



Mechanical Biological Treatment Case Study 1: Ennigerloh Germany

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Summary

Germany, like many countries in the developed world, has introduced stringent legislation governing the disposal of waste to landfill. Since June 2005, it has been illegal to send untreated municipal waste to landfill, and strict guidelines exist for the organic content of waste permitted for disposal.

Consequently, residual waste must now be treated before disposal. Two main alternatives exist: incineration and mechanical biological treatment (MBT). MBT covers a range of technologies, used to stabilise and separate waste into less harmful and/or more beneficial output streams. The use of MBT has become increasingly widespread, particularly in rural areas where there may be opposition to large incineration plants.

This report looks in detail at an MBT plant in Ennigerloh, a town in Nordrhein-Westfalen in the western part of Germany. The plant comprises a mechanical separation facility that produces a refuse derived fuel product, and a biological treatment facility that produces stabilised waste suitable for landfill. The report provides background information on reasons for proceeding with the plant, an overview of the processes at both facilities, details of environmental impact and financial data.

MBT Ennigerloh has enabled the local authority to meet its obligations under current environmental legislation, as well as generating an income from gate fees and sales of RDF product. The plant has also put the local authority in a strong position to meet the challenge of creating a sustainable waste management system and recovering all municipal waste by 2020.

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1 Introduction

Environmental legislation is driving change in the German waste disposal and recycling industry. In 1990, some 70% of residual waste - the waste left after recycling and composting - was sent to landfill untreated. Just 15 years later, legislation came into effect banning the disposal of untreated municipal solid waste (MSW) or commercial waste to landfill, and further constraints are already planned. By 2020, Germany wants to be able to completely recover municipal wastes in order to create a sustainable waste management system with landfills practically abolished. To achieve this goal, considerable effort will be needed to develop residual waste processes that produce only reusable and recyclable substances, thus conserving raw materials.

As a result of the constraints on landfill, Mechanical Biological Treatment (MBT) technologies have become firmly established as an option for the treatment of residual waste alongside incineration or Energy from Waste (EfW) technologies.

The preference for MBT or EfW has tended to be influenced by different political targets in the federal states. However, in general, EfW facilities are mainly used in densely populated urban areas, whereas MBT plants are typically situated in rural areas, close to large landfill sites with huge vacant volumes to give low transport costs and easy disposal of stabilised waste.

1.1 Mechanical biological treatment of waste

MBT covers a range of technologies used to pre-treat residual municipal waste. MBT plant stabilises and separates waste into less harmful and/or more beneficial output streams.

Recyclable components may be extracted either before or after 'stabilisation', which generally involves drying/partial composting to produce a more stabilised residue. The remainder of the waste is screened or sorted into like components and is used to produce either a feedstock for another treatment process (for example, a refuse derived fuel (RDF), or is sent to landfill as a partially stabilised residue.

MBT offers several potential advantages, including:

- recovery of recyclable materials in the residual waste;
- a reduction in the volume of residual waste and therefore a reduction in landfill space needed and disposal costs;
- the removal of potentially hazardous waste components before landfill;
- creation of more stable waste for landfill, reducing methane and leachate production, as well as reducing odour and dust.

The plants also tend to be modular, comprising several small units, making them easier to adapt should waste composition or volumes change.

1.2 The move towards MBT in Germany

In Germany, environmental concerns have led to significant tightening of legislation regarding waste disposal. In 1993, the Technische Anleitung

Siedlungsabfall (Statutory Regulations for Municipal Waste) was introduced, setting high standards for the location, design and operation of landfill sites and on the composition of acceptable waste. The Instructions stipulated that, by 1 June 2005, only material with an organic carbon content lower than 5% could be sent to landfill. This low threshold level meant that residual waste would either have to be incinerated or stabilised prior to disposal. As there was considerable public opposition to incineration in the early 1990s, this legislation generated a great deal of interest in alternative treatment processes that were capable of reducing the organic carbon content of waste.

Between 1995 and 1999, the Federal Environment Agency carried out a study that laid the foundation for MBT technology in Germany. If MBT is used to pre-treat MSW, drastic reductions of biological activity and total organic carbon (TOC) must be achieved. The study found that MBT could achieve these reductions and was equal to incineration in terms of environmental impact, making it a viable alternative to EfW for the pre-treatment of waste. Following this study, there were many discussions on suitable threshold levels for landfill, that could be met economically using MBT technology.

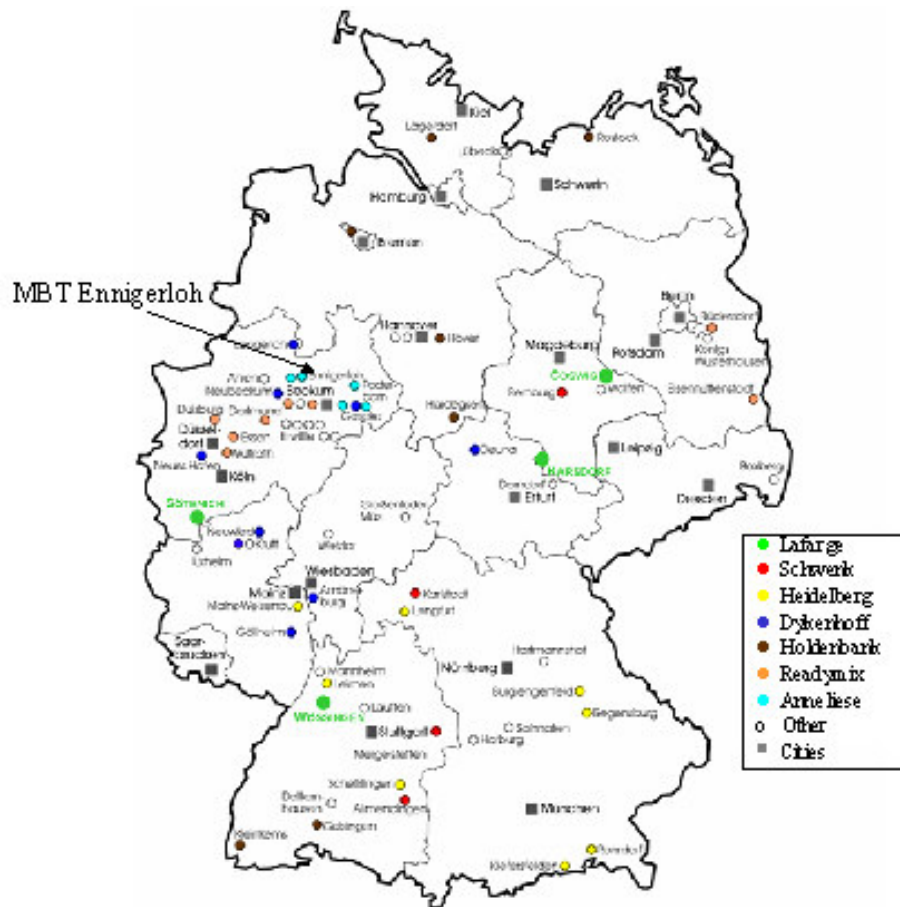
In 2001, the Abfallablagerungsverordnung (the Waste Storage Ordinance) was introduced. This Ordinance transposed the municipal waste provisions of the European Union's Landfill Directive (1999) into German law, and put state-of-the-art MBT plant on an equal footing to incineration plants. The regulations were backed up by the 30 Bundes-Immissionsschutz-Verordnung (the 30th Ambient Air Quality Ordinance), which set strict emission standards for MBT plants.

The requirements for planning and operating MBT plant were therefore established four years before the ban on disposal of untreated MSW and commercial waste came into effect in 2005. Some changes may, however, be needed in the future. Germany aims to recover MSW completely from the year 2020, a move that will prohibit sending even stabilised waste/compost from MBT plants to landfill.

1.3 MBT in Ennigerloh

1.3.1 Reasons for the decision

Ennigerloh is located in Nordrhein-Westfalen in the western part of Germany, approximately 30 km east of Münster. There are a large number of cement kilns close to the town (as shown in Figure 1), as well as several power stations and EfW facilities. This infrastructure was instrumental in steering the local authority to develop a comprehensive waste management strategy as early as 1991.

