is no restriction in also treating a wet organic fraction (e.g. kitchen wastes), garden and park waste, organic waste from hotels and restaurants or paper and board. However typically these last types of waste are not usually treated by these treatments.

The moisture content of intake waste is extremely variable, but it would be expected that green wastes and household wastes have a moisture content of at least 40 – 50 %.

Biological treatments applied to contaminated soil

Characteristic	Desired range
Organic content	0.025 – 25 w/w-%
Solid content	10 – 40 w/w-%
Water content	60 – 90 w/w-%
Solids particle size	<0.635 cm. diameter
Feed temperature	15 – 35 °C
Feed pH	4.5 – 8.8

Table 3.1: Desired inlet feed characteristics for slurry biodegradation processes for soil decontamination [30, Eklund, et al., 1997]

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The effectiveness of slurry biodegradation for certain general contaminant groups is shown in Table 3.2.

Contaminant	Applicability
Organic contaminants:	
Halogenated semivolatiles	2
Non-halogenated semivolatiles	2
Pesticides	2
Halogenated volatiles	1
Non-halogenated volatiles	1
Organic cyanides	1
PCBs	1
Dioxins/furans	0
Organic corrosives	0
Inorganic contaminants:	
Inorganic cyanides	1
Asbestos	0
Inorganic corrosives	0
Non-volatile metals	0
Radioactive materials	0
Volatile metals	0
Reactive contaminants:	
Oxidisers	0
Reducers	0
KEY: 0 = No expected effectiveness - expert opinion is that the technology will not work 1 = Potential effectiveness - expert opinion is that the technology will work 2 = Demonstrated effectiveness - successful treatability test at some scale has been completed	

Table 3.2: Applicability of slurry biodegradation for treatment of contaminants in soil, sediments, and sludges
[30, Eklund, et al., 1997]

3.2. Consumptions of biological treatments

Anaerobic digestion
The consumptions of a mechanical-biological treatment (MBT) containing separation and anaerobic digestion are typically: water, auxiliary materials and energy:

Water
The total water consumption for treatment of 1 tonne of waste is 78 litres. This treatment uses either tap or groundwater. Water is consumed in the following process steps:

- steam production: 22 litres per tonne waste
- production of polymer solution: 56 litres per tonne waste.

Auxiliary materials
The following products (delivered by truck) are used as auxiliary materials:

- anionic polymeric flocculants (polyacrylamide powder): 60 grams per tonne waste
- iron chloride solution (40 w/w-%): 3 kilograms per tonne waste
- anti-foaming products (polyalkylene glycol solution in water): 50 grams per tonne waste.

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Energy

The only energy source which is used during the normal operation of the installation, is electricity, which could be generated on-site, and heat, which may be needed for possible drying processes and for heating the buildings. The electricity use per tonne of waste is 55 kWh_e. This electricity could be generated at the installation itself by the combustion of biogas in a biogas engine (efficiency: 35 %). The biogas consumption for electricity production is 29.1 Nm³ biogas containing 55 vol-% CH_4 (i.e. 37 kg). The electricity production and the energy use is given in the Table 3.3.

Energy type	kWh per tonne MSW	Source
Electricity input	50 – 55	Own production (biogas engine)

Table 3.3: Electricity consumption and production
[54, Vrancken, et al., 2001], [59, Hogg, et al., 2002], [66, TWG, 2003]

Up to one third of the biogas produced is needed to heat the digester itself, since the process requires warm conditions.

Estimates concerning the utilisation of electricity by the plant vary a great deal. In rural AD plants, approximately 20 % of the electricity produced in the process is required for the plant operation, while urban plants may utilise 2/3 of the electricity produced.

Mechanical biological treatments

MBT technique	Aeration rate (Nm³ air/(m³ of waste.h)
Tunnel:	40 – 60
Moving heap pre-degradation after degradation	 5 – 10 1 – 5
Heap	10

Table 3.4: Aeration rates
[132, UBA, 2003]

In quasi-dynamic biological systems the major part of organic waste contents is degraded within the first four weeks of biological degradation. During this period, the highest aeration rates are needed and up to 60 or 70 % of the total heap air supply is consumed. In the case of process interruptions in the pre-biological degradation, biological degradation is deferred towards the later biological degradation phases/aeration fields. The same holds for static processes without turnover. In the case of upstream fermentation, the intensive degradation of the easily degradable organic components occurs in the closed fermenter. Thus the exhaust gas quantities from the after-degradation are strongly reduced compared to fully aerobic degradation processes.

Energy

Aerobic process	Electricity (kWh/t)	Diesel oil (kJ/kg)
Enclosed aerobic digestion	27 – 65 [2]	5
Windrows	0	15
Range[1]	4 – 72 [2]	5 – 132 [3]
[1] Range contains different types of installations with more or less sophisticated gas treatments and without gas treatments [2] Higher end of the range typically corresponds to process with advanced purification of exhaust gases		

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[3] Higher diesel consumptions are associated with a lower electricity consumptions

Table 3.5: Specific energy consumptions of aerobic digestion processes
[59, Hogg, et al., 2002], [66, TWG, 2003], [150, TWG, 2004]

Water
MBT plants sometimes add water to the windrows, as moisture is lost during the aerobic digestion, which could otherwise lead to a shortage of water and halt the aerobic digestion process. This typically occurs during summer and winter months.

In some cases, there is no net water consumption in the process. In the drying process, water is produced (350 litres -in vapour form- per tonne waste). During the aerobic digestion, temperatures of 50 – 60 °C are reached. Thus, water lost from the feedstock becomes water vapour (about 90 %) and is typically released to the air. However, in some cases, some of this water is condensed. The treatment of this condensation water is quite complex.The purified waste water (permeate) is used as process water in the cooling circuit. It is evaporated in the cooling tower. Tap water is only used in the cooling tower as make-up water (10 litres per tonne of waste). However, other sources reported that the water consumption range from 260 - 470 litres per tonne of waste treated.

Auxiliary products
As reported, no auxiliary materials are used in the process, except for the plastic foil used to bale the waste solid fuel.

Biological treatment of contaminated soils
Most often, organic pollutants are used as a source of carbon and energy by micro-organisms. Also, the concentration of nutrients like nitrogen and phosphorus must be adjusted to support microbial growth. Usually, an ammonium salt like NH_4Cl is used for nitrogen addition and phosphorus as phosphate salt. However, micro-organism growth needs lots of elements like vitamins and some metals (Fe, Mg, Cu, etc.). These elements can be naturally present in soil but improvement can be sometimes necessary. C/N/P ratios are sometimes used to determine the total quantity of nutrient necessary. In fact, a regular control of nutrient concentration in soil must be achieved. Polluted soil is sometimes mixed with compost to optimise biological treatment. Compost addition is most often included between 10 and 30 % and never exceeds 40 %. Water is sometimes also used in order to increase the moisture content in the soil.

Oxygen and nutrients (N and P) are added to the contaminated soil to biostimulate the biodegradation. Increasing the micro-organisms flora with specific organisms (e.g. bacteria, fungus), increases the biodegradability of the contaminants.

3.3. Emissions from biological treatments

The specific emissions from biological treatments depend on:

1. volatile components already being a content of the feedstock,
2. the amount and type of waste being treated and
3. on the type of treatment.

For example, wastes derived from biological sources (such as rendering or food industry effluents) are less likely to produce high emission loads. Thus, e.g. the emissions (loads of TOC, methane, N_2O, ammonia, etc.) from the biological treatment of separately collected biowaste (not covered in this document) are comparable to the emissions from the biological treatment of MSW and sludge except for some volatile VOC ingredients from MSW (e.g. fluorinated chlorinated hydrocarbons).

heavy metals in the original material will be well mixed with the rest of the material, by dissolution, extraction or simply by being torn into small pieces during the operation.

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A common characteristic of the biological treatment is that heavy metals and other non-biodegradable components are subjected to dilution by mixing, dissolution in the aqueous phase, become part of the body of the micro-organisms, concentration by loss of moisture and weight and so on. In general, heavy metal compounds are not selectively separated from the waste and not selectively concentrated to a target output material.
Volatile chemical constituents are the most likely to result in fugitive air emissions, together with ammonia. Municipal wastes tend to produce metals in the effluent or sludge.

Anaerobic digestion
Figure 3.1 shows the relevant emissions from anaerobic digestion processes.

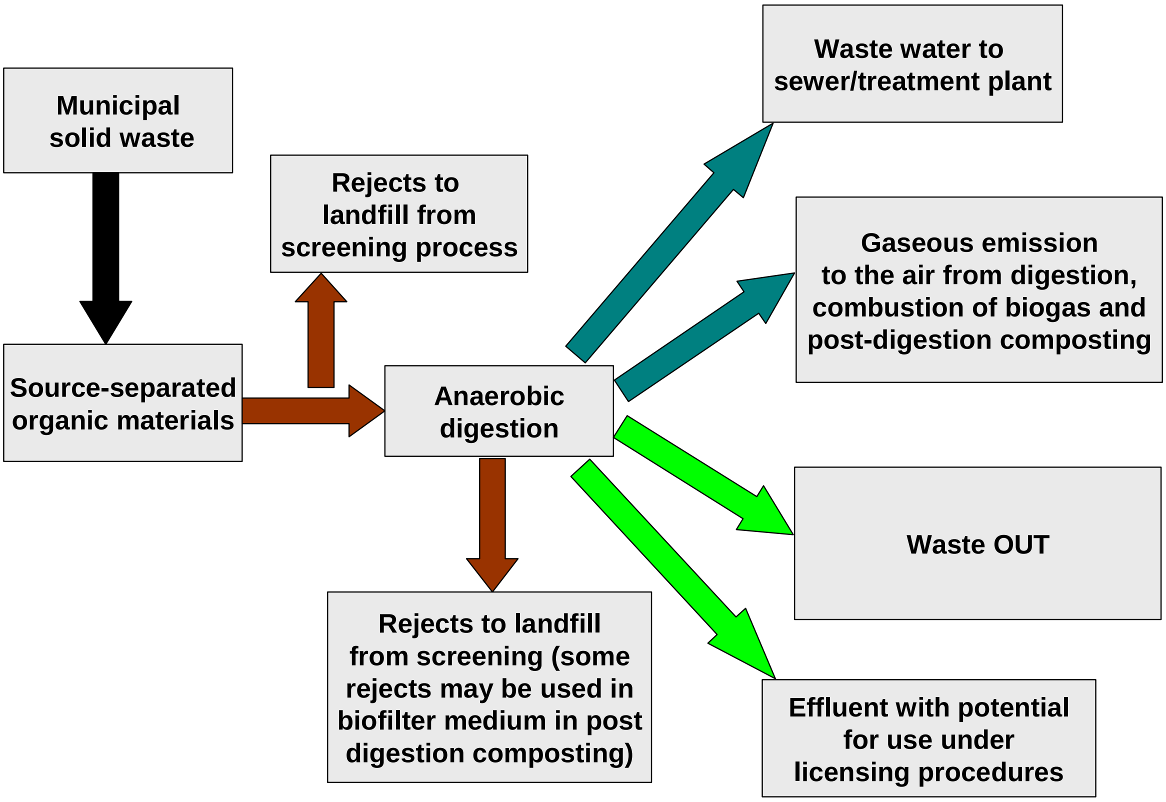

Figure 3.1: Schematic representation of anaerobic digestion inputs and outputs
Note: Brown arrows represent solid materials
Blue Arrows represent emissions
Green Arrows represent waste OUT with some use
[59, Hogg, et al., 2002], [150, TWG, 2004]

Air emissions
This process is enclosed and air emissions are unlikely to occur except during transfer to and from the digester. Anaerobic systems generate less emissions than aerobic systems per kilogram of waste, since the principal gaseous emission (methane) is a desired product. However emissions related to the delivery of waste and mechanical treatment may cause emissions of odours and dust and the aerobic digestion of the digestate may cause a significant odour problem if not properly treated. The emissions generated by the combustion of the biogas are typically higher than the emissions generated during the biogas production process.

A simple mass balance would suggest that, if the input material has a moisture content of 70 %, and if the volatiles solids content of the remainder is 80 %, then the input waste must contain 240 kg of volatile solids. Unscreened stabilised biomass might account for 40 % of the initial weight, of which 40 % might be moisture with the remainder having a volatile solid content of 40 %. This implies a loss of 144 kg, volatile solids, if the incoming material has a moisture content of 70 %.

As already stated, since the digestion process is enclosed, air emissions are unlikely, except during transfer to and from the digester. However, fugitive emissions of biogas are possible from emergency vent valves and from poorly sealed water traps. This can result in a range of hazards, including the risk of fire or explosion, as well as toxicity from contaminant gases such as H_2S and mercaptans (generating odour). Nitrogen gases also are possible.

Particulate emissions are also less likely than from aerobic digestion because the process is enclosed, but there will probably be some waste preparation units which may have larger particulate emissions.

Component	Emissions concentration	Unit	Specific emission (g/tonne of waste)	Specific emissions (g/MJ of methane)
Flue-gas				11000 Nm^3/t
Methane	Fugitive	vol-%	0 – 411	0.1
CO_2	31 – 35.2	vol-%	181000 – 520000	85
CO			72.3	0.25
NO_x			10 – 72.3	
NH_3	Fugitive			
N_2O			0	0.2
SO_x			2.5 – 30	0.15
H_2S	284 – 289	mg/Nm^3	0.033	
TOC (VOC)			0.0023	
PM (e.g. bioaerosol)				
Odour	626	GE/Nm^3		
Chloroform	2	µg/Nm^3		
Benzene	50 – 70	µg/Nm^3		
Toluene	220 – 250	µg/Nm^3		
Ethylbenzene	610 – 630	µg/Nm^3		
m+p+o xylene	290 – 360	µg/Nm^3		
Halogenated HC and PCBs			0.00073	
Dioxins/furans (TEQ)			$(0.4 – 4) \cdot 10^{-8}$	
Total chlorine	1.5	µg/Nm^3		
HCl			0.011	
HF			0.0021	
Cd			$9.4.10^{-7}$	
Cr			$1.1.10^{-7}$	
Hg			$6.9.10^{-7}$	
Pb			$8.5.10^{-7}$	
Zn			$1.3.10^{-7}$	
Fugitive means that fugitive emissions of these components occur but no data have been provided to quantify it				

Table 3.6: Examples of gaseous emissions from anaerobic plants
[33, ETSU, 1998], [54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [150, TWG, 2004]

<u>Water emissions</u>

Although anaerobic systems can be operated in stages to reduce the overall COD in the effluent, they are generally operated for efficient methane production, and the liquid effluent thus tends to be more concentrated than the effluent from aerobic systems.

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The emission species will be similar to those from aerobic systems, but the volume of liquid is much higher and measurements will be needed to calculate emissions (e.g. TOC). The aqueous fraction may be discharged to sewer, or it may go through an aerobic waste water treatment prior to discharge. TOC, total nitrogen, total phosphorus and chloride levels will need to be monitored at the plant inlet and outlet to optimise plant performance, and are probably the most relevant indicators for such optimum performance.

Those units processing biological wastes from the food industries or agriculture are unlikely to produce metals in the liquid emissions. Moreover, the metal content in a discharge may be lower than for an equivalent aerobic system because metal compounds are precipitated and leave with the solid fraction. However, a small amount can appear in the liquid effluent as suspended solids.

The quantity of waste, or excess water generated depends upon a number of factors (extent of biodegradation, moisture content of input wastes and the extent to which the process water is recirculated, the way in which digestate is used -in some cases it is directly applied to land as slurry- and the degree to which steam is used to heat the biomass). Most processes seek to extract excess water from the digestate prior to aerobic digestion of the remaining biomass. In some countries, however, little or no attempt is made to do this and the digestate is used on land as a soil conditioner. Some site studies state 100 – 500 kg per tonne of waste (wet weight). The excess waters are likely to be more polluted from dry systems, since more water is recirculated in the wet systems. Figures for wet and dry systems are given in Table 3.7. The figures on dry and wet systems in Table 3.7 relate to the waste water before removal of the suspended solids. In the post-treatment phase, the liquor from the digestate may be subjected to a process of denitrification, or filtered and/or fed to a decanter, with solids potentially being added to the digestate and the excess water being delivered to sewer.

