Supported by:

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

based on a decision of the German Bundestag

Building Partnerships for a ENVIRONMENTAL PROTECTION made in Germany Sustainable Infrastructure

Study

Recycling and Recovery of the biogenic fractions from municipal solid waste in the PR of China

Universität Rostock Traditio et Innovatio

Tongji University 1907

German RETech Partnership
Recycling & Waste Management
Made in Germany

Imprint

Study realization:

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Rostock, January 2017

This Study was funded as per resolution of the German Parliament by the Federal Ministry of the Environment, Nature, Conservation, Building and Nuclear Safety.
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ISBN 978-3-86009-453-2

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1. Background and aim of the study

Over the last few years, the People's Republic of China (PRC) has made great progress in addressing its waste management challenges. In the metropolitan areas, valuable substances (paper and board packaging, plastic, metals) are already collected and recycled separately. Therefore, their share in the municipal waste is not very high. Municipal waste is also recorded in urban areas. There is however a need for action, especially in the treatment and utilization of biogenic waste, which is still collected together with the residual waste so that its material and energy potential remains unused. In rural areas, waste management in general has to be essentially improved.

The challenges concerning the biogenic fraction of the municipal waste in China and in most countries of the world are manifold. The large amounts of biogenic material and their high water content hereby play an essential role. Larger cities produce more than 1,000 to 20,000 tons of municipal waste each day. On average, Chinese municipal waste contains more than 60 % of biogenic substances/material. These biogenic wastes – which mainly consist of kitchen waste - contain a lot of water, so the overall water content in the municipal waste is also very high, with approximately 60%.

The high organic and water content in municipal waste is a challenge for waste treatment and is very problematic from an ecological and energetic point of view. When landfilled, the humid biogenic fraction produces climatic-sensitive landfill gas and considerably degrades the leachate water quality. When treated in waste incineration plants, the very high organic and water content hinders an efficient combustion. Ecological and energetic potentials are thereby lost. A thermal treatment is thus not sufficiently effective.

In terms of climate protection, the environmentally compatible treatment and utilization of the biogenic fractions is a central key to further succeed in climate protection. Germany has already gained a lot of experience in this area and aims at transferring this knowledge and thus supporting the PRC.

The Chinese government has set ambitious waste management goals. Thus, China aims to increase the proportion of waste that is recycled and treated before the final disposal. In recent years, numerous plants, mainly waste incineration plants, have been erected to treat the municipal waste. The water-related low calorific value of the waste hinders an unproblematic thermal treatment. Sustainable approaches could further support the use of increasing biogenic waste streams.

Regarding this, the study examines possibilities for the separate collection and utilization of the biogenic fractions of the municipal waste in the PRC. For this purpose, in addition to the evaluation of current technical literature, results from our own investigations were evaluated in cooperation with local experts.

The goal of the study is to describe and analyze the current situation of biogenic waste in China and to develop suitable and adapted solutions for its future utilization. The results will be communicated to Chinese participants in form of workshops. This way, the importance of biogenic waste and the need for action should be underlined. Additionally, solutions and possible technologies as well as providers are to be introduced. Furthermore, the results of the study will form the basis for future pilot projects and waste recycling plants.

Municipal waste includes waste from private households (domestic waste, bulky waste, bio-waste, separately collected recyclables such as glass, paper, packaging and metals, etc.), as well as industrial waste resembling household waste (wastes from doctors' offices, administrative buildings, schools and kindergartens). Furthermore, municipal waste also includes market waste, road sweepings and litter, waste from public places, park waste and waste from water management measures (sewage sludge).

The study focuses on the biogenic waste fraction from **municipal waste except for sewage sludge**. In addition, **biogenic waste from restaurants** is taken into account since this waste stream is very significant in China and its current treatment situation is to be changed in the future. The study does not consider hazardous waste.

In European legislation, the terms bio-waste or biodegradable waste are defined. Due to legal differences, different organic materials can be counted among these categories. In order to avoid misunderstandings, the term **biogenic** fraction is therefore used in the study. **Biogenic waste** refers to organic waste that can be decomposed by biodegradation and can ultimately be converted to other organic compounds, such as biogas, or decomposed into its mineral constituents. At the same time, **biogenic wastes** also include waste from various economic sectors and industries, such as agriculture, the food industry, energy production and also private consumption.

2. Development, status and prospects of the circular economy

2.1 Germany

Waste management in Germany is constantly changing due to new political and legal requirements as well as technical and organizational developments and has developed into a large and powerful economic sector. Thus, modern waste management is the result of a long **development process**. Figure 2.1 summarizes this development along a time axis.

The legal foundations for a proper waste management were provided far back in history. With the Prussian local tax act of 1893, municipal finances were reorganized and the prerequisite for the establishment of municipal cleaning facilities was created. Municipalities were henceforth entitled to levy charges for waste disposal. Later, in 1935, the German municipal authorities established the general principle of connection and use of the waste collection system. This ensured the collection of all waste and forbade all illegal disposal routes. In the mid-1960s, cities and municipalities were finally identified as waste disposal authorities, and thus as responsible for waste disposal. During the same period, the first bulletins were drafted on the issues of waste disposal, which were the guidelines for dealing with waste.

From waste disposal to recycling

Until the late 1960s, waste had mostly been deposited on one of the approximately 50,000 uncontrolled landfills. Only about 37 % of the municipal waste was treated and deposited in

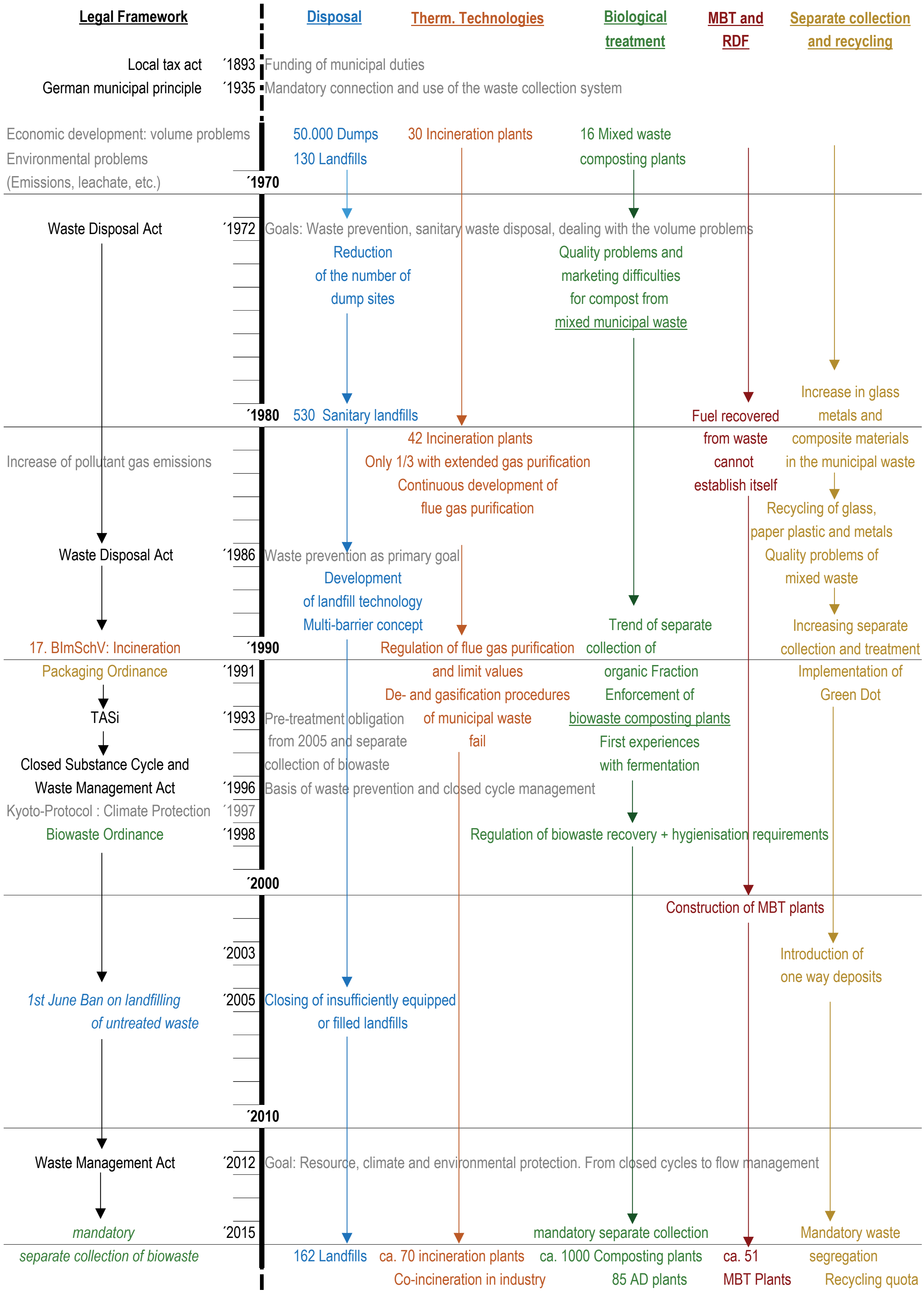


Figure 2.1: Summary of the legal (left) and technical (right) development of waste management in Germany along the time axis

one of the approximately 130 sanitary landfills, 16 composting plants and 30 incineration plants [Billitewski et al., 2013]. Back then, the technologies were not yet mature and caused secondary environmental problems: groundwater pollution by leachate and gas emissions due to degradation of biogenic waste, pollutant emissions from waste incineration and quality problems of mixed waste compost.

In addition, economic growth in the early 1970s led to an increase in industrial production and private consumption as well as disposable packaging and products. During this time waste disposal had, on the one hand, to deal with the waste masses and, on the other hand, to develop an *orderly waste disposal,* preventing any risk for human and animal health. The first constitutional legal framework, the 1972 Waste Disposal Act, should address both problems.

With this law, the number of the original 50,000 uncontrolled landfills was considerably reduced, while at the same time a continuous improvement of landfill technology could be achieved by the end of the 1980s. In the same period, the number of waste incineration plants increased, but still with insufficient flue gas cleaning. Although all the plants had dust-removing facilities, only 1/3 of the plants had an extended flue gas purification system. Because of this and of the increasing share of chemical products in domestic waste, the quantities of emitted pollutants continued to rise.

The technologies for the treatment of mixed waste are not yet environmentally compatible. The first attempts to produce solid recovered fuel (SRF) have been discontinued as there are major problems regarding emissions. Also the composting of the municipal waste could not be implemented. As a result of the above-mentioned change in the household waste composition, with increasing proportions of metals and composite materials, the heavy metal loads increased. Due to its low quality, the compost was not accepted and used by farmers.

First attempts on recovering recyclables from the municipal waste failed. Reasons for that were, among others, the inadequate product quality and the poor efficiency of the sorting systems. From the mid-1980s onwards, individual municipal waste streams have been separately collected (glass, paper).

While good progress has been made in the proper disposal of waste, only poor results could have been achieved in the management of waste quantities. For this reason, the *1986 Waste Act* declared the prevention of waste as a superior objective before recovery and disposal. Waste prevention includes low-waste technologies, the recycling of products, and its recyclable construction, as well as the increase in its service life.

Due to the quality problems of the recovery technologies, a rethinking of the waste disposal routes took place at the beginning of the nineties and the separate collection became more important. The collection of the biogenic fraction separated from the rest of the municipal waste was clearly increasing. Only from this separately collected bio-waste, an economic product could be produced. Composting of separately collected bio-wastes thus gained importance, and in addition, the anaerobic treatment of this fraction as an addition to composting was developing. Therefore, at the beginning of the 1990s, fewer than 10 plants for mixed municipal waste composting and about 80 plants for bio waste composting were operated. Also, at the same time, recycling, which was mainly concentrating on glass, paper, plastic and metal, has proven that a separate collection of the valuable substances is the prerequisite for the production of high-quality secondary raw materials.

With the 17th Federal Emission Control Ordinance of 1990, existing waste incineration plants had to be upgraded with a sophisticated exhaust gas purification system or shut down, and the prescribed limit values had to be met. Despite this regulation, the incineration of waste was still disapproved by the population, as new pollutants such as dioxins became of concern. The 17th Federal Emission Control Ordinance has been constantly revised, the exhaust gas purification systems have been further upgraded and the quality of emissions from waste and waste co-incineration plants are greatly improved. Up to the 2000s, however, not only the number of plants but also the average plant throughput increased. In the area of thermal treatment of municipal waste, tests with degasification and gasification technologies were conducted, which were, however, not accepted.

With the 1991 Packaging Ordinance, users and distributors are obliged to take back and recycle their product packaging according to the principle of "product responsibility". The dual system (symbol "Green Dot") was founded to fulfill this duty.

The multi-barrier concept was implemented in landfilling technology and thus liquid and gaseous emissions were minimized. However, it is easy to see that, above all, the gaseous emissions are not completely prevented. In order to minimize the negative environmental impacts of waste deposition, the pre-treatment of waste became obligatory in 2005 with the Technical Instructions for Waste Management.

In 1996, the Waste Act was amended, forming the Closed Substance Cycle and Waste Management Act. In addition to waste prevention, the focus is on the recycling industry. In addition, the 1998 Biological Waste Ordinance regulates the quality requirements for the recycling of separately collected biogenic waste.

Climate and resource protection are gaining importance

Following the Kyoto Protocol in 1997, the issues of climate and resource protection are becoming more important. Thanks to the strict legal requirements, waste management is able to contribute significantly to climate protection. The methane formation in landfills is avoided, above all, by the ban on the deposition of untreated municipal waste, which was issued in June 2005. Also, the increased material and energy recovery of the waste contributes to climate and resource protection.

At the beginning of the 2000s, mechanical-biological waste treatment was developed in addition to thermal waste treatment in order to meet the pre-treatment requirements. The 30th version of the Federal Emission Control Ordinance hereby regulates the technical standards to be met with regard to emissions. At first, the focus was on the inerting of the biogenic fraction; however later on, the recovery of the high calorific fraction has become more and more interesting. Due to the energetic recovery of the waste, fossil fuels can be replaced.

In 1990, waste management still contributed to about 38 million tons of CO_2 equivalents, while in 2006 it was able to save about 18 million tons of CO_2 equivalents. From 1990 to 2006, waste management reduced its annual emissions of climate-damaging gases by approx. 56 million tons [UBA, 2010]. Furthermore, by 2005, most insufficiently equipped or filled landfills were shut down and the so-called "one-way deposit" was introduced.

Highest global recycling rates – On the path to material flow management

The current version of the Waste Management Act of 2012 provides the path of the waste and closed cycle management to a resource efficient economy. The objective of waste management is to conserve natural resources and manage waste in an environmentally sound manner, so that a sustainable improvement of environmental and climate protection as well as resource efficiency is achieved. Waste is regarded as valuable raw material, whose effective use saves natural resources. While waste prevention leads to a reduction in raw material consumption and environmental pollution, waste recovery has focused on the recycling of raw materials and energy into the economic cycle.

The key to the Waste Management Act is the implementation of the five-stage waste hierarchy: waste prevention, reuse, recycling, other utilization and finally waste disposal. The best option with regard to environmental protection always has priority, although if technical, economic and social aspects are taken into account. This ensures a consistent focus on waste prevention and recycling.

The contribution of waste management to resource conservation is reflected in the world's highest recycling rates, which saves raw materials and primary energy. Nearly 57 % of the municipal waste is recycled. For individual waste fractions, recycling rates are even higher, e.g. for packaging. In 2012, 96.3 % (requirement was 65 %) of the total packaging waste was recovered, and 71.3 % was recycled (requirement was 55 %).

Further emission reduction can also be achieved in the field of climate protection, for example by the increase in capacity in the mechanical-biological pre-treatment.

The Waste Management Act continues the proven division of tasks between private and public waste management companies. According to the ‘polluter pays’ principle, commercial producers and owners of waste are responsible for the disposal of their wastes.

According to the principle of public services, municipalities are responsible for disposal of waste from private households and from other areas of origin.

As a result, waste management in Germany has developed into a large and powerful economic sector with over 250,000 employees and an annual turnover of around 50 billion euros. New impulses are expected with the mandatory segregation of waste paper, waste glass, plastic waste and biogenic waste since 2015.

Innovative waste concepts and technology transfer for resource and climate protection

The future goal of the Federal Government is to further develop the waste and recycling industry into a sustainable resource-efficient material flow management. Thus, the substances and materials bound in the waste are to be completely used to supersede landfilling of waste [BMUB, 2016].

In order to utilize the material potentials of the various waste streams as fully as possible and to meet the quality requirements, the separate collection of waste streams and their separate treatment is essential. This is because the closed cycle system must ensure that pollutants from waste do not re-occur in new products, but are harmlessly discharged.

Waste management in Germany has reached a high technical level. For this reason, the Federal Government supports and promotes sustainable waste management concepts with modern and efficient waste treatment technologies, which can be used to extract raw materials or energy from the waste, as well as the transfer of knowledge and technologies.

2.2 China

China is divided into 4 municipalities (directly under the jurisdiction of the central government), 23 provinces and 5 autonomous and 2 special administrative regions: see table 2.1. In 2015, the total population of mainland China amounted to 1.37 billion, of which 56.1 % was urban population [MOHURD, 2016a]. In 2015, there were 656 cities in China Mainland. The recording of solid waste management data started in 1979 at city level and in 2000 at county level. By 2015 there were 656 cities in China Mainland with a total MSW collection quantity of 191.42 million tons (524 thousand t/d), of which 98 % was treated [MOHURD, 2016a]. And by 2014, there were in total 1596 counties with a MSW collection quantity of 66.57 million tons (182 thousand t/d), of which 71.6 % had been harmlessly treated [MOHURD, 2015].

Table 2.1: Administration structure in China in 2015

Administrative divisions	Administrative units	Levels of cities	No. of cities	Name of cities
Province	34	Cities at provincial level	**6**	Beijing Chongqing Shanghai Tianjin Hong-Kong Macau
province	*23*			
autonomous region	*5*			
Municipality	**4**			
special adm. region	**2**			
Prefecture	334	Cities at prefecture level	291	Note: the data mentioned afterwards refer to cities in China Mainland, i.e. those of Hong-Kong and Macau are not included.
County	2,850	Cities at county level	361	
Township	39,789			
Village	2.64 Million			
			658	

In China, the sources of MSW generally include residential households, markets, commercial locations, public areas, streets, as well temples and religious institutions. Most Chinese cities have experienced uneven development patterns, with both highly modernized and relatively laggard districts in a same period. China is now experiencing rapid economic development and urbanization, which make it confront the stringent challenges in MSW management. The amount of MSW in China has increased rapidly in recent years, and China is now the world's largest producer of MSW. The total amount of collected MSW increased from

25.8 million tons in 1979 [MOHURD, 2016a] to 155 million tons in 2004 (National Bureau of Statistic of China (2005) and to 164.0 million tons in 2011 in cities of China Mainland [MOHURD, 2016a], and by 2015 this figure had reached 191 million tons [MOHURD, 2016a].

These statistics do not include the waste collected by pickers, which are estimated to represent 8-10 % of the total MSW generated.

The MSW generated in China Mainland is predominantly treated via landfilling and incineration. For example, in 2010, 79 % of the treated MSW was landfilled, 19 % was incinerated, and 2 % was composted [MOHURD, 2016a]. In 2015, the harmless disposal rate had reached 98 % in Chinese cities [MOHURD, 2016a].

The following figure 2.2 provides a summary of the legal and technical development of waste management in China.

Regulation and Policy

In 1979, the enactment of Environmental Protection Law of the People´s Republic of China marked a new beginning of environmental protection (law was officially issued in 1989 and revised in 2015). In 1983, the second national environmental protection working conference was held, and the requirements on waste treatment were presented for the first time.

It was not until the early 1980s, when waste management problems became a serious problem attaching great importance by the Chinese government in 1983 (**6th Five-Year Period** 1981-1985), that the requirements on waste treatment were presented for the first time. At the period of the **7th Five-Year Period** (1985-1990), the first sanitary landfill, Hangzhou Tianziling MSW Landfill (Phase I), was built and put into use with an anti-seepage vertical curtain grouting technology (not HDPE membrane). In 1988, the Ministry of Construction issued the first standard on waste treatment technology, Sanitary Landfill Technology Standard for Municipal Solid Waste (CJJ17-88).

During the early 90s (**8th Five-Year Period** 1991-1995), regulations were issued by different authorities: in 1992, the City Appearance and Environmental Sanitation Management Regulation (101st Order) was issued by the State Council, and in 1993, the Urban Municipal Solid Waste Management Regulation (27th Order) was issued by the Ministry of Construction, and was revised in 2007.

In 1995, the requirements on municipal waste treatment and management were extended by a Law on the Prevention and Control of Environmental Pollution by Solid Wastes (No.58). This law was implemented after 1st April 1996, and revised in 2004 and 2014.

Beginning of Modern Sanitary Landfill Construction

During the **9th Five-Year Period** (1996-2000), in 1997, the first waste sanitary landfill was built and put into practice: Shenzhen Xiaping MSW Landfill (Phase I), which used a HDPE membrane as an impermeable layer. Subsequently, the construction technology of sanitary landfills has reached international standard. The following year China started to use the national debt funds to support the construction of sanitary landfills in local cities, which greatly promoted the construction of waste treatment facilities.

During **10th and 11th Five-Year Periods** (2001-2010), big cities and economically developed coastal cities began to build large-scale sanitary landfills, and also some simple

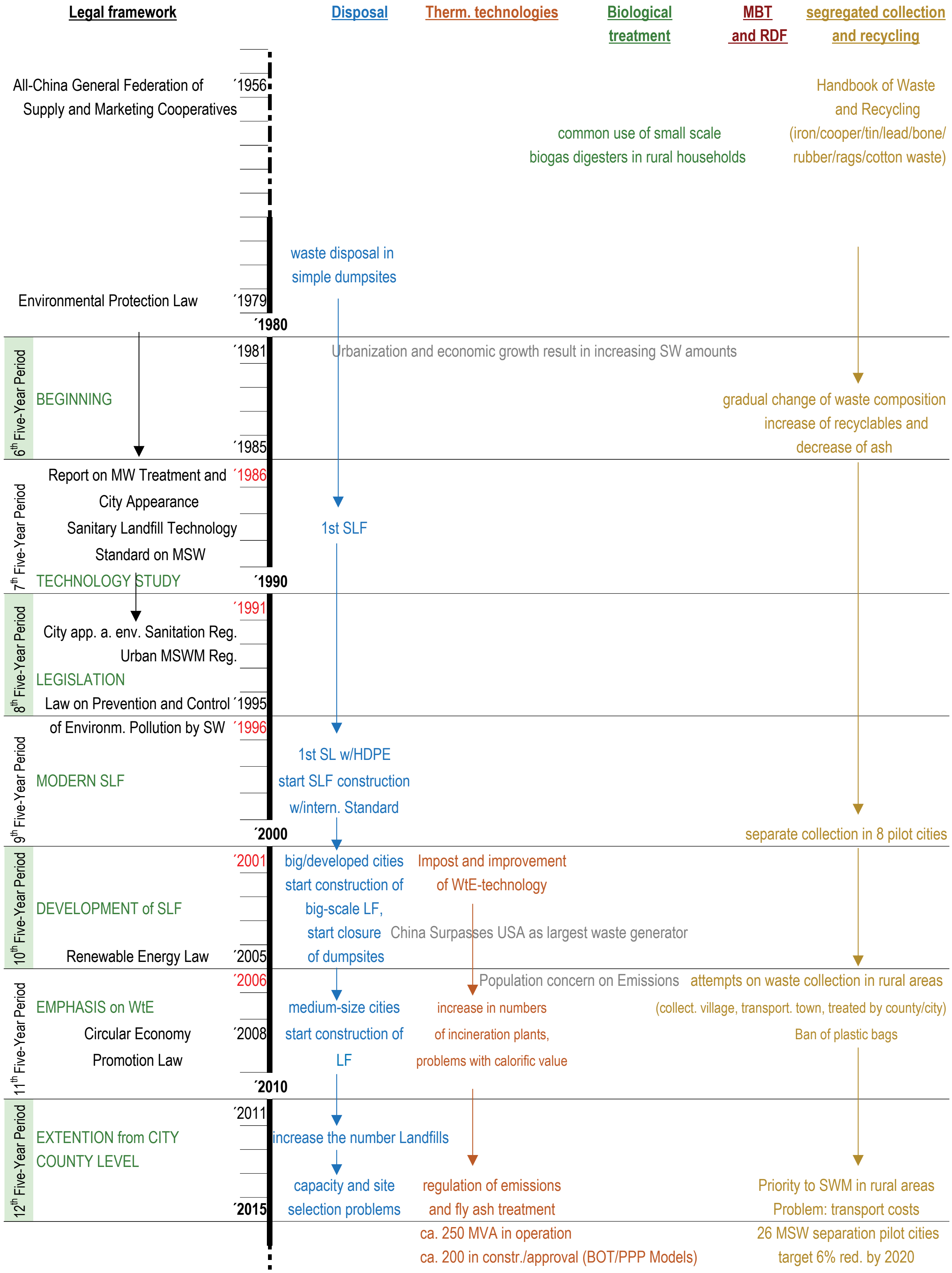


Figure 2.2: Summary of the legal (left) and technical (right) development of waste management in China along the time axis

waste dumpsites without liner systems have been closed; consequently the harmless treatment rate has been improved. After entering in the 11th Five-Year Period, sanitary landfill have been constructed from big cities to small and medium-sized cities as well as in developed counties. Along with the large number of constructions, the leachate treatment project has gradually gained more attention. Meanwhile, landfill assessment work has been carried out by the MOHURD in order to distinguish the different levels of sanitary landfills into 4 grades (I, II, III, IV).

With the development of China Socialist New Rural Construction, the rural environment has also started to gain attention. Attempts at waste collection and treatment in rural areas have been carried out in some provinces.

The Circular Economy Law

The **12th Five-Year Plan** on Circular Economy Development points out that the development of circular economy is an important strategic task for economic and social development in China, and is an important way to promote an ecological civilization and sustainable development. A period in the future should be focused on improving resource productivity, improving the incentive and restraint mechanisms, actively building recycling industrial systems, promoting the renewable resources industry, promoting green consumption, and accelerating the establishment of a resource recycling system, which covers the whole society.

After January 1st, 2009, China has carried out the People's Republic of China Circular Economy Promotion Law (the Chairman’s order No. 4), in order to promote the development of a circular economy, to improve the resource use efficiency, protect and improve the environment and achieve sustainable development. The circular economy is as definite in the law as reduction, as it can be seen that waste utilization is the main line of the circular economy law.

