Separation of Municipal Solid Waste in Treatment Plants

Daniel Schingnitz

Abstract The sustainable management of waste has attained increasing importance due to the rising total amounts of waste, as well as the high diversity of the waste fractions worldwide. Increased urbanization rates are resulting in changes in the economy and demography. The suitable management of generated waste streams and using the high potential of recyclables inside these waste streams are major topics communities have to deal with. Especially in Asian countries, the fast development of the society and the rising amounts of waste is resulting in significant problems in sustainable waste management. As the largest emerging country with the largest population in the world, China faces different waste treatment situations than other developing countries. Several technologies can be used for waste treatment depending on the amounts and compositions of the waste streams. Recycling processes should be used for material recovery, biological treatments for appropriate streams, as well as thermal treatments for energy recovery. Landfills for the disposal of residues generated by the other treatments are also necessary. In the challenge of avoiding the presence of biodegradable waste in landfills and increasing recycling, mechanical biological treatment (MBT) plants have seen a significant increase in number and capacity in the last two decades in Europe. Among the conditions and local challenges in countries in Asia, which are at the beginning in implementing a regulated waste management system, MBT technologies can be a promising approach.

Keywords Mechanical biological treatment, Municipal solid waste, Refuse-derived fuel, Waste composition, Waste management

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Contents

1 Introduction

The sustainable management of waste has attained increasing importance worldwide. The Asian continent is a huge and diverse region. The economy and demography on the continent have been accompanied by increased urbanization rates. High urbanization rates have been pushing the boundaries of cities. Among these, the increasing quantities of generated municipal solid waste (MSW) is one of the significant challenges city governments have been facing. In China, more than 300 million tons of MSW are generated annually, compared with approximately 45 million tons of MSW in Germany each year [1, 2]. The management of MSW encompasses a multidimensional set of activities where different actors, processes, and policies converge and interact. In developing Asian countries, waste separation rates are typically low. This can be ascribed to a number of factors, such as the low awareness of populations of the benefits and need to segregate waste, and the low willingness to comply with segregation practices due to a lack of incentives or penalties. Hence, the utilization of MSW as an energy resource is stirring interest among public authorities around the world, and especially in China. Nevertheless, the Chinese government faces great difficulties in providing MSW management services in rural China.

Several technological means exist to divert solid waste typically destined for a landfill, such as incineration, the composting of organic wastes, and material recovery through recycling. All have the potential to be more sustainable methods than landfilling. Reuse and recycling are aimed at pursuing effective material recovery. For those streams of waste, for which the material recovery is not effectively applicable, energy recovery is the path to be followed. The thermal treatment of waste is an indispensable part of every integrated waste management system. Thus, an integrated waste management system should be designed that integrates the different types of treatment processes: recycling processes for material recovery and biological treatments for appropriate streams, as well as thermal treatments for energy recovery, should be provided with serviced landfills for the disposal of residues generated by the other treatments (see Fig. 1). The transition from waste treatment and landfill dependency to sustainable resource management includes the production of safe, environmentally sound, and marketable outputs. Besides direct combustion (waste incineration) or the biological conversion of organic matter into biogas and/or compost, the energy content of waste can be utilized by producing solid fuels. These secondary fuels can be used in power plants and cement kilns (co-combustion) or in mono-combustion plants. Refuse-

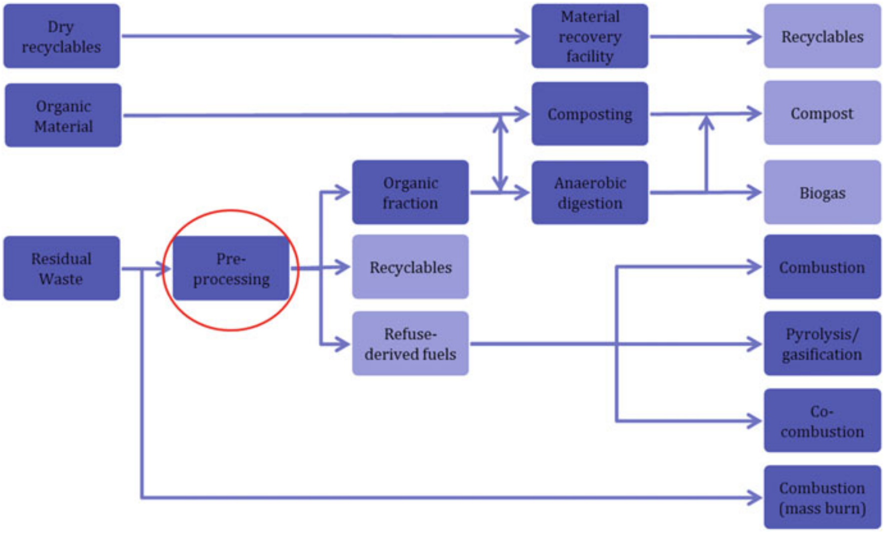

Fig. 1 Treatment options for Municipal Solid Waste (MSW)

derived fuel (RDF) is defined differently across countries: it usually refers to the separated, high calorific fraction of MSW, commercial or industrial wastes.