Components	Units	Dry systems	Wet systems	Amount (g) [1]
Waste water flow	m^3/t			0.47
COD	mg O_2/l	20000 – 40000	6000 – 24000	20 - 530
BOD	mg O_2/l	5000 – 10000	2500 – 5000	
Ammonia				1 – 160
Nitrate				1 – 10
Total N	mg N/l	2000 – 4000	800 – 1200	
Total P				
Cl				
Sulphate				1 – 5
As				
Cd				
Cr				
Cu				
Hg				
Ni				
Pb				
Zn				

[1] Based on 261 litres of waste water/tonne waste (possibly to be reduced to 211 litres by means of a partial re-use of the water used for the production of polymer solution). The range depends on the type of waste water treatment applied

Table 3.7: Typical waste water characteristics from anaerobic digestion
[59, Hogg, et al., 2002], [33, ETSU, 1998], [56, Babtie Group Ltd, 2002], [66, TWG, 2003]

Digested matter and waste

Concerning anaerobic digestion, the sludge or digestate is usually dewatered. The content of heavy metals may be leached out to soil or washed off into watercourses if the digestate is used as a compost, a soil cover or landfilled. In the event the content of heavy metals is too high to allow a land application, the compost/sludge may be used for daily covering at landfills. In this aspect, the groundwater Directive may be applied.

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As the resulting anaerobic sludges are generated in a reducing environment, such sludges may concentrate some compounds such as metal sulphides and some organics (e.g. non-soluble intractable organics). The sludges processed from MSW or sewage sludge with an industrial feed will have a metal content in the waste intake, which will be deposited in the sludge.

The sludge cake, generated in the waste water treatment plant can go for a further chemical purification. If no purification is carried out, the sludge cake needs to be disposed of by landfill or can be (co-)incinerated. The residue of the sand washing is probably not suitable for thermal treatment, due to its low calorific value, and thus is disposed of by landfill.

Mechanical biological treatments
The loss of weight during the aerobic process is about 10 – 20 % of dry substance matter of input waste, equivalent to 30 – 40 % loss referred to the total weight. However, these data do not differentiate between moisture loss and carbon dioxide production. Aerobic systems operated in the open are more likely to create a wide range of emissions because the temperature and moisture content of the process is harder to control. There is much more chance that the material will saturate and produce a liquid emission, and a higher chance of the process turning anaerobic with subsequent emissions of methane.

Various companies co-digested hazardous organic waste streams with municipal or green wastes and low concentration of halogenated organics with aqueous organic wastes. In both cases, it is reasonable to expect the biomass to adapt to a new food source, but it is also reasonable to expect that the temperature rise in composting, or agitation of the tanks in activated sludge systems, will create a discharge to the air of new species.

By contrast to composting plants treating green waste and separately collected biowaste, the material treated in MBT plants may exhibit a broad range of emissions (municipal waste). MBT exhaust gas may contain fluorinated chlorinated hydrocarbons, ammonia, mercury, methane, N_2O and other compounds.

The MBT exhaust gas is partially produced during the mechanical treatment, but mostly is related to the biological process in which heat is released. Depending on the process, management temperatures from 30 up to 90 °C may be reached. Thus a great part of the moisture contained in the waste is driven out. Furthermore, the remains of solvents and of mineral oil carbohydrates can be driven out. Under these boundary conditions, the MBT exhaust gas contains at least the following material groups:

- water in the form of water vapour saturated process exhaust air which is not likely to be below saturation unless unsaturated hall air is added
- degradation products of organic decomposition which are also known from alcoholic fermentation, such as acetone, acetaldehyde, ethanol, methanol, butanol and other short-chained compounds
- solvents, especially benzene, toluole, xylene
- odorous terpenes, mainly limonene and alpha- and beta-pinene
- traces of mineral oil carbohydrates.

<u>Air emissions</u>
There is a limited amount of information available on emissions from aerobic operations. The emissions of air pollutants and odorous substances of MBT plants are:

- waste specific (type, composition, age)
- treatment specific (aerobic degradation, fermentation)
- process specific (type of aeration)
- dependent on operational management
- influenced meteorlogically (weather conditions) in the case of open reactors.

In addition to the release of odorous substances at delivery and during mechanical treatment, the emissions of the plant are mainly determined by the following sources:

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- aerobic degradation
- fermentation
- exhaust air/exhaust gas treatment.

Microbiological degradation releases are from 30 to 50 MJ of heat per kg of organic substance in the waste. This heat leads to the desired self-warming of the material. The surplus heat that exceeds the quantity necessary for maintaining the process temperature is dissipated through evaporation of the water. The water thus fulfils the important function of the heat carrier.

Capacity MBT	Part of the facility	Air renewal, temperature[1], process conditions	TOC (FID)	Concentration of odour		Odour
kt/yr			mg/m³ and g/t respect	spectrum GE/m³	average GE/m³	10^6 GE/h
30	Mechanical treatment and low bunker	Forced ventilation, approx. 2-fold air renewal, 5 – 10 °C during the measurement	40 mg/m³ 20 – 25 g/t	-	-	-
200	Mechanical treatment and low bunker	Forced ventilation, approx. 1.5-fold air renewal, 10 – 13 °C during the measurement	15 – 25 mg/m³ 25 – 55 g/t	150 - 630	390	38
30	Total exhaust air of MBT (2 weeks biological degradation)	Mixture of exhaust air from halls and heaps, approx. 3-fold air renewal, 25 – 30 °C during the measurement	60 – 130 mg/m³ 500 – 720 g/t without methane 10 - 30 mg/m³ approx. 700 g/t methane			
50	Total exhaust air of MBT (16 weeks biological degradation)	Mixture of exhaust air from halls and heaps, approx. 1-fold air renewal, 20 – 30 °C during the measurement	700 – 880 g/t 200 – 700 mg/m³ up to 12000 g/t methane			
70	Exhaust air from biological degradation (fermentation with 8 weeks of biological degradation)	Mixture of exhaust air from halls and heaps, approx. single air renewal, 25 – 30 °C during the measurement	50 – 180 mg/m³ 590 – 720 g/t without methane approx. 80 mg/m³ approx. 1100 g/t methane	8000 – 20000	15000	1200 to bio-filter
[1] There are some systems (air suction systems) where temperatures can reach up to 40 °C						

Table 3.8: Examples of air parameters from some MBT
[132, UBA, 2003], [150, TWG, 2004]

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Some data on air emissions from aerobic operations is shown in Table 3.9 below.

Parameters/ pollutants	Emission to air (values in g/tonne of waste digested) [6]
Flow	Exhaust air: 2500 – 30000 Nm^3/t
Ammonia[3]	5 – 3700 Other data: 0.12 times intake tonnage[1] 20 – 40 mg/Nm^3 [4]
Carbon dioxide	98 – 563 kg/tonne of MSW 482 – 566 kg/tonne of MSW if machinery, energy system and construction are included Other data: 10 – 20 % intake tonnage of waste x 1000 20 % of the intake dry solids
N_2O	11 – 110
NO_x	100
Methane	411 – 2000
Particulate matter[2]	163 – 186
PM_{10}s	e.g. bioaerosols
Odour	50 – 500 GE/m^3
TOC (VOC)[5]	0.7 – 600
AOX	
CFC	
Dioxins/furans	0.1 ng/m^3
Microbes	
Mercury	

[1] Reduce emission factor by 50 % if the system uses forced air or another method to ensure aerobic conditions throughout; increased emission factor if high nitrogen wastes received.
[2] Filter systems on the exit air will reduce general particulate emissions, but not PM_{10}.
[3] If treatment process conditions move away from the range of pH 4 – 8 and with a C:N:P ratio of out of 100:5:1, then larger quantities of other gases may evolve; larger quantities of ammonia may become particularly prevalent if there is too much nitrogen in the feedstock.
[4] Equals 545 – 1090 grams per tonne before any abatement of ammonia (e.g. biofilter).
[5] Methane may represent 1/6 of the TOC amount.
[6] In some cases several ways of calculation or different types of emission data are presented.

Table 3.9: Relevant emissions for MBT operations
[54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [75, UNECE,], [81, VDI and Dechema, 2002], [132, UBA, 2003], [150, TWG, 2004]

Ammonia emissions

Nitrogen in the waste can easily be converted to ammonia, and this is more likely to happen if the C:N ratios are unbalanced (too much nitrogen), or the mass becomes anoxic. For green wastes, this is more likely in the summer months with high levels of grass mowings in the waste and insufficient woody material as a bulking agent. Enclosed aerobic digestion or biodegradation systems with a high forced air injection providing an excess of oxygen produce less ammonia than standard windrows. The ammonia load of the crude gas of MBT plants amounts to between 10 to 560 mg/Nm^3 depending on the process variant, specific exhaust air quantity, etc. With upstream fermentation, up to 1000 mg/Nm^3 may be found in the pre-biological degradation. In addition to its effect of polluting the air, a high ammonia concentration in the crude gas damages the biofilters often used in MBT plants. Therefore, the aim has to be to keep the ammonia load of the crude gas prior to entry into the biofilter as low as possible. Upstream pH controlled acid scrubbers can reliably keep NH_3 concentrations below 10 mg/Nm^3.

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Sites undertake a range of riddling, sieving, grinding and turning operations. *Particulate* emissions occur, but there are no data to quantify them. It is known that most aerobic digestion operations generate a range of fungi, particularly aspergillus. Filters on the exit air will minimise particulate emissions. PM_{10} emissions are a possibility.

Bioaerosols

These are micro-organisms and other tiny biological particles that are suspended in air. They are respirable and generally invisible. Bioaerosols can be produced by the aerobic process. Surveys have drawn particular attention to a fungus called Aspergillus fumigatus. It is found all over the world, especially in soils and in forest litter. It is particularly associated with the aerobic digestion process as it is capable of degrading cellulose (a carbohydrate found in plant material) and is capable of surviving at high temperatures (up to 65 °C). As part of its lifecycle, Aspergillus fumigatus produces tiny spores.

Odour emissions

They may come from anaerobic conditions. Odours are emitted from the surface of open piles, windrows, maturation piles, storage piles and stockpiles. Exhaust gases from controlled aeration systems also contain odourous compounds. Typically the most problematic odorous compounds at aerobic digestion facilities include ammonia, hydrogen sulphide, mercaptans, alkyl sulphides such as dimethyl sulphide, dimethyl disulphide and terpenes. These compounds are present in many feedstocks or are formed during the process through aerobic or anaerobic actions.

Some pesticide

They may be broken down by photolysis, plant metabolisms or microbial action. Others are persistent.

Methane

Methane will also be an issue, although the plant will usually be run in such a way so as to minimise this production. Methane emissions may range from 10 to 2000 mg/Nm^3.

VOCs

Any volatiles in the feedstock will tend to be emitted to the air due to the temperature rises. The crude gas from MBT plants contains a large number of single organic compounds in relatively high but fluctuating concentrations. The TOC concentration (total organic carbon) that records all organic contents is a parameter suitable for monitoring. The MBT crude gas contains TOC concentrations of between 10 to 2000 mg/Nm^3, but up to 7500 mg/Nm^3 have been measured. Open-air heaps have TOC-concentrations above 1000 mg/m^3 due to inevitable anaerobic conditions within the core of the heap. Carbon concentrations of more than 10000 mg/Nm^3 have been recorded at the surface of non-aerated open-air heaps especially with anaerobic conditions within the heap. The main outflow of the TOC occurs during the first hot biological degradation phase, i.e. in the first one or two weeks of biological degradation. Next Table 3.10 shows the list of organic compounds identified in MBTs.

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Alkanes		
1,1-dimethylcyclopentane	4-methylnonane	n-dodecane
1,3-dimethylcyclohexane	5 ratified alkane	n-heptane
1,4-dimethylcyclohexane	5-methylundecane	n-hexane
10 ratified alkane	6 alkylcyclohexane	n-nonane
11 ratified alkane	butylcyclohexane	n-pentadecane
2 ratified ektane	2 C_3-cyclohexane	n-pentane
2 ratified undecane	C_4 –cyclohexane	n-tetradecane
2,3-dimethylpentane	cyclohexane	n-tridecane
2,4-diphenyl-4-methyl-2-pentene	decane	n-undecane
2-methyldekane	dimethylcyclohexane	nonadecane
2-methylheptane	dodecane	propylcyclohexane
2-methylhexane	ethylcyclohexane	tridecane
2-methylnonane	ethylcyclopentane	trimethylbenzol
2-methylundecane	hexadecane	trimethylcyclohexane
3-methyldecane	methylcyclopentane	undecane
3-methylheptane	methylbutane	3 ratified heptane
3-methylhexane	methylcyclohexane	7 ratified nonane
3-methylnonane	methyloctane	2 ratified octane
4-methylheptane	n-decane	ratified dodecane
PAHs		
1,2,3,4-tetrahydromethyl-naphthaline	naphthaline	acenaphthene
1,2,3,4-tetrahydronaphthaline (tetraline)	dimethylnaphthaline	methyldecaline
ethylnaphthaline (vinylnaphthaline)	1-methylnaphthaline	2 -methylnaphthaline
decahydromethyl- naphthaline	methyltetraline	
Acids and esters		
2-butene acidethylester	butyric acidmethylester	hexanal
2-methylbutyric acidethylester	2 carbonacidester	hexanacidethylester
3-methylbutyric acidethylester	6 carbonacid	fattyacidethylester
alkanacidethylester	acetic acid	myristinacidisopropylester
alkanacidethylester (acid $>C_7$)	2 alkanacid	pentanacidmethylester
aceticacid -1-methylethylester	aceticacidalkylester	propanacidethylester
benzoacid	aceticacidbutylester	propanacidmethylester
benzoacidbenzylester	aceticacidethylester	hetradecane acid
butyricacid	aceticacidmethylester	hexadecane acid
butyricacidethylester		
Terpene		
α-pinene	β-pinene	β-myrcene
pinene	D-limonene	3-carene
myrcene	camphor	
Aldehydes/ketones		
1,2-diphenylethanone	3-buten-2-one	hexanal
2,3-butandione	3-hydroxy-2-butanone	methyl-2-butanone
5 2-alkanone	3-pentanone	methylisobutylketone
2-butanone	Acetaldehyde	nonanal
2-heptanone	Acetone	octanol
2-hexanone	acetophenone	pentanal
2-methylpropanal	decanal	ramified 2-heptanone
2-pentanone	diphenylethandione	dodecanal
2-undecanone		
Alcohols		
1-butanol	2-methyl-1-propanol	isopropanol

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1-pentanol	2-methylbutanol	ramified alcanol
2-butanol	3-Methyl-1-butanol	ramified pentanol
2-ethyl-1-hexanol	butanol	ethanol
2-methyl-1-butanol		

Benzenes/alkylbenzenes		
benzene	2 C_6-benzene	methylpropylbenzene
5 C_3-benzene	3-dimethylethylbenzene	propylbenzene
C_4-benzene	ethylbenzene	styrol
1-methylpropylbenzene	ethylmethylbenzene	toluene
15 C_4-benzene	o/m/p-xylene	3-trimethylbenzoene
7 C_5-benzene	methylisopropylbenzole	
Halogenic compounds		
1,1,1-trichlorethane	dichlormethane	tetrachlorethylene
dichlorbenzene	fluorethylene	trichlorethylene
Sulphur compounds		
2-butanthiol	dimethylsulphide	sulphur dioxide
dimethyldisulphide	methanthiol	carbon disulphide
Siloxanes		
cyclohexasiloxane	cyclotetrasiloxane	cyclosiloxane
cyclopentasiloxane	hexamethyldisiloxane	siloxane
octamethylcyclotetra-disiloxane		
Phthalates		
diethylphthalate	dimethylphthalate	
Ethers		
tetrahydrofurane		

Table 3.10: Organic compounds which were verified within the scope of four screening inquiries of exhaust air (three aerobic tests with intensive and after-biological degradation, one anaerobic plant) [132, UBA, 2003]

Chlorofluorocarbons (CFC)

The few available data shows that in MBT plants CFC loads of more than 10 grams per tonne input material may be released depending on the processed waste type (Table 3.11). Leading substances are CFC R11 (trichlorofluoromethane) and R12 (dichlorofluoromethane) which were used frequently in the past.

Parameter (g/tonne)	**Facility A (exhaust air from tunnel)**	**Facility B (exhaust air from biological degradation trommel)**	**Facility B (exhaust air from biological degradation trommel)**	**Facility B (exhaust air from halls)**	**Facility C (exhaust air from biological degradation module)**
Probe spring	Winter	Summer	Winter	Summer	(estimated)
R11	n.d.	8.5	4.1	0.4	2.2 – 2.3
R12	n.d.	11.3	0.2	0.4	1.3 – 1.4
R21	n.d.	n.d.	-	n.d.	n.d.
R113	n.d.	n.d.	<0.05	n.d.	1.9
R114	n.d.	n.d.	0.2	0.4	1.2 – 1.4
n.d. = not detectable					

Table 3.11: CFC emissions from MBT (raw gas) [132, UBA, 2003]

Waste water

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Sites are unlikely to produce a surplus of liquid because the aerobic digestion process emits large volumes of water to the air and generally requires additional liquids as 'top-ups'. If they do, then these will be occasional intermittent flows. Although it is known that some sites have had problems with waste water, the quantities of liquid emissions are likely to be small since aerobic digestion is an exothermic process.