In December 2011, NDRC issued a Notice on Resources, Integrated Utilization Resources Guidelines, and a Large Amount Solid Waste Integrated Utilization Implementation Plan. The notice adhered to the basic state policy of resource conservation and environment protection, and further promoted the resources integrated utilization in the period of the 12th Five-Year, as well as accelerated the development of a circular economy. It put forward the guiding ideology, basic principles, main objectives, key areas and policy measures of resources integrated utilization, and proposed to compile an implementation plan for the solid waste with huge amounts, high recycling potential and wide environmental impact from the manufacture industry, construction industry, agriculture and forestry, etc.

In September 2012, the central government set up a Special Fund for Circular Economy Development, in order to support the key projects in circular economy, the demonstration and promotion of circular economy technology and products, and the capacity for building on circular economy.

Specific content in the 12th Five-Year Plan includes:

- Build a recycling-based service system and promote circular economy development on a social level. Promote the renewable resources recycling system and MSW separation system, and promote green building and green transportation. Fully develop the guiding role of service industry on establishing green low carbon consumption concepts and changing consumption patterns.
- Carry out circular economy demonstration actions, promote demonstration projects, create a circular economy demonstration city, and foster a demonstration enterprise and demonstration park. Improve taxation, finance, industrial investment, pricing and charging policies; improve regulations and standards; establish a statistical evaluation system; strengthen supervision and management; and actively carry out international exchanges and cooperation to promote the development of circular economy.

National Economic and Social Development

In March 2016, the **13th Five-Year Plan** on China National Economic and Social Development was propagated. Chapter 43, Promote Resource Conservation and intensive use, and Section 5, Vigorously Develop Circular Economy, pointed out that circular development is the core concept of the plan, to promote the circulation link between production and living systems, and to speed up the utilization of waste. Make overall arrangements on industrial layout according to the material flow and the integrated correlation. Promote the recycling transformation of industrial parks, and construct an industrial-agricultural compound circular economy demonstration area to achieve a symbiosis between enterprises, parks, and industries. Promote the development and utilization of city mining, and achieve good utilization of industrial solid waste and other waste. Accelerate the construction of harmless treatment systems for restaurant waste, construction & demolition waste and textile recycling, and regulate the development of remanufacturing. Practice a producer responsibility extension system. Improve the renewable resources recycling network, and strengthen the connection between domestic waste recycling and resources recycling.

In June 2016, the MOHURD issued the “Compulsory Waste Classification System (exposure draft)”, and pointed out that by the end of 2020, the key cities should achieve an effective separation of MSW. For the key cities, MSW separation rates should reach more than 90 %, and the recycling and utilization rate should reach more than 35 % (including renewable resources recycling, with the biodegradable waste separated from MSW).

The utilization methods of waste products are refined year by year. For example, the MEP and the Ministry of Industry and Information Technology jointly developed the Guideline of Waste Electrical and Electronic Products Standardization Dismantling Operations and Production Management (2015 Edition) (No. 82 2014), implemented on January 1st, 2015. For imported waste that can be used as raw material, an Imported Waste Management Catalogue (2015) (No. 80, 2014) was also issued, and implemented on January 1, 2015.

3. Legal framework for dealing with waste fractions from the separate and mixed collection of biogenic fractions in the PR of China

The main legislations on MSW management in China are: the Environmental Protection Law of the PRC, issued in1989; the Law of the PRC on Prevention of Environmental Pollution Caused by Solid Waste issued in 1995, the Cleaner Production Promotion Law of the PRC, issued in 2002 and the Circular Economy Promotion Law of the PRC, issued in 2008.

The following table 3.1 provides an overview of the municipal solid waste legislative arrangements in China. A list of laws, regulations and standards is provided in the annex at the end of this report.

Table 3.1: An overview of the municipal solid waste legislative arrangements in China.

Laws and Regulations	Brief Description	Issuer	Effective Time
Environmental Protection Law of the People´s Republic of China	Marked the new beginning of environmental protection	The Standing Committee of the National People's Congress	First passed on December 26, 1989, and revised on April 24, 2014
City Appearance and Environmental Sanitary Management Ordinance	Principle guidelines on city appearance (outdoor advertisement & horticulture) and environmental sanitary (MSW & public latrines) management; Local government would work out practical measurements.	The State Council	First passed on August 1, 1992; revised on January 8, 2011
Regulations Regarding Municipal Residential Solid Waste	Regulations regarding the management of collecting, transferring and treating residential solid waste.	The Ministry of Construction of PRC	First passed on August 10, 1993; 1st revision on April 10, 2007; 2nd revision on May 4, 2015
Law on Prevention and Control of Environmental Pollution Caused by Solid Waste of PRC	China's first comprehensive law on solid waste. Laid framework for setting standards for solid waste storage and disposal, pollution control for landfills for hazardous wastes, discharge standards for livestock, and medical waste incineration and transport. 2004 amendment tightened control imports of foreign garbage.	The Standing Committee of the National People's Congress	First passed 1995, 1st revision on December 29, 2004; 2nd revised on June 29; 3rd revision on April 24, 2015; 4th revision on November 7, 2016
Technical Policies on the Disposal of Domestic Waste and the Prevention of Pollution	Guidance and standards of the technologies applied in the MSW treatment.	The Ministry of Construction of PRC, National Development and Reform Commission	May 29, 2000

Laws and Regulations	Brief Description	Issuer	Effective Time
Comments on Promoting the Industrialization of Municipal Waste Water Treatment and Municipal Solid Waste Treatment	Promotion of private and foreign investment in municipal wastewater and solid waste industry to improve waste disposal in urban areas.	State Development & Planning Committee, The Ministry of Construction, and State Environmental Protection Administration	September 10, 2002
Law for Promotion of Cleaner Production of PRC	Reducing pollution (including waste creation) throughout the manufacturing process by creating incentives for industries.	The Standing Committee of the National People's Congress	First passed on June 29, 2002; 1st revision on February 29, 2012
Law for Environment Impact Assessment of PRC	Emphasize the importance of preventing environmental pollution from source; any new construction must obtain EIA approval before breaking ground. Requires infrastructure and new industry construction to complete EIA that is open to public review. If enforced the increased transparency could potentially help improve waste practices in new industries and landfills.	The Standing Committee of the National People's Congress	First passed on October 28, 2002; 1st revision on July 2, 2016
Circular on Earnestly Accomplishing Environmental Pollution Prevention Work in the Enterprise Relocation Process	This SEPA Circular recommends that enterprises shutting down a facility that generates or handles hazardous wastes, or changing the nature of the land-use activity at the site of such a facility, should obtain site soil and groundwater contamination reports from the local government environmental monitoring stations, submit such reports to local environmental authorities for review, and develop remediation plans based on the findings in the reports.	State Environmental Protection Administration	June 1st, 2004
11th Five-year: Constructing Plan of the City Municipal Solid Waste Harmless Treatment	Constructing Plan of the City Municipal Solid Waste Harmless Treatment	The Ministry of Construction of PRC	September, 2007
Law of the Circular Economy Promotion Law of the PRC		The Ministry of Construction of PRC	August 29, 2008

Laws and Regulations	Brief Description	Issuer	Effective Time
12th Five-Year: General Program of Energy Saving and Emission Reduction	Guidance to reduce the intensity of energy consumption, reduce emissions of major pollutants. Encourage waste incineration power generation and heating, and the promotion of waste into resources.	The State Council	August 31, 2011
12th Five-year: Constructing Plan of the City Municipal Solid Waste Harmless Treatment	Constructing Plan of the City Municipal Solid Waste Harmless Treatment	The Ministry of Construction of PRC	April 19, 2012
Scheme of compulsory MSW segregation (Exposure Draft)	Demonstration cities should Implement waste segregation. Mandatory objects include public institutions, related businesses.	National Development and Reform Commission, The Ministry of Construction of PRC	June 15, 2016
13th Five-year: Constructing Plan of the City Municipal Solid Waste Harmless Treatment	Constructing Plan of the City Municipal Solid Waste Harmless Treatment	The Ministry of Construction of PRC	December 31, 2016
Law of the People 's Republic of China on Environmental Protection Tax	Enterprises and institutions that discharge pollutants directly into the environment and other production and business operators as environmental protection tax payers shall pay environmental protection tax. "Taxable pollutants" as used in this Law refers to air pollutants, water pollutants, solid wastes, construction noise and industrial noise as well as other pollutants.	The Standing Committee of the National People’s Congress	December 25, 2016
Program to Implement Producer Responsibility Extension System	In order to accelerate the construction of ecological civilization and green cycle of low-carbon development of the inherent requirements, in order to promote the supply side of the structural reform and manufacturing transformation and upgrading, EPR system is promoted, i.e. extent the responsibility of producers to their products from the production chain extension of environmental responsibility to product design, circulation consumption, recycling, waste disposal and other life cycle.	The State Council	January 3, 2017

References: CMC, 2004, CMC, 2005, Deffree, S., 2007, World Bank, 2005.

4. Organization, responsibilities and funding of waste management in the PR of China

In most countries, solid waste management is a municipal responsibility. Each country's national legislative and regulatory framework for solid waste management dictates roles and responsibilities at each governmental level, including requirements for private sector service agents and waste generators. Typically, central government laws delegate solid waste service responsibilities to local governments and set basic standards, including occupational and environmental health and safety standards. The regulatory framework in China would be enhanced by a greater separation of management and planning functions from operational functions, as well as separation of policy development and regulations from implementation activities.

4.1 Organization and responsibilities

In China, both central government institutions and regional and local authorities are involved in the MSW management. The Ministry of Environmental Protection (MEP) is responsible for the overall solid waste pollution prevention and control. Different ministries are in charge of the waste management depending on the solid waste categories, which are shown in figure 4.1. The main functions and roles of each department are described in table 4.1.

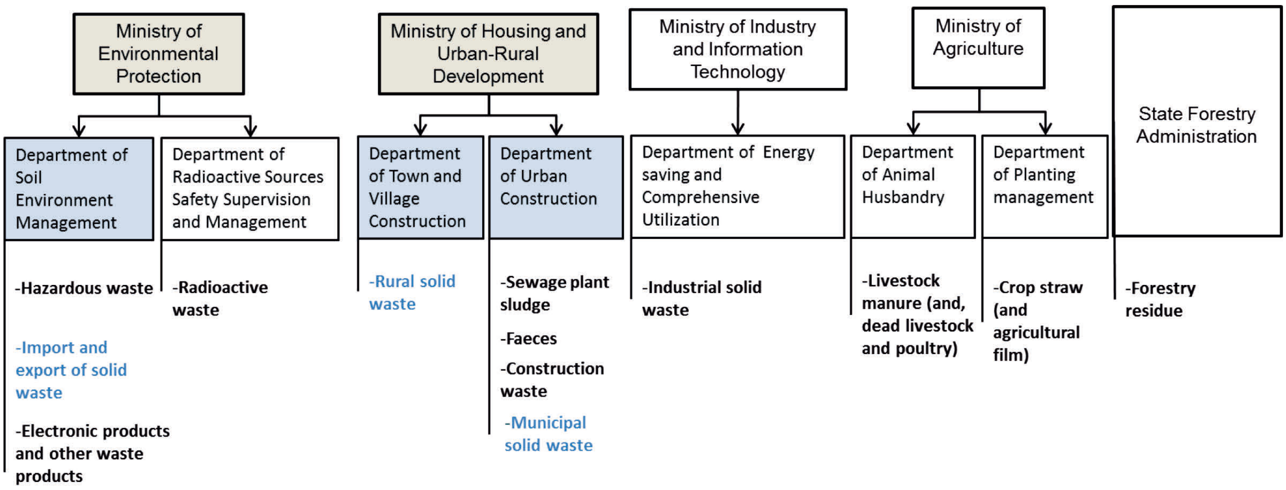


Figure 4.1: Different ministries are in charge of the waste management in PRC

Initially, the National Environmental Protection Agency (NEPA) was founded in the early 1970s, becoming the State Environmental Protection Administration (SEPA) in 1989 and the Ministry of Environmental Protection of the People's Republic of China (MEP) in 2008. Environmental Protection Offices are present at all levels of Chinese administration (see figure 4.2). Branches of these offices are distributed throughout China, which are connected to a hierarchical, nation-wide network. The MEP is in charge of development and implementation of the national strategies for environmental protection, of drafting the laws and related regulations, and of supervising their enforcement on a regional level. It is also responsible for the coordination of environmental issues between the various authorities and regions, the linking of environmental projects to a national master plan, and public relations work [MEP, 2014].

Table 4.1: Framework of solid waste management in China

Solid waste Categories	Responsible Ministry	Sub Department	Main functions	No.
Hazardous waste (including: medical waste, municipal solid waste incineration fly ash, etc.)	MEP	Dpt. of Soil Environment Management	–Responsible for the supervision and management of the soil, solid waste, chemicals, heavy metals and other pollution control. –Formulate and implement policies, plans, laws, administrative regulations, departmental rules, standards and regulations for the pollution control on soil, solid waste, chemicals, heavy metals, etc. –Development of soil environmental function district planning. –Measurement and determination of soil environmental capacity, and carry out assessment of soil environmental carrying capacity. –Organize the implementation of hazardous waste management licensing and export authorization, solid waste import licensing, export registration of toxic chemicals and the registration of new chemical substances. –Pollution discharge permits, total soil pollution control, emission rights trading. –Organize to carry out the declaration and registration of hazardous waste, medical waste and electronics and other industrial products. –Supervision and management of soil environmental protection, agricultural pollution prevention. –Responsible for the implementation of international convention	4.1
Import and export of solid waste	MEP	Dpt. of Soil Environment Management	The same as 4.1	4.2
Electronic prod. and other waste products	MEP	Dpt. of Soil Environment Management	The same as 4.1	4.3
Radioactive waste	MEP	Dpt. of Radioactive Sources Safety Supervision and Management	–In charge of administrative licensing and supervision of the nuclear fuel cycle facilities, radioactive waste treatment and disposal facilities, decommissioning of nuclear facilities, nuclear technology utilization projects, uranium (thorium) mines and associated radioactive mines, electromagnetic radiation devices and facilities, nuclear safety of radioactive material transportation, radiation safety and radiation environmental protection. –Responsible for the supervision and management of radioactive pollution control. –Responsible for the investigation and handling of nuclear facilities and radiation source accidents.	4.4

Solid waste Categories	Responsible Ministry	Sub Department	Main functions	No.
Municipal solid waste	Ministry of Housing and Urban-Rural Development (MOHURD)	Dpt. of Urban Construction	–Compile the development strategy, medium and long-term plan, reform measures, rules and regulations of urban construction and municipal public utilities. –Guide the urban water supply, water saving, gas, heat, municipal facilities, landscaping, environmental sanitation management, urban construction supervision, etc. –Guide the construction of urban sewage treatment facilities and pipe network. –Guide the landscaping work of urban area; –Undertake the work of the national level scenic spot, the world natural heritage project and the world natural and cultural heritage project.	4.5
Rural solid waste	MOHURD	Dpt. of Town and Village Construction	–Compile policy on village and town construction; –Guide the preparation and implementation of town, township and village planning; –Guide the rural housing construction, housing security and rural dilapidated housing rehabilitation; –Suggestions on housing policy of rural settlement farmers; –Guide the improvement of the ecological environment of small towns and villages; –Organize the pilot village and town construction, and guide the construction of the national key towns.	4.6
Sewage plant sludge	MOHURD	Dpt. of Urban Construction	The same as 4.5	4.7
Faeces	MOHURD	Dpt. of Urban Construction	The same as 4.5	4.8
Construction waste	MOHURD	Dpt. of Urban Construction	The same as 4.5	4.9
Industrial solid waste	Ministry of Industry and Information Technology (MIIT)	Dpt. of Energy Saving and Comprehensive Utilization	–Implementation of energy saving and resource comprehensive utilization in industry and communication industry; –Compile the clean production promotion policy; –Participate in the planning and policy making of energy conservation and comprehensive utilization of resources, cleaner production promotion and pollution control. –Organize and coordinate the application of new products, new technologies, new equipment and new materials.	4.10

Solid waste Categories	Responsible Ministry	Sub Department	Main functions	No.
Livestock manure (and, dead livestock and poultry)	Ministry of Agriculture (MOA)	Department of Animal Husbandry	–Guide the animal husbandry structure and layout adjustment. –Organize the standardized production and scale raising. –Formulate relevant standards and technical specifications for animal husbandry, feed industry and grassland; –Compile and implement of the relevant standards and technical standards; –Guide the record and document management of livestock and poultry farms (district). –Participate in the pollution control of livestock and poultry farms.	4.11
Crop straw (and agricultural film)	MOA	Department of Planting management	–Responsible for the management of planting industry (grain, cotton, oil, sugar, fruit, vegetables, tea, mulberry, hemp, flowers, herbs, tobacco, edible fungus)	4.12
Forestry residue	State Forestry Administration		–	4.13

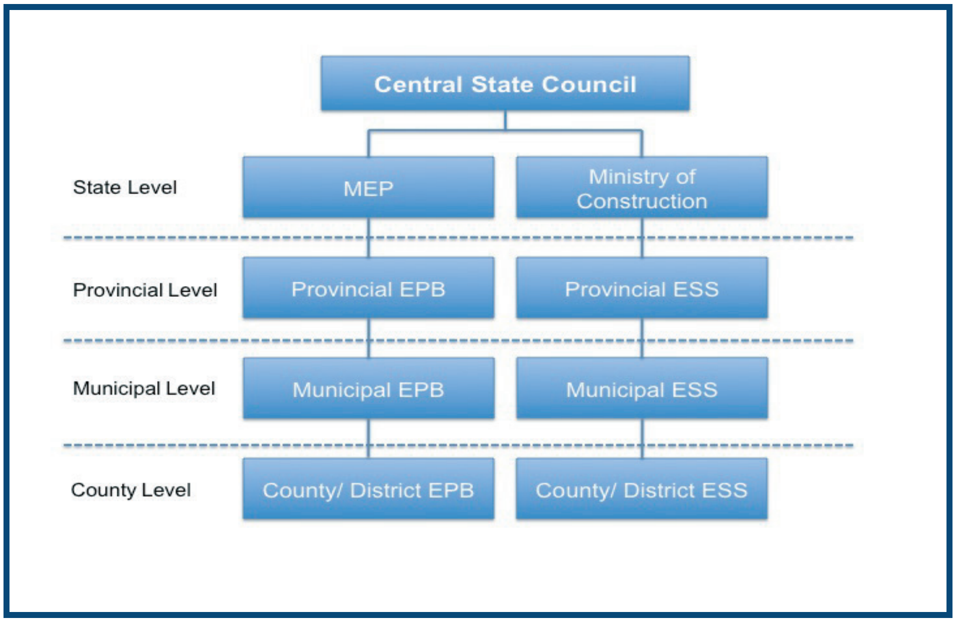


Figure 4.2: Organisational Structure of the Chinese Municipal Solid Waste Management [Mewes 2011]

The second public authority in charge of technical requirements of MSW management is the Chinese Ministry of Housing and Urban-Rural Development (MOHURD). It is in charge of formulating laws and regulations with regard to technical standards of MSW treatment and disposal. It also sets limit values for emissions of the MSW management and waste water treatment. Both ministries in charge of MSW management are represented on the various levels of administration by the 'Environmental Protection Bureau' (EPB) and the 'Environmental Sanitation Section' (ESS).

4.2 Funding

On July 6, 2015, the General Office of the State Council issued the Notice on Guidance on Promoting Public Private Partnership Model in the Field of Public Service. (The General Office of the State Council, No.42, 2015), and on September 24, 2016, the MOF issued the Interim Procedures for the financial management of Public Private Partnership Projects (Financial No.92, 2016), in order to reform and innovate the public service supply mechanism on environmental protection and energy and other public services, and to strongly promote the government and social capital cooperation (Public-Private-Partnership, PPP) model. In environmental protection, municipal engineering, energy, transportation, water conservancy and other specific areas which need to implement the franchise, the infrastructure and public utility franchise management approach should be used for execution. In order to defuse the risk of local government debt, Transfer - Operations - Transfer (TOT), Rebuild - Operations - Transfer (ROT) and the other modes should be actively used, so as to transfer the stock public service project to the government and the social capital cooperation project. Furthermore, in order to improve the scientific decision-making of the new project, Build - Operation - Transfer (BOT), and Build - Operation - Own (BOO) are encouraged according to the local economic and social development situation.

5. Recovery and disposal situation of biogenic components of MSW in China

5.1 Quantities of MSW

The generation amount of MSW in China is generally accounted by the collection quantities. According to administrative divisions, the statistics are divided into three levels, including city (municipalities, city and county level city), county, villages and towns.

Figure 5.1 is the MSW collection quantity in urban areas since 1980, based on the China statistical yearbook. It can be seen that, in recent years, the MSW generation quantity has shown the same trend as urban population growth, while the average MSW generation rate is relatively stable. By the end of 2015, the MSW collection quantity was 191.42 million tons for 656 cities in China, with an MSW generation rate of 1.10 kg/(capita*d).

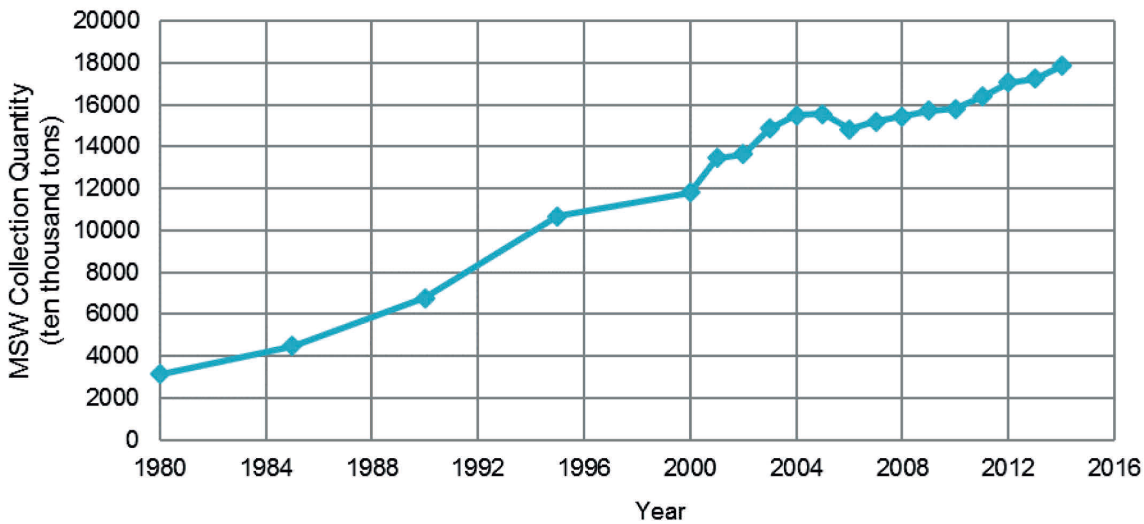


Figure 5.1: MSW collection quantity in China – urban areas (cities)

Figure 5.2 shows the MSW collection quantity of county areas in China since 2000, based on the China statistical yearbook. It can be seen that, by the end of 2014, the MSW collection quantity was 66.57 million tons for 1,596 counties in China, with an MSW generation rate of 1.17 kg/(capita*d).

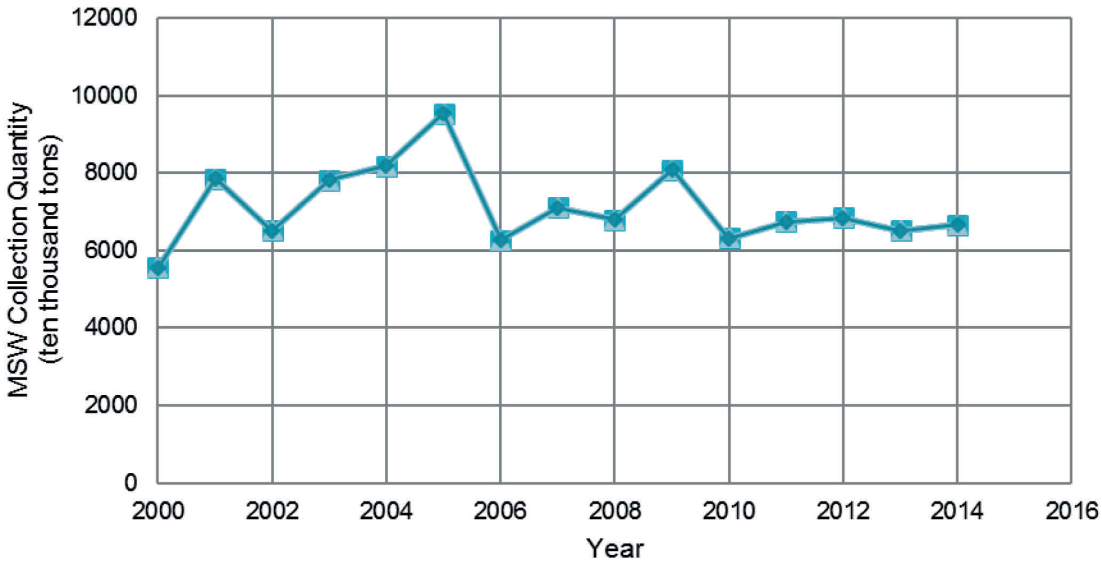


Figure 5.2: MSW collection quantity in China – county areas

By the end of 2015, there were 20,515 towns, 11,315 townships, and 2.64 million villages in China. According to the Statistical yearbook of China's urban and rural construction and the results of the field survey organized by MOHURD in 2011, the MSW from towns and villages has reached 2.1 tons annually. The MSW generation rate of towns and the townships which have town government is 0.20-1.70 kg/(capita*d), while it is 0.79 kg/(capita*d) for the towns and 0.52 kg/(capita*d) for the townships without town government. The MSW generation rate of villages is 0.07~2.1 kg/(capita*d), with the average rate of 0.50 kg/(capita*d). The MSW generation densities in county areas and in village areas are shown in Figure 5.3 and Figure 5.4.