Learning from the experience of the first market failure of RDF in Europe, today the quality of the fuel is receiving significant attention during the production process in order to fulfill market requirements. As landfill taxes in many European countries have risen, as well as the impending Landfill Directive, the market for mechanical biological treatment (MBT) plants has seen significant growth. According to a recent report, between 2005 and 2011, the number of operational MBT facilities in Europe rose by almost 60% to a total of 330 [3]. MBT, which is characterized by the implementation of material-specific treatment, can be combined with energy recovery and/or material recycling and represents a valid and often preferential alternative to conventional thermal waste-to-energy (WtE) plants. Exemplarily, approximately four million tons of RDF from 39 MBT plants were produced in Germany in 2010 [4]. The excessive supply of secondary fuel and the possibility of earning money led to an increased interest in RDF-fired boilers for the mono-incineration of RDF. In 2012, 36 RDF-fired combustion plants existed in Germany with a total capacity in the range of 4.8–5.4 million tons [5, 6]. Nowadays, in Germany different treatment methods for the production of RDF are used, depending on the origin and composition of the waste (see Fig. 2), although more than 60% of the residual waste is still burned directly in WtE plants. In choosing MBT techniques, characteristics like a high organic content of the waste require the combination of mechanical treatment steps, as well as drying processes of the waste or the degradation of the organic content by composting or digestion. The developing national as well as European market for RDF requires standardized quality-assured measurement methods to improve the chances for marketing and to assure environmental standards. The production of RDF from different

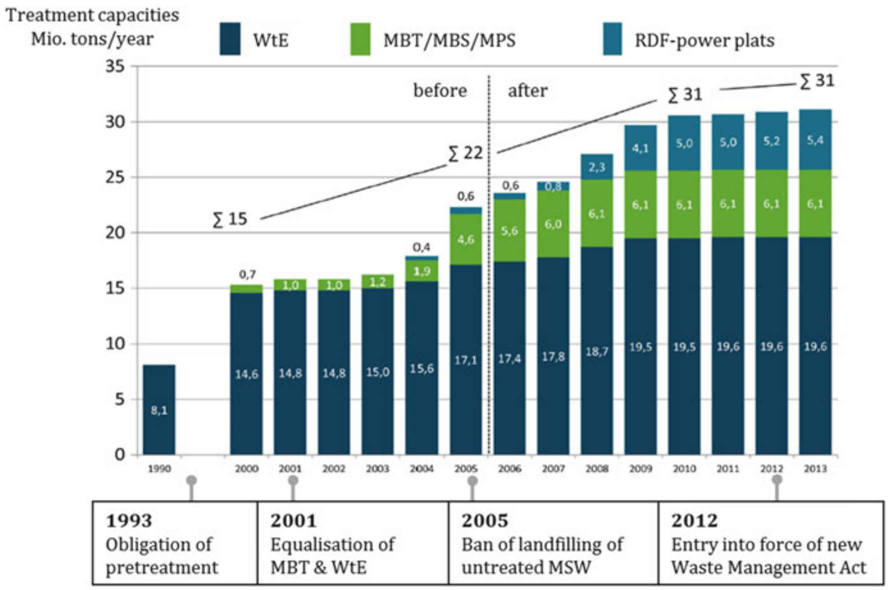

Fig. 2 Treatment techniques for residual waste in Germany [5]

types of waste and their thermal utilization in co-incineration and mono-incineration plants can be useful alternatives with regard to the substitution of fossil fuels. However, the heterogeneous properties of the RDF are problematic during the intended utilization processes. Regular quality controls are required during the treatment and utilization processes.

2 Waste Characteristics and Future Tendencies for Municipal Solid Waste

Considering the management of MSW in developing countries, attention needs to be paid to the characteristics and properties of the waste that is generated, as well as the specific amounts. These include aspects such as the quantities of waste generated, waste composition, density, moisture content, and calorific value. Waste characteristics can differ significantly among developing and developed countries. Comparing the compositions of residual waste in Germany and MSW in China, relevant differences in the content of organics as well as fine fractions are apparent (see Figs. 3 and 4). In Germany, a high concentration of recyclables (e.g., plastics, glass, paper and cardboard, metals) is collected separately. This also influences the composition of the leftover residual wastes. The usual content of organic materials in German residual waste differs between 20 and 40 wt.-%. Of course, the portion of recyclables in residual waste streams is lower than without separate collection systems.