Water parameter	Specific emissions (kg/tonne of MSW)	Concentration of the waste water (mg/l)
Waste water flow	260 – 470	
TOC		40
COD	0.457	120 – 200
BOD_5		20 – 25
HC		10 – 20
BTEX		0.1
AOX		0.5
Chloride	0.152	
Total N		70
Total P		1 – 3
CN	$7.28 \cdot 10^{-5}$	0.2
Sulphide		0.1 – 1
Cd	0	
Cr	0	0.5
Cr (VI)		0.1
Cu	0	
Hg	0	
Mg	0	
Ni	$7.94 \cdot 10^{-4}$	
Pb	$5.96 \cdot 10^{-4}$	
Zn	$2.38 \cdot 10^{-4}$	
Copper and zinc would be expected in any aerobic digestion leachate as they are plant micronutrients. There is a possibility of toxic metals in the effluent although most metals will remain in the aerobic digestion product.		

Table 3.12: Leachate from aerobic digestion
[54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [75, UNECE,], [81, VDI and Dechema, 2002], [132, UBA, 2003], [150, TWG, 2004]

Emissions to land

Aerobic digestion sites should make certain whether or not there are liquid emissions to land, even if they have a concrete base underneath the windrows, as the concrete basement may not be non-continuous, and part of the operation may be on a permeable surface. If the base is impermeable, then there will be a discharge to surface waters or sewer or a collection in sumps. If the aerobic digestion sites are on the landfill, liquid discharges will go to the landfill treatment plant.

There is also a possible problem if excess rainwater falling on the windrows is not evaporated by the heat of the aerobic digestion process. Surplus water would pick up fatty acids and humic acids and solids from the aerobic digestion process and then transfer the discharge to land, surface water or sewer.

Sludge and/or digestate for onward disposal to landfill typically have organic compounds, nitrogen and phosphorous compounds, chloride and chromium.

Biological treatments applied to contaminated soil

Air emission due to *ex situ* biodegradation

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Little information exists on volatile losses from *ex situ* bioremediation processes. Table 3.13 summarises the data available for both slurry-phase and biopile systems. Although these data are limited, volatilisation appears to be a small component of the overall removal of hydrocarbons in these processes.

Contaminants	Emission rate	Total emissions	Biodegradation/ Volatilisation	Notes
Slurry-phase bioremediation				
Creosote	0.07 – 6.3 g HC/h	n.a.	n.a.	Off-gas concentrations peaked during day 1 and decreased to near baseline by day 5
Petroleum sludge	n.a.	910 kg HC	n.a.	425000 kg of soils were treated. Emissions reduced to background by day 6
Petroleum sludge	n.a.	10 - 20 kg/yr; 1.5 kg dredging 30 kg storage tank; 4 kg pond	n.a.	A full-scale system is estimated to have 500 to 2000 kg of VOC emissions
Biopile				
Gasoline	n.a.	n.a.	99 %/1 %	Air emissions measured for the stockpiling/handling, mixing, and curing operations. Mixing component accounted for 96 % of contaminants lost. 73 % of VOCs lost were trapped in carbon units
Petroleum	0.01 kg/hr HC once through; 0.03 kg/hr HC after treatment (carbon)	n.a.	n.a.	Off-gas was also recycled back to the biopiles to further reduce emissions
Petroleum	16 ppb BTEX start-up; 5 ppb BTEX (day 8); <1 ppb BTEX (day 35)	n.a.	>99 %/<1 %	
HC: Total hydrocarbons				

Table 3.13: Summary of emission data for ex-situ bioremediation systems [30, Eklund, et al., 1997]

In open lagoons and in aerobic digestion and land treatment processes, the primary environmental factors which influence air emissions, in addition to the biodegradability and volatility of the waste, are process temperature and wind speed. Emissions tend to increase with an increase in surface turbulence due to wind or mechanical agitation. The temperature affects emissions through its influence on microbial growth. At temperatures outside the band for optimal microbial activity, volatilisation will increase. Emissions from self-contained reactors are also determined by reactor design parameters such as the amount of air or oxygen used to aerate the slurry. Higher gas flows will strip more volatiles out of solution and increase air emissions.

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3.4. Waste OUT from biological treatments

The structure given to this section corresponds to the same one that has been given to Section 2.2, and describes the waste (or products) generated by the biological treatments of waste (the Waste OUT, according to the definition in **Error! Reference source not found.**).

Anaerobic digestion

An overview of the expected waste OUT (based on the source separated MSW input) is given in Table 3.14.

Fractions suitable for energy recovery	Specific amounts (kg per tonne MSW)	Heating value (MJ/kg)	
		Lower	Higher
Biogas [1]	117.5 (75 – 364 Nm^3)	15.4	16.8
Light residue	37.3	12.4	21.5
RDF	257.2	17	25.8
Wood-like fraction	14	4.9	10.0

[1] This lower yield is mainly explained by the higher content of non-degradable material (sand). Yields may vary from season to season (higher yields during autumn/winter).

Table 3.14: Expected waste OUT (based on the standard composition of waste) from the installation [54, Vrancken, et al., 2001], [59, Hogg, et al., 2002]

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<u>Biogas</u>

In the biogas, there are also other constituents in smaller concentrations including carbon monoxide, hydrogen, nitrogen and oxygen. A larger proportion of inorganics and polluting substances in the process will lead to smaller amounts of a 'dirtier' biogas. The constituents of biogas (other than carbon dioxide and methane) can be quite important in its end-use. Table 3.15 shows such the typical composition of a biogas generated by anaerobic digestion.

Component	Biogas concentration (vol-%)	Specific production (g/tonne of waste)	Specific emissions (g/MJ of methane)
CO_2	25 – 50	181000 – 520000	85
Methane	50 – 75	0 – 411	0.1
Water (biogas)	6 – 6.5		
O_2	0.9 – 1.1		
N_2	3.9 – 4.1		
H_2			
H_2S	<0.1 – 0.8		
Ammonia	<0.1 – 1		
Mercaptane	In spores		
Low molecular fatty acids			
Higher molecular substances	traces		

Table 3.15: Composition of biogas generated by anaerobic digestion
[33, ETSU, 1998], [54, Vrancken, et al., 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [132, UBA, 2003]

The biogas may be partly used for the production of power and/or heat (e.g. electricity, building heating, vehicles powered with biogas) by combusting it in a biogas engine. When biogas is used to generate energy, it is possible to generate from 20 to near to 300 kWh of net energy per tonne of waste. Several references have been enclosed in Table 3.16.

Study/process	Net energy production (kWh/tonne of waste)		
	Minimum*	Average*	Maximum*
AN-Anaerob	38	49	60
DBA	45	53	60
Kompo	85	88	90
NOVEM	21	88	154
Plaunener-Verfahren	85	98	110
Waterman BBT		100	
DHV study		102	
White et al		110	
Prethane-Biopaq	80	110	140
IEA Bioenergy	75	113	150
BTA	100	115	130
Dranco	105	131	157
Vrancken		140	
WAASA	120	145	170
IWM	100	150	200
Schwarting-UHDE		154	
D.U.T	254	273	292
* If only one figure is quoted, the reference in question did not provide a range			

Table 3.16: Net energy production figures from different sources
[59, Hogg, et al., 2002], [54, Vrancken, et al., 2001], [150, TWG, 2004]

Solid waste fuel to be used as fuel
More information on this matter can be found in Section **Error! Reference source not found.**. The solid fuel prepared is a presorted mixture of paper and plastics. Washing of the digestion product yields two additional streams a residue and a wood-like fraction, with a residual calorific value that allows thermal treatment. The three streams added together give 308.5 kg solid fuel mix for thermal valorisation. The solid fuel mix has a lower heating value of 16.5 MJ/kg and a dry solids content of 66 %.

Type of waste	%
Organic waste	45
Others	31
Paper/cardboard	13
Plastics	9
Textile	2

Table 3.17: Composition of the solid waste prepared
[54, Vrancken, et al., 2001], [150, TWG, 2004]

Digestate

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The amount of digestate generated ranges from 100 – 500 kilograms per tonne of waste IN. This range is due to an extention of biodegradation, the moisture content of waste IN, the extent of process water recirculation, the way in which the digestate is used and the degree to which steam is used to heat biomass. The composition varies as shown in Table 3.18:

Feedstock	Units	N	P	K	Mg	Ca
Biowaste/RDF	% of TS	1.2	0.68	0.74		0
Source sep. MSW	% of DM	1.90	0.66	0.63	-	-
Source sep. MSW	ppm	20.0	11.9	14.7	11.6	49.7
Source sep. MSW	ppm	11	8	10	-	-
Organic fraction MSW	ppm	1 – 1.3	6 – 12	8 – 12	17 – 26	60 – 110
Fruit/veg from market	ppm	21.9	9.5	10.5	4.7	-
Unsorted MSW	ppm	11	8	10	-	-
Unsorted MSW	ppm	19	13	15	3.67	-

Table 3.18: Chemical characteristics of anaerobic digestate
[59, Hogg, et al., 2002], [150, TWG, 2004]

<u>Other products/waste</u>

Recovered product	Specific production (tonnes per tonne of waste treated)
Nutrient recovery	4.0 – 4.5 kg N/tonne 0.5 – 1 kg P/tonne 2.5 – 3 kg K/tonne
Energy recovery	0.4 – 0.9 MJ electricity per tonne of waste. In addition, CHP plants may generate a similar quantity of heat
Total solid residuals depending on waste	0.3 – 0.6
Quality products for recycling (recovery)	Fibres (0.07 – 0.3) (for composting)
Other residuals possible for re-use with restrictions	Fluids (0.6) Inerts (0.05) Sand (0.08)
Residuals for landfilling or other waste treatment	Overflow sieving (0.02 – 0.1)
Metals (containing ferrous)	0.043
Ferrous metals	0.032
The separation and washing of the digested material yields fractions of inert materials, sand and a fibrous fraction. The inert materials and the sand fraction can be used as a building material. Another output corresponds to the fibrous fraction.	

Table 3.19: Overview of anaerobic technology for the treatment of biodegradable municipal waste
[59, Hogg, et al., 2002], [54, Vrancken, et al., 2001]

Mechanical biological treatments

The aerobic treatments reduce the tonnage of input materials by the conversion of part of the biomass to carbon dioxide and water through microbial actions.

Fractions suitable for energy recovery	Specific amount (kg per tonne MSW)	Heating value (MJ/kg)	
		lower	higher
RDF	300 – 460	16.6	19.9
Fractions not suitable for energy recovery		**Destination and properties**	
Ferrous	32 – 40: 24 ferrous 1 8 ferrous 2	Scrap trade (2 fractions) Pre-separation Post-separation	
Inerts	48.6	Re-use	

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	<40 glass	
Non-ferrous	8 – 10	Recovery
Organic rich material (to biological treatment)	550 - process losses 200 - treated waste for landfilling 350	TOC 18 w/w-% Upper heating value of 6 MJ/kg Density >1.5 t/m^3 (wet) Hydraulic conductivity k_f<10^{-8} m/s

Table 3.20: Waste OUT from MBT
[54, Vrancken, et al., 2001], [59, Hogg, et al., 2002], [81, VDI and Dechema, 2002]

Grey compost
Copper and zinc can be expected to be found in any compost as they are plant micronutrients. Other heavy metals will be associated with whole aerobic digestion only, or by the addition of, hazardous waste streams. In general, metals will be retained in the solid fraction. Metals will bioaccumulate in the compost fraction. Some products recovered by this treatment are shown in the Table 3.21.

Recovered product	Value (tonnes/tonne of waste treated)
Nutrient recovery	2.5 – 10 kg N/tonne of biowaste recovered 0.5 – 1 kg P/tonne of biowaste recovered 1 – 2 kg K/tonne biowaste recovered
Energy recovery	Likely (e.g. through dry stabilisation/separation processes to manufacture RDF). Depending on the configuration, RDF may be (typically) 0.2 – 0.5 tonnes, with a calorific value of around 15 – 20 MJ/kg (sometimes higher). In addition, in some configurations, digestion processes can recover energy from degradation of the biodegradable fraction (can be >100 kWh depending on composition)
Total solid residuals depending on waste (tonnes/tonnes waste)	0.7 – 0.9
Quality products for recycling (recovery)	Metals (0.05)
Other residuals possible for re-use with restrictions	RDF (0.3 – 0.4) Stabilised organic fraction (0.07 – 0.2) ▪ respiration activity (AT_4): <5 – 7 mg O_2/g TS ▪ gas formation: GB21 <20 mg/g TS
Residuals for landfilling or other waste treatment	Heavy and light rejects (0.2 – 0.4)

Table 3.21: Overview of MBT outputs for the treatment of biodegradable municipal waste
[59, Hogg, et al., 2002], [150, TWG, 2004]

The characteristics of the aerobic digested product has the following characteristics: one kilogram of treated waste potentially releases a total load of 1 – 3 g of COD, 0.5 – 1.5 g TOC and 0.1 – 0.2 g NH_4-N into the leachates. The real numbers clearly depend on the intensity respective and the duration of the treatment. Table 3.22 shows the potential emissions from grey compost by gas and leachate.

Emission potential	Unit	Untreated MSW	Mechanical-biological treated MSW
by gas: carbon	litre/kg of dry matter g C_{org}/kg dry matter	134 – 233 71.7 – 124.7	12 – 50 6.4 – 26.8
by leachate: TOC N	g/kg of dry matter g/kg of dry matter	8 – 16 4 – 6	0.3 – 3.3 0.6 – 2.4

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Cl	g/kg of dry matter	4 – 5	4 – 6
Note: Minimum values represent the stabilisation degree reached by more modern MBTs			

Table 3.22: Range of organic carbon, nitrogen and chlorine transfer by gas and leachate [81, VDI and Dechema, 2002]

Biological treatments applied to contaminated soil

	Initial concentration		Final concentration		Removal(a)	
Compound	**Solids (mg/kg)**	**Slurry (mg/kg)**	**Solids (mg/kg)**	**Slurry (mg/kg)**	**Solids (%)**	**Slurry (%)**
Phenol	14.6	1.4	0.7	<0.1	95.2	92.8
Pentachlorophenol	687	64	12.3	0.8	98.2	92.8
Naphthalene	3670	343	23	1.6	99.3	99.5
Phenanthrene and anthracene	30700	2870	200	13.7	99.3	99.5
Fluoranthene	5470	511	67	4.6	98.8	99.1
Carbazole	1490	139	4.9	0.3	99.7	99.8
Note: Treatment carried out using a 190 m^3 reactor (a) Includes the combined effect of volatilisation and biodegradation						

Table 3.23: Performance of a slurry biodegradation process treating wood preserving wastes [30, Eklund, et al., 1997]

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4. Techniques to consider in the determination of BAT

Techniques to consider in biological treatments

This section contains techniques considered to have a good environmental operating performance (e.g use of a good energy system) or that can help lead to a good environmental performance (e.g. environmental management systems). These techniques are applied with biological treatments typically used as part of a whole waste treatment. Biological treatments of waste waters are covered in Section **Error! Reference source not found.**.

4.1. Selection of the appropriate biological treatment

Description

A key technical factor for selecting the appropriate system is its capability to provide proper contact between the organic constituents of the waste and the microbial population. This capability depends primarily on the state of the waste and its concentration. An approximate schematic of the system offering the most capability as a function of these two variables is shown in Figure 4.1.