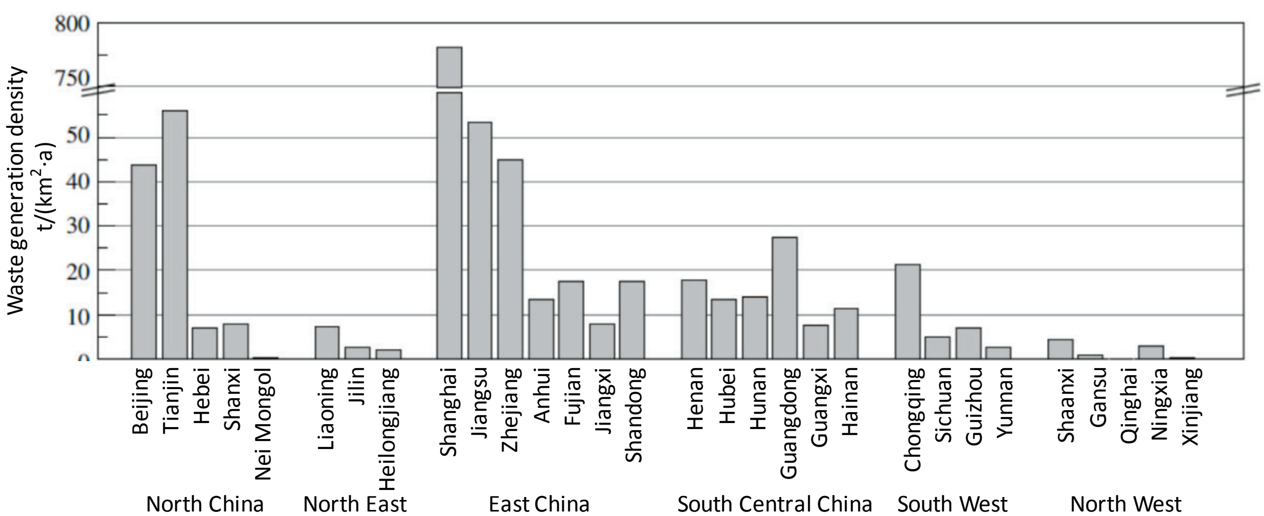


Figure 5.3: MSW generation density in county areas in China [He et al., 2014]

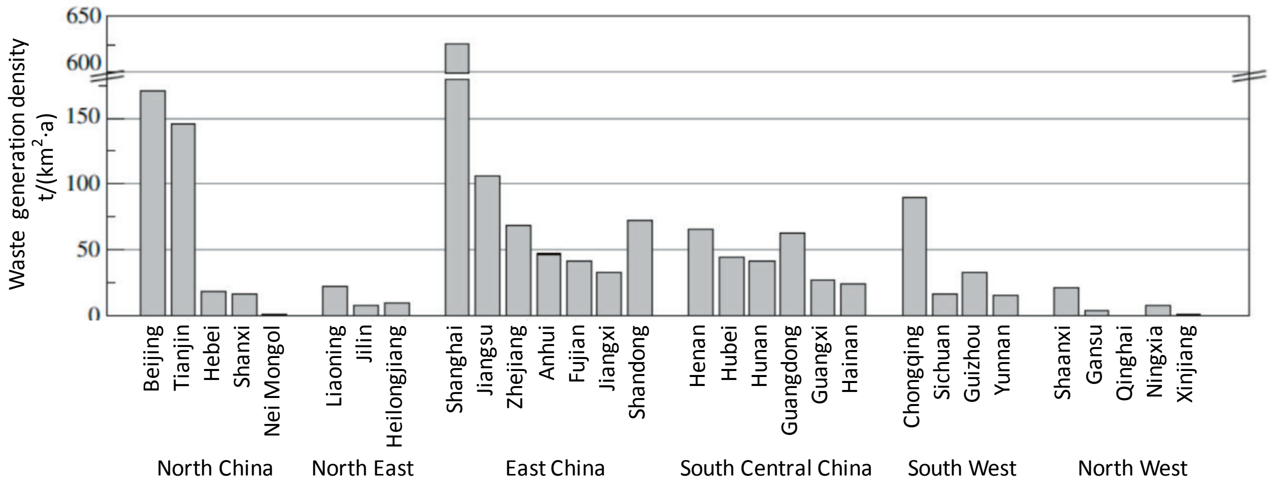


Figure 5.4: MSW generation density in villages in China [He et al., 2014]

5.2 Physical composition of household solid waste

According to the Chinese standard sampling and analysis method for domestic waste (CJ/T313-2009) [UCIS, 2009], the physical composition of domestic waste is divided into 11 categories: kitchen waste, paper, rubber, textile, wood & bamboo, dust, ceramic, glass, metal, and other mixed type (particle size less than 10 mm). The physical components and moisture content of MSW are shown in Figure 5.5 based on the statistics of 17 representative cities in China [Yang Na. 2014, Yang et al., 2015], with kitchen waste of 58 % ±9.8 %, and a moisture content of 55.0 % ±5.5 %.

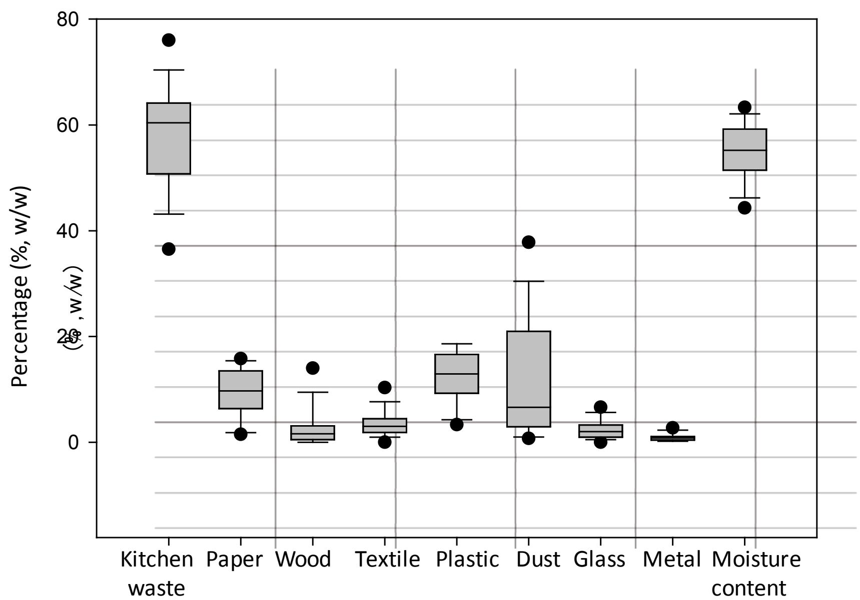


Figure 5.5: Physical composition of MSW in typical cities of China [Yang Na. 2014, Yang et al., 2015]

Figure 5.6 displays the physical composition and water content of MSW based on the data of 11 typical counties, with the proportion of kitchen waste being 44.3 % ±15.1 %, and the water content being 53.2 % ±7.7 %.

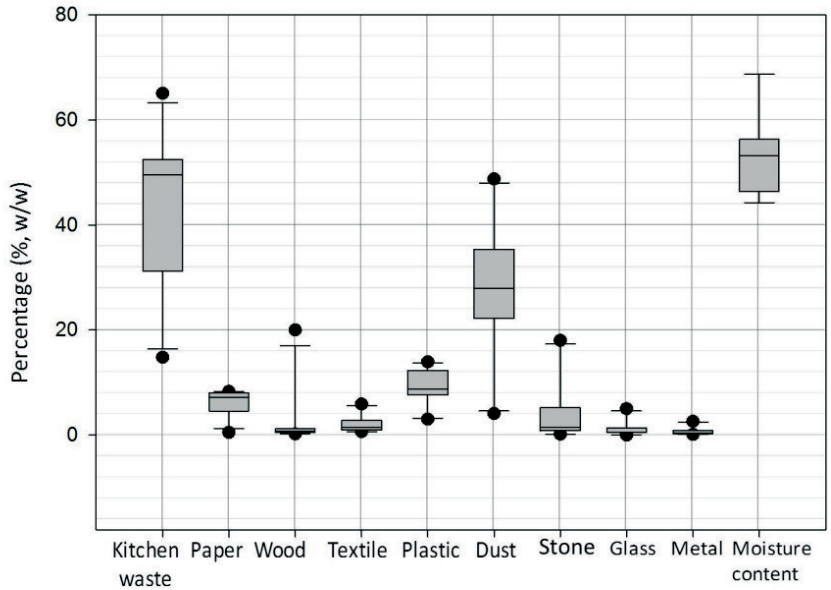


Figure 5.6: Physical composition of MSW in typical counties of China

Figure 5.7 displays the physical composition and water content of MSW based on the data of 13 typical villages [He et al., 2010], with the proportion of kitchen waste being 42.1 % ±12.8 %. In general, the main components of MSW from villages can be divided into 3 categories: (1) food and plant residues; (2) dust (including ash brick, stone etc.); (3) Other waste (mainly plastic, glass, metal and other packaging residues, fabric, paper and other non-durable consumer goods).

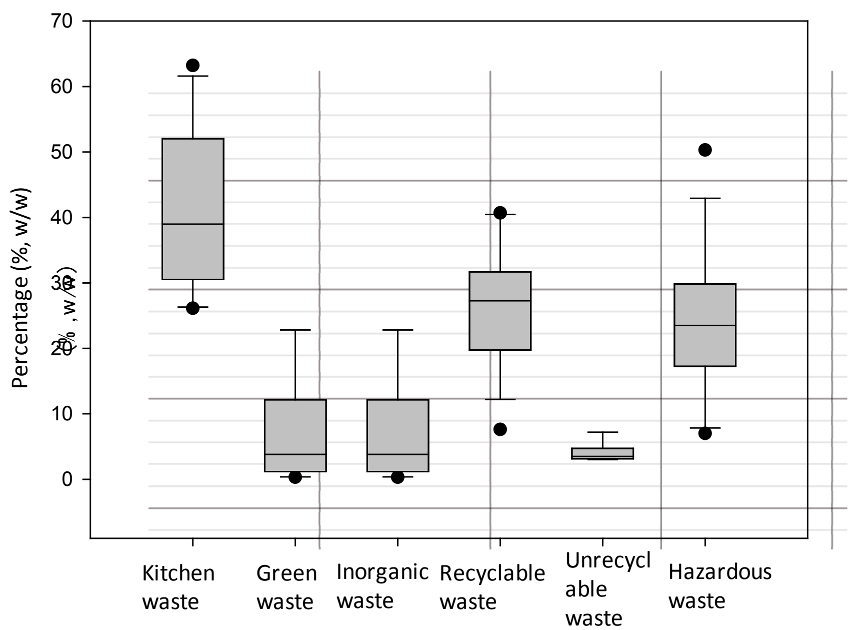


Figure 5.7: Physical composition of solid waste in typical villages of China [He et al., 2010]

5.3 Collection and transportation of mixed collected solid waste

The number of collection vehicles in cities, counties, towns and townships are shown in Figure 5.8. Within the last ten years, the growth rate of sanitation vehicles is 120 %, 120 %, 152 % and 196 %, respectively.

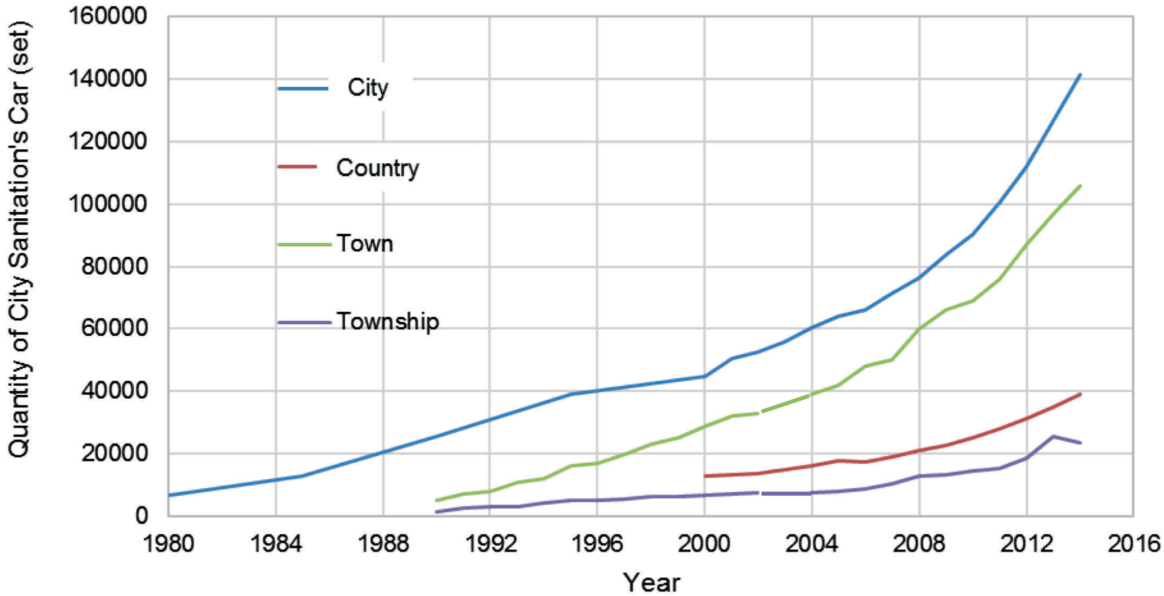


Figure 5.8: Sanitation vehicle quantity in China (1980-2014) [MOHURD, 2015]

For the MSW generated in cities and counties, the waste is collected and treated in its entirely. For the waste generated in towns and villages, there are various waste collection and treatment modes, which are listed in table 5.1.

Table 5.1: Logistic mode of MSW collection and transportation in villages and towns [He et al., 2014]

Logistic mode	Inhabitation area		
	Village	Town	County or city
Centralized mode	Collection – Transportation	Collection – Transportation – Transfer transportation	Collection – Transportation - Treatment
Disperse mode	Collection - Treatment	Collection - Treatment	Collection – Transportation - Treatment
Centralized mode in town and county	Collection - Treatment	Collection- Transfer transportation	Collection – Transportation - Treatment
Centralized mode (town and county treatment respectively)	Collection – Transportation	Collection - Treatment	Collection – Transportation - Treatment
Integrated treatment in county and town	Collection - Treatment	Collection - Treatment - Transfer transportation	Collection – Transportation - Treatment
Integrated treatment in village and town	Collection - Treatment - Transportation	Collection - Treatment - Transfer transportation	Collection – Transportation - Treatment

5.4 Treatment and disposal of mixed collected household solid waste

In China, the term MSW treatment facility mainly refers to MSW incineration plant and sanitary landfill. In 2015, there were 890 MSW treatment facilities in cities and 1187 in counties in the mainland of China. [MOHURD, 2016c].

5.4.1 City

The recent MSW treatment situation is shown in Figure 5.9. By the end of 2015, the treatment rate of collected solid waste had reached 98 %, while the proportions of landfill, incineration and other treatments (mainly biological treatment) are 64 %, 34.8 % and 2 %, respectively, compared with the 2005, when these four values were 44.5 %, 52 %, 5 %, 2.2 %, respectively [MOHURD, 2016a]. In 2015, the amount of waste treated in landfills increased by 66 % compared with 2005, while incineration increased by 692 %, and biological treatment decreased by 3 %. Up to 2015, there were still 67 cities in China that had not yet built harmless treatment facilities [MOHURD, 2016c].

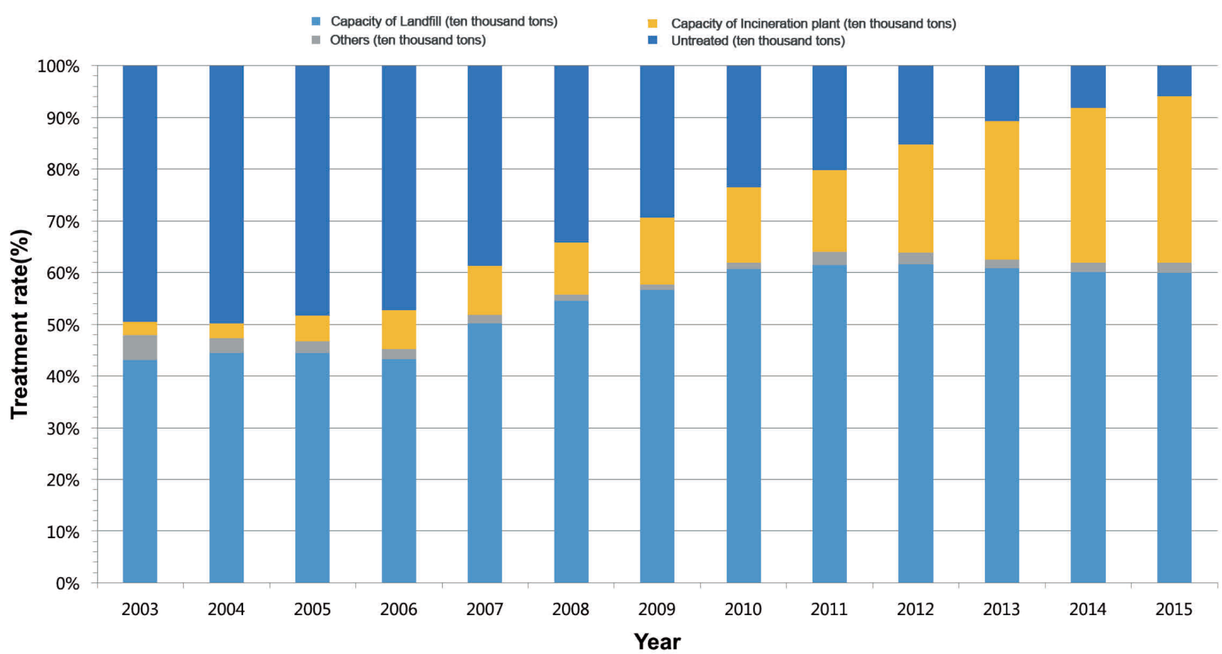
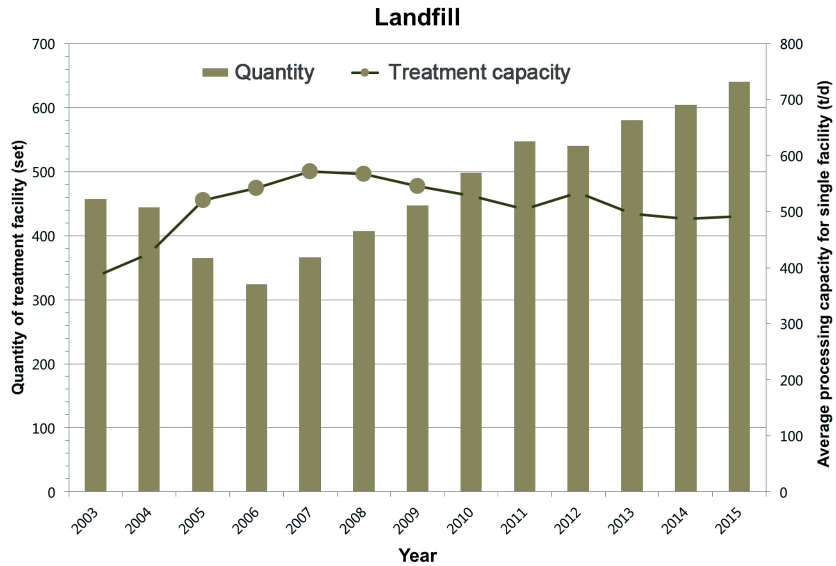


Figure 5.9: MSW treatment in cities of China [MOHURD, 2016a]

Figure 5.10 shows a steady increase of landfill disposal facilities, and the average treatment capacity of a single facility is around 500 t/d. The number of incinerators began to grow rapidly in 2007, while the average treatment capacity of a single facility had reached 769 t/d in 2015. The number of biological treatment facilities was only 30, and the average treatment capacity of the single facility was first increased and then decreased, to only 324 t/d in 2015.



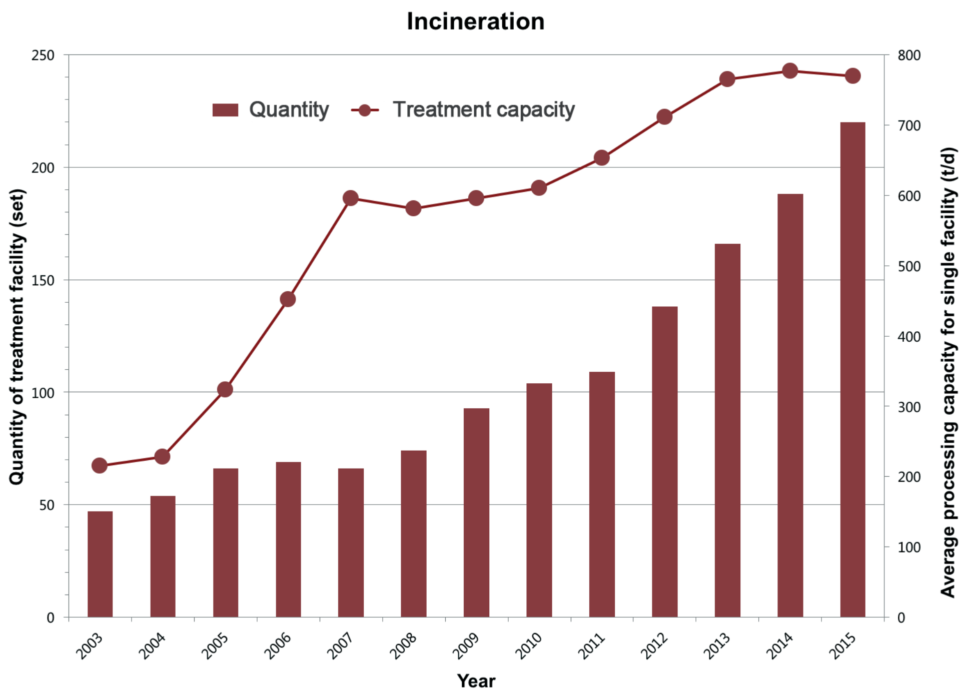
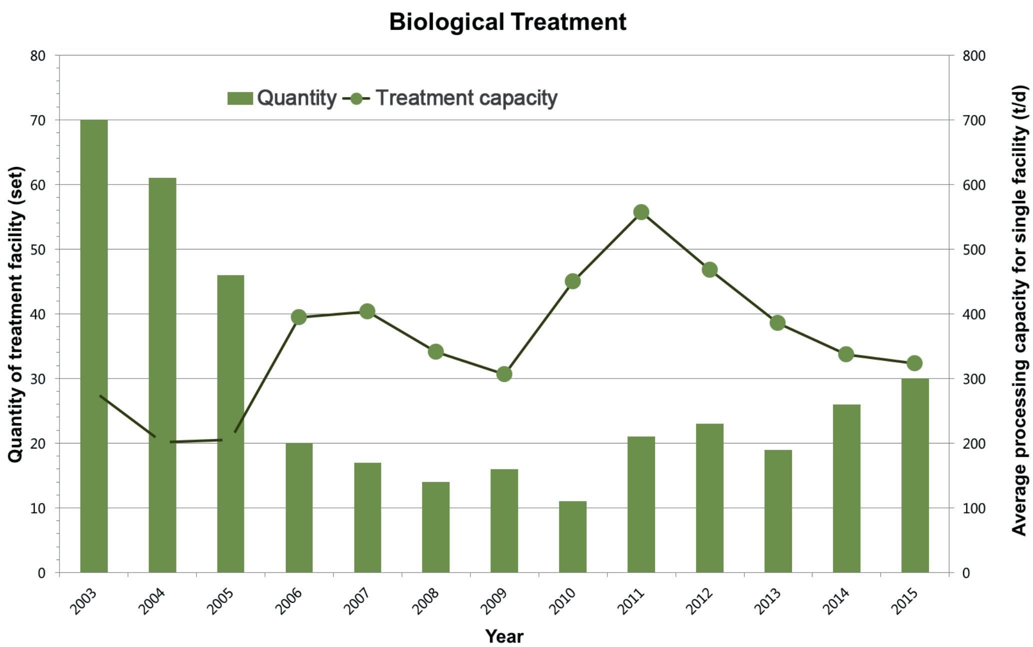


Figure 5.10a: MSW treatment facilities: landfill and incineration (amount and treatment capacity in cities of China [MOHURD, 2016a]



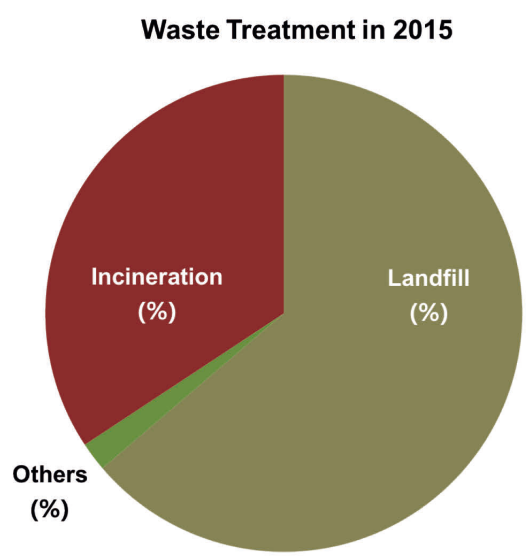


Figure 5.10b: MSW treatment facilities: others (amount and treatment capacity) and share in cities of China [MOHURD, 2016a]

5.4.2 County

The MSW treatment of counties in China has shown a rapid development in recent years. As shown in Figure 5.11, the MSW harmless treatment rate was only 7.2 % in 2005, and in 2014 it had reached 71.6 %, achieving an increase of 6 times in ten years [MOHURD, 2015].

As shown in Figure 5.12, by the year 2014, the MSW treatment rate of the counties in China was 85.7 %, and the harmless treatment rate was 71.6 %, while 425 counties were still without harmless treatment facilities. The harmless treatment rates of different technologies are: landfill 89.4 %, incineration 7.2 %, and other treatment 3.4 %. In the more developed eastern area, both the harmless treatment rate and incineration rate were higher. For the counties of Zhejiang Province, the harmless treatment rate was 99.7 %, while incineration accounted for 38.5 %; for the counties of Fujian Province, 87.2 % and 27 % respectively, and for counties of Jiangsu Province, 83.7 % and 21.5 % respectively.

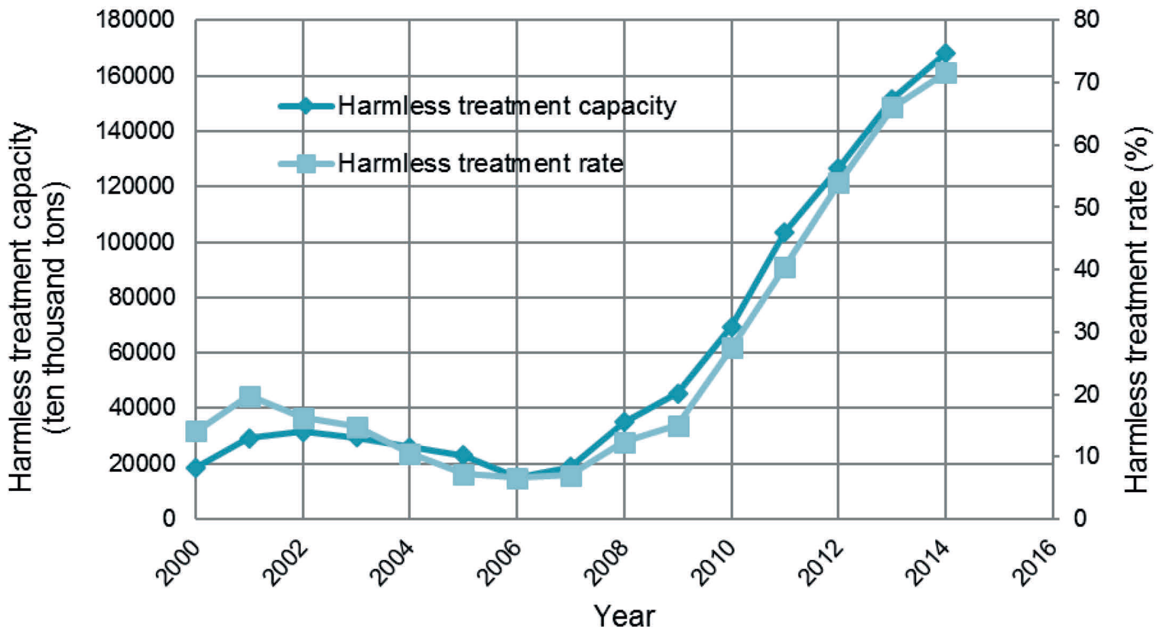


Figure 5.11: MSW harmless treatment in counties of China [MOHURD, 2015].