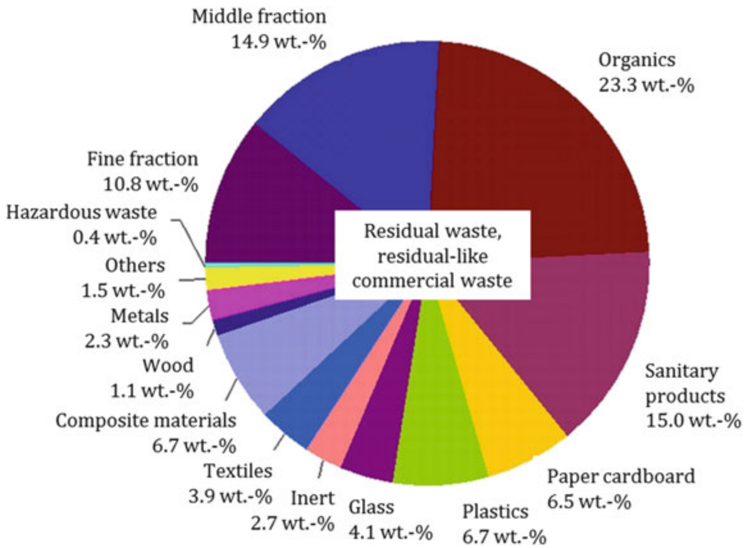

Fig. 3 Typical composition of residual waste in Germany in 2012 [1, 7]

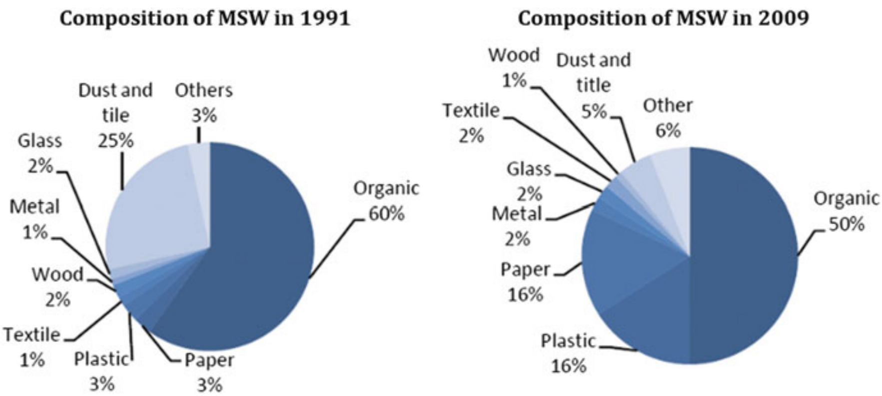

Fig. 4 Typical composition and trends of MSW in China [2]

While comparing the composition of MSW in China between 1991 and 2009, changes in the composition of the MSW can be identified. Due to the changing consumption behavior of the people and the economic growth of the country, the rising content of recyclables, as well as declining ratios of organics is evident in the composition of MSW. The higher concentration of recyclables in generated waste streams can facilitate an efficient mechanical pretreatment of the waste for a sustainable material recovery of recyclables. A separate collection of recyclables in MSW in China is only partly implemented in the major cities. However, in developing countries, the moisture content of waste is 50 wt.-% or higher, while in developed countries it is usually in the range of 20–30% wt.-% [8]. Furthermore, waste that is rich in organics and moisture can also impair the value of (inorganic) recyclables that can be recovered from waste.

Several technologies and methods for treating and processing MSW are also available in developing countries. The prior objective is always to reduce the volume of waste and/or divert waste streams from disposal sites and the natural environment, which are the source of negative externalities. The treatment of waste also offers the potential for recovering resources from discarded materials, either in the form of energy, recycled materials, or soil fertilizer.

In China, uncontrolled landfilling of MSW is still the most common means of waste removal in rural areas. Cities with a high population density, representative of nearly all urban regions in China, start to focus on thermal waste treatment technologies, as well as in some cases also composting techniques for waste fractions with high organic concentrations (see Fig. 5). By using the example of the city of Shanghai, the installed waste treatment techniques illustrate a rising share of incineration and composting of MSW, as well as lower percentages of landfilled and dumped MSW. Nowadays, incineration is one of the waste treatment options endorsed by both national and local governments. In 2010, there were around 160 incinerator plants in operation [12]. Over 560 treatment plants are running to treat approximately 50% of the generated MSW in China, and more than 450 landfill sites are still in operation [2]. MBT is infrequently applied in developing Asian countries. These are typically capital intensive plants with high upfront and maintenance costs, often deployed alongside material recovery facilities compared with landfill or dumping sites. Material recovery of MSW in Asia is mainly realized through informal sector activities. Usually, informal waste sector activities are driven by the need to eke out a living rather than environmental concerns. For the urban regions in China, informal recycling rates were estimated in the range of 17%–38% [13]. By implementing new MBT techniques for Chinese MSW, the amount of recyclables that can be generated from the waste streams can be increased. Also, high organic concentrations causing high water content in the MSW can be treated.