Figure 1 Location of cement kilns in Germany (Source: ECOWEST)

The authority commissioned a study to look at waste composition within the area (see Appendix 1) and to carry out an environmental impact assessment of three alternative waste management options:

- stabilisation/composting of residual waste with subsequent disposal to landfill;
- production of RDF from residual waste and its subsequent combustion at a local cement kiln, along with incineration of the heavy fractions at an EfW plant;
- incineration of all residual waste at an EfW plant.

This study concluded that the second option would have the lowest environmental impact. This option was then subject to further detailed investigations, which concluded that:

- the production of RDF was technically and ecologically possible;
- the composition of the RDF product would be comparable to coal or lignite;
- the combustion of RDF in cement kilns would not exceed emission limits or impact on product specifications;
- the toxicological and environmental impact on the region resulting from RDF production should be low.

1.3.2 Development of the plant

Following positive results from its studies, the local authority decided to proceed with a mechanical separation facility to produce RDF in 1998. A site for the facility was selected north of Ennigerloh (Figure 1).

Tendering for the work began in 1998, with planning permission received in 1999. The contract for operating the separation plant was awarded to ECOWEST Entsorgungsverbund Westfalen GmbH, a regional association set up by three local waste management companies in 2000, to deal with waste from the Warendorf and Gütersloh districts. The plant became fully operational in 2002, with a total capacity of 160,000 tonnes/year.

In 2001, after the introduction of the Waste Storage Ordinance, the local authority recognised that a biological treatment plant would be needed to stabilise the organic waste fraction before it could be sent to landfill. Planning permission for this facility was received in 2003, and construction began the same year. The facility is owned and operated by BIOWEST Biologische Abfallbehandlung Westfalen GmbH, an organisation set up to manage the fine fraction waste from three districts (Warendorf, Gütersloh and Soest). The fine fraction from mechanical treatment plants in Ennigerloh and Soest is sent to the biological treatment facility for composting and stabilisation. Commissioning began in 2004 and the plant became fully operational in 2006, with a total capacity of 100,000 tonnes/year.

Figure 2 shows the Waste Management Centre at Ennigerloh, which includes the mechanical separation plant, the biological treatment plant, a composting facility, a recycling depot and a landfill site with leachate treatment.

Figure 2 The Waste Management Centre at Ennigerloh (Source: ECOWEST)



This comprehensive waste management centre can process many diverse materials, including:

- kitchen waste and garden waste for composting;
- paper and glass for recycling;
- packaging materials, such as paper, cardboard and plastic, some of which is recycled, the remainder being incinerated;
- residual waste for treatment.

MBT Ennigerloh is operational for approximately 14 hours a day, in two shifts. Currently 14 people (total for the two shifts) are required to operate the MBT plant. However, the technology provider expects staffing requirements to reduce to two people per shift in future, by introducing automated equipment to move the compost material between the various composting stages.

2 Mechanical separation facility

The mechanical separation facility to produce RDF in Ennigerloh is owned and operated by ECOWEST Entsorgungsverbund Westfalen GmbH. Construction began in 2000 and took just eight months to complete, with the commissioning phase and trial operations beginning in April 2001. Processing equipment was supplied by Horstmann GmbH & Co KG. In 2002, the plant became fully operational, with a total processing capacity of 160,000 tonnes/year, comprising:

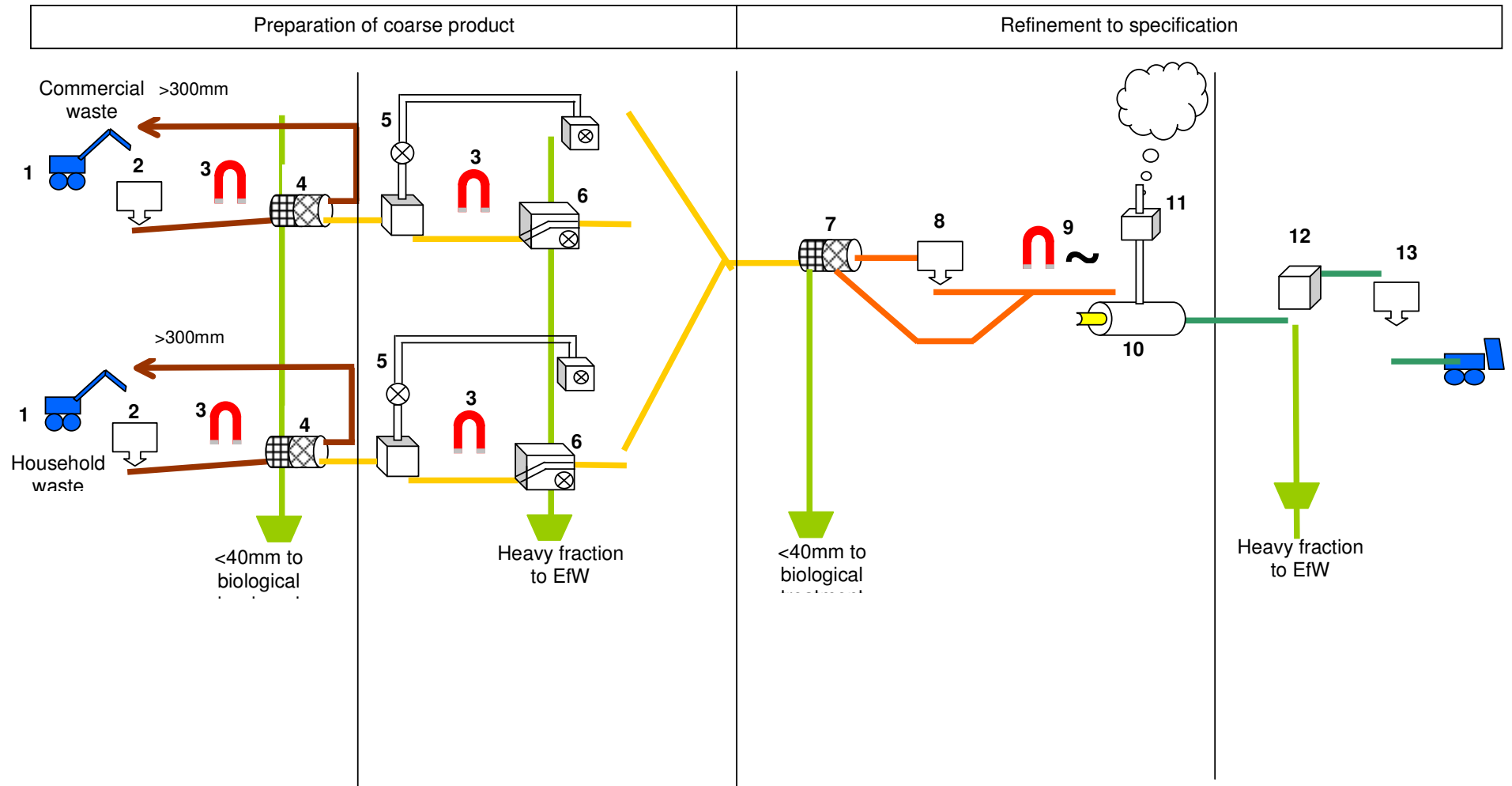
- 74,000 tonnes/year household waste;
- 66,000 tonnes/year commercial waste;
- 20,000 tonnes/year bulky waste.

2.1 The mechanical separation process

The flow diagram in Figure 3 depicts the operation of the mechanical separation facility. The separation process is fully automated, with only a few people required to load waste into the shredder and to oversee the smooth operation of the equipment. Separation equipment, such as screens, air classification and ballistic separators, can be set to achieve the required sorting specification.