5.4.3 Villages and towns

Harmless treatment of MSW in rural areas has not yet been included in the statistical yearbooks. According to the research of MOHURD, the harmless treatment rate of MSW of built town areas is less than 30 %, and for the village area, the harmless treatment rate is less than 10 % [He et al., 2014].

In Eastern China, the waste is centrally treated, with the mode called “collected in villages, transferred in towns and treated in counties”, while in other towns and villages, different technologies have been chosen: dumping (simple landfill), standardized (sanitary) landfill, biological treatment and small incineration [He et al., 2014].

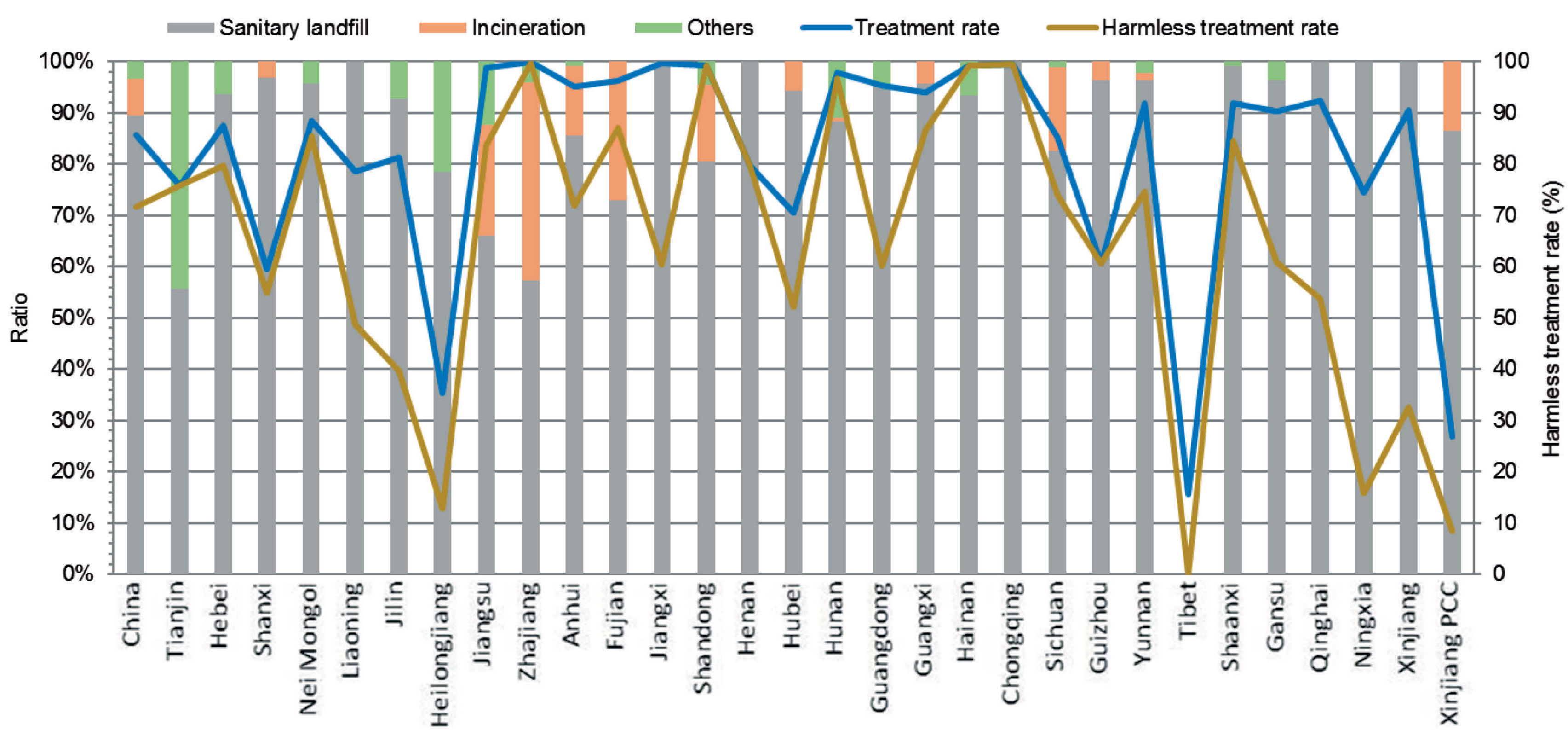


Figure 5.12: MSW treatment situation in various provinces in counties of China (2014) [MOHURD, 2015]

5.5 Costs, revenues and planned investment

According to the National Plan on Municipal Solid Waste Harmless Treatment Facilities Construction in the 13th Five-Year, during the 13th Five Year, a new increase of MSW treatment capacity of 510 thousand t/d is planned (including the continued construction capacity of 130 thousand t/d). The proportion of MSW incineration treatment capacity of total harmless treatment capacity is planned to reach 50 %, and reaching 60 % in the eastern area. A new increase of MSW collection and transportation capacity of 440 thousand t/d is planned. It is planned to encourage the co-treatment of restaurant waste and other organic biodegradable waste, and to aim to construct a new increase of treatment capacity of 34.4 thousand t/d by the end of the 13th Five-Year. For the stock waste treatment, the aim is to implement 803 landfill closure projects.

Therefore, in the 13th Five-Year period, the total investment on MSW harmless treatment facilities construction will be about 251.84 billion RMB. Of this, the planned investment on harmless treatment facilities construction is 169.93 billion, the investment on MSW collection and transportation is 25.78 billion, the special fund on restaurant waste treatment projects is 18.35 billion, the investment on stock waste treatment is 24.14 billion, the investment on MSW separation demonstration projects is 9.41 billion, and the investment on supervision system construction is 4.23 billion. The investment on MSW harmless treatment facilities construction in different provinces in the 13th Five-Year Period is shown in table 5.2.

In the aspect of financing, investment in MSW harmless treatment facilities construction is mainly based on local government input. Local governments at all levels should increase investment and establish a stable source of funds to ensure the completion of the planning construction tasks. At the same time, they should actively guide and encourage all kinds of social capital to participate in the construction of MSW treatment facilities. The state will continue to provide appropriate support on the facilities' construction according to the plan and the key tasks. The state will increase the support for the resources utilization technologies such as incineration. For those facilities that cannot be fully market-oriented operated, policy support, investment guides, and appropriate subsidies should be provided to ensure the facilities' construction and operation. The MSW treatment tariff system will be further improved. A reasonable charging system should be built according to the economic development of different areas. For the areas with satisfied conditions, the charges should cover the waste collection, transportation, treatment and disposal costs. Active research should be undertaken for quantitative charging and differentiated pricing methods. Tax preferential policies should be implemented for the waste treatment related enterprises. Funds guarantees should be strengthened for the operation of waste treatment facilities and the waste treatment fees should be all earmarked for the construction and operation of waste treatment facilities. When the waste treatment fees cannot cover the normal operation of the facilities, the local government should actively take measures to properly compensate and ensure the operation of the facilities.

Table 5.2: Investment on MSW harmless treatment facilities construction in 13th Five Year Period (100 million yuan)

No.	Region	Newly built treat-ment facility	Trans-portation facility	Restaurant waste treat-ment facilities	Stock waste treatment	Waste separation	Supervi-sion sys-tem	Total investment
	National	**1699.3**	**257.8**	**183.5**	**241.4**	**94.1**	**42.3**	**2518.4**
1	Beijing	76.5	7	9	102.5	5	2	202
2	Tianjing	51.5	4.8	4	1	5	1	67.3
3	Hebei	36	9.2	6.6	4	2	1	58.8
4	Shanxi	35.8	3.7	3.6	-	2	1	46.1
5	Inner Mongolia	24.6	5.1	3	3.5	2	1	39.2
6	Liaoning	72.9	25.1	3.9	3.7	2	1	108.6
7	Dalian	19.9	7.2	0.8	12.5	5	1	46.4
8	Jining	27.2	2.7	3	5.1	2	1	41
9	Heilongjiang	55	5.5	4.5	2.4	2	1	70.4
10	Shanghai	37.5	4.3	5.2	0.4	5	1	53.4
11	Jiangsu	52.8	11.7	13.2	3.5	2	1	84.2
12	Zhejiang	86.6	8.8	18.5	2.9	2	1	119.8
13	Ningbo	22.5	9.8	8.8	1	3.8	1	46.9
14	Anhui	108	16.4	5.9	17.3	2.5	1.7	151.8
15	Fujian	18.9	5.2	4.8	-	2	1	31.9
16	Xiamen	21.8	2.8	1.2	-	2	1	28.8
17	Jiangxi	45.7	8.1	3.6	2.7	2	1	63.1
18	Shandong	51	10	4.5	9	2	1	77.5
19	Qingdao	14.4	1	0.6	0	2	1	19
20	Henan	63.1	8.6	9.6	8.2	2	1	92.5
21	Hubei	64.3	11.5	5.3	3.5	2	1	87.6
22	Hunan	70.5	12.4	6.5	7	3	3.6	103
23	Guangdong	134	-	13.7	14.2	2	1	164.9
24	Shenzhen	90.3	6.4	3.3	2.1	2	1	105.1
25	Guangxi	27.2	6	3	3.5	2	1	42.7
26	Hainan	18.3	1	1.2	-	2	1	23.5
27	Chongqing	49.3	6.7	8.4	2.7	5	1	73.1
28	Sichuan	75.2	13.5	5.6	4.6	2	1	101.9
29	Guizhou	33	5.8	2.8	2	2	1	46.6
30	Yunnan	25.9	4.7	3.2	5.1	2	1	41.9
31	Xizang	9.4	5.2	0.6	0.5	2	1	18.7
32	Shaanxi	25.5	4.3	2.4	1.2	2	1	36.4
33	Gansu	38.7	3.5	3	7.5	2	1	55.7
34	Qinghai	54.3	3.8	0.3	2	2	1	63.4
35	Ningxia	9.1	0.9	2.1	3.4	2	1	18.5
36	Xinjiang	40.9	12.8	7.4	2.4	3.8	1	68.3
37	Heilongjiang land reclamation	6.9	1.4	0.4	-	1	1	10.7
38	Xinjiang Produc-tion and Construc-tion Corps	4.8	0.9	-	-	1	1	7.7

The local government should make integrated and overall arrangements for the scale, layout and land use of waste treatment facilities and the planning on waste treatment facilities should be subsumed into the overall land use planning, the overall urban planning and the recent construction planning.

Further needs as are follows: speed up the waste treatment industrialization development and social operation mechanism, and establish the diversified investment mechanism; improve the MSW treatment facilities investment system of the public finance as the leading; and gradually form a diversified investment mechanism, which should be government controlled (society participates and market operates); actively encourage cross regional and cross sectoral cooperation; cultivate and develop specialized and large-scale waste treatment enterprises; improve the market access system with franchise as the core operation; accelerate the application of public private partnership (PPP) model in the field of waste treatment.

5.6 Municipal solid waste treatment plan

According to the National Plan on Municipal Solid Waste Harmless Treatment Facilities Construction in the 13th Five-Year released in December 2016, it is required to rationally distribute MSW treatment facilities, and the cities and counties without treatment facilities will build harmless treatment facilities before 2018. The MSW from towns will be centralized and treated in the nearby county or city MSW treatment facilities. In principle, separate treatment facilities in towns are not suggested (Towns are far from other cities and counties can be considered as specific case). It is planned to accelerate the transformation and upgrading of existing facilities, and gradually reduce the gap on treatment technology among different areas.

In the 13th Five-Year period, a newly built MSW harmless treatment capacity of 0.51 million t/d is planned (including an extended construction capacity of 0.13 million t/d). The proportion of incineration treatment capacity will reach 50 %, and 60 % for the eastern area

Pollution control and monitoring facilities must be in strict accordance with the relevant construction, technical and environmental standards. For the facilities which are not in compliance with the standards, technical upgrading should be carried out as soon as possible or the facility needs to be shut down. The technology chosen must retain the principles of resources priority, safety, environmental protection, energy saving, land saving and economical application. Incineration facilities with a treatment capacity less than 300 t/d and landfills with a treatment capacity less than 0.50 million m^3 are not encouraged. The pilot cement kiln co-processing treatment, reduction of fly ash and biological treatment of classified organic waste can be carried out only on the basis of full demonstration.

In economically developed areas and cities with land resources shortage and large population, incineration is the priority technology. They must reduce the landfill of raw MSW; Waste residues of incineration and facilities of fly ash treatment and disposal should be taken into consideration when incineration facilities are constructed. Adjacent areas are encouraged to build centralized treatment and disposal facilities of incineration residue and fly ash through regional sharing and other means.

For the final disposal method of MSW, sanitary landfills are guaranteed for each area. In principle, the service life of city and county landfills should be more than 10 years for incineration residues and MSW treatment.

Leachate treatment facilities should be built together with MSW treatment facilities; and if possible, the joint construction of a local sewage treatment plant can be considered.

Figure 5.13 and 5.14 show the MSW treatment facilities in 2015 and the planned situation in 2020. The national treatment capacity of 2015 was 758.3 thousand t/d, and plans to increase to 1104.9 thousand t/d in 2020. The treatment rate of landfill, incineration and other treatment technologies in 2015 are 66 %, 31 %, 3 %, respectively; and planning is in place for 43 %, 54 %, 3 % in 2020.

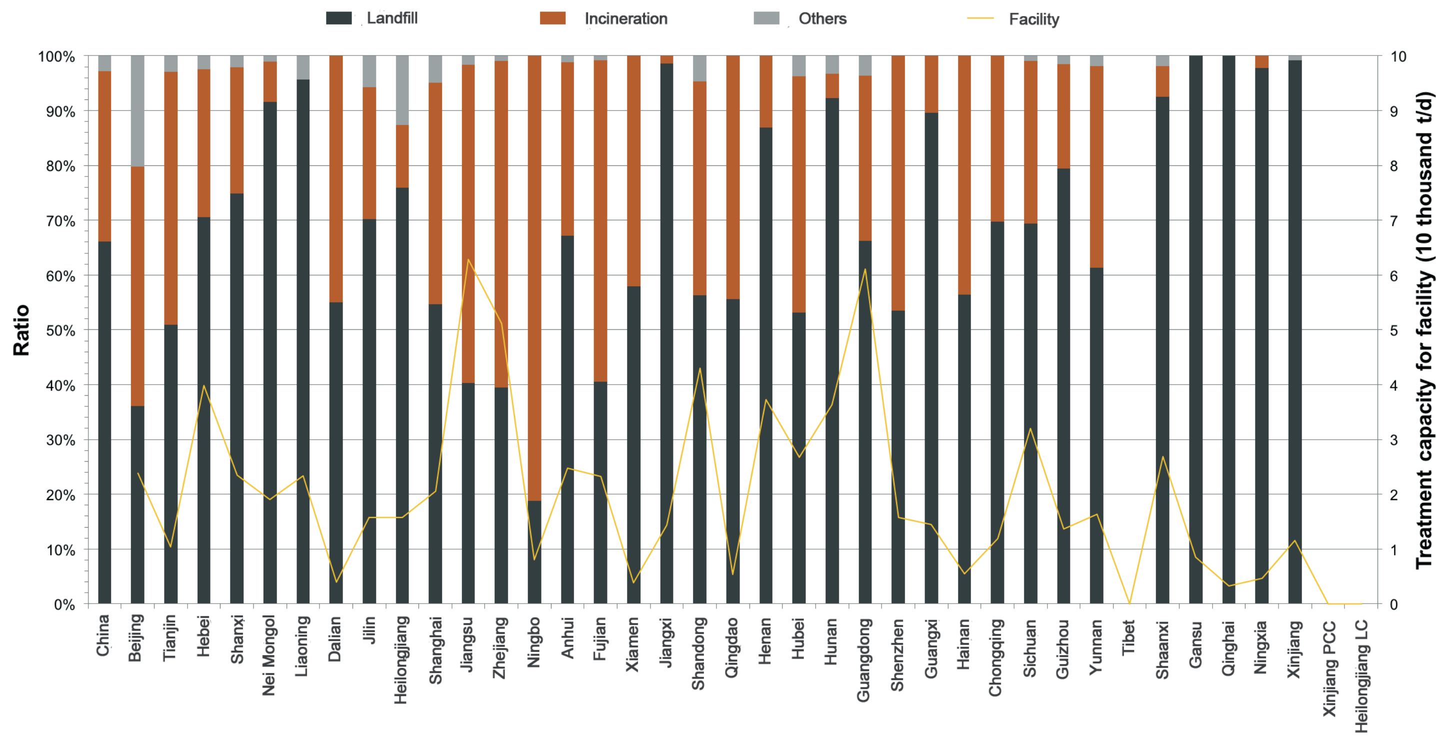


Figure 5.13: MSW treatment facilities in China (2015) [MOHURD, 2016b]

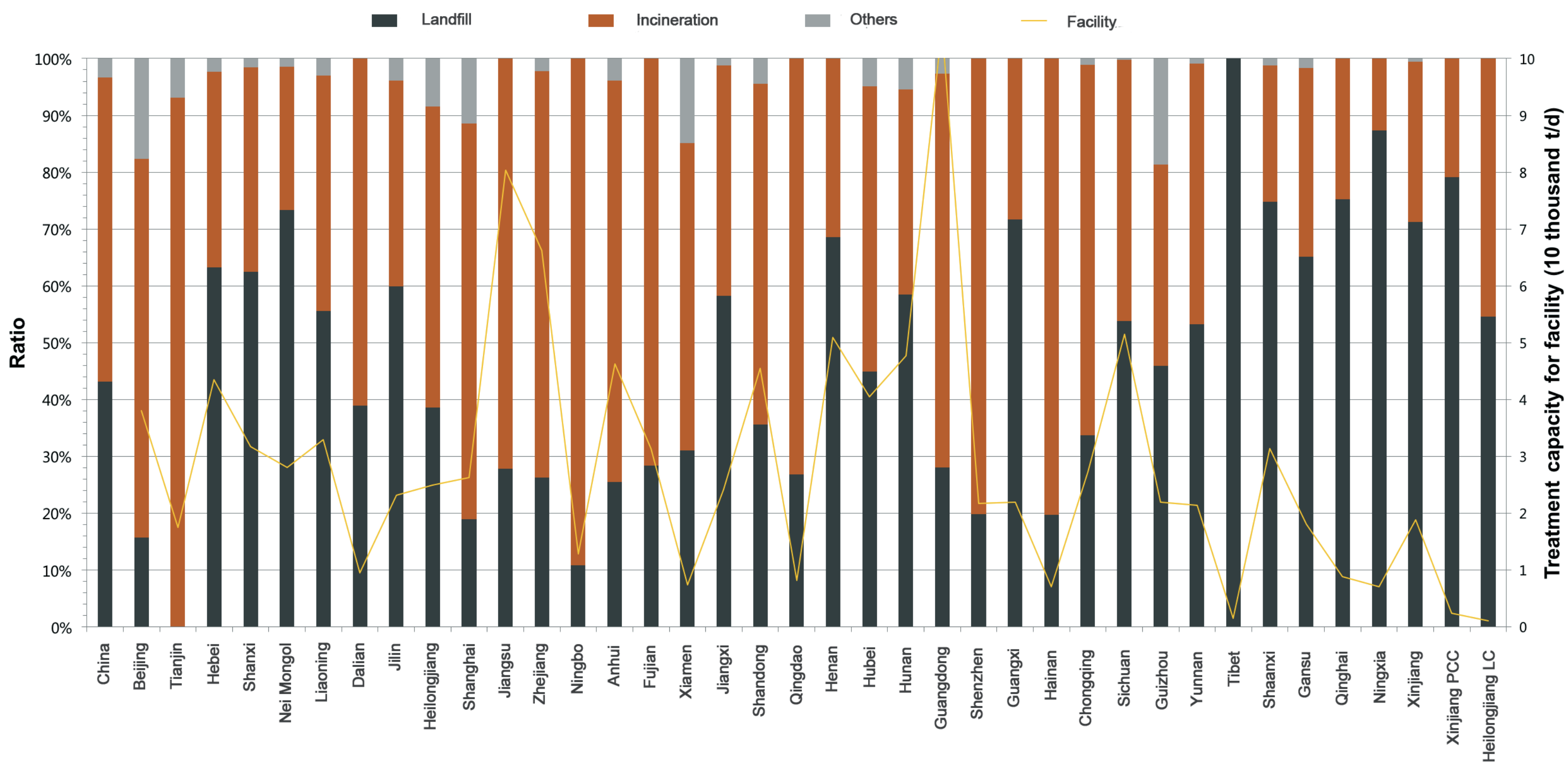


Figure 5.14: Planned MSW treatment facility in China (2020) [MOHURD, 2016b]

5.7 Restaurant Waste (RW)

According to the National Plan on Municipal Solid Waste Harmless Treatment Facilities Construction in the 13th Five-Year, the delivery system linked to classification, recycling and harmless treatment of household waste should be established. A separate classification of kitchen waste and other perishable waste is encouraged.

Further promotion of the harmless treatment and utilization capacity of RW is required. The RW treatment facilities should be planned and arranged according to the generation amount and the distribution of RW in various regions; and the use of RW to produce oil, biogas, organic fertilizer, feed additives, etc., is encouraged. The co-processing of RW and other organic biodegradable waste is encouraged. A treatment capacity of 34,400 t/d is newly increased by the end of 13th Five-Year. During the 13th Five-Year period, the special fund for RW treatment projects is 18.35 billion RMB, and the special fund for MSW separation projects is 9.41 billion RMB.

Mature and reliable technology and equipment should be chosen according to the local RW generation amount, composition and physicochemical properties. Technology selection shall comply with the standard of "Technical code for food waste treatment”, and RW conversion to fertilizer, animal fodder and energy are all encouraged. The RW accounting system should be established and the RW collection rate and collection system covering rate should be further improved. The RW should be collected timely and in accordance with the related regulation, to prevent environmental pollution during the RW collection and transportation process. Strengthening the product monitoring is required, especially product quality control and product flow monitoring, and the fertilizer and animal fodder produced by RW should be safe and should strictly abide by the related standard.

During 12th Five-Year, the RW treatment capacity increased to 13,000 t/d. In the 13th Five-Year period, the planned newly build RW treatment capacity is 34,400 t/d. The distribution in different provinces is shown in Figure 5.15.

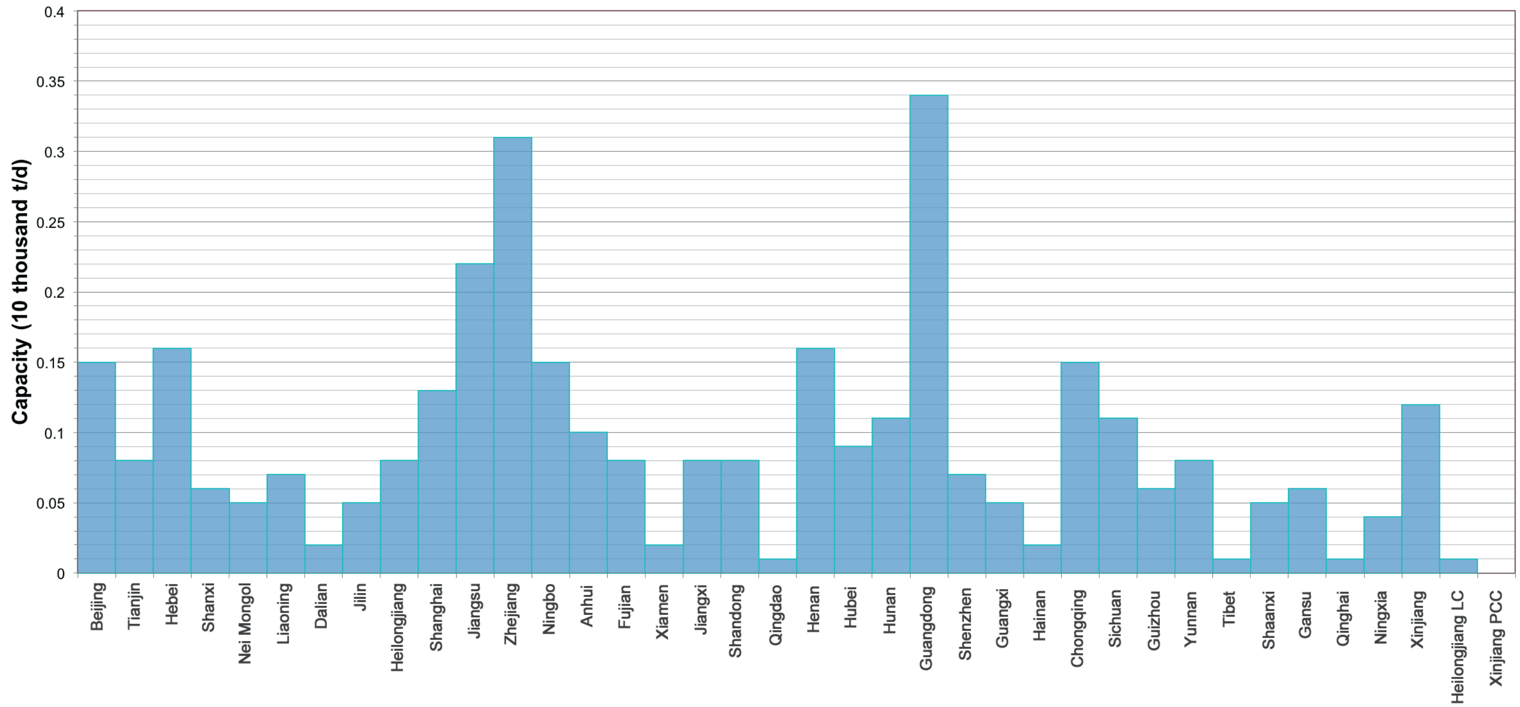


Figure 5.15: Planned restaurant waste treatment capacity in 13th Five-Year

6. Technical state-of-the-art for the utilization and disposal of biogenic waste

In Germany the municipal waste fractions glass, paper, packaging, bulky waste, e-waste, hazardous waste and green and bio-waste are collected separately, Figure 6.1. Despite all efforts put in the segregated collection, an important quantity of biogenic waste is still contained in the residual waste. Therefore, there are two main fractions of biogenic waste in municipal solid waste: a clean wich is fraction separately collected and suitable for material recovery and a mixed fraction in residual waste.