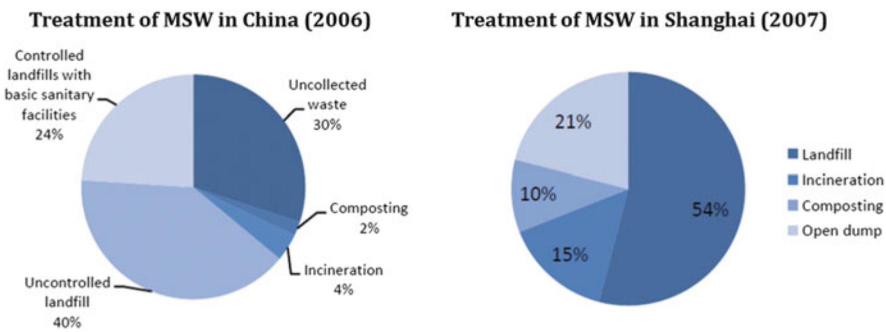

Fig. 5 Treatment techniques for MSW in China [2, 9–11]

3 Mechanical Biological Treatment Techniques for Municipal Solid Waste

Between different fractions, the organic part presents the major component of MSW in developing countries. Because of its biodegradation in landfills under anaerobic conditions, this is the major fraction affecting waste pollution in landfills. The reduction in the organic fraction of MSW to be landfilled can be obtained by three different approaches: (1) source-separated collection of organic fraction of MSW to produce compost; (2) MSW burning using WtE techniques to produce energy, and (3) MBT of MSW to produce a stabilized or a compost-like material prior to landfilling. Also, the original purpose of MBT plants – as they were in operation in Europe during the 1990s – was to divert from landfills disposable biodegradable substances that are associated with the main polluting emissions (landfill gas and leachate). As a consequence, the long-term pollution potential of landfills can be decreased significantly in the overall purpose of protecting the environment and human health. MBT plants have some basic principles in common: they generally integrate mechanical processing with a bioconversion step. The waste is mechanically pretreated in order to prepare it for subsequent biological processing. Besides homogenization and shredding, this may include the separation of metal fraction (ferrous and nonferrous) for material recycling or a high calorific fraction for energy recovery. The biological treatment consists of either aerobic degradation (rotting and composting) to reduce the share of biodegradable substances and produce a stabilized material for environmentally sound landfilling or biological drying. This produces RDF for energy recovery and provides an option for advanced material recovery (metals and plastics) from the dried waste output by mechanical posttreatment. Or finally, a combination of anaerobic digestion (fermentation) for biogas production and aerobic stabilization prior to the final disposal of the residual fraction.

Comparing all possible MBT processes for MSW, the processes are usually divided into two basic principles (see Fig. 6). The major difference in these two basic principles is the order of mechanical and biological treatment steps. The processes can be used for the treatment of MSW and/or residual wastes.

On the one side, separation processes using mechanical and biological treatment steps always start with a mechanical sorting of the waste stream by using separation technologies (magnets, eddy current separator, and near-infrared detectors) as well as classifying technologies (sieves) for material recovery. Also, the separation of the fine fractions for the following biological treatment step is done using sieving processes. Fractions with larger grain sizes usually include higher concentrations of recyclables and are therefore more suitable for mechanical sorting steps. The downstream biological treatment can be done for fine fractions with high organic contents by using aerobic treatment steps (rotting and composting) or anaerobic processes (digestion). By using digestion processes, biogas is produced, which can be used for heat and electricity production. The length of the biological treatment can vary so that biostabilized products show different degrees of biological stability. Finally, organic