- 1 Commercial waste and household waste are delivered separately to the plant. Due to their different waste composition and characteristics, the two waste streams are handled separately in the first part of the mechanical separation process.
- 2 Materials visually identified as not being suitable for the sorting process are separated out in the storage area, for example bulky waste and long strings (these can get tangled in the machines). This oversized reject fraction is sent to the EfW plant for incineration. Suitable material is then shredded to reduce waste size to less than 300 mm.
- 3 Magnets are installed at various stages above the belts transporting shredded waste to remove ferrous materials for recycling.
- 4 The shredded waste is separated into three fractions in a rotary screen: fine fraction (<40 mm), medium-sized fraction (40-300 mm) and coarse fraction (>300 mm). The fine fraction is transferred automatically by belt to the biological treatment facility in the adjacent building, while the coarse fraction is transported back to be reshredded.
- 5 The medium-sized fraction is transported to air classification, where light materials, such as foils and paper, are separated out for RDF production.
- 6 The remainder of the medium-sized fraction goes through a ballistic separator, which separates out heavy materials, such as glass, stones, hard plastic and wood. This heavy fraction is collected and transferred to the EfW plant for incineration. The ballistic separators can be programmed to separate out certain types of materials, eg light plastic, by varying the velocity and angle of the transport belt.

Figure 3 Flow diagram of the mechanical separation process



If demand exists, the medium-sized fraction and light material generated after air classification and ballistic separation can be sent to third-party organisations, for the production of secondary fuel or for incineration in fluidised bed incinerators. Alternatively, the medium-sized fraction from the household waste and commercial waste streams is combined at this stage and continues through the mechanical separation facility, to produce an RDF product for use in power stations or cement kilns.

Figure 4 Preparation of < 80mm RDF product (Source: ECOWEST)



- 7 The combined medium-sized fractions pass through a two-stage rotary screen. In the first stage, any remaining fine fraction (<40 mm) is screened out and transferred to the biological treatment facility. In the second stage, the medium-sized fraction falls through the screen.
- 8 Any oversized material passes through a shredder before rejoining the medium-sized fraction waste stream.
- 9 Any remaining ferrous and non-ferrous metals are separated out of the waste stream.
- 10 The damp waste material is air dried in a rotating drum, heated either by natural gas or landfill gas.
- 11 Emissions from the rotary drum are cleaned by regenerative thermal oxidation in the flue gas cleaning system.
- 12 After drying, light materials, such as ash, are removed in a final air classification stage, carried out at a low transport belt speed (5 – 6 m/s compared with 30 m/s in the previous air classification stage). This operation decreases the contamination level and improves the RDF product quality. Any remaining heavy fraction is separated out and transferred to an EfW.

- 13 At the end of the mechanical separation process, a fluffy, dry material with a screen size of 80 mm is produced. This material is either:
- supplied to power stations, for example, for direct use as an RDF product;
 - supplied to other organisations as a base material for production of alternative, customer-specific secondary fuel products;
 - shredded to give a product with a screen size of 30 – 80 mm and a loading density of 0.04 - 0.2 tonne/m³, according to market demand, for use in, for example, the cement industry.

Further details of the end product and its uses are given in section 2.2.

Figure 5 Refinement of RDF product to specification (Source: ECOWEST)



2.2 Refuse derived fuel product

2.2.1 Background

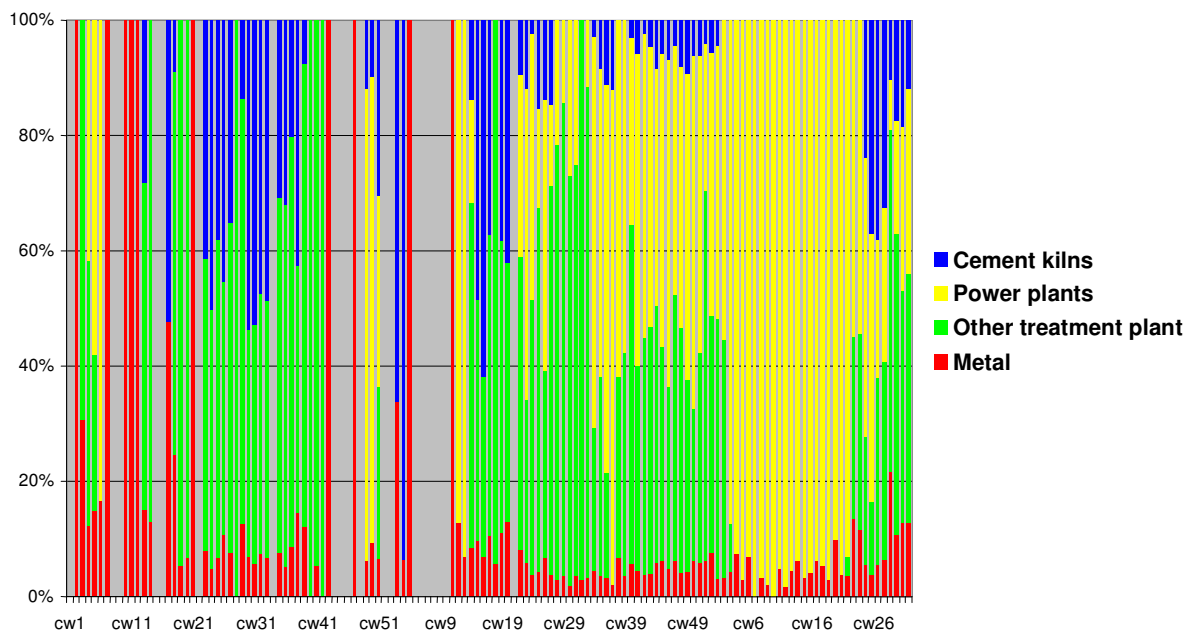
In the past, EfW plants and co-combustion facilities in Germany were competing for RDF products, because commercial waste was typically sent to landfill. However, since it became illegal to send untreated MSW and commercial waste to landfill in June 2005, there has been a steady increase in the amount of RDF on the market and supply currently outstrips demand, even though several regions have insufficient thermal capacity to treat their waste. While it is recognised that EfW, MBT and co-combustion need to form part of an integrated waste management system in order to divert untreated waste from landfill, work is needed to find markets for RDF and to promote the use of co-combustion.

2.2.2 RDF market for MBT Ennigerloh

In Ennigerloh, the local cement industry was seen as a key customer for RDF when the mechanical separation facility was designed and built. The plant produces a light and fluffy RDF product, because the burning characteristics are more suited to cement kilns than those of the dense pellets produced by many other facilities. Cement kilns require homogenous burning characteristics, and pellets are generally too dense and heavy to provide this.

Since the MBT plant became operational, however, many cement kilns have closed, which has had an impact on demand for the RDF product. Figure 6 shows how the market for RDF product and metals generated from MBT Ennigerloh has changed since January 2003, and demonstrates the need for the plant to be flexible and follow market demand.

Figure 6 Market for RDF product and metals from MBT Ennigerloh (Jan 2003 – Aug 2005 shown in calendar weeks)



2.2.3 Composition of RDF product

Table 1 shows the composition of the RDF product generated since 2002 (median values). The calorific value has increased significantly, due to the higher volume of commercial waste now delivered to the plant. This increase in commercial waste has also resulted in a higher ash content. Detailed physical and chemical composition of the RDF is provided in Appendix 2.

Table 1 Composition of RDF product (median values January 2002 to September 2005)

	2002	2003	2004	2005 *
Calorific value (kJ/kg)	16,500	17,800	18,100	18,700
Dry matter (%)	91.20	92.60	93.10	93.70
Ash content (%)	15.75	13.50	15.45	16.70
Chlorine (%)	0.91	0.97	0.80	0.73
Fluorine (%)	0.04	0.04	0.04	0.01
Sulphur (%)	0.10	0.10	0.10	0.13

- Up until 01/10/2005

MBT Ennigerloh is currently working towards accreditation for its RDF product under the RAL Gütezeichen (German quality scheme) for RDF products. Accreditation criteria include the analysis of heavy metals, but exclude ash content or other physical parameters. The threshold levels needed for accreditation are shown in Table 2, along with analysed levels for the RDF product at MBT Ennigerloh (median values for product generated between 8 August 2002 and 4 October 2005). These results indicate that the RDF product is well within the threshold values for accreditation.