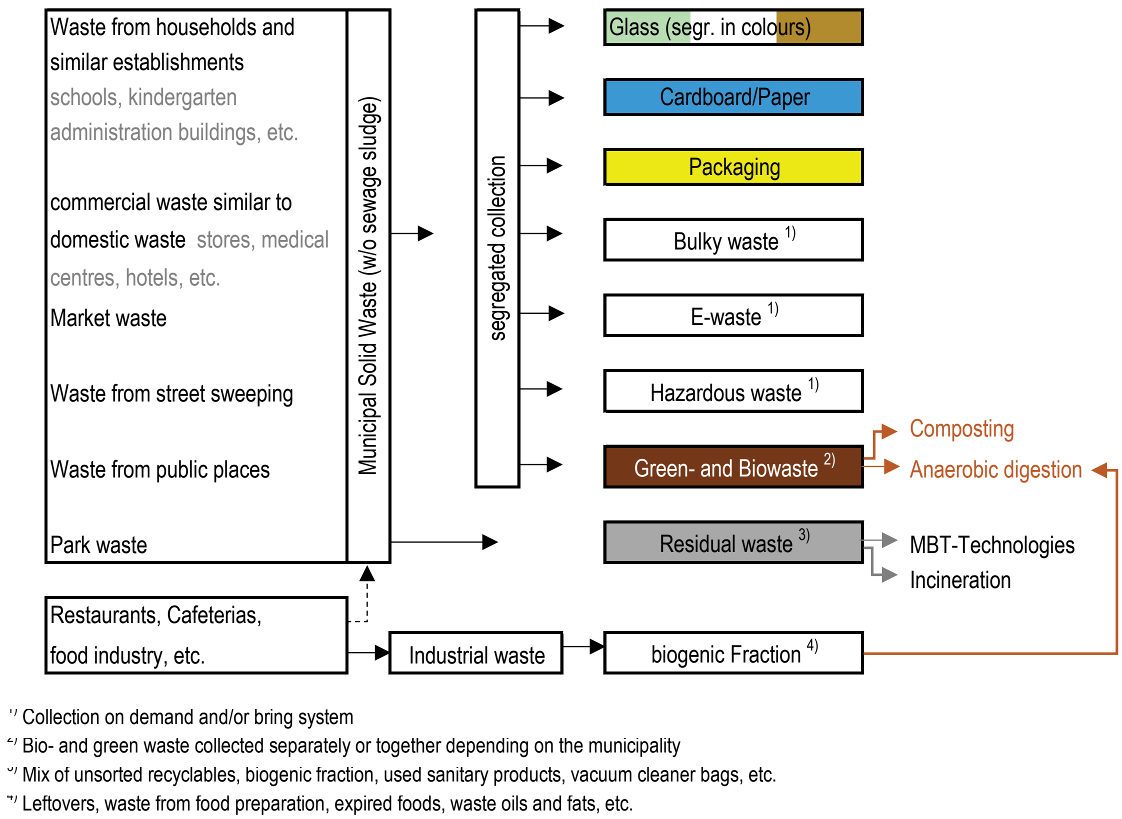


Figure 6.1: Summary of sources of municipal solid waste and waste fractions collected separately.

This Chapter will give an overview of the state-of-the-art technologies for the collection, utilization and disposal of biogenic waste from the segregated collection (Chapter 6.1) as well as the biogenic fraction contained in the residual waste (Chapter 6.2, separate collection, treatment and utilization).

6.1 Separate collection, treatment and utilization

6.1.1 Legal background and importance for resources and climate protection

For all municipal waste fractions, there are legal requirements as to how they are to be collected, transported, recycled or treated. German legislation on waste management is characterized by a large number of European directives, which have to be transposed into national law.

The central directive is the **European Waste Framework Directive** (Directive 2008/98/EC), which contains important requirements for German waste law. Article 4 specifies a waste hierarchy that prioritizes the long-term use of products (waste prevention and preparation for re-use); material recovery (recycling) comes in as the second and the last option is energy recovery.

The long-term use of products and material recovery reduces the need for energy-consuming and environmentally damaging production of new raw materials. Furthermore, energy recovery can make a sustainable contribution to resource and climate protection in terms of efficiency.

Article 8 grants extended producer responsibility to all those who develop, manufacture, process, sell or import products. This includes the withdrawal of used products and waste as well as financial responsibility for its sustainable exploitation. The goal is to improve reuse, prevention and recycling. Furthermore, the products should be usable several times, technically durable and, after they have become waste, be suitable for proper and harmless recovery and environmentally compatible disposal.

The **European Council Directive** 1999/31/EC of 26th of April 1999 on landfill sites requires EU countries to gradually reduce the amounts of biodegradable waste on landfill sites to reduce its environmental impacts. This target can only be achieved by segregating and recycling. By 2030, a maximum of 10% of the municipal waste may be deposited on landfills in the EU.

In Germany, the first federal ordinance regulating waste legislation was created in 1972 with the Waste Disposal Act. Today, the **Waste Management Act** (KrWG) is the core of waste legislation. The closed substance cycle waste management is even more focused on resource, climate and environmental protection. The five-step waste hierarchy of the European Waste Framework Directive has been implemented. Based on this, the waste management measure which is most appropriate to ensure the protection of the general public and the environment has to be chosen.

So far no specific regulation is prescribed; it is assumed that the energetically and material recovery are equivalent if the calorific value of the segregated waste fractions is 11,000 kJ/kg (§ 8 para 3 KrWG). The intention is to prevent the use of energy from low-caloric waste as its combustion does not provide a relevant contribution to resource conservation and thus cannot be regarded as a preferred environmental option.

In addition, recycling is promoted and secured by the introduction of the nationwide mandatory segregated collection for bio waste (§ 11 para. 1 KrWG) as well as of paper, metal, plastic and glass waste (§ 14 para 1 KrWG). By 2020, a recycling rate of at least 65% has to be reached for municipal waste (§ 14 KrWG). Furthermore, there is a general prohibition of mixing hazardous waste with other waste streams in the future (§ 9 para 2 KrWG). The separate collection of bio-waste and recyclables should increase the efficiency at the waste material usage.

After the ban of landfilling of untreated municipal waste the only possibility to reduce the annual emissions of climate-damaging gases in Germany, is the increased use of material and energy by increasing the efficiency of waste treatment plants and, in particular, by increasing the material recycling of waste streams (compare chapter 6.2.1).

6.1.2 Collection and transport

The separate waste streams are collected by the citizens in waste disposal containers located at their residential buildings. This collection system is referred to as a curbside system. It mainly collects paper and cardboards (blue bin), lightweight packaging (yellow bin/ bag) and organic waste (usually brown bin). Reusable waste separated from households is also collected at central collection points. This so-called bring system is mainly used for packaging, glass (separated into green, brown and white glass) and old textiles. The collection at recycling centres and recycling points is also part of the bring system. There are different collection systems for bulky waste. Batteries and electrical appliances can be returned to the retailer, a special form of the bring system. The retailer also takes back returnable beverage containers.

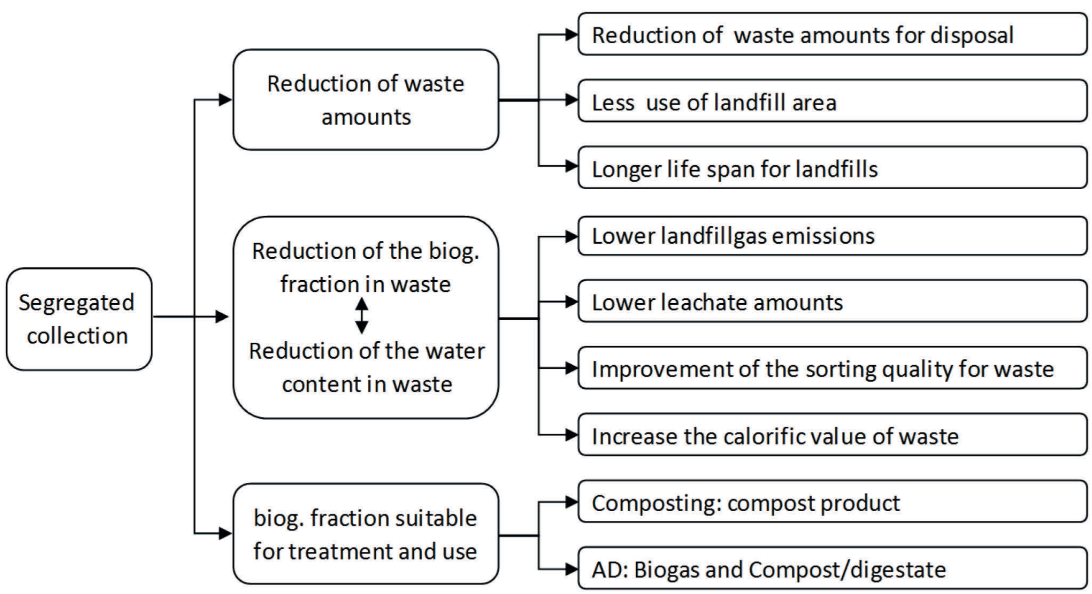


Figure 6.2: Importance of segregated collection for climate and resource protection

Some of these collection systems are not uniform throughout Germany. However, in any case, a fraction of the municipal waste which is not recyclable remains as the so-called residual waste.

In Germany, waste segregation is the answer to tackling several environmental problems arising from waste management. Since the biogenic fraction is the main factor responsible for climate relevant-emissions, the segregated collection and treatment of this fraction has significantly reduced these emissions. The separate collection of bio-waste is also a precondition for the production of high-quality composts and therefore for the recirculation of organic matter and nutrients. Furthermore, the segregated collection of biogenic waste and its recycling reduces the amounts and changes the composition of residual waste as well as it reduces its water content. Figure 6.2 summarizes the different benefits achieved by the segregated collection of biogenic waste.

Figure 6.3 shows the development of waste segregation in Germany over time. While the amount of residuals has decreased, the amounts of the different recyclable fractions (including bio-waste) have increased. Since 2004 the amounts of recyclable materials collected separately was bigger than the amount of residual waste.

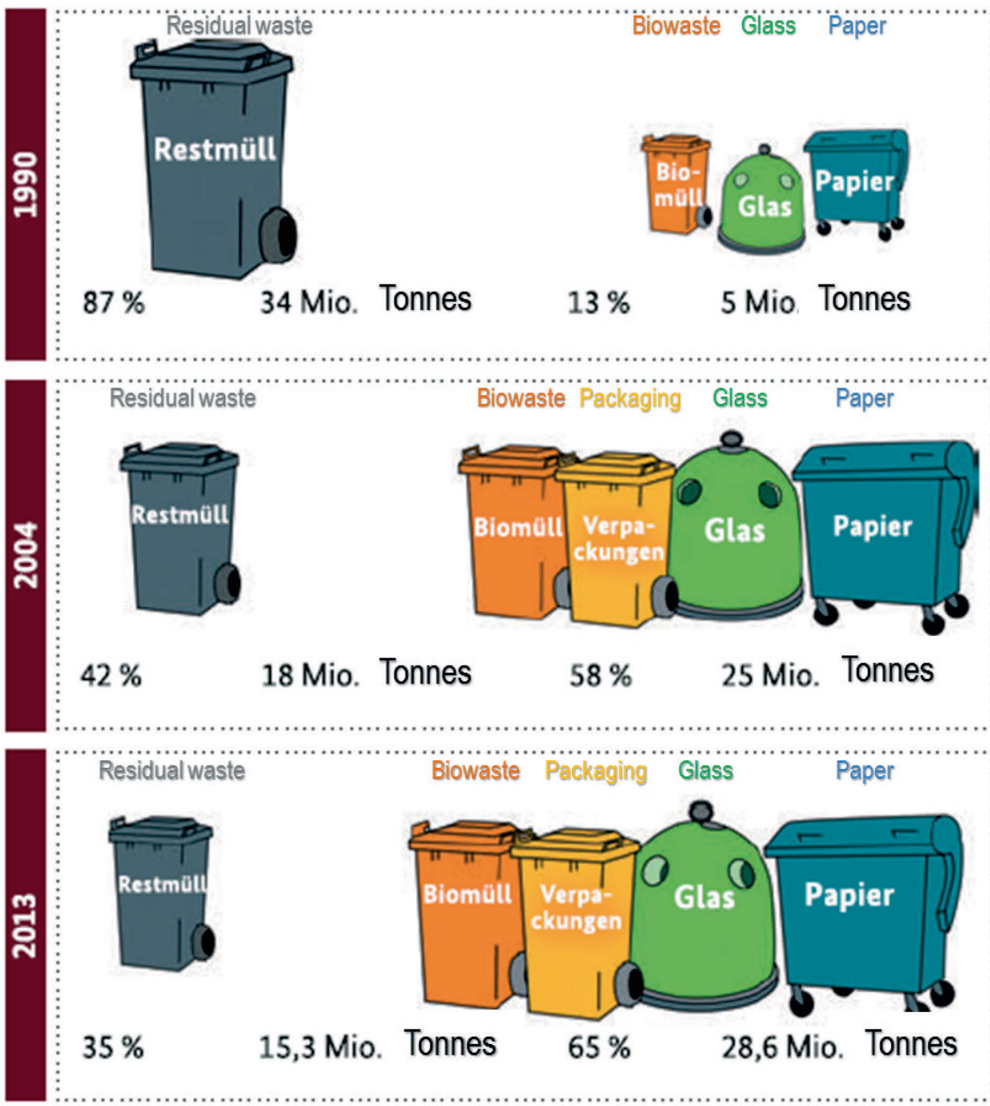


Figure 6.3: Development of segregated collected amounts of different recyclables and residual waste in Germany [BMUB, 2015]

In 2014, about 9.8 million tons of biogenic municipal waste was collected. These include bio-waste, mainly kitchen waste, and green waste from households, green waste from parks and municipal green areas, commercial waste and food waste. In Germany, a large proportion of agricultural residues, such as manure and dung, do not count as bio-waste since they are not disposed of as waste.

The municipalities determine whether kitchen and green waste from households should be collected jointly or separately, as well as whether the collection is carried out as curbside or bring system.

In densely populated areas, the curbside collection system is most usually used for biogenic waste. Only in sparsely populated areas, the population needs to bring the biogenic waste, mostly only the green waste fraction, to central collecting points. There are a variety of different containers and vehicles in different sizes available for collection at household level, and at central collection points as well as for collection and transport.

Depending on the need, there are different collection containers from plastic bags to bins (usually made of plastic) in different sizes. A wide variety of vehicle models are used, adapted to the waste collection system.

6.1.3 Process and technologies

Composting and anaerobic digestion are the main state-of-the-art technologies to recycle biogenic waste. Both make use of natural processes, but while composting is an aerobic process, anaerobic digestion works under the absence of oxygen. Figure 6.4 gives an overview of the different technologies.

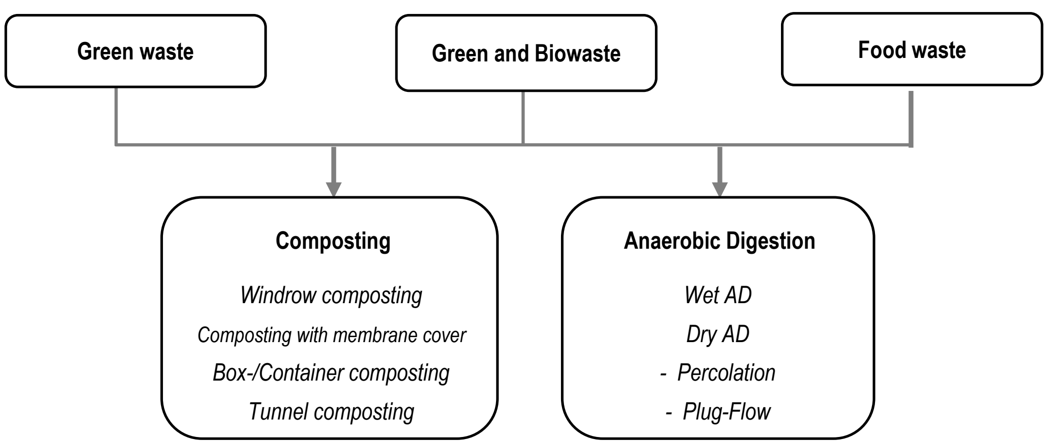


Figure 6.4: Established technologies and treatment systems available for the recycling of bio-waste

Which technology is the most suitable depends on the composition of the biogenic waste. For wet bio-waste from households and household-like institutions as well as for food waste, anaerobic digestion is a good option for the energetic use (biogas) and the subsequent material utilization of the digestate.

For lignin and cellulosic plant material in green and bio-waste, composting is the best option. In the case of composting, only material recovery is possible. If the share of wood-containing components in green waste is high, these components could be sorted and used as fuel for energy production in a biomass heating plant.

Both, the material recycling of compost and digestate on soil as well as the energetic utilization of biogenic waste, contribute to the protection of the climate and resources. Figure 6.12 (in chapter 6.1.4, Emissions) compares the benefits in terms of emissions of the recycling of biogenic waste. A combination of both uses such as biogas production from biogenic waste and the subsequent use of digestate as organic fertilizer (multiple uses) is at present the preferred option in Germany.

In Germany, farmers are the main beneficiaries of the recycling of biogenic waste. In 2014, almost all of the digestate from AD was used as fertilizer [BGK, 2016]. By this practise considerable amounts of mineral fertilizers were replaced and the biogenic waste recycling products contributed to the (conservation of the) soil fertility. Figure 6.5 summarizes the benefits of applying compost and digestate.

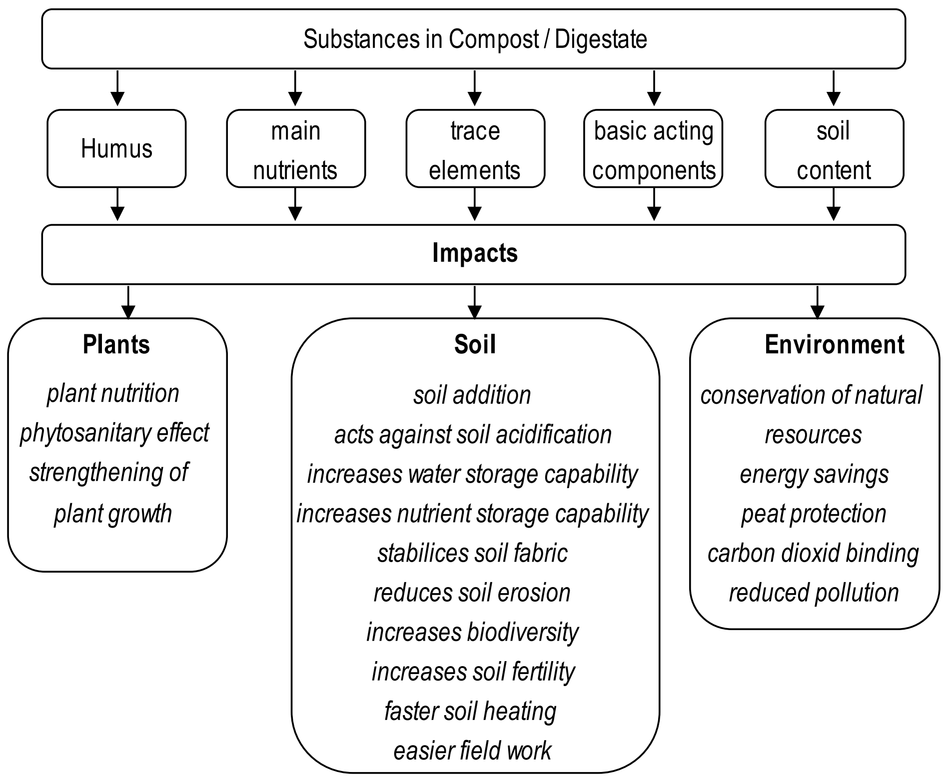


Figure 6.5: Components of compost and their effects on plants, soil and environment [VHE, 2016; modified].

6.1.3.1 Composting

<u>PRINCIPLES</u>: Composting is an aerobic biological process that involves a series of different microorganisms decomposing organic materials and converting them into a biologically stable product used as a valuable soil supplement. In a well-managed composting system the loss of organic matter during the transformation process can range from 30-60%. As shown in Figure 6.6, composting is monitored and controlled, aerobic conditions are maintained. This includes a high-temperature, **active composting phase,** that reduces or eliminates pathogens

and weed seeds (harmlessness) as well as a slower phase, **curing phase**, in which the compost reaches maturity and stability [Nelles et al., 2017].

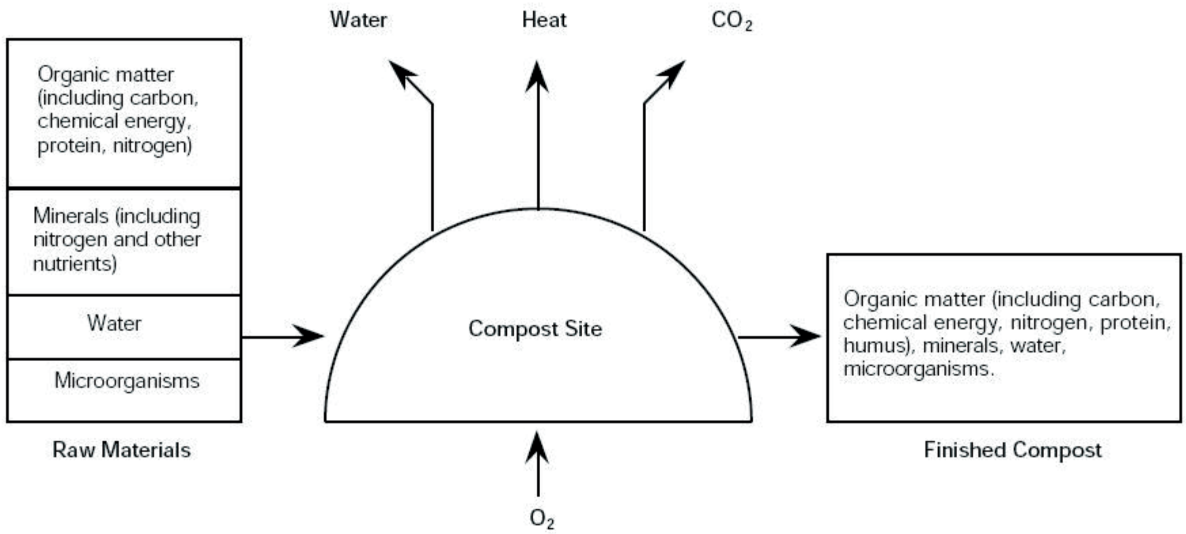


Figure 6.6: The composting process [Rynk et al., 1992]

PROCESS MANAGEMENT PARAMETERS: Several key process management parameters are commonly used to monitor and control the composting progress. Figure 6.7 provides a summary of the different control parameters to define optimal composting conditions and the product quality assurance. These parameters apply to all composting methods and technologies. However, the emphasis placed on each parameter varies from facility to facility, depending upon feedstock types, composting technology, and operator experience.

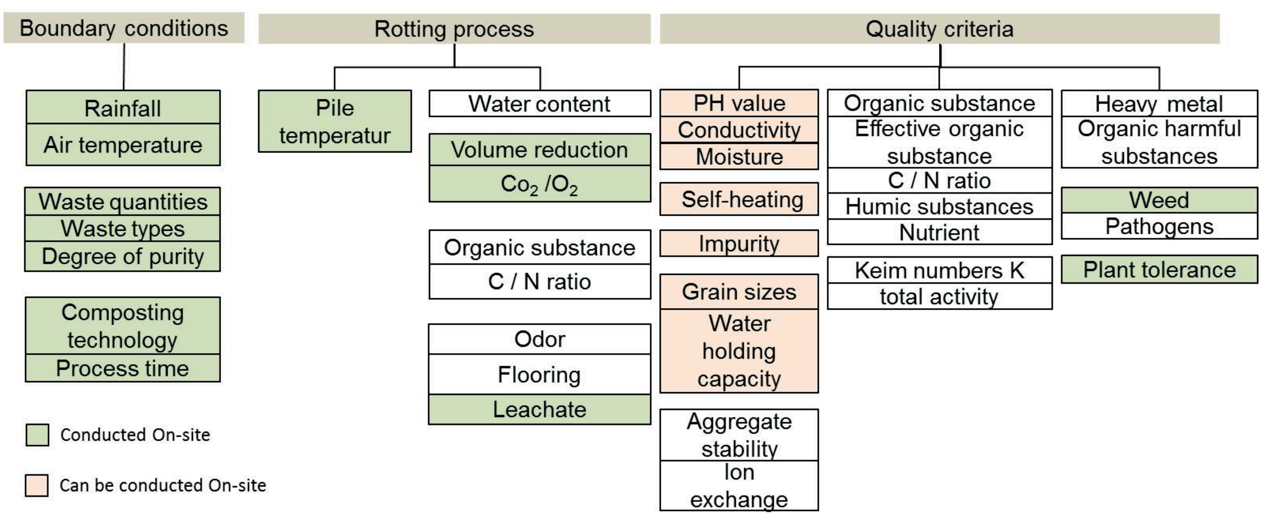


Figure 6.7: Control and quality assurance parameter for composting and final product [Schriefe, 1998]

TECHNOLOGIES: Although all composting technologies make use of degradation processes, the available technologies differ considerably. The compost technologies concentrate on the active rotting step. Curing mostly takes place in windrows. The following figure shows a layout of a compost facility.