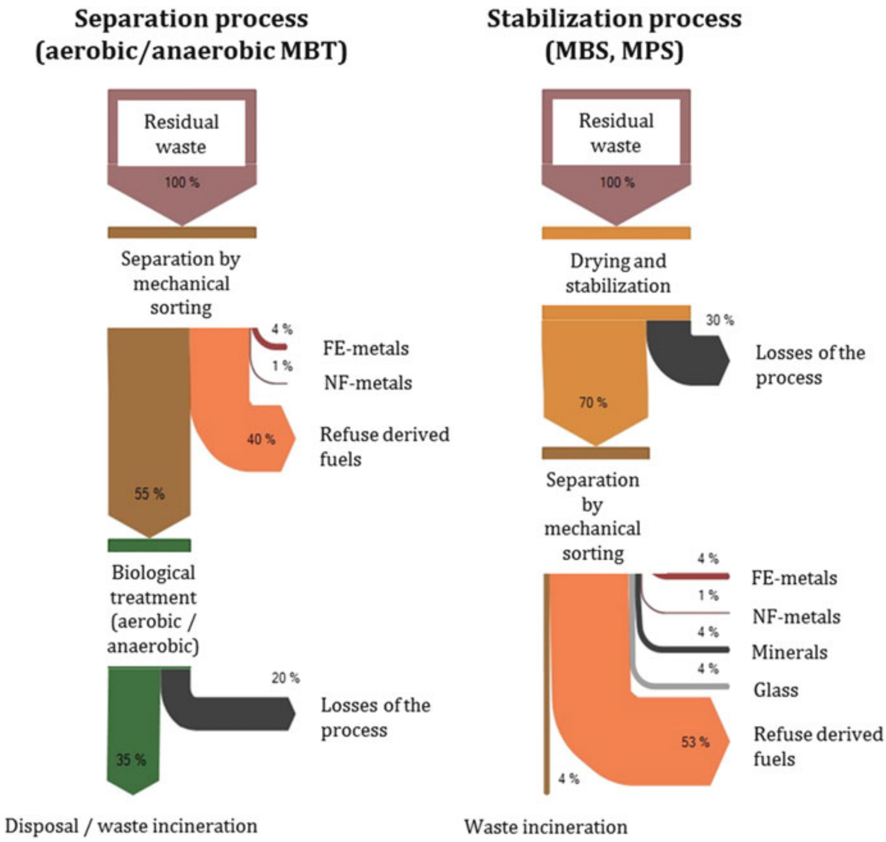

Fig. 6 Basic principles of Mechanical Biological Treatment (MBT) processes for MSW [14, 15]

concentrations can be minimized, and in the case of digestion biogas can be produced for energy recovery.

On the other side, stabilization processes can be used for MSW treatment as a second basic principle. Therefore, the waste stream is treated biologically by using drying or stabilization techniques as a first step. The aim of this stabilization is reducing the water content and the concentration of organic materials. Common techniques for the stabilization of MSW are biological and physical treatment. Biological stabilization processes operate by using the effect of self-heating the waste due to the activities of microorganisms, which decompose the organic material. The generated heat leads to drying, and the microorganism reduces the organic content of the waste. Using physical stabilization processes also ends up reducing the water content of the waste. Therefore, additional energy – usually fossil fuel – is necessary. Accordingly, physical stabilization causes higher treatment costs than biological stabilization but can result in less water content. The need for fossil fuel as an auxiliary fuel is the major reason that the processes of physical stabilization of MSW are not widespread in Germany and Europe. After the stabilization of the

MSW, the separation of recyclables and valuables is done by using mechanical sorting processes.

Both treatment process principles generate fractions of recyclables and RDF, as well as always a final fraction for landfilling or WtE processes as a residue. The ratio of recyclables and RDF depends significantly on the composition of the generated MSW. The aim of removing recyclables from the waste stream is to separate materials that have enough value to make their recovery worthwhile. The shredded and in some cases pelletized fraction of combustibles such as RDF can be used in mono- or co-incineration plants. Using MBT techniques in Germany, it is possible to generate RDF in different qualities of approximately 50 wt.-% of the input material by stabilization processes and approximately 40–45 wt.-% by using separation techniques [14, 15].

4 Mass Balances for Mechanical Biological Treatment

On the basis of German circumstances, the following figures show the mass balances of MBT processes including anaerobic digestion (see Fig. 7), as well as biological stabilization processes of residual waste (see Fig. 8). As already mentioned, using the principle of separation processes, it is possible to recycle 1–2 wt.-% of metals, 40–45 wt.-% of RDF for downstream mono- or co-combustion processes, as well as approximately 8–10 wt.-% of biogas for combined heat and power generation. The separation process of residual waste generates lower amounts of RDF with higher qualities compared with stabilization techniques like those in Fig. 6. RDF, which is sorted using mechanical treatment techniques in a first step, does not include high concentrations of organic materials. Usually, fractions with high calorific values like plastics, composite materials, wood, textiles as well as paper and cardboard are separated. Besides the high calorific values, these fractions are characterized by lower chlorine concentrations, little water and ash content, and nearly no biological activities.

The RDF produced is preferably used for co-combustion in cement kilns. Plastics made out of polyvinylchloride have to be removed from the RDF stream because of their significantly higher chlorine concentrations, which can cause corrosion processes while combusting.