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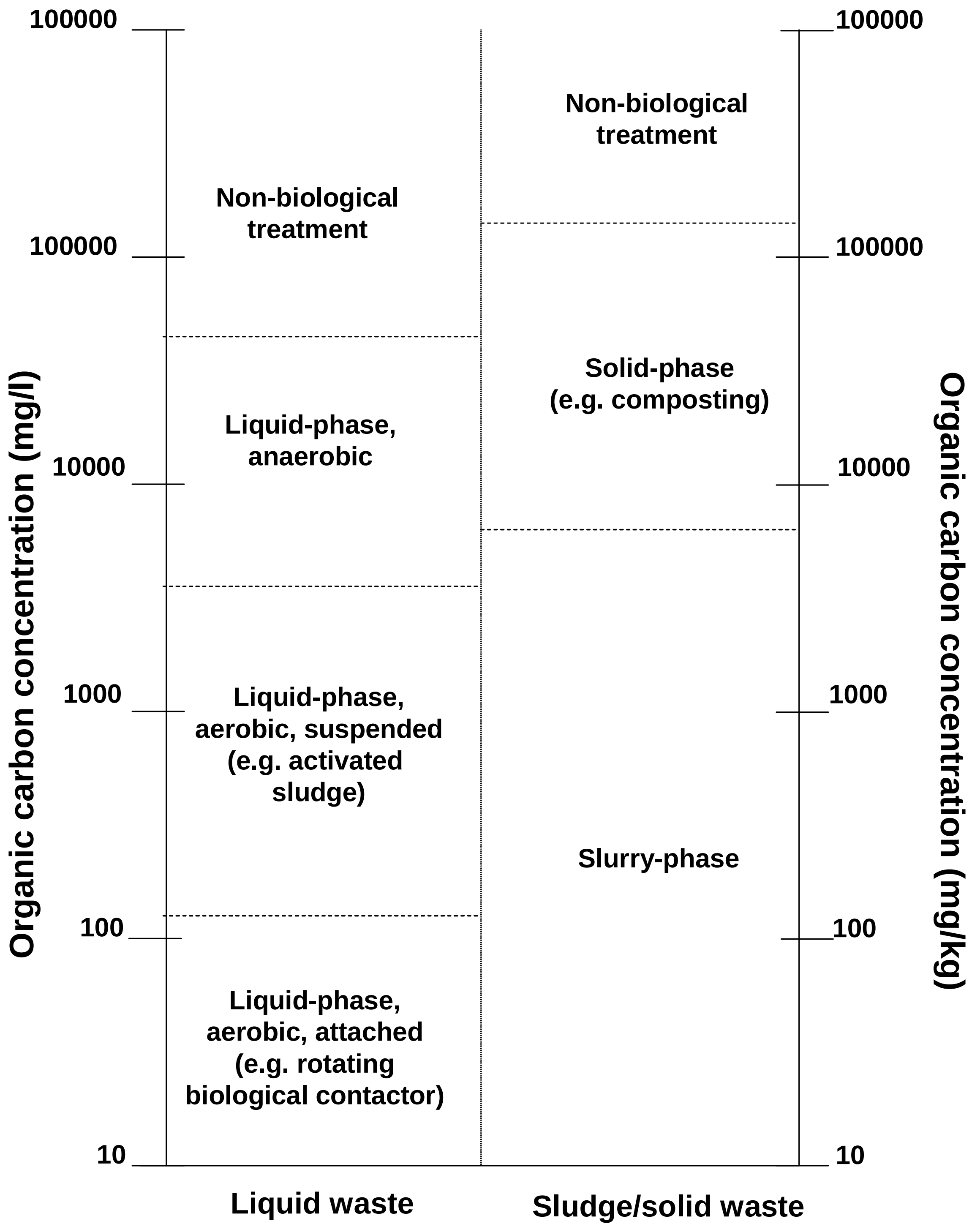

Figure 4.1: Selection of an appropriate biological treatment system as a function of concentration and the form of waste
[53, LaGrega, et al., 1994]

In addition, fully enclosed or encapsulated bioreactors help to better control the biological treatment and avoidance of fugitive emissions (e.g. VOC, odours, dust).

Achieved environmental benefits
Selecting the appropriate biological treatment for the waste to be treated helps to avoid operational problems as well as to extract the major benefit from the waste (e.g. use as fuel).

Operational data
Important features, for consideration, of the selected biological system are the uniform distribution of the nutrients and moisture of the waste to be treated (homogeneity) as well as the availability of treatment selected.

Driving force for implementation
Waste hierarchy may give some guidance on what type of treatments can be used. However, it may be that when applying the waste hierarchy without a good underlying analysis, a good result may not be achieved. It has been reported that in the case of sewage sludge treatment, because of the low energy content of biologically treated sewage sludge in relation to thermally dried sewage sludge, a good option may be to either select anaerobic digestion and thermic drying and/or incineration for different wastes.

Reference literature
[53, LaGrega, et al., 1994], [150, TWG, 2004]

4.2. Specific storage and handling techniques for biological treatments

Description
Some techniques related to storage and handling techniques in biological waste treatment include:

a. having reception pits or equalisation tanks
b. housing and equipping the waste treatment installation (including acceptance area and bunker), mechanical treatment, storage facilities and all biological treatment steps) with an exhaust air collection device (containing dust, TOC, ammonia, odours, germs), and where applicable, a removal facility. Air exchanges three or four times per hour are common
c. purifying the exhaust air or re-using it, e.g. as supply air for biological degradation
d. keeping the pollution of the exhaust air low by:
    - avoiding traffic routes through the delivery area
    - using surfaces and work equipment that are easy to clean
    - minimising the storage time of wastes in the delivery area
    - cleaning the floor of the hall regularly with an appropriate sweep-suction cleaner or industrial vacuum cleaner
    - cleaning sunshades, conveyor bands and other equipment at least once per week
e. using a combination of automated and rapid action doors with so-called air curtain installations, which in practice could also act as a lock, with the opening times of the doors being kept to a minimun. This can be helped by the insertion of sensor-controlled rolling shutter gates or flap gates and by sufficient dimensioning of the manoeuvring area in front of the hall. It needs to be recognised that the discipline of the hall and vehicle fleet staff is at least equally important to actually realise the short opening times. It also needs to be ensured that sufficient maintenance of the doors is carried out as required and stick to the appropriate operation. Installing an air curtain creates a curtain of surrounding air in the open door that prevents the ingress of air from the hall. For an underground bunker, which the vehicles approach backwards and then tip over their load, the installation of a curtain with the vehicle outline behind the actual door may be a way to minimise air exchange during unloading as far as possible
f. closing feed bunkers constructed with a vehicle sluice; in open warehouses and during unloading of waste vehicles, the bunker waste gas is removed by suction and fed into a waste gas treatment facility.

In addition during storage and handling, the following measures are suitable for dust minimisation:

g. depositing dust through defogging systems, although this is not mandatory
h. using suction to extraction point sources and hall air, with subsequent dedusting

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i. applying coverage of the belt conveyor
j. preventing or minimising large falling heights at interband transmissions
k. using slowly running comminution aggregates
l. regularly cleaning aggregate areas, hall floors and traffic routes
m. using a tyre washing plant to prevent dispersion of waste by the vehicles into the outer areas of the plant.

Also anaerobic decomposition in the storage of waste materials from a civic amenity site/transfer station comprising high levels of grass mowings during warm wet periods should be actively avoided. Typically grass has a high moisture content, and mats together to prevent ingress of oxygen. If the waste has been piled up in a transfer station for a day or so, then bulked into a container and stored in a pile in wet weather, anaerobic conditions will set in. Another possibility for moisture ingress is through unprotected windrows after prolonged wet weather causing aerobic decomposition to cease, so these should be suitably protected or covered.

Achieved environmental benefits
It is important in liquid waste biotreatment systems that the flow of substrate is relatively constant to maintain correct operation, otherwise unexpected emissions can be caused. Some techniques are focused on preventing emissions into the air. For example, temperature rises in waste heaps containing organic matter due to increased biological activity, may occur within short periods of time and may result in air emissions (total C, odour).

Due to the higher temperatures inside the hall, in winter an airflow profile develops at the hall gates, with warm air leaving the hall in the upper part of the opening and cool air entering at the bottom.

Residual wastes may contain large amounts of small-grained particles. Therefore, in the bunker considerable dust emissions can be expected due to the tipping and loading processes with mobile tools, which should be retrieved or deposited as close to the source as possible.

Operational data
The storage areas are usually filled from road tankers or from a pipe to the source.

Applicability
Due to the wide range of biological treatment procedures covered here as well as types of wastes (e.g. containing volatile components, odour), there are some techniques that may be not be applicable to some biological treatments (e.g. activated sludge, aerated lagoons, MBT, in-situ bioremediation, oil contaminated soil und sludge, production of biogas to be used as fuel,...). Some applicability exceptions identified in the techniques below which can be found in the description section above are the following:

- technique b for the last steps of biological treatment or after treatment
- technique e is typically applied to waste no so odours are emitted
- technique f is typically applied to high odour waste.

Driving force for implementation
Related to technique b from the description section above, three or four air exchanges where operators work is applicable by Italian regional law. In areas where operators do not work, two exchanges per hour are typically applied. Technique f comes from a special requirement of TA Luft for fermentation plants and a general provision of the 30 BlmSchV german regulation. Technique m is also a general provision of the 30 BlmSchV German regulation.
Reference literature
[56, Babtie Group Ltd, 2002], [132, UBA, 2003], [150, TWG, 2004]

4.3. Selection of feedstock for biological systems

Description
Some issues to consider are:

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a. the presence of substances which are not subject to beneficial treatment such as, toxic metals need to be limited for entering into the biological processes. For example, some mechanical treatment may help to accomplish such limitations
b. adding sewage to the organic fraction of municipal solid waste increases the nutrient level as well as adding moisture content. Other wastes that can also have benefits are organic industrial wastes, food processing wastes and agricultural wastes
c. whilst the process itself is an important aspect, the quality of the feedstock probably has the biggest effect and so it is vital to maximise its quality. Both admissible waste types and separation processes are important here. Some techniques include:
   - the right balance of the nutrient content (e.g. nitrogen vs. carbon content)
   - minimising the presence of toxic and unwanted materials (including heavy metals, pathogens and inert materials)
   - recognising that any non-biodegradable components of waste which are fed into an anaerobic digester, and will not be affected by the process, simply take up unnecessary space. To maximise the benefit of using the technique (both environmental and economic) and to minimise the cost, it is important to minimise the presence of these components in the anaerobic digestion feedstock
d. not mixing different types of waste if not proved to be appropriate. This is related with Section **Error! Reference source not found.**
e. continuous learning about the influence of the waste characteristics on the operational settings as aggregates, mass flow, volumes, biological degradation variables (e.g. temperature, CO_2) as well as measured (gaseous) emissions (e.g. use of continuously acquired emission data (raw gas and/or clean gas), VOC, methane, for the adjustment of settings, i.e. automatic control of biological processes)

Achieved environmental benefits
Avoids toxic compounds entering the biological systems, i.e. toxic in terms of reducing biological activity. A good balance of the nutrient content avoids emissions, for example of nitrogen compounds.

If non-biological active parts of the feedstock are separated from the feedstock, such streams can be easily re-used or recycled (e.g. glass, metals)

Cross-media effects
The addition of sewage sludge to the organic fraction of MSW may have bad effects on the biological treatment itself, the exhaust gas quality that is generated during the biological treatment or the quality of the waste OUT.

Operational data
In the case of technique c (see description section above) an integral biological drying of municipal waste is undertaken, as typically the presence of plastics and other non-biodegradable materials can represent an advantage for aeration, preventing anaerobic zones, which leads to lower emissions.

Reference literature
[55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [150, TWG, 2004], [153, TWG, 2005]

4.4. Generic techniques for anaerobic digestion

Description
Some techniques include:

a. having a close integration between waste management and water management. This would be helpful for further developments and for management to make improvements and gather data
b. recycling the maximum amount of waste water to the reactor, to facilitate any dissolved organic material being converted to biogas
c. operating the system under thermophilic digestion conditions, in order to increase the pathogen destruction, biogas production rate (hence higher energy recovery) and the retention time
d. measuring TOC, COD, N, P and Cl levels in inlet and outlet flows, in order to balance feeds and to ensure good methane production

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e. controlling relevant parameters in digestion water, digestion residue and waste water in regular intervals in order to ensure good operation of the installation
f. having closed feed bunkers constructed with a vehicle sluice. In open warehouses and during unloading of waste vehicles, the bunker waste gas is to be removed by suction and fed into a waste gas treatment facility
g. having adequate space particularly for the storage area on the basis of the estimated monthly utilisation
h. designing, constructing and operating the facility in order to prevent soil contamination due to sewage water
i. re-using the condensed water vapours arising from ventilation of the windrows (maturing process) and the accumulated water only in the case of open aerobic digestion treatments in order to humidify the solid waste and in the case that olfactory nuisances may be avoided.

Although anaerobic systems can be operated in stages to reduce overall COD in the effluent, they are generally operated for efficient methane production and the liquid effluent tends to be more concentrated than effluent from aerobic systems, and requires an aerobic final treatment stage. This could be via a discharge to sewer, or though a second stage on site process.

Achieved environmental benefits
Increases the efficiency of anaerobic digestion and allows better use of their products. Minimising the quantity of potentially toxic materials is also an important consideration for the quality of the end-product. Anaerobic systems are effective at breaking down ring compounds (for example, phenols) and generate methane that can be utilised as a fuel. However, not all compounds derived by the anaerobic breakdown of aromatic rings (e.g. xenobiotica) can be mineralised under anaerobic conditions. Anaerobic treatment steps therefore need to be followed by a subsequent aerobic degradation step in order to lead organic material to a full mineralisation.

Odour emissions of 500 – 1000 GE/m³from anaerobic treatment can be reached by using an appropriate combination of biofilter and scrubber if the NH_3 content is higher than 30 mg/Nm³.

Cross-media effects
The use of sludge in anaerobic digestion needs to be decided on a case-by-case basis, since the heavy metal concentration in sludge may present difficulties for the operator to meet the tight limit values for quality composted products which exist in some EU countries.

Operational data
The high degree of flexibility associated with anaerobic digestion is claimed to be one of the most important advantages of the method, since it can treat several types of waste, ranging from wet to dry and from clean organics to grey waste. The suitability of the method for very wet materials, for instance, has been addressed as an important feature in those scenarios where source separated food waste cannot be mixed up with enough quantities of bulking agents such as yard waste (namely, waste from many metropolitan districts).
Anaerobic biological systems are sensitive to chlorinated and sulphur compounds, pH and to temperature fluctuations and may require a pre-acidification stage.

Recycling of waste water (technique b in the description section above) may result in a increase of the concentration of of toxic/inhibiting compounds that may cause negative effects on the biological treatment.

Thermophilic digestion conditions (technique c in the description section above) may not be useful or possible for all applications (e.g. adaptations of micro-organisms communities for the degradation of chlorinated aromatic compounds or dechlorination of specific xenobiotica cannot be achieved under thermophilic conditions, no thermophilic microbial population can be adapted to the compounds to be treated).

In certain circumstances, it is necessary to control relevant parameters in digestion water, digestion residue and waste water, at regular intervals in order to ensure a good operational mode of the installation (technique d in the description section above). In these cases the parameters mentioned are not sufficient for process control. According to the aim of the treatment (landfilling, fertilisers), parameters for the control of the output have to be fixed according to further use.

Applicability

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The main area of concern in anaerobic digestion is the guarantee of the long term performance of a plant, which is of course key to its economic feasibility. This risk can be reduced through technological developments but the associated costs of these can affect the economics in the short term. The building of more plants in the future will further operating knowledge and this may increase confidence (see Section **Error! Reference source not found.**). Technique e in the description section above is appropriate to reduce odour emissions.

Economics

Specific investment costs are generally much higher than with aerobic digestion. Having a close integration between waste management and water management would be helpful for further development. This would reduce the extra costs related to the discharge of excess waters from anaerobic digestion to a waste water treatment plant. However, in reality this occurs only rarely across Europe, most often where water utilities are involved in the process.

Driving force for implementation

Better management of the process and requirements of the Landfill Directive. Techniques from e to h in the description section above are requirements under the German TA Luft regulations and technique e is necessary for odour reduction.

Example plants

This treatment method is relatively rare at present (it is only part of waste management strategies in four countries, Germany, Austria, Belgium and Denmark, although some applications are also found on mixed or residual wastes in France, Spain and Italy, and a small-scale plant is also known to be in operation in the UK). Recent developments in source separation schemes in Italy and Spain suggest an optimistic view for the future availability of quality feedstock.

It is also worth mentioning that anaerobic digestion is experiencing the fastest growth take-up across Europe in Spain, thanks to public funding of facilities through EU programmes. Such funding reduces the overall management costs, since depreciation is one of main cost factors.

Reference literature

[33, ETSU, 1998], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [114, Hogg, 2001], [150, TWG, 2004], [153, TWG, 2005]

4.5. Increase the retention time in the anaerobic digestion processes

Description

Involves allowing the digestate to spend more time under degradation conditions.

Achieved environmental benefits

A higher retention time will enable more extensive biodegradation and subsequently a better quality digestate and thus can increase the biogas production. Having a high enough temperature and a long enough retention time will ensure that the material is mature, free from pathogenic bacteria and seeds and generate lower odour emissions.