Table 2 Threshold values for accreditation of RDF (30 mm screen size)

Element	Heavy metal content (mg/kg dry matter) ¹				
	Median value (Threshold)	Median value 20 – 40 mm (Analysed)	80 th percentile value ² (Threshold)	80 th percentile value (Analysed)	
Cadmium (Cd)	4	0.7	9	1.0	
Mercury (Hg)	0.6	0.2	1.2	0.5	
Thallium (Tl)	1	1.0	2	1.0	
Arsenic (As)	5	1.4	13	2.2	
Cobalt (Co)	6	4.5	12	7.1	
Nickel (Ni)	25 ³ 80 ⁴	26.0	50 ³ 160 ⁴	48.4	
Selenium (Se)	3	1.0	5	1.0	
Tellurium (Te)	3	1.0	5	1.0	
Antimony (Sb)	25	20.0	60	43.6	
Lead (Pb)	70 ³ 190 ⁴	103.5	200 ³ - ⁵	162.0	
Chromium (Cr)	40 ³ 125 ⁴	63.0	120 ³ 250 ⁴	120.0	
Copper (Cu)	100 ³ 350 ⁴	91.0	- ⁵ - ⁵	130.0	
Manganese (Mn)	50 ³ 250 ⁴	110.0	100 ³ 500 ⁴	162.0	
Vanadium (V)	10	4.8	25	7.2	
Tin (Sn)	30	15.0	70	25.4	
Beryllium (Be)	0.5	0.1	2	0.1	

- 1 The threshold values for heavy metals are valid for MSW with a calorific value ≥ 16 MJ/kg and industry-specific waste with a calorific value ≥ 20 MJ/kg. Below these calorific values, there is a linear decrease of the heavy metal threshold. Wastes with calorific values above these levels are not accepted.
- 2 The highest result out of five analyses is excluded from the assessment.
- 3 RDF generated from industry-specific waste.
- 4 RDF generated from the high calorific fraction of MSW.
- 5 Setting of the threshold value delayed until better data are available from RDF production.

The accreditation process requires the analysis of one sample taken from every 500 tonnes of RDF product over a period of one year. MBT Ennigerloh began the accreditation process in October 2005, taking samples daily, which means that analyses are carried out approximately every 200 tonnes. Consequently, ECOWEST expected to complete the accreditation process within six months and aimed to receive accreditation in April 2006.

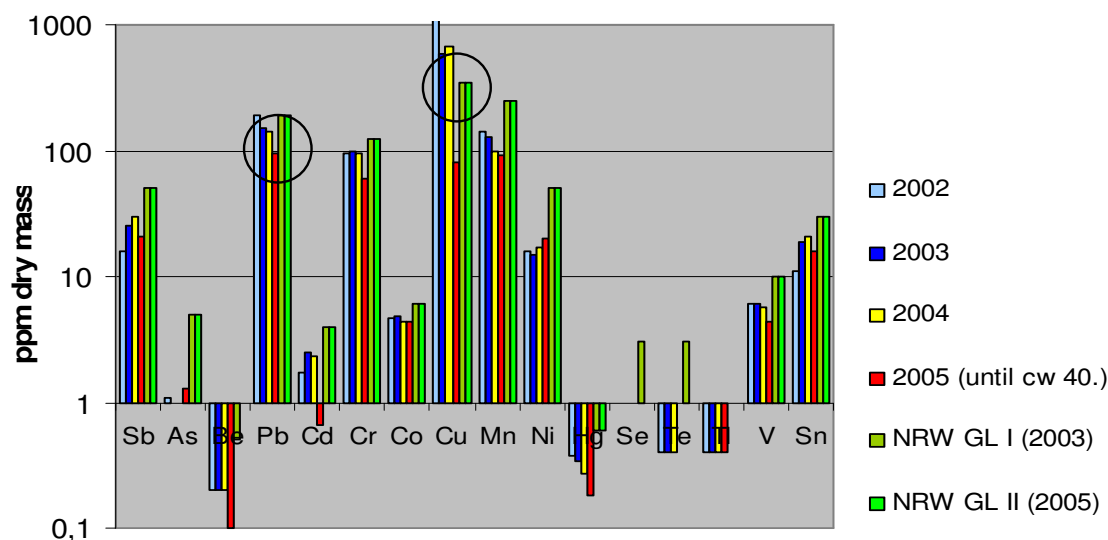
2.2.4 Refining RDF production

Analysis of the chemical, physical and calorific parameters of the RDF product (as presented in Appendix 2) is insufficient for assessing co-combustion characteristics. Results need to be considered alongside customer requirements. MBT Ennigerloh has continuously improved and refined the quality of its RDF product in close co-operation with the cement industry and power stations.

Heavy metals

MBT Ennigerloh has analysed the heavy metal content in its RDF product since operations began in 2002. In some instances, the heavy metal content has exceeded regional guidelines for Nordrhein-Westfalen (NRW GL I in 2003 and NRW GL II in 2005), with levels of copper and lead exceeding the guidelines as late as 2005, as shown in Figure 7.

Figure 7 Concentration of heavy metals compared with regional guideline levels



In an effort to reduce heavy metal contamination, regular checks were introduced to assess the type of material delivered and to identify the deliveries with larger amounts of waste containing heavy metals. As a result of these checks and improvements to the separation process, the concentration of heavy metals has been reduced and is now below the threshold levels for RAL Gütezeichen accreditation, as shown in Table 2.

Details of heavy metal concentration analyses can be found in Appendix 2.

Chlorine-containing materials

The cement industry needs an RDF product with a low chlorine content, because chlorine weakens cement and reduces its quality. MBT Ennigerloh has therefore taken action to reduce the amount of chlorine in its RDF product (see Table 1), thereby making it suitable for more forms of co-combustion and potentially increasing market demand. Hand-held analysis units are used to identify chlorine-containing material, such as polyvinyl chloride, in the delivered waste. Any identified material is separated out prior to processing, reducing chlorine contamination.

Figure 8 On-site identification of chlorine-containing waste material

**Calorific value**

In co-operation with its customers in the cement industry and power stations, the calorific value of the RDF product has been increased, averaging around 18,400 kJ/kg in 2005. There will, however, always be a certain degree of variation in calorific value because of variations in the waste input, even with continuous improvement of the mechanical separation process. A storage hall is currently being built at MBT Ennigerloh, to enable the company to mix RDF product prior to despatch, to yield a fairly consistent calorific value.

3 Biological treatment facility

The biological treatment facility in Ennigerloh is owned and operated by BIOWEST. Biologische Abfallbehandlung Westfalen GmbH. Construction began in 2003, with trial operations beginning in October 2004 and the commissioning phase beginning in March 2005. As for the mechanical separation facility, processing equipment was supplied by Horstmann GmbH & Co KG.

The plant became fully operational in 2006, with a total capacity of 100,000 tonnes/year of organic waste, which is delivered from two mechanical sorting plants in Ennigerloh and Soest. Originally, the composting process was intended to process 80,000 tonnes/year fine fraction and 20,000 tonnes/year sewage sludge. Sewage sludge was added during the first six weeks of the commissioning phase, but analysis revealed that the stabilised waste material did not meet the threshold levels set for waste suitable for landfill (see Table 3 in Section 3.2). As a result, the processing of sewage sludge was abandoned.

3.1 The biological treatment process

The various stages of biological treatment are outlined in Figure 9, including the re-circulation of process water and process air, while Figure 10 shows the mass flow of material going through the facility. The biological treatment facility began its final commissioning phase in March 2005. As part of the commissioning process, carried out by the technology provider Horstmann, threshold values for landfill had to be achieved for 10 consecutive weeks before the operation could be handed over to BIOWEST. Commissioning was completed in summer 2006.