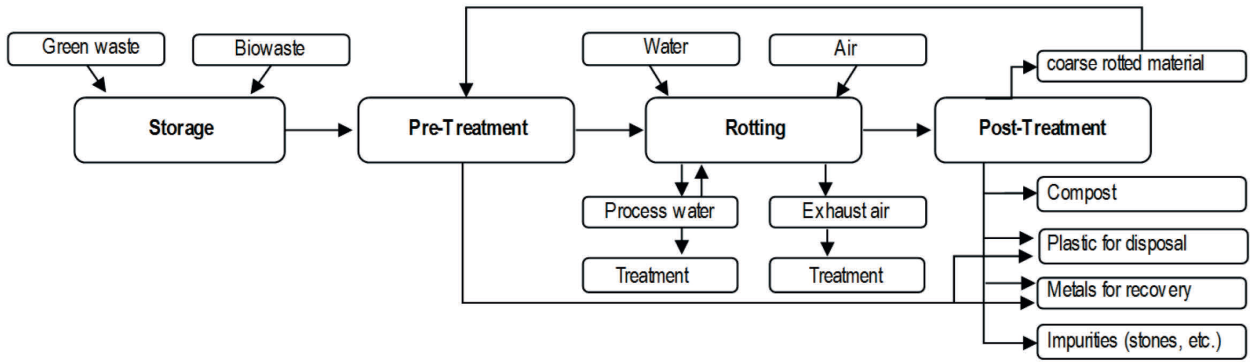


Figure 6.8: Simplified layout of a composting facility

The treatment capacity of composting plants can vary from less than 1,000 to more than 100,000 Mg/a. Depending on the capacity, input material, local conditions and requirements, the layout of the plant differs significantly. Usually, different types of mechanical treatment (separation, size reduction, turning, mixing, etc.) are applied before, during or/and after the composting process.

Facilities are commonly classified considering whether the active rotting system is:

- Merely for "green" waste or for bio-waste from segregated collection
- Open, enclosed or in-vessel
- Passively or actively aerated
- Static, semi-dynamic or dynamic (mechanical agitation/turning)

The differentiation between open, closed and in-vessel facilities considers whether the rotting process takes place outdoors, in enclosed buildings or in reactors. The consideration of this aspect is of importance mainly when analyzing emissions but also when considering construction costs [Rettenberger et al., 2012].

Both the aeration and the mechanical turning enhance the air supply in the compost and therefore influence the rotting time. In passive aeration systems the porosity of the compost material determines the air exchange rate. In this case the turning is used to re-establish the air content within the material.

In the following, the most common technologies will be briefly described.

Windrow composting

Windrow technology can range from simple open windrow (outdoor) to enclosed systems in a building as well as passively and actively aerated systems. Windrow composting implies forming long rows of triangular or trapezoid cross sections. The dimensions depend on the windrow turning machine and are important to allow the generation of sufficient heat and the air supply.

Windrow composting is suitable for a wide range of feedstock and facility capacities with low infrastructure requirements. The disadvantages are the relatively long composting times of several weeks and the large area requirements. Furthermore, in open systems the high odour potential is a problem.

Extended beds

Extended bed composting systems can be seen as a special form of windrow composting, where the organic material is formed to a wide “extended windrow” instead many narrow ones. In this way, the area requirements can be significantly reduced. Extended bed systems are therefore suitable for larger feedstock amounts and are mainly enclosed. Usually, in enclosed systems, in-floor forced aeration (positive or negative) and turning are combined. The composting time in extended beds ranges from 45 to 90 days [Kern et al., 1998, Zachäus, 1995].

Encapsulation with semi-permeable membrane cover

This technology was developed as an improvement to the open windrows system, to enhance operation and reduce odour emissions. Emission- and process-control is accomplished by the semipermeable behaviour of the membrane in combination with forced aeration. The system is considered as an enclosed technology.

The membrane is semi-permeable to gases but larger odour-causing molecules cannot diffuse through the small pores. On the inner side of the membrane, condensation water accumulates, absorbs the odorous compounds and precipitates back to the windrow. Back in the windrow odorous compounds are further decomposed. The cover reduces run-off and leachate problems as well as loss from evaporation. Furthermore, the cover reduces vector attraction [Nelles et al., 2017].

Channel and tunnel composting

These enclosed technologies combine forced aeration and agitation. In both aerations, watering and turning can be regulated separately for each channel or tunnel. In channel systems the waste material is piled between walls open to the roof. The feedstock is piled vertically to the sides, so that the space requirements are lower than in windrow composting. Since the channels are placed in a building, corrosion and exhaust air treatment problems are the same as of closed windrow composting systems.

Tunnel systems are closed to the top, minimizing in this way the exhaust air volume, which reduces building damage due to corrosion. Some tunnel systems have only aeration but no agitation components. The composting period depends on the length of the tunnel, turning frequency and desired compost quality. Common composting periods range from 2-12 weeks [Nelles et al., 2017].

Box- and container composting

These are in-vessel, static technologies. The volume of rotting boxes is 50-60 m^3 while the volume of rotting containers is 20 m^3 and these can be transported. Both systems are actively aerated. They both also have a leachate collection system and treat exhaust gases with a bio-filter. The technologies are modular so that it is easy to expand the capacity by adding a new box or container. However, due to the low capacity of each box/container their suitability for large-scale operations is limited.

The following table provides a summary of the different composting technologies mentioned above.

Table 6.1: Summary of the technologies used utilizing the aerobic process.

Treatment system	Capacity t/y	Energy input		Area needed	Time weeks		Operation cost	Investment
		dsl	elec		intensive	curing		
Windrow composting (enclosed)	1 000 - 50 000	M	M	H	3	8-10	L-M	M
Windrow enclosed with membrane cover	1 000 - 50 000	M	L-M	H	3	8-10	L-M	M
Tunnel composting line	15 000 - 100 000	L	M-H	L	1,5	8-10	M	M-H
Box-/Container composting	100 - 15 000	L	M-H	L	1,5	8-10	M	H

L: Low, M:Medium, H: High

6.1.3.2 Anaerobic Digestion

PRINCIPLES: Anaerobic digestion (AD) is a biological process that uses microorganisms to break down organic material in the absence of oxygen. Critical environmental conditions, such as moisture content, temperature, and pH levels, are measured and controlled within the reactor to maximize biogas generation and waste decomposition rates. The most important product of the AD process is biogas; it can be used as fuel and consists primarily of methane (CH_4) and carbon dioxide (CO_2).

TECHNOLOGIES: AD technologies comprise a mechanical pre-treatment stage before the digestion, the digestion itself and a post treatment of the digestate, as well as the energy use of the biogas. Generally, the pre-treatment consists in the removal of metals and oversized materials. To enhance the digestion process, a more homogenous input material can be achieved by reducing the size of the feedstock (pulping, cutting, drumming, etc.). Figure 6.9 shows the simplified layout of a digestion facility.

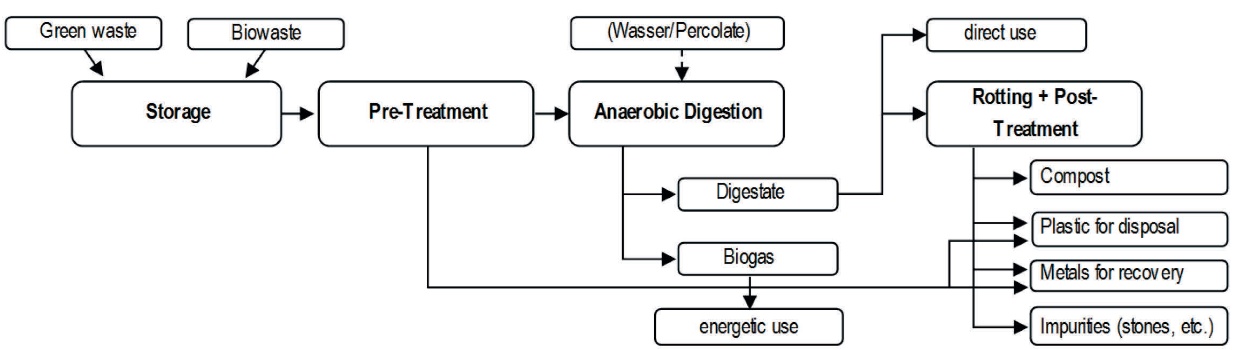


Figure 6.9: Simplified layout of an anaerobic digestion facility with pre- and post-treatment

There are a wide variety of engineered systems for AD available, designed to optimize the biological process in order to produce biogas rich in methane for energy recovery. All technologies are enclosed and have specially designed vertical or horizontal reactors, where the feedstock break down takes place. In the following, different criteria used to classify AD technologies are presented [Nelles et al., 2017].

Wet /dry digestion

The classification between wet and dry AD considers the dry solids content of the substrate. While the dry matter content in wet digestion ranges from 3-15%, it can vary from 15-45 % in dry digestion systems. Figure 6.10: Different anaerobic digestion processes and their optimal dry matter content. Since wet digestion deals with materials suspended or dissolved in water, the feedstock material is pumped and the process is carried out in stirred, sealed digesters (tanks). The mixing is essential for different reasons. One is to ensure sufficient contact between the microbes and the substrate since the liquid substrate mixture is prone to get split into two or more layers leading to lower gas production. Another is to make sure that the optimal average solid retention time is maintained. Input material, which can be easily converted to liquid, like food waste, is best suitable for wet systems.

The dry matter content of the feedstock for dry systems can differ significantly, thus showing a different “structure”. The feedstock for dry systems can consequently include materials such as garden waste and crops straw. Compared to wet systems, dry systems are less susceptible to physical contaminants (sands, fibers, etc.). Due to the input material´s composition, the feed-stock is usually piled in place [Nelles et al., 2017].

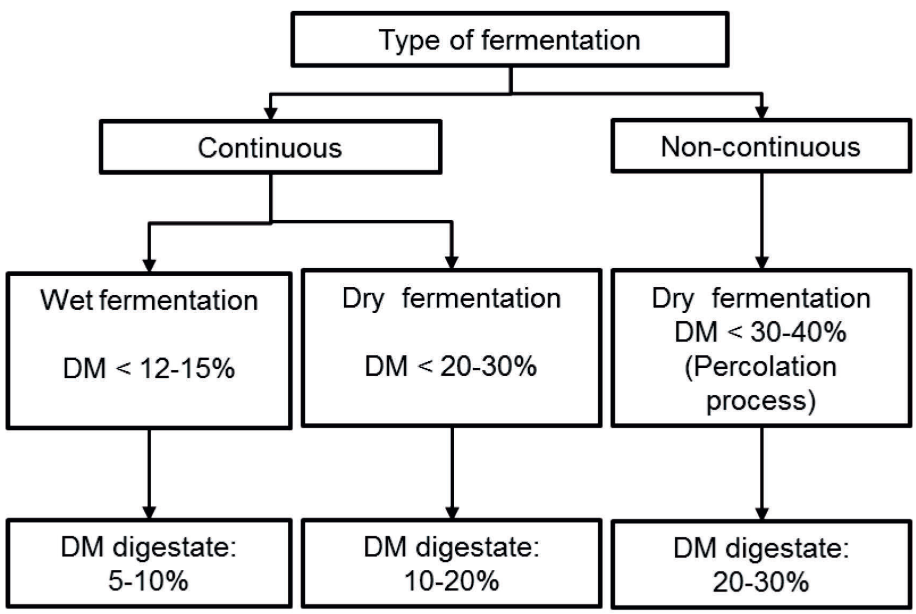


Figure 6.10: Different anaerobic digestion processes and their optimal dry matter content [BMUM, 2009]

The two main systems applied for the treatment of source segregated MSW are percolation and plug flow systems. The *percolation* technology usually uses a container or garage digester with a percolation drainage system to irrigate the feedstock. The anaerobic process lasts for 4 to 8 weeks (retention time). In percolation technologies the structure of the feedstock is essential to allow the irrigation of the percolate throughout the whole digestion process. The height of the feedstock pile in the digester is limited to 2-3 m to avoid compaction at lower layers.

In the *plug flow* technology a horizontal lying cylindrical or rectangular digester is equipped with an agitation system. The electric driven agitators mainly promote the degassing. The direction of the agitation is changed periodically, so that the feedstock movement through the digester is a result of the material fed to the digester and takes place as a plug-flow continuously pushed forward by the fresh material [Kern et al., 1998, Zachäus,1995].

Single- or two-stage systems

AD systems can be also designed as single or two stage systems. In a single stage digestion system, all stages occur in the same vessel, at a pH between 6 and 7, which is not the optimal of the involved microbes. Two stage systems attempt to optimize the pH for the microorganisms by operating in two different vessels with different conditions. A disadvantage of this division is higher costs for the construction and operation.

Mesophilic or thermophilic systems

There are two favorable temperature ranges in technical AD systems: the thermophilic range, 45-60°C and the mesophilic range, 30-45°C. To sanitize the material in mesophilic systems a pasteurization unit is used. Nowadays, both systems are equally widely used for the treatment of source segregated organic waste.

Continuous or batch systems

Technical AD can be operated as a continuous or as a batch process. In continuous systems, substrate is regularly fed and digestate removed to achieve an approximately continuous biogas quantity and quality production. In batch systems, the digester is filled and closed for the digestion period, so that biogas amounts and quality vary with time. To reach more continuous qualities and amounts of biogas, parallel batch systems can be used and operated consecutively [Nelles et al., 2017].Table 6.2: Summary of the technologies used utilizing the anaerobic digestion process.

Table 6.2: Summary of the technologies used utilizing the anaerobic digestion process.

Treatment system	Dry AD (kitchen and green waste)						Wet AD (kitchen waste)					
Parameter	Capacity t/y	energy	Time weeks	Net energy output	Operation cost	Investment	Capacity t/y	energy	Time weeks	Net energy output	Operation cost	Investment
Single systems	10 000 - 100 000	L-M	2-4	L	L-M	L-M	3 000 - 250 000	M-H	2-6	L	L-M	L-M
two-stage systems		L-M	2	M	M-H	M-H		M-H		L-M	H	H
Mesophil systems		L-M	2-4	M	L-M	L		M-H		L-M	L-M	L
Thermophil systems		M-H	2	H	M-H	M-H		H		M	H	H
Continuous systems								M-H		L-M	L	L-M
batch systems		L-M	2-4	M	L-M	M						

L: Low, M:Medium, H: High

6.1.4 Operation of facilities

Figure 6.11 illustrates the objectives and necessary aspects to be controlled to ensure the proper operation of facilities. Individual aspects, which could be especially important for China, are explained in detail.

STAFF: The staff must be well trained. A theoretical basis only is not sufficient. Especially for the biological composting process practical experience is necessary. In Germany, the profession of "waste supplier and disposer" exists for personnel working in waste treatment plants.

With regard to the number of personnel, no general statement can be made, since composting and/or AD plants differ greatly in the plant technologies and sizes. Depending on how the input or output is carried out (by wheel loader or automatically), on whether and how the implementation of the compost heaps is handled as well as on whether it is a closed (indoor) or open (outdoor) composting facility or an AD plant, the numbers will vary [Nelles et al., 2017].

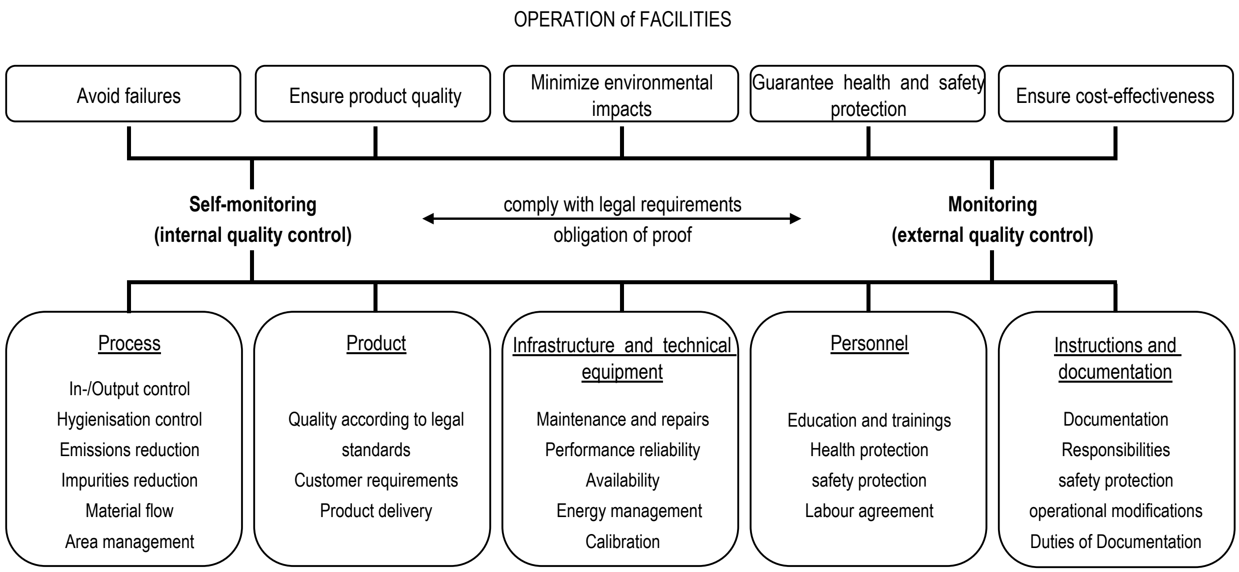


Figure 6.11: Target of facilities operation and aspects to be monitored

In General, however, it can be assumed that at least one mechanic must be on site for the operation and maintenance of mechanical processing units as well as one electrician for the electrical components. A driver can also be required to operate mobile devices (wheel loaders, trucks, etc.).

For the centrepiece of the plant, the biological process, a responsible person is needed who has extensive knowledge of biology and its influence factors. The person must be able to make adjustments based on the input or the process parameters (moisture, pH, temperature, etc.) in order to avoid problems in the biological process. Furthermore, the person should also be able to carry out sampling processes in order to ensure a good quality of the final product.

QUALIFICATION/TRAINING: Especially for the person responsible for the bioengineering, a long practical training in an already established and well-functioning plant would be recommended. In order to deal with all seasonal fluctuations in climate and waste composition, one-year training would be welcome. A major problem is the long-term connection of the operating crew, whereby new staff has to be re-trained again and again. This point is described in detail in chapter 6.2.3.

CORROSION PROTECTION: The plant's design should be of high quality and its maintenance should be fast and accurate in order to prevent or reduce corrosion. Without long-lasting and functional corrosion protection, steel structures are already damaged after only a few years. Huge losses can therefore be avoided by proper corrosion protection.

EMISSIONS: The state-of-the-art treatment of biogenic waste can contribute to climate protection, since it avoids emissions, which would have arisen without the treatment, as Figure 6.12 illustrates.

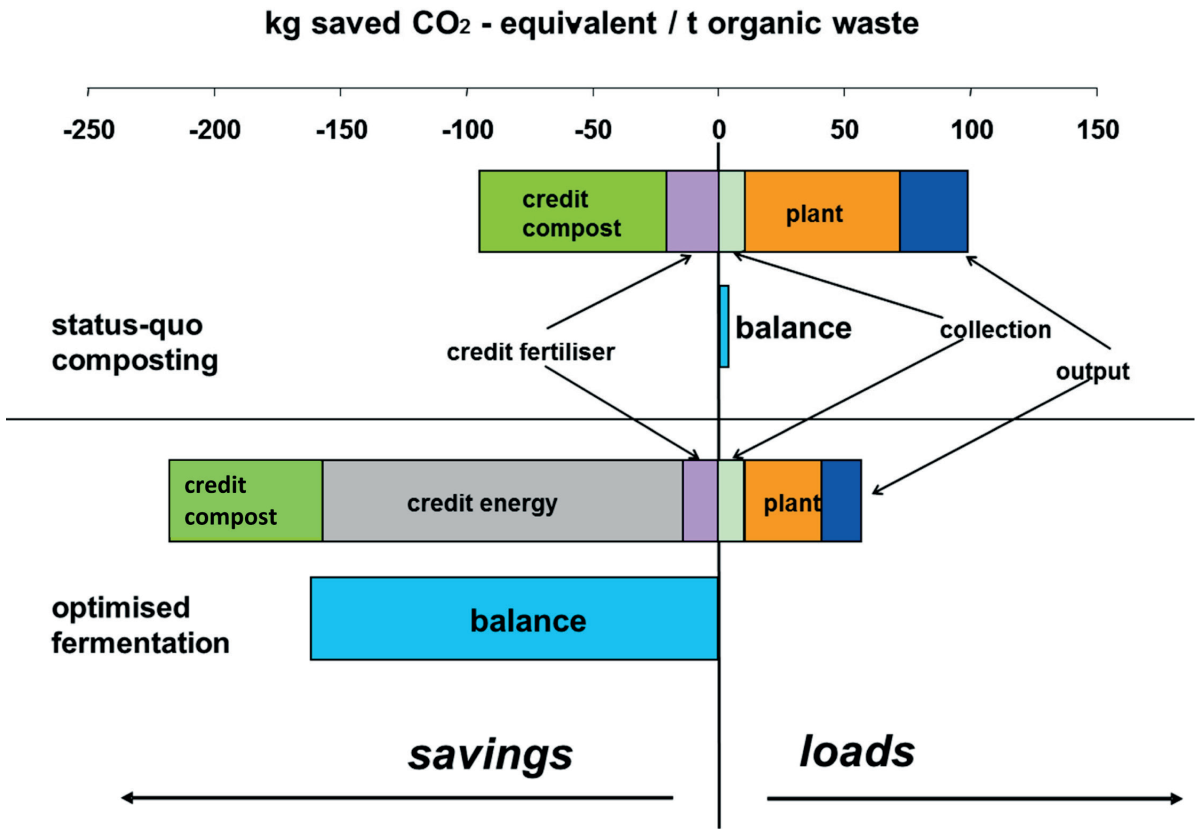


Figure 6.12: Comparison of emissions avoidance [UBA, 2015]

Thanks to the treatment of segregated biogenic waste, emissions from waste management could be decreased. Table 6.3 shows and compares the emissions from biogenic waste recycling with the total emissions in Germany. With a share of 0.1% the emissions from biogenic waste treatment are low.

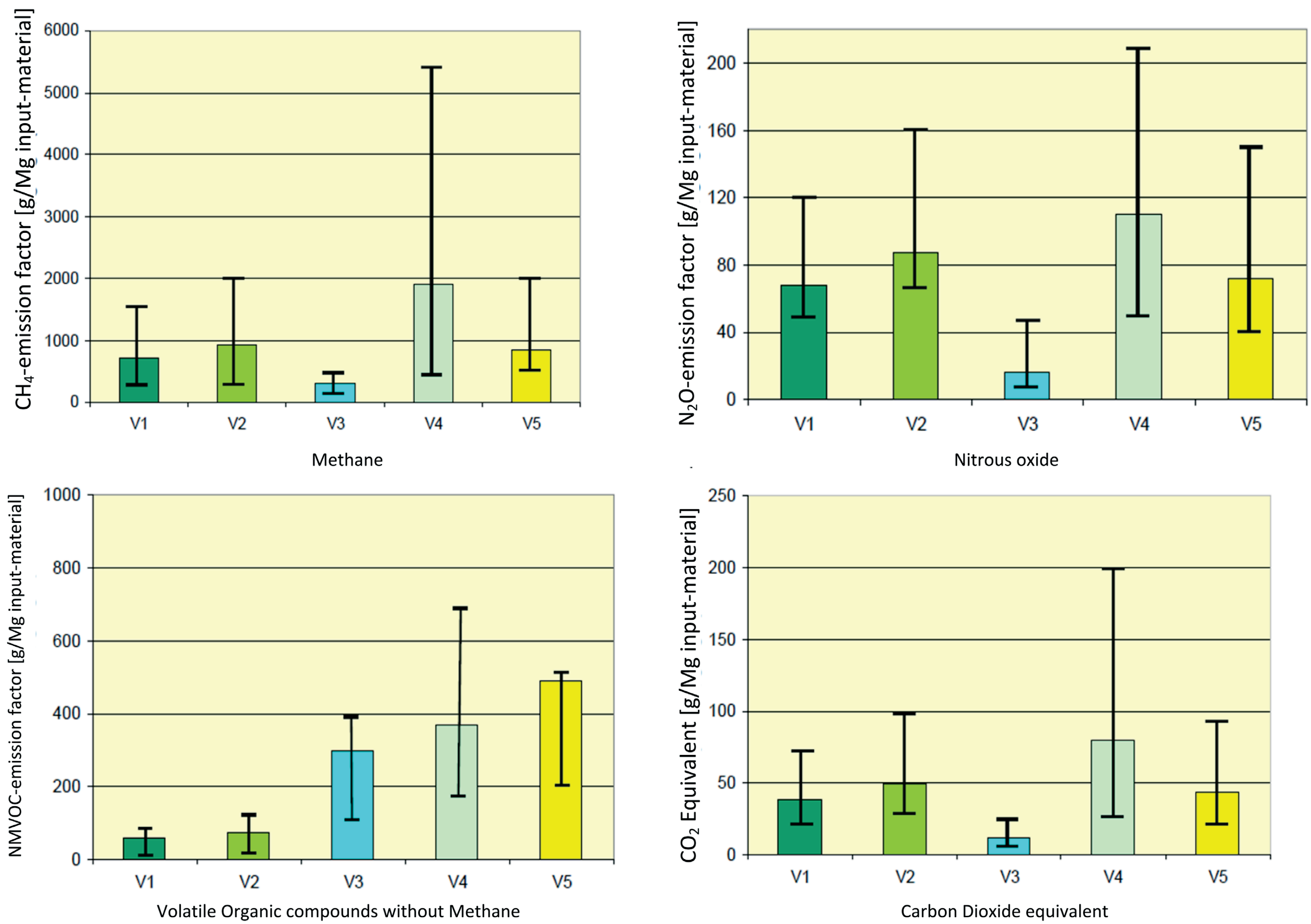
Table 6.3: Emission factors for the total recycling (treatment process + storage + product application) of organic- and garden-waste in Germany, calculated for the data base mean

		treatment-process (average) [1]	product-storage [2]	product-application [3]	sum [1] to [3] (average) [4]	emission in Germany [5]	part [4] of [5] (average) [6]
CH_4	Gg/a	23.48	0.0009	0.005	**23.49**	**2,324**	**1.011 %**
NMVOC	Gg/a	2.90	---	---	**2.90**	**1,284**	**0.226 %**
NH_3	Gg/a	1.59	0.1187	0.712	**2.42**	**597**	**0.405 %**
N_2O	Gg/a	0.56	0.0302	0.181	**0.77**	**216**	**0.357 %**
CO_2-Äq.	**Gg/a**	753.77	9.0299	54.179	**816.98**	**805,959**	**0.101 %**

Nevertheless, emissions from composting and AD facilities are an important aspect to be taken into account during operation. Figure 6.13 gives an overview of gas emissions from different composting facility types. The wide range between the maximum and minimum values shows that emissions can vary significantly and that there is a huge potential to improve the emissions situation.

Scientific findings have shown that the amount of methane, nitrous oxide and ammonia emissions is less dependent on technical equipment than on now operating plants (UBA, 2015). Therefore, the awareness rising of the staff in proper operation to avoid emissions is crucial.