Using biological stabilization processes, it is possible to generate up to 50 wt.-% of RDF as well as ferrous and nonferrous metals in a similar range by using separation processes. There is no additional option for energy production from the waste stream by producing biogas. The higher amounts of RDF separated are characterized by lower quality because of the higher contents of organic materials. This results in lower calorific values and in some cases higher chlorine concentrations. So, the RDF for stabilization processes seems to be more suitable for usage in (brown)coal-fired power plants and mono-incinerators for RDF.

Comparing all different kinds of MBT processes for residual waste in Germany, it is obvious that in total, half of the residual waste is used as RDF and only less

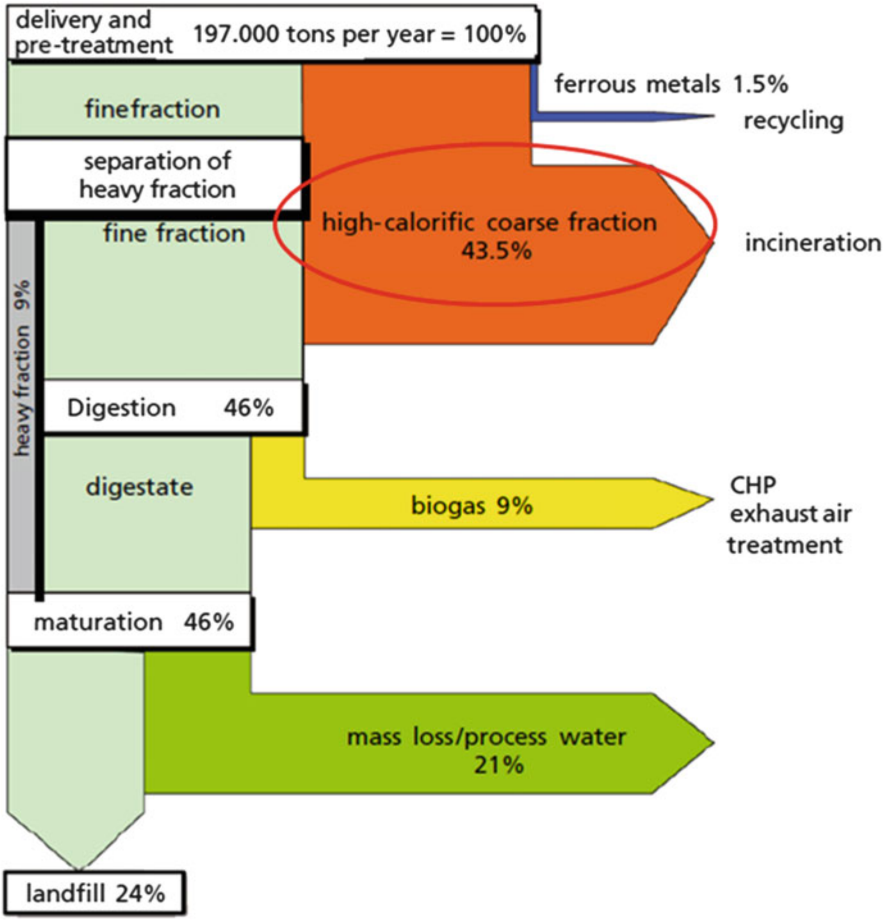

Fig. 7 Mass balance of anaerobic MBT process of residual waste in Germany [4]

contents are used for material recovery and biogas production (see Fig. 9). In Germany, only 5 wt.-% of the treated residual waste is sorted out by MBT for material recovery. Major components for material recovery are ferrous metals because of their concentration inside the waste streams, as well as the easy method of sorting by magnets. Also, relevant amounts of fractions like nonferrous metals and inerts are removed for material recovery. Ferrous and nonferrous metals are recycled into new steel and metal products. Inert materials can be used for road or landfill construction. Also, removed batteries can again be added to the process of battery recycling. Fractions like textiles as well as paper and cardboard collected comingled with the other fractions of the residual waste are not suitable for material recovery processes due to the high amount of impurities. Also, composite materials are difficult to use for material recovery because of their high heterogeneity and the need for complex separation steps by mechanical systems for the single materials. In both cases, processes for