Figure 9 Process stages for the biological treatment facility at Ennigerloh (Source: ASA Journal (amended))

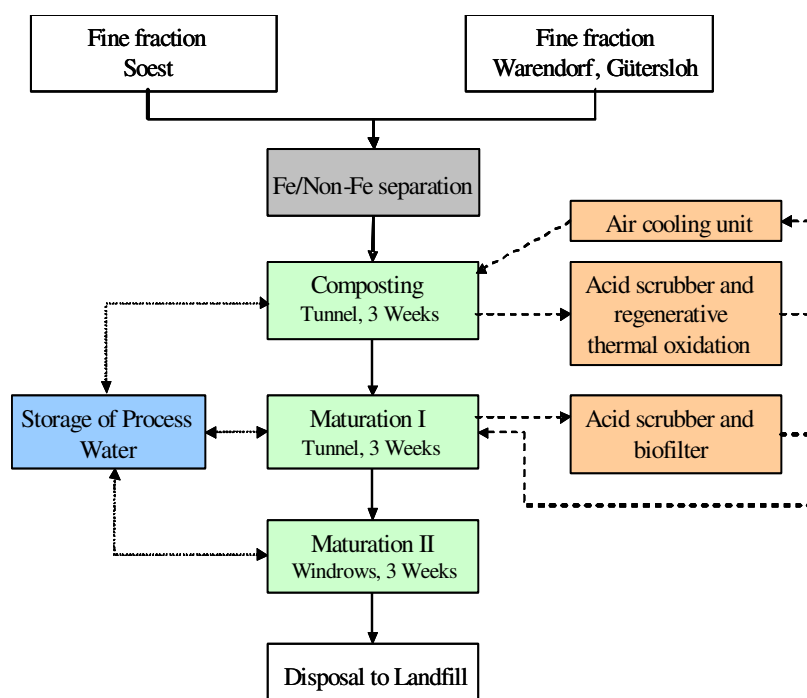
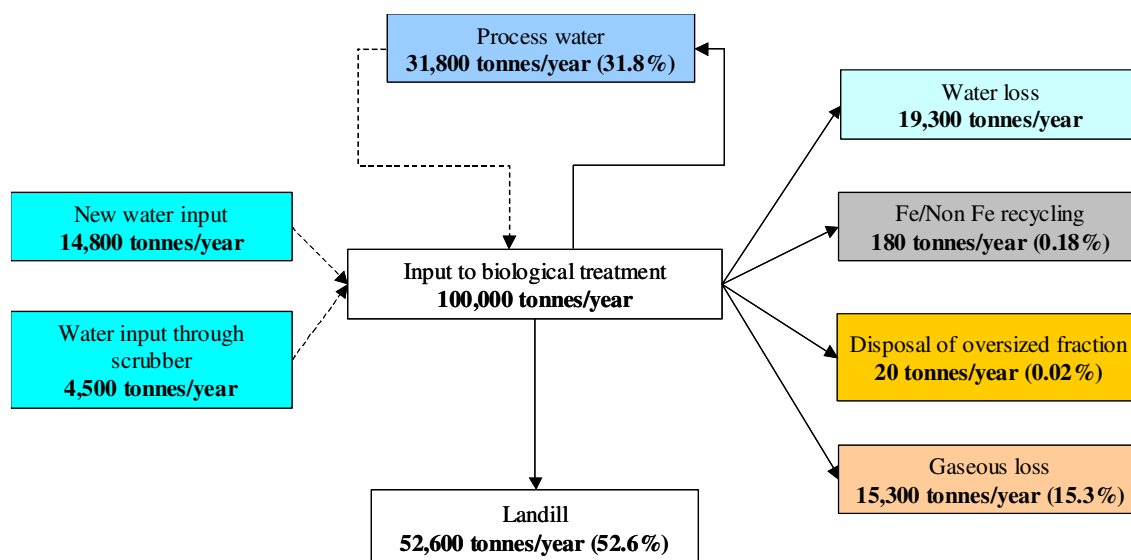


Figure 10 Mass flow of material going through the biological treatment facility at Ennigerloh (Source: ASA Journal (amended))



3.1.1 Waste delivery and separation of metals

The fine fraction separated out in the mechanical separation facility at Ennigerloh is transported directly into the biological treatment facility on belts. The fine fraction that is brought to the site from the mechanical separation facility at Soest is added, and the combined material is then transported on belts to the composting tunnels. Any ferrous and non-ferrous metals are separated out before the material reaches the tunnels.

Figure 11 Main hall, showing waste transport belt and composting tunnels



3.1.2 Active composting process (in tunnels)

The composting process takes place in batches in 16 tunnels, each 32 m long and 6 m wide. Material remains in the tunnels for three weeks, with an automated system being used to turn material once a week. Temperature,

moisture and oxygen levels are continuously monitored and controlled, with more water or air being added automatically when required. Process water is re-circulated and no water is discharged. Process air is also re-circulated via a gas cleaning system, which consists of an acid scrubber and a regenerative thermal oxidiser, as required by German legislation.

3.1.3 Maturation phase I (in tunnels)

After 21 days, the composted material is transported via belts into a second set of 16 tunnels, each 32 m long and 6 m wide, for the first maturation phase. This phase also takes place in batches, and takes a further three weeks. As for the composting stage, maturation takes place in an enclosed and controlled atmosphere, although the watering and exhaust gas cleaning systems are slightly different from those in the composting tunnels. Exhaust gas from the first maturation phase is re-circulated via an acid scrubber and a biofilter.

3.1.4 Maturation phase II (in open bays)

The second maturation phase takes place in 11 open concrete bays, where the remaining moisture is reduced by aeration. This maturation phase typically takes three weeks, with the actual duration being dictated by the time needed for the stabilised waste material to reach the threshold limits for landfill.

3.2 Stabilised waste material

By the end of the biological treatment process, the volume of waste will have been reduced by around 40% and the stabilised waste material will have a similar consistency to soil. The Waste Storage Ordinance, introduced in Germany in 2001, set strict threshold values that must be met before waste from MBT plants can be disposed of to landfill.

3.2.1 Threshold values for disposal of MBT waste

MBT is used in Germany to pre-treat MSW, and drastic reductions in biological activity and total organic carbon (TOC) content must be achieved to meet the thresholds set for disposal of waste to landfill. Table 3 shows the current threshold values. Stabilised waste does not have to meet all threshold values: some of the parameters are alternative measures. For example, the biological degradability may be determined by respiration activity (AT4 parameter) or gas formation rate (gas production GB 21 parameter); and the organic component may be determined by TOC content (dry matter) or gross calorific value.

Table 3 Threshold values for disposal of MBT waste to landfill in Germany

Parameter	Threshold value	Comments
AT4	≤ 20 mg O ₂ /g dry matter	Limit for non-encapsulated treatment
AT4	≤ 5 mg O ₂ /g dry matter	Compost may be alternatively used
Gas production GB 21	≤ 20 NI/kg dry matter	Compost may be alternatively used
TOC (eluate)	≤ 250 mg/l	
TOC (dry matter)	$\leq 18\%$	Compost may be alternatively used
Gross calorific value	$\leq 6,000$ kJ/kg	Compost may be alternatively used

3.2.2 Actual values of stabilised waste from MBT Ennigerloh

Samples of waste are analysed at the end of the second maturation phase. Where the threshold levels for landfill have not been achieved after nine weeks, the compost material will stay in the maturation bays for a few days longer. If the key parameters remain above the threshold levels, the material may be stored temporarily on the landfill site before disposal, to allow further composting to take place. Permission for such temporary storage was granted for a period of one year, beginning during the commissioning phase, but BIOWEST is able to apply for an extension if this practice becomes necessary.

Analysis results for waste composted during the commissioning phase, however, show that the key parameters for composted material generally fall well below the threshold levels (Table 4). The only parameter that many MBT plants in Germany are currently finding it difficult to meet is that for TOC (eluate). At MBT Ennigerloh, the threshold level has been met in over 80% of analyses, which is currently accepted by the authorities. So far only two batches of treated material have been rejected for landfill, both during the commissioning phase. The composting process has subsequently been optimised, with changes made to the air supply during the active composting phase.