Cross-media effects

The achieved benefits have to be balanced against a lower possible loading rate, which reduces the throughput and thus increases the economic cost per tonne treated.

Applicability

An increase in the biogas production typically has an effect on the quality of the digestate and biogas. Then, an optimisation of the amount of biogas, biogas quality and quality of digestate needs to be carried out.

Reference literature

[59, Hogg, et al., 2002], [150, TWG, 2004]

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4.6. Techniques for the reduction of emissions when biogas is used as fuel

Description

The biogas from the fermenter is dehumidified and solid particles are removed before it is used as fuel by either an external user or for internal use. Biogas can be used in gas motors, e.g. block unit heating power plants, gas boilers, vehicles or for other uses such as fuel for VOC thermal abatement techniques. Two types of emission techniques can be followed. The first type relates to the cleaning of the biogas before using it, in order to reduce the emissions after its combustion, and the other relates with the abatement of emissions after the combustion of the biogas. Both types of techniques are covered here, some specific measures include:

a. reducing hydrogen sulphide emissions by scrubbing the biogas using iron salts, adding those iron salts into the digester or biological oxidation by a controlled addition of oxygen
b. using selective catalytic reduction (SCR) (Section **Error! Reference source not found.**) to reduce reduce NO_x
c. using a thermal oxidation unit to reduce CO and hydrocarbons
d. using activated carbon filtration
e. equipping those plants with biogas storage and an emergency flare.

Note that when flaring any biogas that cannot be used on-site or upgraded to natural gas quality, the outlet temperature of the flue-gas should be at least 900 °C and the residence time 0.3 sec. The maximum aimed concentration of sulphur compounds in biogas is 50 ppm, or a removal efficiency of at least 98 %.

Among the abatement procedures that may take place in a separate treatment step are: biological scrubbing processes (biological oxidation of the sulphide to sulphur or sulphuric acid), gas scrubbing with water or organic solvents, dry filters composed e.g. of lake iron ore, and adsorption, e.g. to activate carbon.

Some guidance for large combustion plants using biogas have been referenced in the LCP BREF.

Achieved environmental benefits

Parameter	Biogas	Exhaust gas
AOX	<150	
CO		100 – 650[1]
Dust		<10 – 50
NO_x		100 – 500 [2]
H_2S		<5
HCl		<10 – 30
HF		<2 – 5
Hydrocarbons		<50 – 150
SO_2		<50 – 500

Data in mg/Nm^3 at 5 % O_2
[1] when using spark ignition engines with low heat capacity (e.g. <3 MW_{th}) the value of 650 may be difficult to achieve. In those cases, 1000 can be seen as more achievable.
[2] when using pilot injection engines with a low firing capacity (e.g. <3 MW) the achieved values are 1000. The lower end of the range can only be achieved with abatement

Table 4.1: Achieved emission values with the use of good engines and abatement techniques [54, Vrancken, et al., 2001], [117, DG Env, 2001], [132, UBA, 2003], [150, TWG, 2004]

Cross-media effects

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Addition of substances as iron salts or oxygen into the anaerobic reactor may be counterproductive to the fermentation process.

Operational data
The utilisation of oxidation catalysts (technique a from the Description section above) is typically used as a short term tool due to corrosion problems that may generate.

Applicability
Cleaning of biogas (except dewatering and removal of solids) before power/heat generation in gas motor and flue-gas cleaning are not usually necessary, according to some information, to reach many of the values given in Table 4.1. Those emission values are typically met by motor adjustments alone. The only expection highlighted is the co-fermentation of pig manure. The biogas generated typically requires desulphurisation because of the high sulphur content, especially in order to prevent corrosion of the unit using the biogas.

Economics
Secondary measures to reduce emissions from flue-gas when biogas is used as fuel. It is considered not economically viable nor environmentally justified for small power/heat installations. In order to reflect such an issue, for example in Germany, installations smaller than 3 MW_{th} have higher emission limit values.

Driving force for implementation
At least three MS have legislation regulating the emissions when using biogas as fuel.

Reference literature
[54, Vrancken, et al., 2001], [117, DG Env, 2001], [132, UBA, 2003], [150, TWG, 2004]

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4.7. Increasing the energy efficiency of the electricity generators and anaerobic digestion systems

Description
Some issues to consider are:

a. for good energy efficiency, a biogas with an energy content of between 20 and 25 MJ/Nm^3 is preferable
b. electrical conversion efficiencies will vary according to the combustion plant. Practical experience with small scale combustion engines with a rated capacity of less than 200 kW indicate an electrical conversion efficiency of around 25 %, larger plants (up to 17000 kW) can have a higher conversion efficiency of around 36 %. If there is also the added possibility of heating water from the engine's exhaust, this can increase the overall conversion efficiency to 65 – 85 %
c. installing biogas engines with efficiencies higher than 30 % is essential for achieving good overall energy efficiency.

Achieved environmental benefits
Increases the energy efficiency of anaerobic digestion processes. Some data on the energy production are presented in the following two tables (Table 4.1 and Table 4.2). Ranges in these tables are wide, and probably reflect not only the differences in performance across plants, but also across the feedstocks input.

	Net energy production (kWh/tonne of waste)		
Source	Minimum[1]	Average[1]	Maximum[1]

1		100	
2		102	
3		110	
4	80	110	140
5	75	113	150
6	100	115	130
7	105	131	157
8	120	145	170
9	100	150	200
10		154	
11	254	273	292
[1]If only one figure is quoted, the reference in question did not provide a range			

Table 4.2: Net energy production figures that can be achieved under optimum operation of anaerobic digestion processes
[59, Hogg, et al., 2002]

Parameter	Low value (kWh/t waste)	High value (kWh/t waste)
Biogas yield	70 Nm^3/t waste	140 Nm^3/t waste
Percentage methane	55 %	60 %
Calorific value of biogas	385	840
Electricity generated (30 % efficiency)	116	252
Electricity for export (70 % of electricity generated)	81	176
Heat recovered for CHP option (70 %)	189	412
Heat exported for CHP option (80 % of that recovered)	151	329

Table 4.3: Electricity and heat generated from anaerobic digestion
[59, Hogg, et al., 2002]

Example plants
Many examples of anaerobic digestion plants exist worldwide.

Reference literature
[59, Hogg, et al., 2002]

4.8. Techniques to improve mechanical biological treatments

Description
Some techniques include:

a. using filters on the exit air to minimise particulate emissions
b. reducing emissions of nitrogen compounds by optimising the C:N ratio and using acid scrubbers
c. avoiding anaerobic conditions in aerobic treatment installations (where the waste gets starved of oxygen, usually due to it being saturated) by:
    - introducing sufficient woody materials to the mixture (e.g. wood chips), and keeping the structure open. This also helps to reduce the impact of excess nitrogen
    - avoiding waste materials that have both a high water content and limited interstices between the waste materials for water to drain down through the waste under gravity
d. controlling the air supply using a stabilised air circuit. A good adjustment of the aeration can be carried out by controlling the CO_2 concentration per segment or by on line measurements of certain parameters (e.g.

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O_2, temperature, moisture, methane, VOC, CO_2) of the air supply/exhaust air. This guarantees a sufficient air supply, irrespective of the composition of the waste. The process air is collected from the halls, the exhaust system, etc.

e. using air circulation in order to increase the concentration of carbon compounds in the air. This makes thermal afterburning a feasible alternative for a biological filter. Under these conditions only, e.g. 2500 – 8000 Nm^3 of air per tonne waste need to be treated (related with Section 4.11)
f. fully establishing the feedstock specifications
g. carefully positioning the windrows to enable proper access for forming and turning
h. efficient balancing of water to minimise the production of leachates
i. providing impermeable hard standing over a sufficient area to allow machinery movements to turn windrows and also to provide space for leachate collection drainage
j. introducing a high permeability drainage layer, such as wood chips, in the windrow construction to allow leachate drainage and airflow into the windrows
k. making provisions for leachate collection with recirculation systems, in order to feed the leachate back into the windrows to maintain the optimum moisture content and also to facilitate the leachate treatment
l. treating the condensation water by buffer, bioreactors and ultrafiltration. The purified waste water (permeate) can then be used as process water in the cooling circuit that it is evaporated in the cooling tower
m. using as a solid fuel the filter cake generated on the dust filters of the air treatment system
n. thermally insulating the hall ceiling of the biological degradation hall in aerobic processes in order to minimise the generation of condensate
o. recycling process waters or muddy residues within the aerobic treatment process to completely avoid water emissions
p. installing and then operating the conveyor and storage systems, as well as internal treatment equipment for process waters and vapour condensates, in such a way that they do not give rise to relevant diffuse (fugitive) emissions
q. the pretreatment of the biological treatment feedstock to optimise the biological treatment. This may include mechanical techniques like: separating substances which are rather unsuitable for biological treatment, interfering substances and pollutants, as well as optimising the biological degradation of remaining wastes by increasing both availability and homogeneity
r. controling the air emissions of organic compounds, particulate matter, odour, ammonia, mercury, nitrous oxide (N_2O) and dioxins. Some techniques for this are mentioned in Section **Error! Reference source not found.**.

Achieved environmental benefits

MBT plants are very flexible. They can be built on a modular basis. Some of the above techniques avoid odour, nitrogen and methane emissions.

Optimised biological processes combine a reduction of emissions to water and air during treatment in the treatment plant. Furthermore, another environmental benefit is that mechanically biologically pretreated waste is characterised by a marked reduction in volume, water content and gas formation potential, as well as having a significant improvement in leaching and settlement behaviour in landfills. Another benefit is that a high calorific waste stream is separated which can be incinerated with energy recovery.

Mechanical and physical treatments used as a pretreatment to optimise the conditions for the subsequent biological treatment (e.g. mixing, homogenising, moistening) are adjusted to enhance the separation of valuable materials (e.g. ferrous materials), inhibiting materials or materials for which a biological treatment is not suitable. Sometimes the separation enhances more than one type of material mentioned above.

Related with technique c (see description section above), however, a controlled amount of anaerobic conditions obtained in well regulated processes may be of interest in aerobic treatment due to the production of methane, which can be used as an energy input for thermal-regenerative exhaust gas treatment (and if in addition the quality of the waste OUT still fulfils the requirements, the exhaust gas treatment is optimised, and security arrangements (prevention of explosion and security for employees) are sufficient.

Cross-media effects

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VOC emissions from MBTs cannot be avoided because of VOC already in the waste IN and the VOC generated by the biological process. Thus, requirements like housing / fully enclosed bioreactors, collection of exhaust air and effective treatment of exhaust air (limit values for the emissions) reduce such emissions. Aerobic systems (MBT) are suitable for treating wastes containing VOCs. In addition, anaerobic systems may result in well pretreated wastes but still may have a high potential for emissions (ammonia and other compounds generated during anaerobic treatment) and a high biological reactivity (under subsequent aerobic conditions). Therefore, a combination of anaerobic (pretreatment) and aerobic treatment steps are typically required.

Concerning technique c from the description section above on introduction of sufficient woody materials, generally in MBTs there is enough structural material given by the feedstock (MSW). Input of woody materials can cause problems in meeting landfill criteria (e.g. TOC).

Related to e from description section above, when the recirculating air has high humidity, the treatment of the exhaust air may cause problems. In such a case, it is necessary to condense water vapour and thus the condensate water needs to be treated and cooling is necessary to condensate the water.

Related to technique o from the description section above, the aerobic treatment has to take into account that accumulation of recycled substances can result in undesired effects (salinisation --> inhibitory effects, recycling of N-compounds --> higher air emissions of N-compounds (e.g. ammonia, laughing gas).

Operational data
Aerobic biological systems are generally more robust than anaerobic systems, and are less sensitive to chlorinated and sulphur compounds, pH and temperature fluctuations and do not require a pre-acidification stage.
Good operational practice will determine whether or not the site remains aerobic. It is in the operator's best interest to maintain aerobic conditions, to avoid odour problems and to speed up aerobic digestion rates. Anaerobic conditions may lead to occasional problems, i.e. not a regular event, which still need to be recorded in the site diary.

When the relative humidity of the exhaust air is high (more than 90 %), the emission of particulates is low.

Applicability
MBT is widely used for the treatment of MSW, sludges and other types of waste. Aerobic systems may be unsuitable for treating wastes containing VOCs, which may be emitted to the air. Aerobic systems are less effective at breaking down ring compounds (for example, phenols) than anaerobic systems.

Driving force for implementation
The Landfill Directive's acceptance criteria for biodegradable waste. These criteria aim to decrease the biodegradable content of the waste, thereby leading to a significant reduction of gas and leachate emissions from landfill.

Example plants
Widely used throughout Europe. Aerobic systems are used to reduce the putrescible and moisture content of whole waste prior to landfill or for the production of waste derived fuels enclosed. This is a common practice prior to landfill in Europe.

Reference literature
[31, Greenpeace, 2001], [54, Vrancken, et al., 2001], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [114, Hogg, 2001], [116, Irish EPA, 2003], [132, UBA, 2003], [150, TWG, 2004], [153, TWG, 2005]

4.9. Aerobic digestion of slurries

Description
Biological treatment of slurries.

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Achieved environmental benefits
An example process is a two-step batch process used to treat creosote waste. This involves suspending creosote waste with surfactants in a vessel for seven days at 20 % solids and then transferring the supernatant to a polishing reactor for 14 days of additional biological treatment. This produces the PAH reductions shown in Table 4.4 below:

Constituent	Initial concentration (ppm)	Final concentration (ppm)
Phenanthrene	13000	<100
Fluorene	7000	<100
Fluroanthrene	8000	<500
Pyrene	6000	<500
Benzo(a)pyrene	9000	<100
Benzo(b)fluoranthrene	13000	<500
Benzo(a)anthrarene	11000	<100

Table 4.4: Reported reduction in polycyclic aromatics
[53, LaGrega, et al., 1994]

Cross-media effects
The agitation not only homogenises the slurry but also promotes the volatilisation of contaminants.

Applicability
Wastes can be sludges or solids. It is applied in the treatment of wood preserving wastes, creosote waste, petroleum refining sludges and contaminated soil.

Reference literature
[53, LaGrega, et al., 1994]

4.10. Aeration control of biological degradation

Description
Some techniques include:

a. applying overpressure operation
   - this has the following advantages:
     - lower risk of wetting and compaction of the aeration floor
     - rectified flows of air and natural heat emission
     - low requirements for the construction of the aeration floor
   - however, there are also disadvantages:
     - mixing of heap air and hall air
     - intake of air saturated with water vapour into the hall
     - limited accessibility of the hall
     - high corrosion of the constructive elements and machines with increased abrasion and maintenance costs
     - it is not possible to determine the process parameters of the exhaust air
     - biological degradation can only be controlled through indirect measurements and experience
     - separate treatment and purification of heap and hall exhaust air is not possible

b. applying suction (under pressure) operation
   - suction operation by contrast to overpressure operation has the following advantages:
     - only minor pollution of the hall air with heap air
     - low corrosion of the constructive elements and machines
     - hall is accessible during heap aeration
     - possible to determine the process parameters in the heap exhaust air
     - separate collection and treatment of heap air possible
   - the disadvantages of suction operation are:
     - higher requirements for the construction of the aeration floor

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- danger of wetting the distance and diffuse air layer

c. having aeration floor with slitted plates and a basement cellar to ensure an even aeration of the complete moving/turning
d. adapting aeration to the biodegradation activity of the material by segmentation of the biological degradation area in separately controllable aeration fields. Also by regulating the air quantity per aeration field depending on the temperature and oxygen content, by frequency-controlled ventilators or by alternating the cyclic operation
e. ensuring that there is an even flow through the biodegraded material in tunnel system floors, by using embedded punched pipes and relatively high pressures
f. using heat-exchangers to lower the exhaust gas temperature and humidity, in order to ensure a heat discharge in circulating air systems.

Achieved environmental benefits
The aims of aeration are to:

- ensure a sufficient oxygen content in the heap
- prevent methane formation in anaerobic areas
- discharge any methane generated
- lead off the released reaction heat
- allow biogenic drying (in MBT plants with dry stabilisation).

Cross-media effects
The aims mentioned above have to be balanced against the competing aim of minimising the air quantity and evaporation losses.

Operational data
In static biological systems, there is no turnover. Generally the rule holds that the shorter the turnover intervals (with simultaneous watering), the greater is the danger of the heap running dry. Watering the heap without turning often only humidifies the layers near the surface.

Applicability
In encapsulated systems such as tunnel, box or container, aeration of the biologically degraded products occurs under pressure and by circulating air operation. In the housed hall systems both pressure and suction systems are used.