In Germany, the requirements for emission reduction from composting and AD plants are included in the Technical Instructions on Air Quality Control ("TA Luft"). Among others, minimum distances, requirements for a closed construction of composting plants and emission values for odour and dust emissions are regulated.



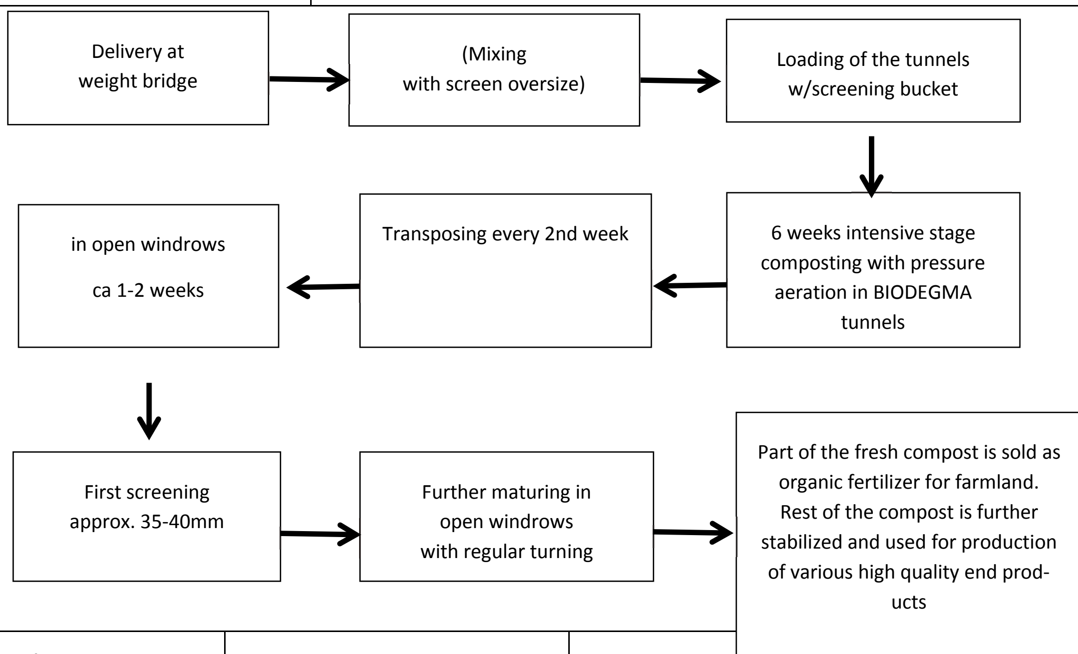
V1: Closed Composting
V2: Semi-closed composting
V3: Composting with semi-permeable membrane
V4: Open composting of bio- and green waste
V5: open composting of green waste

Figure 6.13: Emissions from different types of composting facilities [BGK, 2010]

6.1.5 Selected references

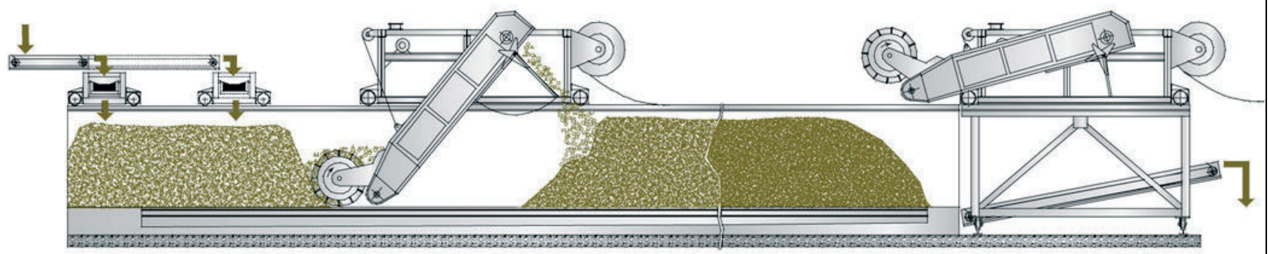
6.1.5.1 Biodegma

Name of the facility:	**Composting plant Weiterstadt**
Type of the facility:	**Composting plant using BIODEGMA technology**
Location:	**DE-64331 Weiterstadt**



Facility's owner:	Da-Di Werk, Darmstadt	Design	
Facility's operator:	Da-Di Werk, Darmstadt	**Mechanical processes**:	Screening bucket at the front end loader
Facility's provider:	BIODEGMA GmbH		
Start-up date:	2005	Biological treatment: Composting	
Type of waste:	Source separated kitchen waste, green waste	Process: - Windrows, -Tunnel, etc. - Aeration	BIODEGMA tunnels
Capacity:	9,000 tpa	Duration:	6 weeks
No. Personnel:	2.5	Exhaust air treatment	Semipermeable Membrane
No. shifts: Hours/day:	1 8	**Products (Outputs):**	fresh compost as organic fertilizer various high quality mature compost products

6.1.5.2 Biofix

<table>
<tr><td>Name of the facility:</td><td colspan="3">Kompostierungsanlage Hogstadt, Stavanger, Norwegen</td></tr>
<tr><td>Type of the facility:</td><td colspan="3">Composting with biofix</td></tr>
<tr><td>Location:</td><td colspan="3">Stavanger, Norwegen</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Facility’s owner:</td><td>Interkommunalt Vann og Avlops- og Renovas-jonsverk (IVAR)</td><td colspan="2">Design</td></tr>
<tr><td>Facility’s operator:</td><td>IVAR</td><td rowspan="3">Mechanical processes:</td><td rowspan="3">Mix-Shredder (if necessary irrigation)
Fe separation</td></tr>
<tr><td>Facility’s provider:</td><td>Sutco Recycling Technik GmbH & Co KG</td></tr>
<tr><td>Start-up date:</td><td>2000</td></tr>
<tr><td rowspan="2">Type of waste:</td><td rowspan="2">Biological fraction, kitch-en waste from separate col-lection</td><td colspan="2">Biological treatment Composting</td></tr>
<tr><td rowspan="4">Process:
- Windrows, Tunnel, etc.
- Aeration
- other</td><td rowspan="4">- 8 lines, 45 m long, in rotten hall
- Suction ventilation
- embedded biofilter with min-eral filter material
(Not Sutco delivery)</td></tr>
<tr><td>capacity:</td><td>100-150 t/d (min/max)</td></tr>
<tr><td>Area:</td><td>4,800 m²</td></tr>
<tr><td>Products (Outputs):</td><td>Compost with Rottegrad IV</td></tr>
<tr><td>No. shifts:</td><td>1</td><td>Duration:</td><td>Time spent in lines - 4 Weeks</td></tr>
<tr><td>Investment cost:</td><td>4.3 Mio DM</td><td>Exhaust air treatment</td><td>Acid washers, Embedded biofilter</td></tr>
</table>

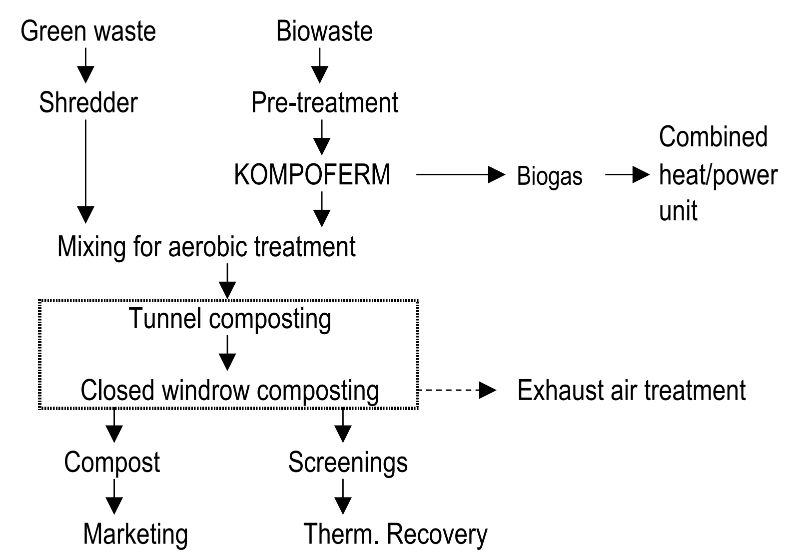
6.1.5.3 Tunnel composting

Name of the facility:	**Abfallwirtschaftszentrum Linkenbach**
Type of the facility:	**Tunnel composting**
Location:	**Linkenbach, Kreis Neuwied**

Facility's owner:		Design	
Facility's operator:	Abfallentsorgungsanlage Linkenbach Landkreis Neuwied Steinstraße 1 56317 Linkenbach	**Mechanical processes:**	shredding, sieving < 80 mm Fe-separation, entry in rotting tunnels
Facility's provider:	Sutco RecyclingTechnik GmbH		
Start-up date:	2014		
Type of waste:	Household waste	Biological treatment Composting	
		Process: - Windrows, - Tunnel, etc. - Aeration	Tunnel composting 16 tunnels, 1 time converting, Afterwards thought after-composting
capacity:	160 Mg/*day*	Duration:	4 weeks IC ≥ 4 weeks AC
Area:	5.820 m²	Exhaust air treatment	RTO and Biofilter
Products (Outputs):	AT_4 < 15 mg O_2/g TS DOC < 800 mg/l	**Special features**	Two automatic tunnel entry systems with moving bridge
No. shifts:	1		
Investment cost:	5,3 Mio €		

6.1.5.4 Kompotec

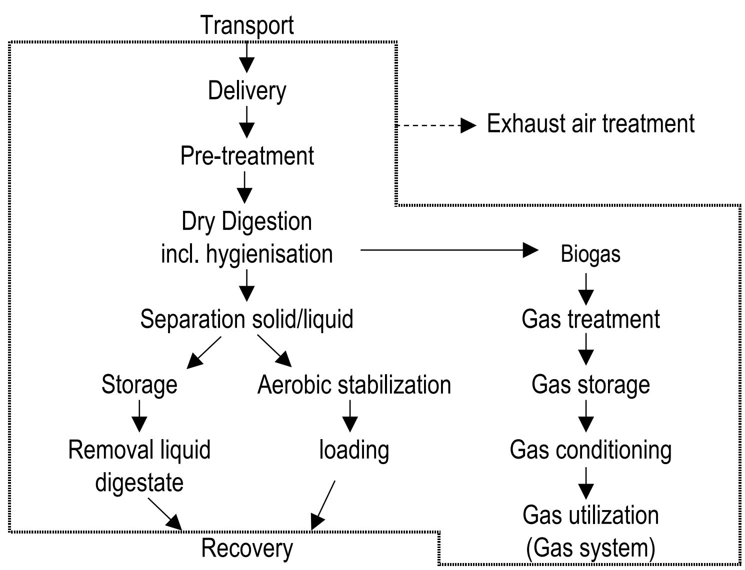
Name of the facility:	**Kompostwerk Gütersloh** **KOMPOTEC Kompostierungsanlagen GmbH**
Type of the facility:	**Biowaste fermentation and composting**
Location:	**33334 Gütersloh, Germany**



Facility's owner:	KOMPOTEC Kompostierungsanlagen GmbH	Design	
Facility's operator:		**Mechanical processes:**	Screen drum, Magnet, shredding
Facility's provider:	Eggersmann Anlagenbau GmbH		
Start-up date:	1993	Biological treatment: Composting	
Type of waste:	Bio-waste fron households Greenwaste	Process:	Dry anaerobic digestion Tunnel composting windrow composting
Capacity: [Mg/*day*]	65.000 tpy, 260 tpd	Exhaust air treatment	Biofilter
No. Personnel:	9	**Products (Outputs):**	Quality compost Biogas Electric energy Metals Screenings for thermal recovery
No. shifts: Hours/day:	10		
Area	43.000 m^2		

6.1.5.5 BSR (AD, Biokraftstoff)

Name of the facility:	**Bio-waste Treatment Plant Berlin**
Type of the facility:	**Anaerobic Digestion**
Location:	**Berlin**



Facility's owner:	BSR Berliner Stadtreinigungsbetriebe	Design	
Facility's operator:		**Mechanical processes:**	Pre-treatment incl. equalization for feeding of digesters 2 stage dewatering
Facility's provider:	STRABAG Umwelttechnik GmbH		
Start-up date:	2013	Biological treatment:	
Type of waste:	Source segregated bio-waste	Process:	2 dry digesters TF 2200 Post composting fermentation residues in 6 aerated boxes
Capacity: [Mg/*day*]	60 000 tpa	Exhaust air treatment	Chemical scrubber and biofilter
No. Personnel:	14	Others	Biogas treatment up to natural gas quality with gas refinement by pressure less amine washing (BCM process)
Area	2,7 ha	**Outputs:**	Biogas, Compost

6.2 Mixed collection, treatment and utilization

6.2.1 Legal background and importance of resources and climate protection

Also for residual waste, a mixture of different not sorted recyclables, bio-waste, hygienic waste, etc., there are different legislations, mainly regulating its treatment.

The **European Council Directive 1999/31/EC of 26th of April 1999** on landfill sites requires EU countries to gradually reduce the amounts of biodegradable waste on landfill sites. The aim is to only deposit treated wastes. By 2030 a maximum of 10 % of the municipal waste in the EU may be deposited on landfills.

Following the five-step waste hierarchy in the German **Waste Management Act** (KrWG), the most appropriate measure to ensure the protection of the general public and the environment has to be chosen. In case of mixed residual waste, recovery is best before a disposal takes place.

In 1993, the **Technical Instructions on the Utilization, Treatment and Other Disposal of Municipal Waste (TASi)** mentioned for the first time a pre-treatment obligation for municipal waste, which had to be implemented from 1st of June 2005. The TASi formulated the following principle: "In particular, it should be achieved that practically no landfill gas develops, that the organic seepage water load is very low and that only small settlements as a result of a biological decomposition of organic constituents in the deposited waste occur". Today, the Waste Management Act requires the treatment of waste to reduce its quantity and harmfulness, and to sustainably use energy or waste arising from disposal (§ 15 KrWG).

The **German Landfill Ordinance** implements the requirements of the European and German regulations, in which Annex 3 (Table 2) prescribes assignment criteria for waste to be disposed of in landfills, which can only be obtained after pre-treatment of the waste (inerting). The destruction or conversion of the organic substance in the waste to be deposited is a prerequisite for compliance with these assignment criteria. The following Table 6.4: Criteria for landfill of MBT-Output material are shown.

Table 6.4: Criteria for landfill of MBT-Output material [Müller et al, 2007& EC, 2001]

Parameter	Germany	EU Landfill Directive	Unit
Total organic carbon (%w/w)	≤ 18	/	
Respiration activity AT_4 (within 4 days)	< 5	< 10	mg/g DM
Gas formation rate within 21 days (GB_{21})	< 20	/	l/kg DM
Total organic carbon in eluate (TOC_{eluate})	< 250	< 500	mg/l
Upper caloric value	≤ 6000	/	kJ/kg

Waste inerting results in the prevention of landfill gas formation in the landfills. The waste pre-treatment processes (waste incineration and MBT) use the energy content of the waste to be treated. Both contribute to climate protection (Figure 6.14). The ban for landfilling of untreated waste has made a fundamental contribution to the reduction of greenhouse gas emissions.

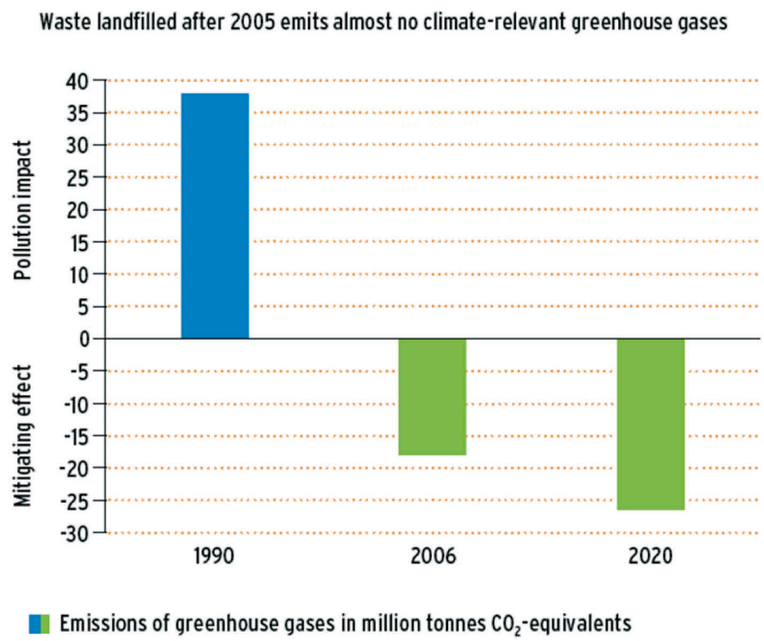


Figure 6.14: Influence of the treatment of landfilled waste on the greenhouse gas emissions and savings [IFEU Study, 2010, Ökoinstitut e.v]

The treatment of residual waste and mixed municipal waste can mainly achieve energy recovery, as RDF and material recovery for recycling is only in limited degree. Only metals can be separated and recovered in profitable qualities. These secondary raw materials reduce the use of primary energy and reduce the emissions of climate relevant gases.

By capturing the landfill gas of old landfills and the subsequent energetic use of it, another contribution is made to climate protection. However, even with the latest landfill technology, only a maximum of 25% of the resulting gas emissions can be collected! Landfills with untreated waste (neither inertized nor stabilized) still emit large quantities of climate-relevant landfill gas!

In the years 1990 to 2006, German waste management was able to reduce its annual emissions of climate-damaging gases by a total of approximately 56 million tons. This was due in particular to the ban on landfilling of untreated municipal waste, Figure 6.14, as well as to an increased material and energetic use of waste [UBA, 2010]. In Germany, the emissions from waste management can only be further reduced by increasing the efficiency of waste treatment plants and, in particular, by increasing the material recycling of waste streams.

6.2.2 Process and technologies

Mechanical-biological treatment (MBT) is a generic term for the integration of a number of waste management processes such as materials recovery facilities (MRF), RDF production, mechanical separation, sorting and composting. MBT of waste gained importance with the entry into force of the European Landfill Directive (Council Directive 99/31/EC of 26 April 1999 on the landfill of waste) on 16.07.1999 (see Chapter 6.2.1). At present only waste incineration and MBT-technologies are available as pre-treatment options for mixed MSW.

The design and technical solution of MBT facilities is determined through the input material and the quality of the desired output, Figure 6.15. Considering this, it is clear that plants/operation concepts vary and are difficult to compare.

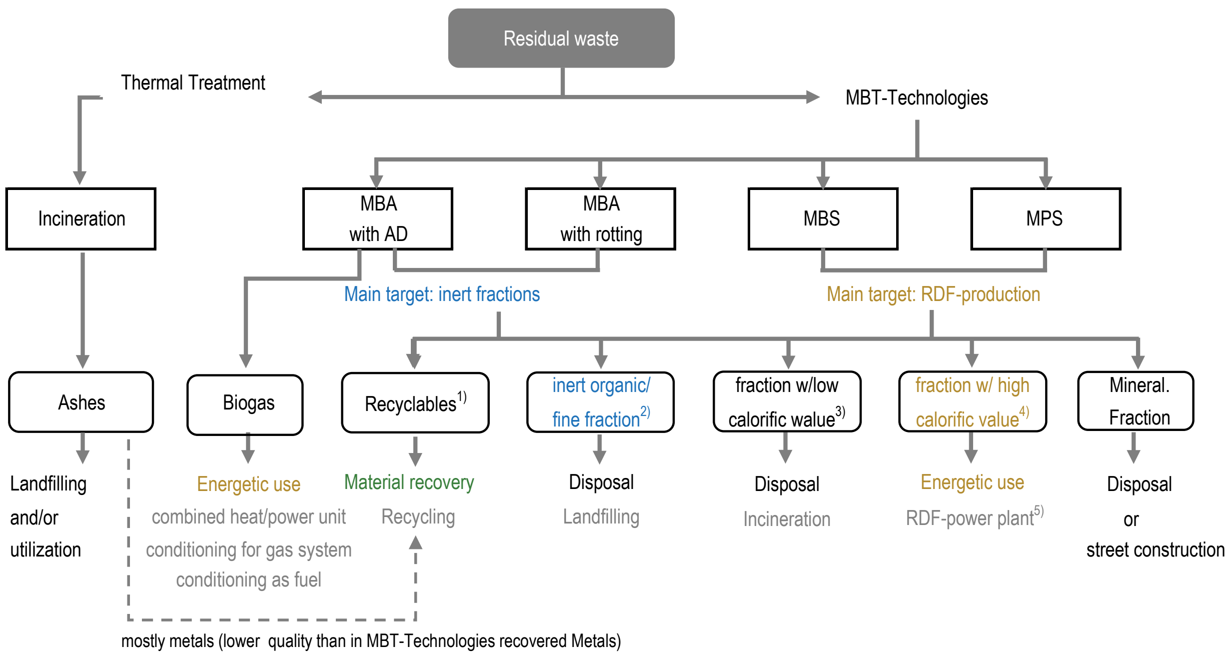


Figure 6.15: Concepts of residual waste treatment facilities and their outputs

Despite these facts, MBT facilities can be classified into three main groups: Mechanical-biological Treatment (MBT), Mechanical-Biological Stabilization (MBS) and Mechanical-Physical Stabilization (MPS). Their simplified layout is shown in Figure 6.16. The latter class is also denominated as mechanical treatment technology, as there is no biological step involved. However, they are counted as MBT if the facility produces RDF/SRF

Both processes, composting and AD, were explained in detail in the previous chapter on biological treatment of source segregated biodegradable waste. In both cases the final product is a stabilized material, which can be safely disposed in a landfill. The aerobic option is the most commonly used as it is easier to manage.

MBT – Mechanical Biological Treatment

MBT is the most common method for material-specific waste treatment and aims to produce a stabilized fraction for landfilling. In these MBT plants, the input waste is separated into different material flows: recycling materials, energy recovery materials and materials for further biological treatment. In the biological treatment the degradation of organic material takes place in a controlled environment within a matter of months. The biological treatment at an MBT plant therefore reduces the potential of producing landfill gas by more than 95% [Nelles et al., 2017].

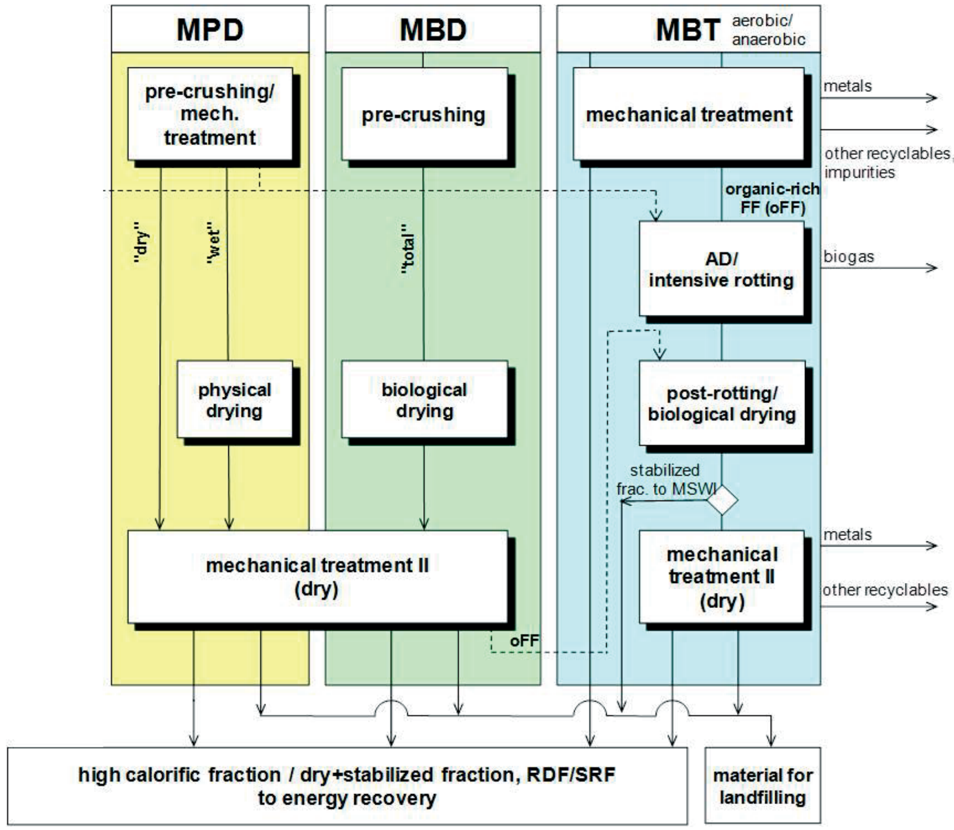


Figure 6.16: Simplified layout of the different MBT-Technologies [Ketelsen, 2015]

MBS – Mechanical-Biological Stabilization (also MBD - Mechanical Biological Drying)

MBS plants are optimized for the production of RDF/SRF. In the MBS the waste is stabilized in a biological drying step prior to mechanical separation. Bio-drying is a form of composting where the heat produced during the aerobic biological activity is used to dry the waste. Depending on the process concept, either the whole waste amount or only to the high calorific fraction is treated biologically. After a conditioning step, the waste is fed to the biological drying, where it will primarily lose moisture and achieve a low degradation of the organic matter. In this way, most of the biomass content from the waste can be included into the RDF/SRF, which not only enlarges the RDF/SRF quantities, but also reduces the biodegradable material to be landfilled. [Nelles, 2013; Nelles et al., 2017].

In the subsequent mechanical treatment of ferrous and non-ferrous metals, inert materials and impurities are segregated and the high calorific fraction is divided into one or more RDF/SRF with different qualities.

MPS – Mechanical-Physical Stabilization (also MPD – Mechanical Physical Drying)

Since this plant concept has no biological step it will only be described shortly. In the MPS the high calorific fraction of the waste is separated by means of mechanical and physical processes and pre-treated to a RDF/SRF. The pre-treatment comprises the segregation of the low calorific fraction and metals together with a multistage crushing. If necessary, hazardous fractions are separated and the high calorific fraction dried using thermal energy (heat).