Table 4 Analysis results for stabilised waste from MBT Ennigerloh

Parameter	Sample 18/10/2005	Sample 03/11/2005	Sample 08/11/2005	Threshold value
Total material > 10 mm (%)	20.8	22.2	33.2	
Contaminants > 10 mm (%)	17.7	19.5	31.8	
Dry matter (%)	63.1	66.4	82.8	
AT4 (mg O ₂ /g dry matter)	0.1	0.5	1.6	≤5
TOC (dry matter)	7.8	8.4	8.7	≤18
TOC (eluate)	154	178	248	≤250

4 Environmental Impact

Germany has strict emission limits in place for exhaust gas from MBT plants. The threshold values, which are similar to those for waste incineration plants, are shown in Table 5. Biofilters alone or combined with acid scrubbers cannot meet these limits and thermal treatment, such as regenerative thermal oxidation (RTO), is usually required to reduce the volatile organic compounds to a sufficient level.

Table 5 Emission limits for exhaust gases from MBT plants in Germany¹

Parameter	Measurement period	Emission limits
Dust	Daily mean	10 mg/m ³
	Half-hour mean	30 mg/m ³
Dioxin	-	< 0.1 ng/m ³
Total organic carbon	Daily mean	20 mg/m ³
	0.5 hour mean	40 mg/m ³
	Load ¹	55 g/tonne
Nitrous Oxide	Load ¹	100 g/tonne
Odour	All value	≤ 500 OU/m ³ ²

- Mass-specific emission of the pollutant as applied to the mass of the waste input, calculated by:

$$Load = \frac{Exhaust\ air\ volume \times concentration}{Waste\ input(mass)}$$

- OU = odour units

4.1 Gas cleaning in the mechanical separation plant

Generally, mechanical separation should take place under pressure and with particle filters in place to control the generation of dust particles. Particle filters are currently being installed at MBT Ennigerloh.

RTO is used to reduce the level of organic compounds in the exhaust gas from the rotating drum dryer (step 10 in Figure 3). The RTO unit can treat 20,000 - 25,000 m³/hour of exhaust gas.

4.2 Gas cleaning in the biological treatment plant

Different gas cleaning technologies are applied to each composting stage.

4.2.1 Exhaust from the active composting process

Exhaust gas from the composting tunnels is first treated in an acid scrubber (with a capacity of 44,000 m³/hour), which removes acid gases, such as hydrogen chloride and sulphur oxide. The gas then passes through two regenerative thermal oxidation devices (Figure 12), each with a maximum capacity of 36,000 m³/hour (giving a total capacity of 72,000 m³/hour), which

¹ Kuehle-Weidemeier, M., Results of continuous measurement of exhaust gas from intensive processing. International Symposium MBT 2005.

oxidise any hydrocarbons present. Treated gas is then re-circulated back to the tunnels for the active composting process.

Figure 12 Regenerative thermal oxidation device used to clean exhaust gas from the active composting tunnels



During the commissioning phase, it became apparent that more air than expected was being utilised during the active composting process. Consequently, the volume of exhaust gas is larger than expected, which causes problems in the gas cleaning system. Only one acid scrubber is fitted, which limits the volume of gas that can be treated to 44,000 m³/hour; however, 56,000 m³/hour exhaust gas is currently passing through the acid scrubber, exceeding its capacity. As a result, some contamination is occurring in the RTO devices. MBT Ennigerloh plans to install an additional acid scrubber in the future to overcome the capacity shortfall.

Exhaust gas from the composting process contains siloxane, which poses another problem for the RTO devices. Siloxane produces silica during combustion which, combined with other elements in the exhaust gas, forms a hard deposit. As these deposits accumulate, gas cleaning efficiency decreases due to clogging of the device surface. The RTO devices need cleaning approximately every five or six weeks, which takes one or two days and reduces the capacity of the gas cleaning system. Initially, the technology provider estimated that cleaning would be needed every four months, but the more frequent cleaning requirements may result from overloading of the acid scrubber and subsequent contamination of the RTO devices. MBT Ennigerloh plans to install a third RTO device in the near future, to provide additional capacity during cleaning periods.

4.2.2 Exhaust from the first maturation phase

The commissioning phase highlighted that an acid scrubber would be needed to treat exhaust gas from the first maturation process before it reached the biofilter, and that the cooling and watering procedure needed to be improved. The device used to moisten the air in the maturation tunnels was therefore modified to work as a wet scrubber. This device now cleans and moistens the exhaust gas, which is then re-circulated via a biofilter to the maturation tunnels.

5 Economic analysis

The Statutory Regulations for Municipal Waste in 1993 and the Waste Storage Ordinance in 2001 introduced new criteria for landfill operation, and further technical requirements for landfill sites have also been introduced. Consequently, the investment associated with waste management in general and landfill in particular has increased significantly in recent years.

Details of the capital expenditure associated with the Waste Management Centre at Ennigerloh since 1993 is given in Table 6.

Table 6 Capital expenditure at the Waste Management Centre, Ennigerloh since 1993

Investment	Approximate cost (€ million)
Construction of landfill base	13.5
Landfill gas collection	4.3
Collection and treatment of leachate	6.8
Composting plant for source-segregated organic waste	13.0
Mechanical separation plant for RDF production	14.0
Biological treatment plant for mixed waste	25.0
Infrastructure	11.9
Total investment	88.5
Landfill aftercare	31.8
Annual charges for MSW incineration plant	2.5

A breakdown of the total costs for the MBT facility is shown in Figure 13.

Figure 13 Cost breakdown for the MBT plant

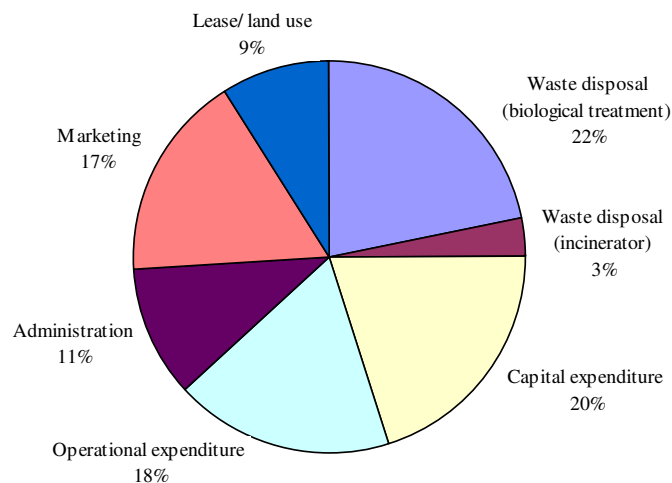


Table 7 provides a breakdown of the current gate fees for the MBT plant, disposal charges, and the market price for the RDF product with an indication (where possible) of how the costs are expected to change in the future.

Table 7 Breakdown of current gate fees and potential future changes

Process	Material	€/tonne	Future changes
MBT	Mixed household waste and commercial waste	87	
Incineration	Materials unsuitable for MBT; separated heavy fraction	120 ¹	Significant increase expected due to insufficient capacity for waste treatment in Germany
Landfill	Stabilised waste after composting	54	Relatively stable
Markets for RDF	Sorted and refined RDF products	70 ²	Potential increase of 15 - 20% over the next 3 - 4 years

1 Gate fee for waste with a calorific value of 10 MJ/kg. In reality, waste material is delivered with a calorific value of 12 MJ/kg due to the increase in commercial waste, hence the gate fee increases.

2 Average price for the three types of RDF product generated at MBT Ennigerloh.

Since June 2005, it has been illegal to send untreated waste to landfill, and both household and commercial waste must either be pre-treated in MBT facilities or be sent for incineration. However, the calorific value of commercial waste typically exceeds the specification of incineration plant, which is usually set at 10 MJ/kg. As a result, the throughput of the incineration plant is reduced and commercial waste is having to be stored at these facilities. It will take a number of years to increase incineration capacity in certain parts of Germany, and it is therefore expected that the disposal costs for commercial waste will increase significantly in the next few years.