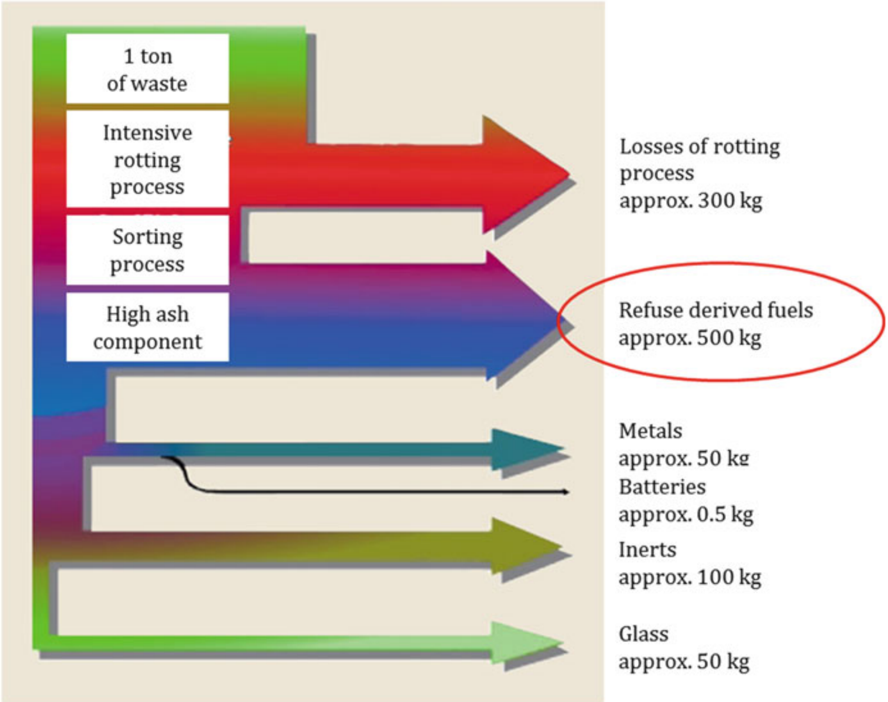

Fig. 8 Mass balance of aerobic Mechanical Biological Stabilization process of residual waste in Germany [16]

energy recovery (WtE) seem to be suitable and metals contained can be removed from the generated slag.

The German mass balance for MBT processes is influenced by a lot of factors. First of all, the practiced segregation at the source influences the composition of the leftover residual waste. By the separate collection of recyclables and in some cases also of biowastes, MBT techniques reach fewer ratios in the case of material recovery and biogas production.

Currently in Germany, the RDF produced from residual waste is mainly used in mono-incineration plants for electricity, heat, and/or steam production. Approximately 36 RDF power plants combusted 4.8 million tons of RDF by using grate firing or fluidized bed incineration systems [6]. The co-incineration of RDF in coal-fired power plants as well as cement industries for the substitution of fossil fuels (coal, gas, and oil) is realized in approximately 40 German plants by using 2.3 million tons of RDF [6]. The requirements for RDF utilization in different mono- or co-combustion plants differ. Cement kilns make high demands on the quality of the produced RDF, especially for calorific value, chlorine content, and water content. Mono-incineration plants can handle RDF with less quality and without major problems. Figure 10 illustrates an overview of the usage of high calorific fractions from

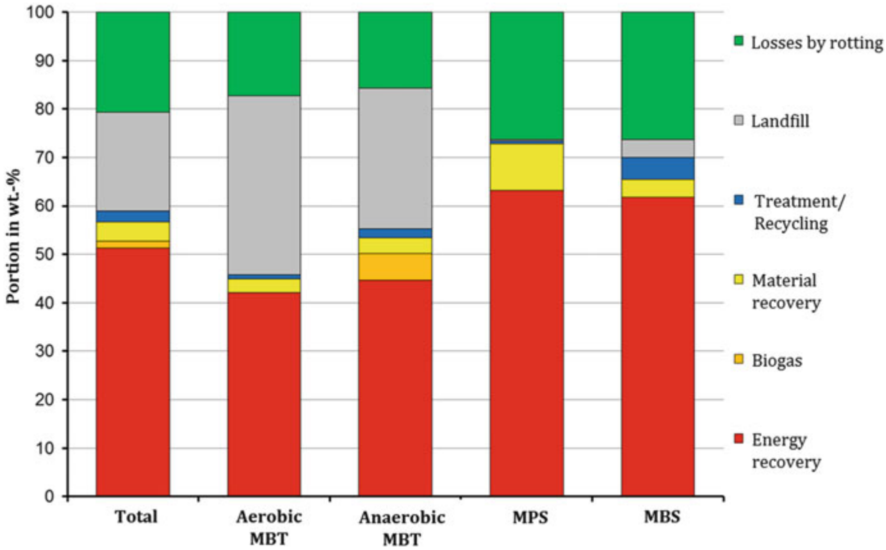

Fig. 9 Mass balance of MBT processes in Germany in 2011 [4]

waste in incineration plants in Germany over the last 20 years. Therefore, the rising amounts of used RDF in mono-incinerators can be analyzed.