Economics
The construction investment costs of an aeration floor with slitted plates and basement cellar are 40 to 50 % higher than those of other available systems (e.g. aeration tubes or channels in the bottom of the hall).

Reference literature
[132, UBA, 2003]

4.11. Management of exhaust gas in MBTs

Description
A good exhaust gas/exhaust air management system contains the following elements:

a. separate collection of exhaust air partial flows
b. minimisation of the exhaust gas through multiple use/cascade-use, circular guidance
c. minimisation of the exhaust gas through anaerobic degradation of organic substances (fermentation with utilisation of biogas instead of aerobic digestion)
d. treatment of partial flows with a combination of biological, chemical, physical and thermal treatment components

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e. reduction of specific exhaust air emissions to between 2500 and 8000 Nm^3 per tonne of waste by installing circular guidance across heat-exchangers and by discharging the excess heat as a precondition for an effective circular guidance
f. re-use of the exhausted air as far as possible. The remaining air needs to be treated before being disposed of to the air
g. treatment of the exhausted gas from the delivery area, such as low bunkers and underground bunkers with or without mechanical treatment of the delivered wastes or the recycling of the gas as the air supply (process air) for biological degradation
h. installation in closed rooms with locks or equivalent facilities of the unloading sites, feed bunkers and receiving bunkers or other equipment for delivery, transport and storage of the input substances. The aim of this measure is the minimisation of diffuse emissions. In locks this is achieved by suction of the airlock area so as to keep the ambient pressure below atmospheric pressure
i. for machines, apparatus or other equipment used for mechanical treatment or for physical separation of the waste, e.g. by crushing, classing, sorting, mixing, homogenising, dewatering, drying, pelletising or pressing, the management system needs to ensure that potential diffuse emissions are minimised through encapsulation or suction (focal point suction) of the individual aggregates
j. use of closed containers for the removal of goods emitting dust
k. used of encapsulated or housed systems for the conveyance and treatment of fermentation residues. The exhaust air from these systems is to be collected (hall and source suction), preferrably so it can be re-used within the process or for it to be treated
l. splitting of the total volume flow that is to be treated into heavily polluted exhaust gas and lightly polluted exhaust air. Therefore, the choice of a suitable system for the treatment of the lightly polluted but odour prone exhaust air plays a key role in MBT plants with long term biological degradation. However, the system is completed by further components, such as an acid scrubber (absorption of ammonia), a dust filter and an oxidation facility for the treatment of higher polluted streams mainly from the pre-biological degradation stage. The type of the oxidation facility (thermal, chemical, physical) and the exhaust gas quantity from the pre-biological degradation that has to be treated have to be adapted to the chosen process concept and fixed in each individual case
m. monitoring exhaust gas emissions on line and using data for the adjustment of biological processes
n. using of absorption/desorption and combustion systems in case the concentration of the carbon compounds is low.

Achieved environmental benefits
Reduces air utilisation and exhaust air emissions.

Operational data
The exhaust gas management affects both the construction and process engineering of the facility. The following factors play key roles in any exhaust gas management strategy:

- minimisation of hall volume
- segmentation of the operation units
- close-to-source measures for the active and passive minimisation of emissions.

Applicability
Mechanical biological treatments (MBT)

Reference literature
[132, UBA, 2003], [150, TWG, 2004]

4.12. Abatement techniques for biological treatments

Table 4.5 shows air abatement techniques reported to be applied in biological treatment plants. These are described in detail in Section **Error! Reference source not found.**.

1. Technique	2. Section number

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	where it is covered
3. Generic prevention	4. Section **Error! Reference source not found.**
5. Adsorption	6. Section **Error! Reference source not found.**
7. Biofilters	8. Section **4.13**
9. Chemical scrubbing	10. Section **0**
11. Low-oxidative processes	12. Section **Error! Reference source not found.**
13. Incineration	14. Section **0**
15. Catalytic combustion	16. Section **0**
17. Regenerative thermal oxidiser	18. Section **0**
19. Non-thermal plasma treatment	20. Section **Error! Reference source not found.**

Table 4.5: Air abatement techniques used in biological treatment plants

4.13. Waste gas treatment

Biofilters

Description

'Biofilter' is the generic term covering all biological oxidation processes taking place in a packed system. This includes conventional trickling filters, bioscrubbers (microbial population supported in scrubber liquor) or biobeds (packed system using soil, peat and bark).

The biofilter consists of an apparatus filled with decomposable material such as compost, bark or a mixture of turf and heather, etc. Micro-organisms (fungi, bacteria, viruses and algae) are resident on the material. The exhaust airflows through the material while the micro-organisms decompose the harmful substances. Water and airflow normally run countercurrently. A biofilter is not a filter in the mechanical sense (i.e. it does not lead to a separation of particles), but it is a reactor where a certain range of harmful substances are metabolised to harmless substances. The desired qualities of a biofilter are outlined in Table 0.1.

Characteristic	Description
Filter media	Biologically active, but reasonably stable
	Organic matter content >60 %
	Porous and friable with 75 – 90 % void volume
	Resistant to water logging and compaction
	Relatively low fines content to reduce gas headloss
	Relatively free of residual odour
	Specifically designed mixtures of materials may be desirable to achieve the above characteristics
Moisture content	50 – 80 % by weight
	Provisions must be made to add water and remove bed drainage
Nutrients	Must be adequate to avoid limitations
	Usually not a problem with aerobic digestion gases because of the high NH_3 content
pH	7 to 8.5
Temperature	Near ambient, 15 – 35 or 40 °C
Gas pretreatment	Humidification could prove to be useful in order to achieve near 100 % inlet gas humidity

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	Dust and aerosols may be removed to avoid media plugging, but for most biofilters this is not a problem (unless they have a tissue layer in the bottom)
Gas loading rate	<100 m^3/h-m^3, unless testing supports higher loadings
Gas residence time	30 - 60 seconds, unless testing supports shorter residence time
Media depth	>1m, <2 m
Elimination capacity	Depends on media and compound (typically in the range 10 – 160 $g.m^{-3}.h^{-1}$)
Gas distribution	The manifold must be properly designed to present a uniform gas flow to the media

Table 0.1: Qualities of biofilter media
[59, Hogg, et al., 2002]

In contrast to the biofilter, in bioscrubbers the micro-organisms are not fixed in the bioscrubber on organic materials. The biomass swims quasi free in the suspension, which is sprayed on the exhaust gas in a countercurrent flow. The principal difference this brings about is that the absorption of the harmful substances is local and is separated from the metabolism.

In an aerosol can treatment facility, the exhaust air from the different operational parts is led through an air-permeable filter layer by means of ventilators. While the airflows through the filter layer, the degradable contents are decomposed by micro-organisms that populate the filter. In order to ensure that the filter layer remains air-permeable, which is essential for the supply of air oxygen to the micro-organisms, the exhaust air is cleaned beforehand so that solids (dusts) are removed. Simultaneously, cleaning moisturises the exhaust air, which is necessary to prevent drying of the filter layer. The biofilter, thus, represents an aerobic fixed bed reactor for the biochemical decomposition of organic substances. The biofilter, e.g. with an area of 1800 m^2, can treat an exhaust air stream of approximately 200000 m^3/h, which results in a specific filter load area of 111 m^3/m^2/h. Below the biofilter, there are supply areas that are utilised by the different treatment facilities (provision for treatment and dispatch). This area is designed as a collection tray. Moreover, a stationary foam extinguishing installation is present.

Achieved environmental benefits
Reduces odour and VOC emissions from natural compounds and from the synthesis of inorganic compounds (e.g. H_2S and NH_3), aromatic and aliphatic compounds (e.g. acids, alcohols, hydrocarbons). Other compounds that may be degraded are non-chlorinated solvents, mercaptans, amines, amides, aldehydes and ketones. The treatment capacity ranges from 50 - 150 $Nm^3/h/m^2$ depending on the type of pollutant.

Substance (group)	Input concentration (mg/Nm^3)	Output concentration (mg/Nm^3)	Biofilter efficiency (%)
Aldehydes, alkanes			75
Alcohols			90
AOX, aromatic hydrocarbons (benzene)			40
Aromatic hydrocarbons (toluene, xylene)			80
NMVOC			83
PCDD/F			40
Odour			95 – 99
NMVOC (Values in total carbon)	30 – 70	10 – 40	80

Table 0.2: Biofilter efficiency in MBT waste gas treatment
[81, VDI and Dechema, 2002]

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The removal efficiency of a biofilter is determined by the gas residence time in the media bed. Effective residence times typically range from 30 to 60 seconds for most aerobic digestion applications. Studies have reported high removal efficiencies for specific compounds such as H_2S (>99 %), methyl mercaptan, dimethyl disulphide, dimethyl sulphide (>90 %) and various terpenes (>98 %).

Environmental benefits include low energy requirements and the avoidance of potential cross-media transfer of pollutants. Measurements in the practical application of biofilters in physico-chemical treatment plants have shown results of approx. 95 to 98 % degradation for organic solvents, with concentrations in exhaust air to be purified from 400 to 1600 mg/Nm³.

In biological treatment plants, malodorous gases will be fed through a scrubber (e.g. acidic wet scrubber), which reduces the ammonia content to an acceptable level for the biofilter. The biofilter removes odours and any remaining ammonia. The filtering process does not create any compounds that are harmful to the environment and after use, the filter can be treated by composting and additional waste will not be generated. The levels of ammonia and odour after treatment are <1 mg/m³ and 1000 – 6000 ouE/m³ (90 % reduction), respectively.

Table 0.3 and Table 0.4 show the effectiveness of biofilters applied to MBTs.

Parameter	**Concentration (µg/m³)** min – max	**Effectiveness (%)** min – max	**Concentration (µg/m³)** min – max	**Effectiveness (%)** min – max	**Concentration (µg/m³)** min – max	**Effectiveness (%)** min – max
Acetaldeyde	2100 – 2500	78 – 89	46 – 740	89 – 96	4900 – 6100	99
n-Butylacetate	150 – 425	97 – 99	30 – 120	83 – 96	170 – 980	73 – 99
Ethylbenzene	250 – 310	12 – 42	60 – 190	27 – 61	250 – 740	16 – 43
2-Ethyltoluene	180 – 220	33 – 41	25 – 105	14 – 89	80 – 270	25 – 55
3,4-Ethyltoluene	480 – 640	23 – 45	70 – 260	38 – 96	230 – 1000	48 – 77
Limonane	1700 – 4300	29 – 40	810 – 2200	94 – 98	1300 – 3700	30 – 63
Toluene	490 – 550	16 – 39	130 – 280		460 – 1000	7 – 36
m/p-Xylene	850 – 1400	9 – 42	280 – 620	30 – 71	720 – 2000	19 – 45
o-Xylene	260 – 290	23 – 41	60 – 150	7 – 63	160 – 650	20 – 45
Acetone	2450 – 2900	99 – 100	1200 – 2800	99 – 100	4700 – 8200	93 – 97
2-Butanone	960 – 2800	99 – 100	80 – 770	94 – 99	370 – 11000	95 – 100
Ethanol	5200 – 5300	100	88 – 750	94 – 99	14000 – 18000	100
α-Pinene	370 – 700	8 – 44	280 – 790	53 – 83	560 – 930	5 – 39
β-Pinene	330 – 800	12 – 44	120 – 300	53 – 81	230 – 490	38 – 49

Table 0.3: Concentration ranges for some parameters of the exhaust air from MBTs, showing the retention efficiency of the biofilter for these compounds
[132, UBA, 2003], [150, TWG, 2004]

Biological exhaust gas purification processes are able to reduce the exhaust air/exhaust gas contents from municipal waste treatment plants only to a limited extent (typically NMVOC of more than 300 g/t waste). Table 0.4 shows some measurement results from well maintained biofilters with upstream air humidifiers.

Compounds of the exhaust air	**Separation efficiency (%)**		
	Facility A	**Facility B**	**Facility C**
Acetaldehyde	-18 to -99	99	99
n-Butylacetate	83 – 96	73 – 99	97 – 99
Camphor	60 – 88	60 – 90	88 – 91
Dichloromethane	-53 to -80	-300 to -33	43 – 62
Dimethyldisulphide	44 – 78	-55 to -89	10 – 31
2-Hexanone	75 – 80	-	80 – 82
Naphthalene	50 – 75	38 – 93	58 – 82
Phenol	-25 to - 79	75 – 88	47 – 94
1,4-Dichlorbenzene	0 – 73	-1900 to -89	-130 to -13

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Ethyl benzene	27 – 61	16 – 43	12 – 42
2-Ethyl toluene	14 – 89	25 – 55	33 – 41
3/4-Ethyl toluene	38 – 96	45 – 77	23 – 45
Limonene	94 – 98	30 – 63	29 – 40
Styrene	64 – 89	44 – 66	21 – 50
Toluene	29 – 50	7 – 36	16 – 39
m/p-Xylene	30 – 71	19 – 45	9 – 42
o-Xylene	7 – 63	20 – 45	23 – 41
Acetone	99 – 100	93 – 97	94 – 97
2-Butanone	94 – 99	95 – 100	99 – 100
Ethanol	94 – 99	100	100
Ethylacetate	74 – 93	82	97 – 99
α-Pinene	59 – 83	5 – 39	8 – 44
β- Pinene	53 – 81	38 – 49	12 – 44
Benzene	0 – 17	-	0 – 20
Trichlorethene	-108 to -3	67 – 90	20 – 46
Combinations of air humidifiers and biofilters may provide varying purification power for organic substances of the first and second group			

Table 0.4: Separation efficiency of organic compounds in the biofilter [132, UBA, 2003]

Table 0.5 gives a summary of current measurement results from the biofilter of an aerosol can treatment facility. Note that other parts of the exhaust air of the treatment process are treated by the in-house high temperature incineration facility.

Component	Average concentration of raw gas	Average concentration of cleaned gas
Total carbon (FID)	206	49
CHC/CFC	9.69	8.17
Benzene	1.07	0.35
Aromatic compounds	35.4	8.07
Ester, alcohols	80.8	0.57
Results from 2003 and data in mg/m^3		

Table 0.5: Raw gas and treated gas by a biofilter in an aerosol can treatment facility [157, UBA, 2004]

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Cross-media effects

N_2O and NO emissions are typically increased. However, it has been demonstrated that the use of an acid scrubber for ammonia (NH_3) removal prior to biofiltration can reduce potential N_2O and NO emissions. Methane is neither biodegradated nor produced by the biofilter. Terpenes are produced by the biofilter itself and arise from the degradation of any wooden materials in the biofiltering media. Some references question whether biofilters really decrease VOCs since, they claim, VOCs are actually produced by the biofilter itself.

The degrees of decomposition of the studied biofilters in MBT plants for single compounds are not as high as for several special applications in industry (80 % or >90 %). For non-methane TOC (NMTOC) they achieve on average an efficiency rate of only 40 – 70 %. For methane, the efficiency is close to 0 %. The decomposition efficiency for single compounds in the exhaust gas of MBT plants exhibit good values for NMTOC (e.g. acetone, acetaldehyde, limonene and ethanol), moderate values for BTEX and no reduction for CFCs.

The partly low degradation efficiencies for NH_3 also with a potential inhibition of carbon decomposition, may be improved by the use of acid scrubbers (e.g. sulphuric acid for the absorption of ammonia) instead of neutral scrubbers. The NH_3 emissions will be minimised not only because they are odorous but also because, in the biofilter, close C/N relations of the MBT exhaust air may lead to the formation of NO and N_2O.

Operational data

Biofilters are typically one metre thick of porous material. The material used in the biofilter is usually a mix of green compost typically mounted over a certain structure. These systems are very easy to be built and maintained. High porosity (80 – 90 %), the humidity (60 – 70 %), pH, temperature, and the contact time between the nutrients need to be controlled for good biofilter performance. The humidity in the biofilter can be maintained with a special water system or by humidifying the gas to be purified before it is passed pass through the biofilter.

The NMVOC removal in biofilters strongly depends on the temperature (e.g. weather conditions), which can reduce the efficiency of the biofilter.

In some cases, the materials used for the biofilter media may not be able to fully satisfy the demands for all the essential nutrients of the micro organisms in the biofilter for a longer time. In these cases supplying additional nutrients can significantly increase the efficiency of the biofilter.

The pressure drop is less than 50 mm H_2O. The surface load per unit area of the biofilters should not exceed approx. 80 Nm^3/m^2 x h.