The anticipated increase in the market price for RDF products shows that MBT Ennigerloh needs to retain flexibility in its mechanical separation process, and improve or modify its RDF product as required. Furthermore, with increasing gate fees for incineration, the capacity balance between MBT treatment and incineration will become increasingly important.

6 Conclusions

Environmental legislation continues to drive changes in the waste management industry in Germany. Strict regulations governing the composition and characteristics of waste suitable for landfill have led to a shift change in waste disposal routes. Since the 1990s, there has been increasing interest in mechanical biological treatment as a method of pre-treating waste, with several studies concluding that the process offers a viable, environmentally-sound alternative to incineration of residual waste.

At Ennigerloh, waste composition analysis and environmental assessments confirmed the suitability of MBT as part of the local authority's waste management strategy. In 1998, the local authority decided to proceed with a mechanical separation facility to produce refuse-derived fuel, with local cement works and power stations obvious customers. In 2001, following the introduction of the Waste Storage Ordinance, the local authority realised that biological treatment would be needed to meet landfill specifications, and a facility was built on the same site. The Waste Management Centre at Ennigerloh also houses a landfill site with leachate treatment, a recycling depot and a composting facility.

The mechanical separation facility became fully operational in 2002, and can process 160,000 tonnes of residual waste each year. The RDF product generated is particularly suited to co-combustion in cement kilns, offering homogeneous burning characteristics. The product is also used by power stations and as a base material for other organisations looking to produce customer-specific secondary fuel products. Since operations began, there has been an increase in the amount of commercial waste being processed, which has resulted in an RDF product with a higher calorific value. The mechanical separation process retains flexibility, enabling improvements or modifications to be made to the RDF product, maximising its market potential. MBT Ennigerloh is currently working towards accreditation for its RDF product, which will also make it more attractive to potential customers.

The biological treatment facility became fully operational in 2006, and can process 100,000 tonnes of fine fraction waste each year. Waste is typically composted for nine weeks, with active composting being followed by two maturation phases. Since operations began, only two batches have failed to meet the thresholds set for MBT waste disposal to landfill. Both of these batches were processed during the commissioning phase, and modifications were subsequently made to the active composting phase to prevent reoccurrence.

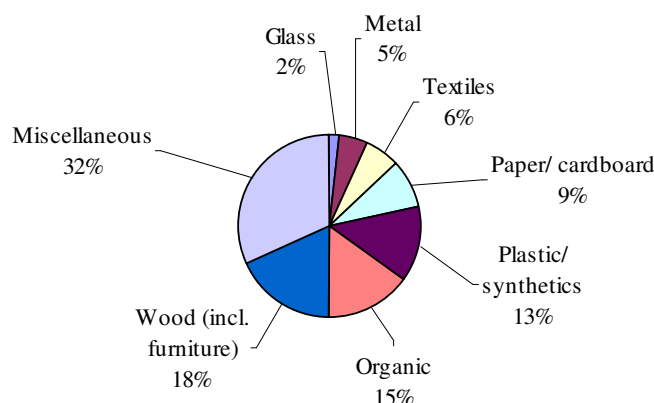
MBT Ennigerloh has been designed to minimise its environmental impact. Exhaust gas cleaning systems are in place at both facilities to ensure that emission limits are not exceeded.

Treatment and disposal options are both needed for a balanced, integrated waste management system. The MBT Ennigerloh presents an integrated approach with the biological fraction stabilised under controlled conditions and then landfilled in conformity with the Regulation, while intermediate and heavy fractions are incinerated and the high-calorific fraction is processed to generate RDF which is utilised in local cement kilns and power stations.

7 Appendix 1 Waste composition data

Waste composition analysis was carried out in 1991, as part of the initial investigations to assess the environmental impact of various waste management options. The results are shown in Figure 15.

Figure 14 Composition of municipal solid waste for the Ennigerloh region, 1991 (Source: ECOWEST)



Further analysis was undertaken, to determine the chemical composition and characteristics of the waste fractions, and identify those materials best suited to generating an RDF product acceptable to the market, while reducing contamination of the RDF material. The remaining waste fractions would need to be stabilised in a biological process prior to being sent to landfill, or be sent to an EfW plant for incineration.

The ultimate destination of the household and commercial waste components delivered to the mechanical separation facility is summarised in Table 8. Due to the waste composition, approximately 50% of commercial waste is suitable for generation of RDF, compared with only 28.5% of household waste.

Table 8 Destination of waste sent to the mechanical separation facility at Ennigerloh (Source: ASA Journal)

	Commercial waste	Household waste
Biological treatment	20%	50%
Incineration	23%	10%
Metals for recycling	6%	2.5%
Water	1%	9%
RDF	50%	28.5%

A breakdown of the waste supplied to the mechanical separation facility (classified according to the European Waste Catalogue (EWC)² categorisation) is shown in Tables 9 and 10. Table 9 details actual waste delivered in August and September 2005, while Table 10 gives estimated annual waste inputs.

Table 9 Waste input to the mechanical separation facility from 01/08 to 25/09/2005 (Source: ECOWEST)

EWC code	Waste fraction	% of total
02 01 04	Waste plastics (except packaging)	0.35
04 02 22	Wastes from processed textile fibres	0.01
15 01 02	Plastic packaging	0.01
15 01 05	Composite packaging	0.00
15 01 06	Mixed packaging	7.17
15 02 03	Absorbents, filter material, wiping cloths and protective clothing, other than those mentioned in 15 02 02.	0.00
17 06 04	Insulation materials, other than those mentioned in 17 06 01 and 17 06 03	0.01
19 05 01	Non-composted fraction of municipal and similar waste	1.45
19 12 12	Other wastes (including mixture of materials) from mechanical treatment of wastes, other than those mentioned in 19 12 11.	9.88
20 01 39	Plastics	0.01
20 03 01	Mixed municipal waste (household)	63.29
20 03 01	Mixed municipal waste (commercial)	17.82
Total		100.00

² The European Waste Catalogue (EWC) classifies waste materials and categorises them according to what they are and how they were produced. The catalogue was revised and updated in 2002 (EWC 2002, Commission Decision 2000/532/EC). It is designed to form a consistent waste classification system across the European Union. Each waste type is assigned a six digit code, made up of three, two digit sub-codes.

Table 10 Estimated annual waste input to the mechanical separation plant (Source: ECOWEST)

EWC code	Waste fraction	% of total
02 01 04	Waste plastics (except packaging)	<1
03 01 05	Sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04	<1
12 01 05	Plastic shavings and turnings	1
15 01 06	Mixed packaging	4
19 05 01	Non-composted fraction of municipal and similar waste	1
19 12 04	Plastic and rubber	1
19 12 10	Combustible waste According to the regional guideline, this includes all categories of 20 01 xx, 20 02 xx, 20 03 xx.	85
19 12 12	Other wastes (including mixture of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11.	8
Total		100

Note: The first two digits of the EWC code describe the main industry sector:

- 02 Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing.
- 03 Wastes from wood processing and the production of panels and furniture, pulp, paper and cardboard.
- 04 Wastes from the leather, fur and textile industry.
- 12 Wastes from shaping and physical and mechanical surface treatment of metals and plastics.
- 15 Waste packaging; Absorbents, wiping cloths, filter materials and protective clothing not otherwise specified.
- 17 Construction and demolition material (including excavated soil from contaminated sites).
- 19 Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use.
- 20 Municipal wastes (household waste and similar commercial, industrial wastes) including separately collected fractions.