For developing countries, the specific amount of recyclables compared with the input material of the MBT process can be even higher due to the missing separation of recyclables at source. Also, a more significant reduction in organic contents can be reached by using MBT processes because of the higher concentrations of bio-wastes in MSW. The treatment of MSW with separation or stabilization processes can improve the characteristics for downstream WtE processes, as well as increase the amount of material recovery of MSW. Common thermal incineration technologies are technically and economically challenging because of the lower calorific value of waste streams that are rich in organics and moisture. Specific approaches and methods are therefore required for designing adequate waste management systems in China. Therefore, MBT techniques can be one example of suitable pre-treatment of MSW before landfilling or incineration.

Sustainable material recovery from MSW always involves the demand on recyclables as well as the suitable recycling processes. Also, the generation of RDF in developing countries requires power plants that are going to use the RDF produced. If power plants are still using fossil fuels at cheap prices, there will be no market for RDF, and the expenditures of MBT for the MSW generated will be higher than the economic benefits. Also, the material recovery of plastics will generate no significant economic advantage in the case of low prices for fossil fuels. In addition, despite the common characteristics shared among cities in developing countries, their specific circumstances can vary significantly, especially within a big country like China, calling for the need for framework-specific waste management approaches.

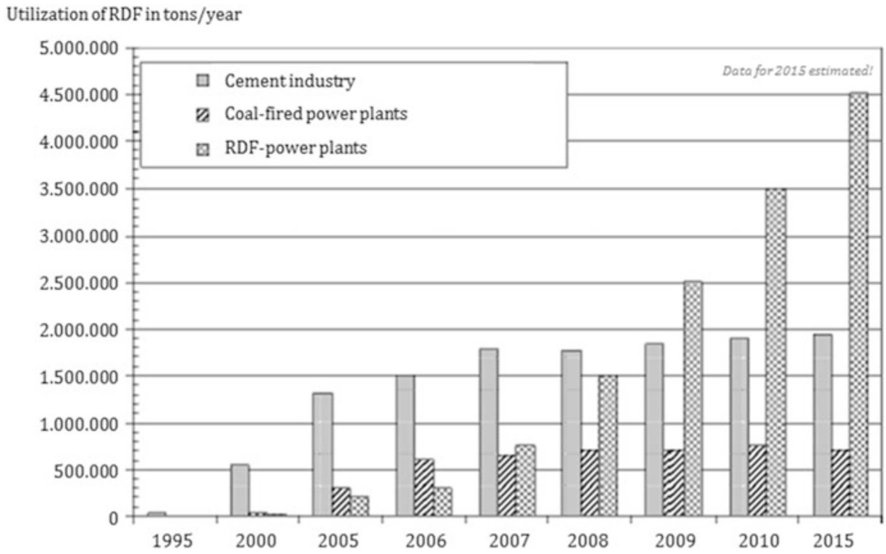

Fig. 10 Utilization of Refuse-Derived Fuels in Germany [17]

Fig. 11 Waste Management concept for developing countries [18]

5 Conclusions

The rapid urbanization progress and the continuous improvement of rural residents' living standard contribute to the increase in MSW in China. As the largest emerging country with the highest population in the world, China faces different situations for MSW treatment than other developing countries. Meanwhile, the method of source-separated collection of MSW in rural areas is different from urban areas in China. Worldwide experience shows that the source-separated collection of MSW is an effective method for the enhancement of waste reduction and recycling. The separation of waste significantly influences the amount and value of the resources that can be recovered from the different MSW streams, and therefore it is the backbone of any approach in the reuse and recycling of waste. The separation of waste at the source is a participatory measure that requires the cooperation of those who generate waste, such as individuals, households, or commercial establishments. In the challenge of avoiding the presence of biodegradable waste in landfills and increasing recycling, MBT plants have seen a significant increase in number and capacity in the last two decades in Europe. The aim of these plants is separating and stabilizing the quickly biodegradable fraction of the waste, the production of RDF as a substitute fuel for energy recovery, as well as recovering recyclables from mixed waste streams. In addition, the mechanical treatments performed in MBT plants allow for the recovery of valuable materials such as iron and aluminum. Also, the content of organics can be reduced by composting or the digestion of organic materials. Minimizing the biological activity of waste streams benefits in fewer emissions while landfilling (leachate and landfill gas). By raising the fuel-relevant parameters (e.g., content of combustibles and heating value), it can also improve the usage of the MSW for common thermal processes (WtE). The waste composition principally affects the magnitude of the benefits associated with recycling. One of the advantages of using MBT techniques is the flexible system, which is viable with small flow rates as well as larger flow rates of the waste and – compared with incineration plants – lower investment costs. Among the conditions and local challenges in countries which are at the beginning of implementing a regulated waste management system, MBT technologies can be a promising approach. Finally, a suitable MSW management system includes several steps for waste collection, separation, and treatment, as well as the final disposal, depending on the waste streams and the characteristics of these waste fractions (see Fig. 11).

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