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Some issues to consider include:

- incoming air must have a relative humidity of >90 % (this may require the use of a humidifier)
- particulates must be removed
- hot gases may need to be cooled closer to the optimal activity temperature for aerobic micro-organisms, generally 25 to 35 °C and the potential temperature rise across the bed of up to 20 °C needs to be taken into account
- the major operating parameters, such as the off-gas temperature and the back-pressure, need to be checked daily
- the moisture content in the filters needs to be monitored regularly
- a low temperature alarm needs to be fitted to warn of freezing, which can damage the filter and could affect the growth of the microbes
- the packing media must be supported to allow a fast, even airflow without any pressure drop
- the media needs to be removed when it starts to disintegrate, thus affecting the airflow (bark is less resistant than, for example, heather)
- the choice of media and supporting system affects the power requirement for maintaining the airflow, with the power needed to overcome the bed resistance being the largest operational cost
- consideration needs to be given to the effect of a loss of biomass due to the introduction of toxic compounds and a stand-by procedure needs to be developed for such an event.

Even in the case of optimisations (combinations with bio-scrubbers instead of water scrubbers) a low and reliable emission cannot be permanently achieved. For the odorous emissions, a strong reduction can be achieved (with only the filter's innate smell remaining) if an appropriate conditioning of the exhaust air is carried out.

In the case of flue-gas treatment from aerobic digestion of the digestate generated in anaerobic treatments, the concentration of ammonia is rather high (>30 mg/Nm^3) being in this case necessary to chemically pretreat the flue-gas before it is guided to the biofilter.

Applicability
Biofilters are applied for great volumes of exhaust gas streams which carry low organic loads in the particular exhaust gases but which have intensive odours. Concentrations of components to be treated need to be relatively stable for a good performance. Biobeds have been installed on waste treatment sites for the abatement of odorous emissions. Applicable to all types of WWTP.

Biofilters are used for the treatment of exhaust gases in aerosol can treatment facilities, thermal distillative drying of sludge, biological treatment (MBT) plants and Ph-c plants. In Ph-c plants, biofilters are used for the adsorption of the volatile components to compost material and for the biological decomposition of the adsorbed components by micro-organisms in the compost material. If the biofilter is in danger of desiccating, the exhaust air that is to be cleaned has to be moisturised.

Biofilters are suitable only for low polluted exhaust gas streams and are thus only used for the purification of the hall exhaust air streams. Flue-gas cleaning by biofilters or biological cleaning generated in anaerobic digestion plants has been proven to be of value.

Economics
Biofiltration and bioscrubbing have lower operating costs than many other air pollution control technologies for treating low concentrations of biodegradable organic pollutants. Bioscrubbers have the higher maintenance cost of the two. Treatment gas flows of more than 1500 Nm^3/h are considered cost-effective. Investment cost of EUR 550000 for a biofilter applied to treatment of WWTP odours with a flow of 1800 Nm^3/h.

Characteristics	Value
Input flow range (Nm^3/h)	<100000
Input VOC concentration (g/Nm^3)	<1
Efficiency (%)	<90 %

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Need for preliminary de-dusting	No
Risks	Destruction of micro-organism
Residues	Yes
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	15
Fuel/gas (kWh)	-
Alternative fuel or biogas	
Reactant (kg)	Barks
Costs	
Investment costs (EUR/t capacity)	10 to 20
Operational costs (EUR/t waste fuel produced)	<1
Maintenance costs (EUR/t waste fuel produced)	<0.25

Table 0.6: Consumptions and costs of biofilters
[122, Eucopro, 2003]

Driving force for implementation
Reduction of odour emissions. The German and Austrian Governments have set limit values for MBT facilities for odour emissions with 500 GE/Nm^3 and for VOCs (Austria: 100 g/t treated waste, Germany: 55 g/t treated waste). Furthermore, such systems cannot achieve the TOC emission limit values demanded by some German standards (e.g. less than 55g TOC per tonne of MBT input and a TOC concentration of less than 20 mg/Nm^3).

Example plants
Widely used in the sector. Applied in the treatment of flue-gases from biological treatment plants and from physico-chemical treatment of waste waters and immobilisation. It is also commonly used in other industrial sectors, such as in the chemical, iron and steel, and food industries and in waste water treatment plants. Many examples of the use of biofilters exist in the EU.

Reference literature
[52, Ecodeco, 2002], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [59, Hogg, et al., 2002], [66, TWG, 2003], [81, VDI and Dechema, 2002], [121, Schmidt and Institute for environmental and waste management, 2002], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [135, UBA, 2003], [150, TWG, 2004], [157, UBA, 2004]

Scrubbing

Description
Absorption techniques are typically called scrubbers. Some techniques include:

a. having in place a scrubber system for the major inorganic gaseous releases (e.g. Cl_2, ClCN, HCl, H_2S, NH_3, NO_x), organic compounds (e.g. VOC) and odour from some unit operations treating certain types of waste (containing these volatile compounds), which have a point discharge for process emissions. In circumstances of highly variable emissions, the installation of a secondary scrubber unit to certain pretreatment systems may be a solution if the discharge is incompatible, or too concentrated for the main scrubbers
b. correctly operating and maintaining the abatement equipment, including the handling and disposal of spent scrubber medium.

Water sprays are a commonly used control method for particulate matter emissions. The addition of dust control chemicals such as polymers or acrylics to the water increases the effectiveness of the spraying.

Achieved environmental benefits

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Reduces emissions to air of VOC, acids, ammonia, particulates, etc. Increases the efficiency of pollutant adsorption, due to the particle-gas contact (particularly relevant for the removal of acid gases by basic particles injected at the scrubber, if applicable).

Cross-media effects
This technique generates liquid effluents and sludge that require further treatment.

Wet scrubbers generate steam plumes. Releases from wet scrubber vents need to be hot enough to avoid visible plume formation in the vicinity of the vent. This is to prevent the condensation or adsorption of environmentally harmful substances by the condensing water vapour. Exhaust gases from a wet scrubber can be heated by the use of waste heat to raise the temperature of the exhaust gases and to prevent immediate condensation on the exit from the vent. This procedure also aids the thermal buoyancy of the plume.

Operational data
Usually some level of air monitoring will be carried out, either at the scrubber discharge or at the site boundary. Typically the monitoring of the exit gases from the scrubber systems/filter systems is spasmodic. The assumption is that the abatement systems are fit for this purpose and will reduce the emission to an acceptable background release. Discharge points may be monitored on a quarterly or monthly basis for those acid gases that are expected to be collected.

Water supply and effluent disposal facilities must be available. Monitoring provisions include:

- pH, flowrate and level of scrubber liquors and scrubber pressure drop
- pressure drop monitoring with alarms
- periodically monitoring the exit concentrations under different operating conditions.

There also needs to be a programme in place for the regular changing of absorbent in the absorption units.

Applicability
Suitable for high flow, low concentrations (e.g. 1 – 200 mg/Nm^3 VOC), low temperature gas streams and when the pollutant is chemically reactive (or soluble in the case of VOC contaminants).

These techniques are typically applied to point source emissions related to those compounds which result from the collection of gas from a vessel or area and which are passed on either via abatement or direct to a stack or vent. This technique can be used for the treatments of off-gases generated during the loading of storage tanks.

Acid scrubbers are applied to capture the ammonia emissions liberated during the acidic treatment in the re-refining of waste oils. Mineral oil scrubbers are also used to trap VOCs and odours in waste oil treatment facilities.

Hypochlorite or hydrogen peroxide may be used for cyanide scrubbing and odour control. A two-stage system could be utilised, e.g. alkali and oxidiser scrubbers in series. Water supply and effluent disposal facilities need to be available to run these systems. There needs to be a programme for the regular changing of absorbent in the absorption units.

Alkaline potassium permanganate or hypochlorite can be used as oxidisers for the treatment of cyanide compounds.

Economics
Table 0.7 below shows a summary of scrubbing costs for emission controls for area sources applied to excavation and removal.

Emission control technique	Material cost (USD/m^2)	Comments
Water spray	0.001 (varies)	Assuming municipal water cost of 1 USD/1000 litres. Water requires constant re-application. Water

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		truck rental: 500 USD/week.
Additives: Surfactant Hygro salt Bitumen/adhesives	 0.65 2.58 0.02	Costs vary with chemical use

Table 0.7: Summary of costs for emission controls for area sources applied to excavation and removal [30, Eklund, et al., 1997]

Example plants

A common use is the treatment of extracted air from the reactor vessel with a scrubber liquor, typically a caustic solution. The process is extensively applied in Ph-c plants (e.g. wet scrubbing). Used as a pretreatment, e.g. before biofilters, for the treatment of the exhaust gases of biological treatment plants.

Pretreatment processes capable of liberating toxic gases tend to have their own scrubbing systems, with the scrubber vent leading into the main site exhaust system, and with the aqueous liquors being treated in the plant.

All of the oxidation systems seen in the UK have their own local scrubber systems, and the residues from both the oxidation and the scrubber solutions are treated in the main plant. Where the plant has a total exhaust system for the site, the exhaust from the oxidation scrubbers typically goes through the main plant exhaust scrubbing system prior to discharge to the air.

Caustic scrubbing is employed to strip hydrogen sulphide in plants treating waste oil.

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [55, UK EA, 2001], [56, Babtie Group Ltd, 2002], [86, TWG, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

Chemical scrubbing

Description

Chemical exhaust gas treatment can be one-step or multi-step scrubbing with chemical scrubbers. Up to now, plants of this type have been produced, e.g. as one-step or multi-step carrier material cleaners with controlled pH values in each step or with an addition of oxidants.

Achieved environmental benefits

Scrubbers of this type are well suitable for removing single components (e.g. ammonia).

Cross-media effects

This scrubber is required for the reduction of N-compounds prior to the subsequent treatment. Multistage exhaust air scrubbers (acid-alkaline), or scrubbing with H_2O_2, can only reduce the concentration of certain components (e.g. VOCs) due to the high crude gas concentrations generated especially by recirculating treatments.

Applicability

A state-of-the-art technique in biological treatment (MBT) plants is a combination of acid scrubbers and thermal regenerative exhaust gas treatment. The release of the treated exhaust air is carried out via a stack.

Driving force for implementation

It is reported that scrubbed gas concentrations required by a German regulation cannot be reached by these systems alone.

Example plants

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Currently no information is available on its use as an independent treatment step in biological treatment (MBT) plants. All information in this section corresponds to experiences in other types of plants.

Reference literature
[132, UBA, 2003], [150, TWG, 2004]

Incineration

Description
In the decontamination of thermal exhaust air, the exhaust air is treated in a combustion chamber at temperatures of up to 850 ºC and for a minimum residence time of at least 2 seconds. Within this space of time, the harmful substances will be totally oxidised and the cleaned gas can then be released to the air.

In biological treatment plants, incineration can be differentiated into post-combustion, with or without heat recovery. As in thermal post-combustion, the carbohydrates are oxidised to carbon dioxide and water in a combustion chamber.

Achieved environmental benefits
Used for VOC control and will usually require the addition of supplementary fuel to support the combustion process. The operator can offset the cost of the supplementary fuel when there is a requirement elsewhere on site for the waste heat that is generated. Values of less than 50 g of VOC per tonne of waste can be achieved with this technique.

In biological treatment plants, by using special heat-exchangers, high quality heat recovery of up to 98 % may be achieved. These high rates of heat recovery are based on the use of special ceramic heat-exchangers, which combine a high mass and a large surface area in an ideal way.

Operational data
Usually requires the addition of supplementary fuel to support the combustion process. The flowrate is 1500 Nm^3/h and the operating temperature is 1050 – 1200 ºC. The specification of 850 ºC with 2 seconds residence time may be justified in waste incineration when a complete flue-gas treatment installation achieves the full removal of residual contaminants. The burning conditions are more extreme (e.g. 1100 ºC with 2 seconds residence time) to completely destroy some odorous and VOC components as well as destroy dioxins and dioxin pre-cursors.

Table 0.8 shows the energy requirements of incineration for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Incineration	9	8	6.2	3.2
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 0.8: Energy requirements of incineration for different hydrocarbon concentrations in the gas
[30, Eklund, et al., 1997]

Applicability
There are no limits for its application.

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Economics

The following two tables (Table 0.9 and Table 0.10) show cost data for incineration.

Treatment	Maximum flow (Nm^3/h)	Capital cost (USD)
Incineration	110	13000[1]
	160	25000[1]
	915	44000[1]
Internal combustion engine	96	62000
	160	50000
[1] The cost includes blower, sampling valves, and controls. Heat recovery systems are not included		

Table 0.9: Capital costs for controlling VOC emissions from soil venting extraction systems [30, Eklund, et al., 1997]

Capital cost (GBP)	Operating cost (GBP)
30000	3000
Incineration of 2.5 kg fuel oil/hour @ GBP 0.13p/litre Capacity: 10000 t/yr Oil types: used lubricating oils Process operation: batch Waste gas flow: 0 – 50 Nm^3/hr Age of plant: 10 years old Age of pollution control equipment: 2 years old	

Table 0.10: Cost of controlling releases for air from a typical oil recycling plant using incineration [42, UK, 1995]

In biological treatment plants, cost-efficiency of the operation is determined by the size of the volume flow to be treated and by the pollutant concentrations. The ideal conditions are autothermal operation, where the amount of energy released by the combustion of the pollutants exactly corresponds to the energy demand for maintaining the combustion temperature. The necessary heating energy can, in this case, be gained completely from the combustion of the carbohydrates. This energy demand is directly dependent on the degree of heat recovery. Pollutant concentrations are low making heat supply necessary and, consequently, generating high operation costs.

Driving force for implementation

Waste Incineration Directive (2000/76/EC).

Example plants

At least two waste oil treatment plants use such a system. Used in biological treatment plants.

Reference literature

[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004]

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Combined combustion

Description

In some plants where combustion takes place, it is possible to inject polluted air collected in the workshop directly into the secondary air circuit of the burner or into the primary air that goes into the burner. This might require a specific adaptation of the combustion process (modification of gas cleaning and stability of combustion).

Achieved environmental benefits

- synergy with existing combustion facilities
- allows an energy recovery from burning the VOCs in the combustion.

Table 0.11 shows VOC removal data using combined combustion.

Characteristics	Value
Input flow range (Nm^3/h)	<50000
Input VOC concentration (g/Nm^3)	~ 3 <explosion limit of the compounds
Output VOC concentration (mg/Nm^3)	10 – 50
Need for preliminary de-dusting	no
Residues	no
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	*
Fuel/gas (kWh)	*
Costs	
Investment cost (EUR/t capacity)	*
Operational costs (EUR/t waste fuel produced)	*
Maintenance costs (EUR/t waste fuel produced)	*
*depends on each case	

Table 0.11: VOC removal using combined combustion
[122, Eucopro, 2003]

Cross-media effects

- not available during maintenance of the burner
- specific instrumentation and valves must be installed to prevent a 'domino effect' between each process
- fluctuations in quality or quantity of the VOC could cause some trouble in the combustion system.

Applicability

Needs prior dilution with air when an explosive concentration may be reached.

Economics

Adaptation costs can be high. The operator can offset the cost of the supplementary fuel when there is a requirement elsewhere on site for the waste heat that is generated.

Driving force for implementation

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Waste Incineration Directive (2000/76/EC).

Example plants
Used for the preparation of waste fuel from hazardous waste and laundering of waste oils.

Reference literature
[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

Catalytic combustion

Description
The polluted air is burned but, in this technique, the combustion temperature is reduced by the use of a catalyst. The catalyst allows the same destruction efficiency of the VOC at a lower temperature.

In biological treatment plants, catalytic combustion may be used to remove TOC from the exhaust gas. The pollutants are oxidised at temperatures between 200 and 500 ºC using noble-metal or metal oxide catalysts.

Achieved environmental benefits
- low fuel consumption
- complete destruction of VOC
- efficiencies range from 95 to 99.9 %
- output concentrations of 5 – 50 mg C/Nm^3 are achievable. The actual range depends on the type of compound and the input concentration.

Table 0.12 shows VOC removal data using catalytic combustion.

Characteristics	Value
Input flow range (Nm^3/h)	20000 – 50000
Input VOC concentration (g/Nm^3)	1 – 3
Output VOC concentration (mg/Nm^3)	10 – 50
Need for preliminary de-dusting	Yes
Risks	Catalyst poisoning
Residues	no
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	25 – 75
Fuel/gas (kWh)	70 – 140
Reactant (kg)	Catalyst
Costs	
Investment costs (EUR/t capacity)	20 – 30
Operational costs (EUR/tonne waste fuel produced) Electricity Fuel/gas	 1 – 3 1 – 2
Maintenance costs (EUR/t waste fuel produced)	<1

Table 0.12: VOC removal using catalytic combustion
[122, Eucopro, 2003]

In biological treatment plants, purification efficiencies of more than 99 % can be achieved.