8 Appendix 2 Detailed physical and chemical composition of the RDF product

80mm trocken

Zeitraum	09.07.2003	23.09.2005	Anzahl	Minimalwert	Median	Mittelwert	80. Perzentil	90. Perzentil	Maximalwert
Physikalische Eigenschaften	Korngröße	80mm							
	Heizwert	kJ/kg FS	92	9,800	18,050	18,143	20,800	22,790	29,600
Zusammensetzung	Trockenrückstand	Gew.-% TS	96	72,40	92,10	90,82	95,50	96,55	99,00
	Aschegehalt	Gew.-% TS	92	10,50	16,33	19,91	22,14	24,21	225,00
	Chlor	Gew.-% FS	92	0,25	0,69	0,74	1,00	1,17	2,20
	Fluor	Gew.-% FS	42	0,00	0,01	0,01	0,01	0,01	0,02
	Schwefel	Gew.-% FS	42	0,06	0,12	0,12	0,15	0,17	0,21
Schwermetallgehalte	Antimon	mg/kg TS	42	3,00	10,00	20,13	18,60	29,20	310,00
	Arsen	mg/kg TS	42	1,00	1,25	1,33	1,50	1,60	2,90
	Beryllium	mg/kg TS	1	0,01	0,01	0,01	0,01	0,01	0,01
	Blei	mg/kg TS	42	33,00	69,00	90,36	128,00	150,00	320,00
	Cadmium	mg/kg TS	42	0,27	0,51	0,88	0,75	0,94	12,00
	Chrom	mg/kg TS	42	28,00	57,00	102,50	98,40	184,00	620,00
	Kobalt	mg/kg TS	42	0,60	3,65	6,30	7,30	11,90	47,00
	Kupfer	mg/kg TS	42	34,00	63,00	133,29	118,00	150,00	2.000,00
	Mangan	mg/kg TS	42	55,00	93,00	102,07	120,00	130,00	330,00
	Nickel	mg/kg TS	42	9,90	25,50	36,66	40,60	60,90	170,00
	Quecksilber	mg/kg TS	42	0,06	0,18	0,28	0,28	0,33	2,90
	Selen	mg/kg TS	1	1,00	1,00	1,00	1,00	1,00	1,00
	Tellur	mg/kg TS	1	1,00	1,00	1,00	1,00	1,00	1,00
	Thallium	mg/kg TS	42	1,00	1,00	1,00	1,00	1,00	1,00
	Vanadium	mg/kg TS	42	2,10	4,50	4,54	5,28	6,08	11,00
	Zink	mg/kg TS	n.b.						
	Zinn	mg/kg TS	42	5,30	13,50	23,95	30,80	39,60	250,00
PCB	PCB Summe	mg/kg TS	1	0,25	0,25	0,25	0,25	0,25	0,25
Aschezusammensetzung	Phosphat (P2O5)	Gew.-% TS	42	1,70	2,42	2,46	2,82	3,15	3,34
	Aluminiumoxid (Al2O3)	Gew.-% TS	42	5,90	8,05	8,60	9,41	11,57	13,80
	Calciumoxid (CaO)	Gew.-% TS	42	21,70	28,35	28,18	30,48	31,42	37,00
	Eisenoxid (Fe2O3)	Gew.-% TS	42	2,21	4,19	4,40	5,00	5,39	8,91
	Kaliumoxid (K2O)	Gew.-% TS	42	1,37	1,90	1,91	2,26	2,43	2,60
	Magnesiumoxid (MgO)	Gew.-% TS	42	1,90	4,17	4,19	4,52	4,77	6,36
	Natriumoxid (Na2O)	Gew.-% TS	42	0,60	6,62	6,45	7,78	8,10	10,10
	Siliciumoxid (SiO2)	Gew.-% TS	42	16,40	22,85	23,03	25,18	26,69	28,70
Bezugsgrößen	Hausmüll	%				63,6%			
	hmb Gewerbeabfälle	%				21,3%			
	prod.-spez. Gewerbeabfälle	%				16,5%			
	Baustellenabfälle	%				0,0%			
	DSD-Sortierreste	%				2,0%			

ECOWEST
Dr. Hubert Baier

12.10.2005

30mm ofenfertig

Zeitraum	08.08.2002	04.10.2005	Anzahl	Minimalwert	Median	Mittelwert	80. Perzentil	90. Perzentil	Maximalwert
Physikalische Eigenschaften	Korngröße	30mm		<20mm: 96,6%	20-40mm: 3,4%				<40mm: 0,0%
	Heizwert	kJ/kg FS	68	13,500	18,250	19,466	22,520	26,060	32,200
Zusammensetzung	Trockenrückstand	Gew.-% TS	69	77,40	93,30	92,86	96,76	97,54	98,90
	Aschegehalt	Gew.-% TS	69	7,39	18,35	19,07	23,78	25,80	50,20
	Chlor	Gew.-% FS	69	0,25	0,61	0,75	1,10	1,30	2,60
	Fluor	Gew.-% FS	39	0,00	0,01	0,01	0,01	0,01	0,01
	Schwefel	Gew.-% FS	39	0,07	0,13	0,13	0,15	0,21	0,31
	Phosphor(gesamt)	Gew.-% FS	2	0,07	0,07	0,07	0,07	0,07	0,08
	Kohlenstoff	Gew.-% FS	5	43,00	47,50	47,46	49,14	51,62	54,10
	Wasserstoff	Gew.-% FS	5	6,24	7,30	7,18	7,76	8,13	8,50
	Stickstoff	Gew.-% FS	5	0,60	0,76	0,93	1,23	1,29	1,35
	Sauerstoff	Gew.-% FS	5	23,20	32,50	30,86	33,70	33,90	34,10
	Restkohlenstoff	Gew.-% FS	5	4,40	5,80	6,58	8,16	8,88	9,60
	Biomasse Anteil	%	5	47,60	71,80	67,24	74,64	75,32	76,00
Schwermetallgehalte	Antimon	mg/kg TS	40	6,30	20,00	29,36	43,60	52,90	140,00
	Arsen	mg/kg TS	40	0,80	1,40	1,77	2,24	2,93	5,00
	Beryllium	mg/kg TS	2	0,10	0,10	0,10	0,10	0,10	0,10
	Blei	mg/kg TS	40	26,00	103,50	115,75	162,00	190,00	330,00
	Cadmium	mg/kg TS	40	0,28	0,68	1,39	1,00	1,23	26,00
	Chrom	mg/kg TS	40	21,00	63,00	106,83	120,00	145,00	780,00
	Kobalt	mg/kg TS	40	0,90	4,50	5,37	7,06	8,91	15,00
	Kupfer	mg/kg TS	40	37,00	91,00	393,48	130,00	304,00	8.100,00
	Mangan	mg/kg TS	40	44,00	110,00	119,30	162,00	191,00	270,00
	Nickel	mg/kg TS	40	6,90	26,00	43,52	48,40	62,60	380,00
	Quecksilber	mg/kg TS	40	0,10	0,19	0,37	0,47	0,58	3,70
	Selen	mg/kg TS	2	1,00	1,00	1,00	1,00	1,00	1,00
	Tellur	mg/kg TS	2	1,00	1,00	1,00	1,00	1,00	1,00
	Thallium	mg/kg TS	40	1,00	1,00	1,00	1,00	1,00	1,00
	Vanadium	mg/kg TS	40	2,10	4,80	5,37	7,20	9,30	10,00
	Zink	mg/kg TS	n.b.						
	Zinn	mg/kg TS	40	7,40	15,00	23,03	25,40	33,30	200,00
PCB	PCB Summe	mg/kg TS	n.b.						
Aschezusammensetzung	Phosphat (P2O5)	Gew.-% TS	37	1,72	2,45	2,42	2,70	3,00	3,40
	Aluminiumoxid (Al2O3)	Gew.-% TS	37	5,80	7,93	9,37	8,89	10,12	60,00
	Calciumoxid (CaO)	Gew.-% TS	37	17,50	26,30	25,93	29,04	29,98	32,10
	Eisenoxid (Fe2O3)	Gew.-% TS	37	2,39	4,27	4,43	5,38	5,50	6,25
	Kaliumoxid (K2O)	Gew.-% TS	37	1,03	1,72	1,76	2,05	2,30	2,71
	Magnesiumoxid (MgO)	Gew.-% TS	37	3,11	3,94	4,00	4,39	4,58	5,33
	Natriumoxid (Na2O)	Gew.-% TS	37	3,41	6,70	6,77	7,89	9,13	10,70
	Siliciumoxid (SiO2)	Gew.-% TS	37	18,60	22,60	23,00	24,24	26,92	30,50

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