Cross-media effects
The catalyst is sensitive to some compounds (e.g. metal and organic), and their build up may progressively decrease their efficiency.

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In biological treatment plants, among the disrupting substances are catalyst toxins, such as organometallic compounds, organic silicon compounds and arsenic compounds. The treatment of halogenated compounds, organic sulphur compounds and organic nitrogen compounds is possible only to a limited degree. Methane can be catalytically reduced to CO_2 only under certain conditions. High temperatures of over 600 ºC are necessary for the catalytic oxidation of methane. The energy use of a thermal treatment without heat recovery is very high. The catalytic-thermal oxidation in biological treatment (MBT) is, therefore, questioned under both an economical and environmental point of view.

Operational data

- needs a gas pretreatment in some cases (e.g. ESP, bagfilters and gas scrubber)
- needs prior dilution with air when explosive concentrations are reached
- the energy consumption is lower than for incineration.

Table 0.13 shows the energy requirements of catalytic combustion for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Catalytic combustion	2	1.2	0	0
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs. The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 0.13: Energy requirements with catalytic combustion for different hydrocarbon concentrations in the gas
[122, Eucopro, 2003]

In biological treatment plants, the operating life of such catalysts may be more than 30000 operating hours, depending on the operating temperature and on the disrupting substances in the process gas.

Applicability

Given the numerous interfering factors, the practical applicability of catalytic oxidation in biological treatment plants seems problematic. Furthermore, operational experience from biological treatment (MBT) plants is not available.

Economics

The cost of investment is relatively high. Table 0.14 shows the capital costs for controlling VOC emissions from soil venting extraction systems.

Treatment	Maximum flow (Nm^3/h)	Capital cost (USD)
Internal combustion engine	96	62000
	160	50000
Catalytic oxidation	160	25000[a]
	320	31000 – 69000[a]
	800	44000 – 86000[a]
	1600	77000[b]
	8000	140000
[a] Includes burner, blower, flame arrestor, gauges, filters, knockout pot, sampling port, controls, and skid mounting [b] Dilution system available for an additional 22000 USD.		

Table 0.14: Capital costs for controlling VOC emissions from soil venting extraction systems
[30, Eklund, et al., 1997]

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Driving force for implementation
Waste Incineration Directive (2000/76/EC).

Reference literature
[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [132, UBA, 2003], [150, TWG, 2004]

Regenerative catalytic oxidiser

Description
VOCs are burned in combustion chambers at a temperature ranging from 750 to 950 °C. The energy produced by the combustion of the VOCs is used to preheat the polluted air on the ceramic bed before combustion. The combustion temperature can be adapted according to the VOC concentration. The polluted process air is heated to the necessary reaction temperature by a heating system and then guided over a combined catalyst and heat accumulating bed reactor. In this reactor, the process air is decomposed to CO_2 and water. The heat from this reactor is then guided over a second combined bed reactor and accumulated there. After this reactor's accumulator bed has been heated, the process air stream is switched so that it enters the second reactor. The heat from the second reactor is then used to preheat the process air, whilst the pollutant oxidation takes place in the first reactor. During further operation, the unit is switched cyclically between the two stages described above.

Achieved environmental benefits
- high VOC destruction rate (>99 %)
- reduced use of fossil fuel or waste fuel (high energy efficiency)
- at high VOC concentrations (>3 g TOC/Nm^3), it is possible to operate in an autothermal zone. This means that minimum external energy is needed to be added to sustain the reaction.

Table 0.15 shows VOC removal data using regenerative catalytic oxidation.

Characteristic	Value
Input flow range (Nm^3/h)	20000 – 80000
Input VOC concentration (g/Nm^3)	2 – 4 with peaks of up to 10
Output VOC concentration (mg/Nm^3)	15 – 50
Efficiency (%)	>99 %
Need for preliminary de-dusting	Yes
Risks	
Residues	No
Consumption (per tonne waste fuel produced)	
Electricity (kWh)	10 – 50
Fuel/gas (kWh)	50 – 200*
Alternative fuel or biogas	Yes
Reactant (kg)	-
Costs	
Investment costs (EUR/t capacity)	10 – 25
Operational costs (EUR/t waste fuel produced) Electricity Fuel/gas	 1 – 3 2 – 6
Maintenance costs (EUR/t waste fuel produced)	<1
*according to the VOC concentration	

Table 0.15: VOC removal using regenerative catalytic oxidation
[122, Eucopro, 2003]

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Cross-media effects
High energy consumption if there is only a low VOC concentration.

Operational data

- accepts fluctuations of VOC concentrations
- needs prior dilution with air when an explosive concentration may be reached
- needs a de-dusting when dust concentration inlet is higher than 20 mg/Nm^3.

Table 0.16 shows the energy requirements of regenerative catalytic oxidation for different hydrocarbon concentrations in the gas.

Parameter				
Hydrocarbon concentration in the gas (g/Nm^3)	0.5	1.5	3	6
Regenerative catalytic oxidation	0	0	0	0
Heating energy in kWh required for the treatment of 100 Nm^3/h of gas contaminated with VOCs. The flows that have been treated range from 500 Nm^3/h up to 11000 Nm^3/h				

Table 0.16: Energy requirements with regenerative catalytic oxidation for different hydrocarbon concentrations in the gas
[122, Eucopro, 2003]

Applicability
It is designed for low to medium VOC concentrations because of its low energy costs.

Economics
Low operation costs and high investment cost.

Driving force for implementation
Waste Incineration Directive (2000/76/EC).

Reference literature
[30, Eklund, et al., 1997], [42, UK, 1995], [66, TWG, 2003], [86, TWG, 2003], [122, Eucopro, 2003], [126, Pretz, et al., 2003], [150, TWG, 2004]

Regenerative thermal oxidiser

Description
The aim of a regenerative thermal oxidiser is the permanent and high quality recovery of a large part of the heat energy that is necessary for heating the waste gas stream to the required oxidation temperatures for treatment.

This heat energy is stored in flow-through heat-exchangers. Such heat-exchangers consist either of a ceramics fill material or are fin heat exchangers. The performance of this recuperative process is expressed by the degree of heat recovery achieved, which is defined as follows:

$$\text{Performance} = 1 - \frac{T_{\text{scrubbed gas}} - T_{\text{crude gas}}}{T_{\text{combustion chamber}}}$$

T= temperature

The incoming exhaust air is heated up in the 'hot' heat-exchanger bed. The air is heated up to a temperature a few degrees below that of the combustion chamber, depending on the heat storage capacity. In the combustion chamber, oxidation takes place. In the case of low pollutant concentrations in the process air, the missing energy has to be brought in by primary energy sources. After passage through the combustion

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chamber the exhaust gas, which is now at the reaction temperature, gives off its heat to a ‘cold’ heat-exchanger bed.

Due to the high energy demand for heating up the exhaust gas and due to the optimal heat exchange the greatest part of the heat stored in the ‘hot’ heat-exchanger bed is given off to the exhaust gas after appox. 120 seconds. Conversely the hot exhaust gas heats up the ‘cold’ heat-exchanger bed.

Achieved environmental benefits

The realised heat recovery rates vary between 90 and 98 % depending on the pollutant content of the exhaust gas. An additional supply of energy in this case is not necessary. With regards to the required values for the scrubbed gas, the systems currently available on the market differ in the technical method utilised for ensuring the lowest scrubber gas values. This is necessary because at the stream reversal point, remnants of the crude gas may pollute the scrubbed gas. Systems optimised with respect to this problem can achieve scrubbed gas concentrations of less than 10 mg/Nm^3.

Operational data

In order to maintain permanent operation, the stream direction has to be controlled in such a way that the heat-exchanger bed when heated up at a given time can be used for heating up the waste gas. This results in an alternating heating and cooling of the respective heat-exchanger beds.

Also crucial for the design of the plant is the amount of the enthalpy chemically bound in the pollutants that are to be oxidised. The operation is autothermic if the sum of the heat stored in the heat-exchanger beds and the reaction enthalpy released is sufficient to maintain the necessary temperature in the combustion chamber.

If the enthalpy bound in the pollutants is not sufficient to reach oxidation temperature, this has to be achieved and ensured by the use of an external energy supply. Some individual providers realise this by the installation of controlled burners in the combustion chamber, others enrich the exhaust gas with the additional combustibles so that the system can be kept in autothermic conditions. In this case, the plant can be operated flamelessly. In energy-optimised plants, an energy consumption of 8 kWh heat output per 1000 Nm^3 of waste gas can be expected.

For the starting period until reaching operational temperature and during operation with low organic substance concentrations (<2 g C/Nm^3), an external energy supply is necessary due to the as yet insufficient energy storage in the heat-exchanger beds. In the starting phase of flameless systems electrical heating is usually used, otherwise the heat energy can be brought in by natural gas or propane gas burners.

For operation with gaseous waste fuels such as landfill gas or biogas, it needs to be taken into account that these gases may be contaminated by pollutants. For starting an operation that has not yet reached the required combustion chamber temperatures, these gases should not be used. This can only be done with conventional fuels such as natural gas or propane gas. Additionally it has to be ensured in the safety chain that in the event of any service interruption and the resulting decrease of the temperature in the combustion chamber, the supply of the waste fuels is regulated and thus always available.

Applicability

In the context of research projects and for plant operation, combinations of acid scrubbers and regenerative thermal oxidisers have proven valuable. This process combination has advantages in terms of cleaning capacity as well as in terms of operational costs.

Example plants

In practice, there are several different designs of regenerative thermal oxidisers, which differ primarily in the design of the individual heat-exchanger beds and in the selection of the heat-exchanger material. For low concentrations, these processes have become widely used in post-combustion with heat recovery.

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Regenerative thermal oxidisers have been used in Germany for several years for the purification of biological treatment (MBT) plants' exhaust gas. In Austria, an MBT plant has also recently installed and started operation of these types of systems.

Reference literature
[132, UBA, 2003], [150, TWG, 2004], [152, TWG, 2004]

Odour management in biological treatment plants

More information can be found in Section **Error! Reference source not found.**.

Description
Effective operational management can help control the formation of odours. This includes:

a. processing incoming feedstock as soon as possible
b. ensuring proper stabilisation of the biomass within the retention time in enclosed buildings, so as to ensure only odourless materials are present in the open curing stage
c. avoiding an early refining step to reduce the particle size too far, which would hinder the diffusion of air through the material that still has to complete its biochemical transformation (a smaller particle size could cause the aerobic digestion to lose structure and make anaerobic decomposition more likely)
d. preventing the formation of leakage puddles (e.g. ensuring proper slopes to paved surfaces)
e. avoiding the external stockpiling of coarse rejects from pre-process screening steps, as these would also contain a certain percentage of fermentable materials
f. withdrawing the exhaust air from the odorous sections of the process (tipping, deep bunkers storage of input fermentable materials, pretreatment, early process steps. Sometimes also the curing section can be enclosed and exhaust air treated)
g. designing the withdrawal system to prevent any loss of exhaust air from windows, doors, etc.
h. fitting the facility with properly dimensioned abatement systems
i. ensuring proper maintenance of odour abatement technologies is carried out
j. using surfactant reagents
k. providing enclosed leachate collection/storage tank(s), to minimise odour emissions while holding liquor prior to recirculation and/or off-site disposal
l. providing stored leachate treatment, such as aeration, to prevent septic conditions causing odour
m. providing odour abatement, to control emissions from specific sources, such as odour masking atomisers
n. designing the enclosed buildings in such a way so as to have a negative air pressure, to prevent odour emissions from doorways.

Achieved environmental benefits
Prevents or decreases odour emissions.

Cross-media effects
The use of surfactant reagents will not completely eliminate odour, especially if the choice of reagent is based on a characterisation of the compounds in the odour-causing aerosol.

Operational data
When applying technique 'n' (see Description section above), the airflow to maintain a negative air pressure, is sometimes given in how many hours are necessary to exchange the air inside the building. The high this value is, the higher the odour concentrations are achieved inside.

Applicability
Besides prevention, often aerobic facilities have to tackle odour issues through the treatment of the exhaust air, above all where they feature high capacities and/or involve short distances from dwellings.

Example plants

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A good number of facilities across Europe are currently employing technologies that help in the running of aerobic digestion activities even in most crowded areas, provided design and management of the plant consider odour problems with the proper care.

Reference literature

[59, Hogg, et al., 2002], [116, Irish EPA, 2003], [150, TWG, 2004]

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5. Best available techniques

BAT is to:

1. use the following techniques for storage and handling in biological systems (see Section 4.2):
    a. for less odour-intensive wastes, use automated and rapid action doors (opening times of the doors being kept to a minimum) in combination with an appropriate exhaust air collection device resulting in an under pressure in the hall
    b. for highly odour-intensive wastes, use closed feed bunkers constructed with a vehicle sluice
    c. house and equip the bunker area with an exhaust air collection device.

2. adjust the admissible waste types and separation processes according to the type of process carried out and the abatement technique applicable (e.g. depending on the content of non-biodegradable components) (see Section 4.3)

3. use the following techniques when applying anaerobic digestion (see Sections 4.4 and 4.5):
    a. application of a close integration between the process with the water management
    b. a recycling of the maximum amount of waste water to the reactor. See some operational issues that may appear when applying this technique in Section 4.4
    c. operate the system under thermophilic digestion conditions. For certain types of wastes, thermophilic conditions cannot to be reached (see Section 4.4)
    d. measure TOC, COD, N, P and Cl levels in the inlet and outlet flows. When a better control of the process is required, or a better quality of the waste OUT, more parameters are necessary for measuring and controlling
    e. maximise the production of biogas. This technique needs to consider the effect on the digestate and biogas quality.

4. reduce the air emissions of the exhaust gas when using biogas as a fuel by restricting the emissions of dust, NO_x, SO_x, CO, H_2S and VOC by using an appropriate combination of the following techniques (see Section 4.6):
    a. scrubbing the biogas with iron salts
    b. using de-NO_x techniques such as SCR
    c. using a thermal oxidation unit
    d. using activated carbon filtration.

5. improve the mechanical biological treatments (MBT) by (see Sections 4.2, 4.3, 4.8, 4.10, **0**):
    a. using fully enclosed bioreactors
    b. avoiding anaerobic conditions during aerobic treatment by controlling the digestion and the air supply (by using a stabilised air circuit) and by adapting the aeration to the actual biodegradation activity
    c. using water efficiently
    d. thermally insulating the ceiling of the biological degradation hall in aerobic processes
    e. minimising the exhaust gas production to levels of 2500 to 8000 Nm^3 per tonne. Levels below 2500 Nm^3 per tonne do not have been reported
    f. guaranteeing a uniform feed
    g. recycling process waters or muddy residues within the aerobic treatment process to completely avoid water emissions. If waste water is generated, then this should be treated to reach the values mentioned in BAT number **Error! Reference source not found.**
    h. continuously learning of the connection between the controlled variables of biological degradation and the measured (gaseous) emissions
    i. reducing emissions of nitrogen compounds by optimising the C:N ratio.

6. reduce the emissions from mechanical biological treatments to the following levels (see Section 4.12)

Parameter	Treated exhaust gas
Odour (ouE/m^3)	<500 – 6000
NH_3 (mg/Nm^3)	<1 – 20

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For VOC and PM, see the generic BAT **Error! Reference source not found.**
The TWG recognised that N_2O (see Section **4.13**) and Hg also needed to be added to this table, however not enough data were provided to validate values on these issues.

by using an appropriate combination of the following techniques (see Section **Error! Reference source not found.**):

a. maintaining good housekeeping (related to BAT number **Error! Reference source not found.**)
b. regenerative thermal oxidiser
c. dust removal.

reduce the emissions to water to the levels mentioned in BAT number **Error! Reference source not found.**. In addition, restrict the emissions to water of total nitrogen, ammonia, nitrate and nitrite as well (see Section **Error! Reference source not found.** and the concluding remarks Chapter **Error! Reference source not found.**)

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6. Emerging techniques

Biological degradation times in MBT processes
The minimal biological degradation times required to comply with the landfill criteria with sufficient operational reliability will have to be determined by future experience with the new optimised MBT plants.

Phytoextraction of metals from the soil
In the field of environmental reclamation through biological process, the methodology known as phytoremediation has recently received mounting attention from operators in the field. Phytoremediation encompasses various techniques used for cleaning up both soil and water. For metal contaminated soil, phytoextraction represents one of the best solutions from the eco-environmental point of view. Through this technique, metals are absorbed and transported from the soil to the harvestable tissues of plants.

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