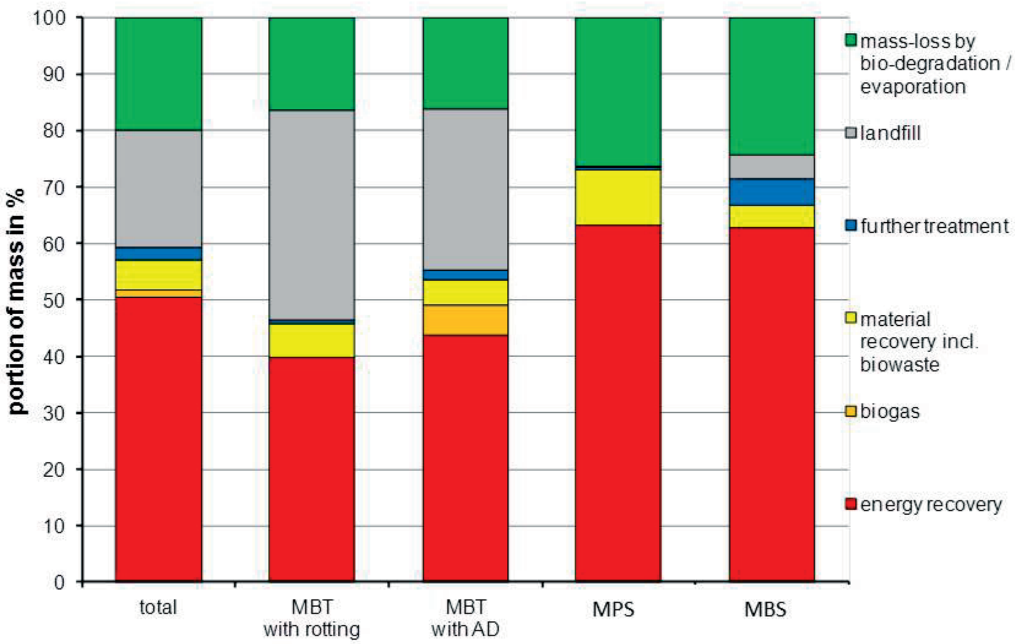


Figure 6.17: Distribution of output fraction of MBT/MPD/MBD in 2012 [Ketelsen, 2015]

6.2.3 Operation of MBT-Facilities

Figure 6.11 in Chapter 6.1.4 already illustrated general aspects of the operation of facilities, which also apply to MBTs. In the following, important details in the operation of MBT will be considered in detail.

PERSONNEL: The personnel required for the operation of an MBA system depends on the type and size (throughput) of the plant as well as on the shift work. At the same time, the number of personnel required will also depend on whether they work in the mechanical or biological part of the plant. In general, it can be assumed that the following personnel with the respective qualifications are needed:

- One plant manager who should be an engineer in the field of mechanical engineering, electrical engineering or a comparable discipline and who is responsible for the whole plant,
- 1-3 mechanics responsible for the mechanical units. This includes problem-solving, e.g. clogging, but also the maintenance and the lubrication,
- 1-3 electricians, who do not have to be engineers, but are very competent in problem solving, to take care of the electrical system in general, electrical circuits and motors,

- 15-20 sorters (semiskilled workforces) who work for the quality control and assurance (no active sorting)
- 1 person responsible for the biological process (see section 6.1.4),
- Optionally, depending on the throughput, 1-2 drivers for mobile devices (otherwise also locksmiths)

As mentioned briefly in Chapter 6.1.4, the longer-term connection of the team to the company is a frequent problem abroad. Based on the experience of the project partners, the workforce changes up to three times in the first 5 years of operation. The main reason is a low salary for the qualification requested. However, the continuous training is time-consuming and costly and should therefore be avoided.

SHIFTS: In order to ensure the operational safety of the plant, a maximum of a 2-layer operation is recommended on six days a week. One mechanic and one electrician should be on site for each shift.

Furthermore, one cleaning shift should work each week (either 8 hours in one shift or 4 hours in two shifts). 3-shift operation is not recommended, since otherwise there will be delays due to malfunctions, maintenance and/or cleaning cannot be carried out at all or only problematically with additional special shifts.

START-UP AND OPERATION: After the construction, the plant is commissioned. During the so-called "cold commissioning", the functionality of the system is checked. No material is applied yet, but it is checked that everything works in the plant. This is followed by the so-called "warm commissioning", in which the system is to run for at least four weeks and various throughput and quality tests are carried out. Only then does the trial run for about three months start, during which the workforce alone tests the operation. Practical experience shows that a second training is often necessary after this time. It is therefore advisable to consider a service contract with follow-up support.

DOCUMENTATION: The exact and detailed documentation of the plant is very important for later operation. This should not include the original planning, but the actual design ("as-built"), so that also additionally installed components (lamps, switches, pumps, etc.) are documented.

MAINTENANCE: The selected technology also plays a fundamental role in wear and maintenance. Whereas system components such as conveyor belts or ventilation systems show negligibly little wear, shredders are the most maintenance-intensive units. It can be assumed that the knives have to be replaced every 4-6 weeks, which affects the costs. One way to reduce the maintenance work and costs is to keep the fraction that is to be shredded small.

MOBILE MACHINES: In the operation of an MBT system, additional mobile machines (forklifts, trucks, containers, scissors lifts, etc.) are used. The planning should include enough space for their navigation.

CONSUMPTION: The operating consumption for MBT systems varies and depends on the treatment process itself as well as on the process intensity. Thus the different units have different consumption. Particularly, electricity-consuming are, for example, shredders and the compressors of the NIR technology.

A study conducted in Germany in 2012 showed that MBT plants with fermentation and plants with biological and physical drying consume an average of about 20-30 kWh/t more electricity than MBT plants with a rotting process. However, a high range of specific power consumption was found within each system group, as can be seen in Figure 6.18. For this reason, energy management systems as well as optimization processes are implemented to further reduce the specific power consumption. For comparison, the specific electricity consumption for waste incineration plants is approx. 100-120 kWh/t.

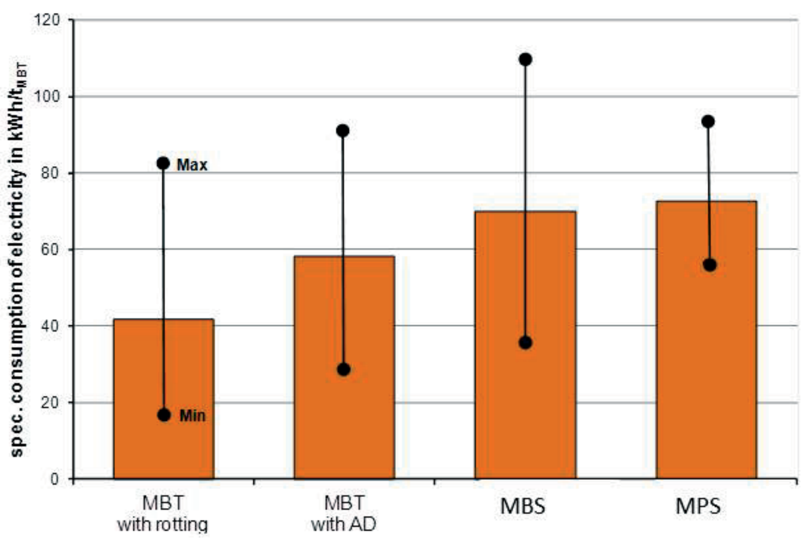


Figure 6.18: Specific power consumption of selected MBT plants in Germany [Ketelsen, 2015]

In the same study, the specific natural gas consumption of MBT and MBD systems was also determined. On average, this amounted to 40 kWh/t (= 4 m³ natural gas). However, this also showed a range of values within each system group as shown in Figure 6.19. These differences result from different handling concepts for the exhaust air (elimination of exhaust air to regenerative thermal oxidizer - RTO, bio-filters and dust-filters, organic exhaust air pollution at RTO) and the operation management. The significantly high specific gas consumption in MPD plants is due to thermal drying of solid waste in the drum dryer.

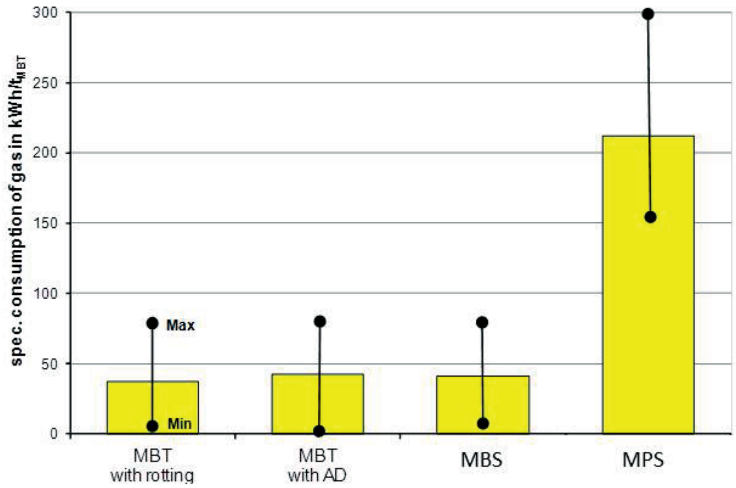


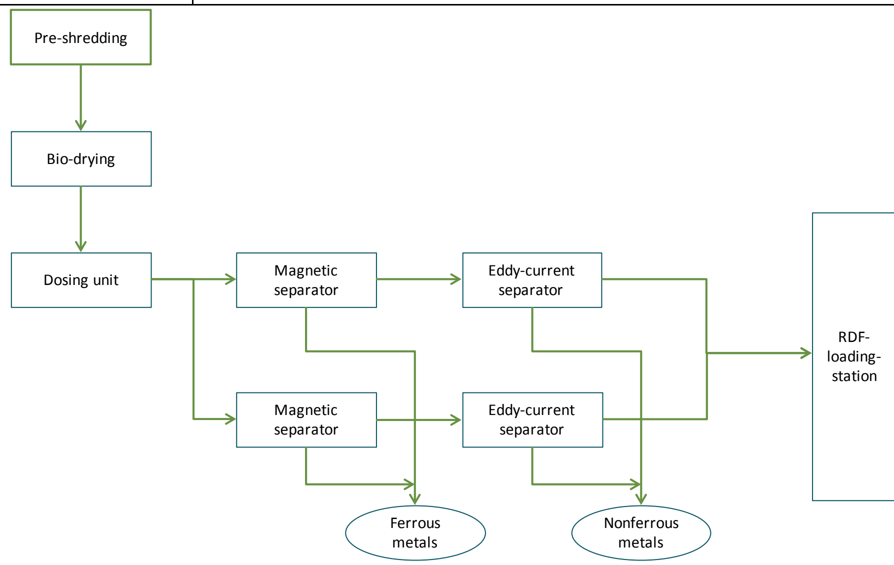
Figure 6.19: Specific natural gas consumption of MBT/MBD/MPD in Germany [Ketelsen, 2015]

The additional energy required in MBT plants with fermentation is mainly covered by the use of the biogas produced during fermentation. Due to the release of the remaining biogas during the rotting process, the RTO is an autothermic process.

6.2.4 Selected references

6.2.4.1 Bio-drying

Name of the facility:	**A.R.T. Trier**
Type of the facility:	**Mixed household waste treatment plant with bio-drying section**
Location:	**Trier, Germany**

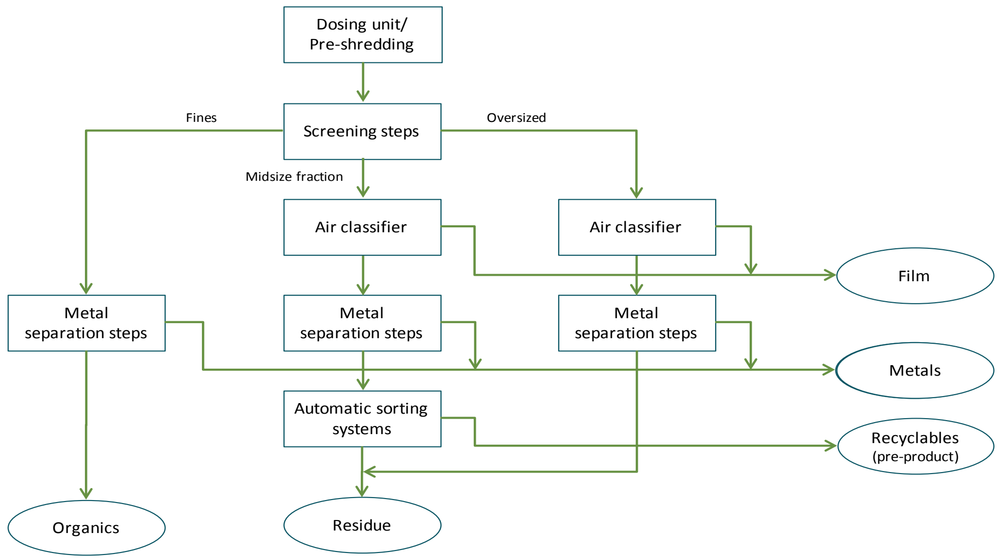


Facility's owner:	A.R.T. (Zweckverband Abfallwirtschaft Region Trier)
Facility's operator:	RegEnt GmbH
Facility's provider:	Fa. Herhof
Start-up date:	05/2007
Type of waste:	– 500 t/day mixed household waste – 120 t/day bulky waste
Area:	15.000 m²
Products (Outputs):	- Metals - RDF
No. Personnel:	12
No. shifts: **Hours/day:**	– Bio-drying: 24/7 – Mechanical treatment: 2 shift operation (Mon - Fri)
Investment cost:	13.000.000 €

Design	
Mechanical processes:	– Pre-shredding – Automatic crane system for loading and clearing of drying boxes – Metal separation: suspension magnets und eddy-current separators – Loading station RDF
Biological treatment Drying	
Duration:	10 to 14 days
Exhaust air treatment	Air scrubber, regenerative thermal oxidation (RTO)
Special features	12 drying boxes, capacity 600 m³ each

6.2.4.2 Mixed household waste treatment plant

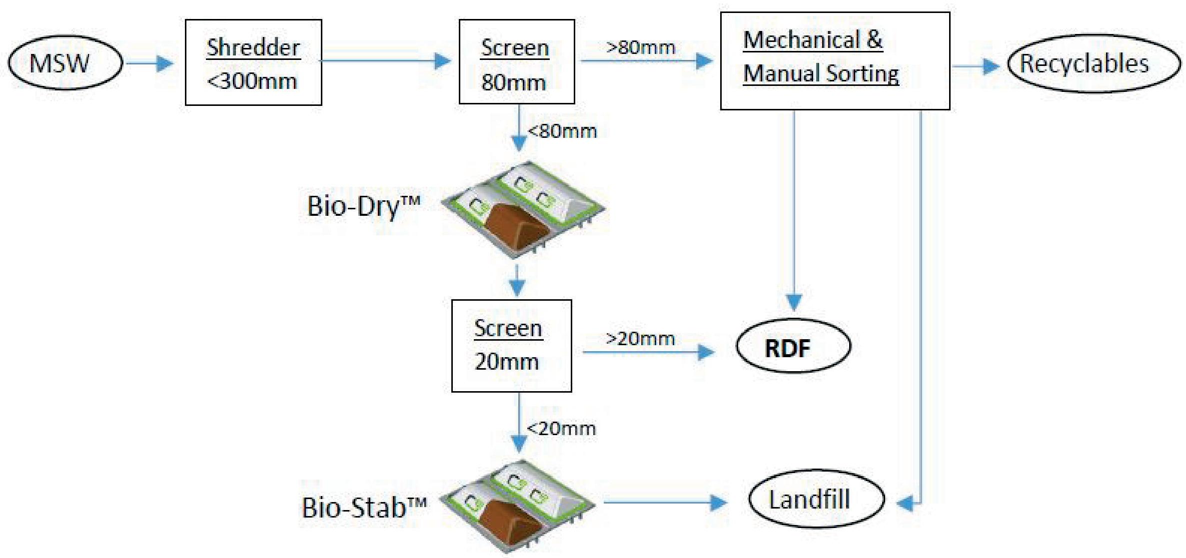
Name of the facility:	**Sortiva Alkmaar**
Type of the facility:	**Mixed household waste treatment plant**
Location:	**Alkmaar, The Netherlands**



Facility's owner:	HVC	Design	
Facility's operator:	HVC	**Mechanical processes:**	- screening steps: separation of oversized material and fines (organics) - air classification - manual sorting film and paper as an option - Automatic sorting systems for production of mixed recyclables - magnetic and eddy-current separators
Facility's provider:	tbd		
Start-up date:	tbd		
Type of waste:	mixed household waste		
capacity: [Mg/*day*]	400		
Area:	/		
Products (Outputs):	- Mixed recyclables (pre-product) - Film - Metals - RDF - Organics for anaerobic treatment	Biological treatment Anaerobic Digestion	
		Process: - Wet/dry - Meso- / Thermophil - Single/multistage - other	Wet anaerobic treatment
No. Personnel:	tbd	Duration:	/
		Exhaust air treatment	/
No. shifts: Hours/day:	2-shift operation	**Special features**	
Investment cost:	tbd		

6.2.4.3 MBT biological drying

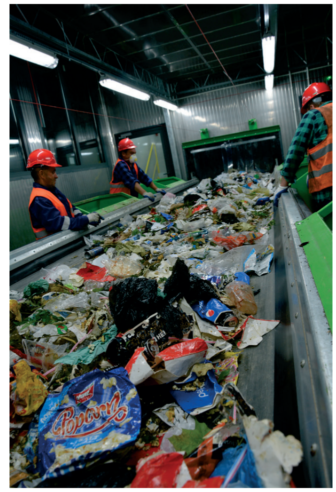
Name of the facility:	**Wolan Duka**
Type of the facility:	**Mechanical- Biological Treatment of MSW**
Location:	**Glinianka, Poland (30km SE of Warsow)**



Facility's owner:	P.P.H.U Lekaro	Design	
Facility's operator:	P.P.H.U Lekaro	**Mechanical processes:**	FHF Anlagentechnik GmbH (Horstmann)
Facility's provider:	CONVAERO, FHF (Horstmann) & others	**Biological processes:**	CONVAERO Sales & Services GmbH
Start-up date:	In stages since 2006	Biological treatment Stabilisation	
Type of waste:	MSW & dry recyclables	Process: -windrows, Tunnel, etc. - Aeration - other	Process: -windrows, Tunnel, etc. - Aeration - other
capacity: [Mg/*day*]	1200	Duration:	Duration:
Area:	30,000 m²	Exhaust air treatment	Exhaust air treatment
Products (Out-puts):	Recyclables, RDF, stabilised fines	Biological treatment Drying	
		Duration:	19 days
No. Personnel:	200 incl. waste collection trucks drivers	Exhaust air treatment	Through membrane
No. shifts: Hours/day:	2 shifts operation + 1 shift cleaning	**Special features**	Through membrane
Investment cost:	/		

6.2.4.4 MBT biological sorting and composting plant

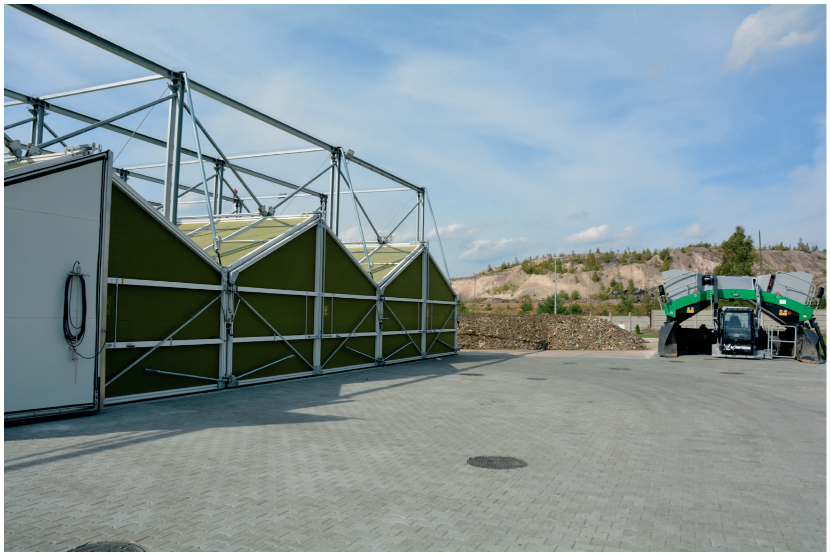
Name of the facility:	**Zakład Utylizacji i Unieszkodliwiania Odpadów Komunalnych in Siedliska near Ełk**
Type of the facility:	**MBA**
Location:	**Siedliska near Ełk, province warmińsko-mazurskie**

Facility's owner:	Przedsiębiorstwo Gospodarki Odpadami „Eko–MAZURY" Spółka z o.o.	Design	
Facility's operator:	Przedsiębiorstwo Gospodarki Odpadami „Eko–MAZURY" Spółka z o.o.	**Mechanical processes:**	Sorting & composting plant designee by Sutco-Polska Sp. z o.o.
Facility's provider:	Sutco-Polska Sp. z o.o. - Sorting and composting technology provider		
Start-up date:	28.11.2011	Biological treatment	Composting
Type of waste:	Mix communal waste / separately collected waste	Process: -windrows, Tunnel, etc. - Aeration - other	Composting plant in dynamic system BIOFIX Aeration system in the floor
capacity: [Mg/day]	Sorting plant 280 Mg/day Composting plant 21000 Mg/a	Duration:	4 weeks
Area:	Technology hall: approx. 4000 m2	Exhaust air treatment	By biofiltr
Products (Outputs):	Ferrous metal, nonferrous metal, glass, paper, cardboard, PET green, PET blue, PET white, film mix, film transparent, film white, high caloric fraction	**Special features**	
No. Personnel:	45 per shift		
No. shifts: Hours/day:	2 shifts per day 13 h/day		
Investment cost:	57 040 795,82 PLN net price (industrial plant)		

6.2.4.5 MBT biological composting plant

Name of the facility:	**Zakład Gospodarki Komunalnej „Bolesław” Sp. z o.o. in Bolesław**
Type of the facility:	**MBA**
Location:	**Bolesław, province małopolskie**



Facility's owner:	Zakład Gospodarki Komunalnej „Bolesław” Sp. z o.o. in Bolesław	Design	
Facility's operator:	Zakład Gospodarki Komunalnej „Bolesław” Sp. z o.o. in Bolesław	**Mechanical processes:**	Designie by Sutco-Polska Sp. z o.o.
Facility's provider:	Sutco-Polska Sp. z o.o.		
Start-up date:	02.06.2015	Biological treatment Composting	
Type of waste:	Mix communal waste / separately collected waste	Process: -windrows, Tunnel, etc. - Aeration - other	Composting plant in static system BIODEGMA Tunnels with an opening roof Aeration system in the floor
capacity: [Mg/*day*]	Sorting plant 138 Mg/day Composting plant 21 000 Mg/y	Duration:	3-4 weeks, not less than 21 days
Area:	Technology hall: approx. 2300 m^2	Exhaust air treatment	By membrane Gore
Products (Outputs):	Ferrous metal, nonferrous metal, tetrapack, cardboard, paper mix, PET white, PET green, PET blue, PET mix, Film PE white, Film PE mix, high caloric fraction, glass, PE/PP	**Special features**	
No. Personnel:	33 per shift		
Investment cost:	12 995 000,00 PLN net price (technological equipment)		

7. Approaches for the utilization and disposal of biogenic waste in the PR China

When considering a strategy for waste management it has to be considered, that this does not only imply the selection of a technical solution but much more the development of a waste management system including other aspects interconnected with the technology. Such a system needs to consider the management and administration entity, the legislation, financial aspects, monitoring, and technology as core element of the overall system. Furthermore, all involved stakeholders need to be taken into account: waste producers but also the informal sector and personnel working in waste management, etc. Figure 7.1 illustrates the aspects and stakeholders to be considered in a waste management system.

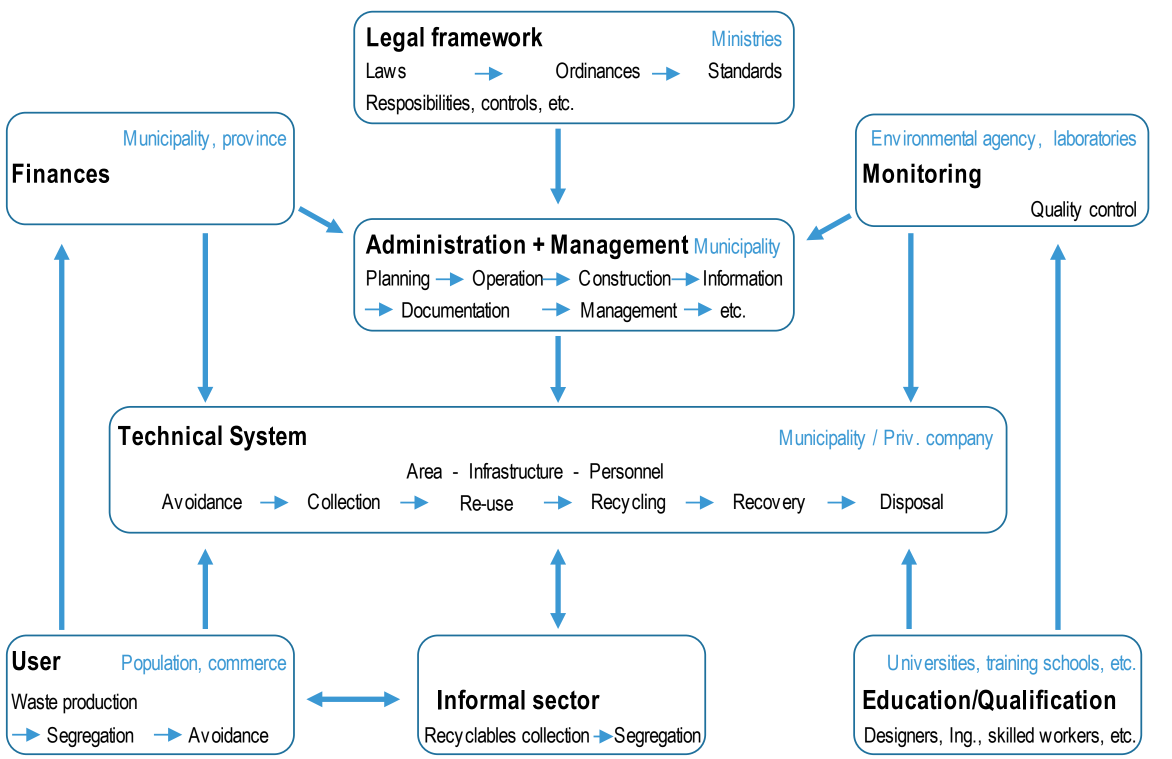


Figure 7.1: Aspects and stakeholders to be considered in a waste management system

Legislation is an important element in solid waste management (SWM) since the different laws, ordinances and standards are essential to define and regulate the responsibilities, timeframes, environmental protection limits, product quality, etc. The legal framework should also specify what actions need to be taken in case of incompliance of any regulation. If there are regulations missing, the strategy might not work, as some aspects in the SWM strategy are not clear. Ministries are mostly in charge of enacting the legal framework.

In Germany, municipalities are the entities responsible for waste management. This does not only mean to perform the waste collection and treatment but much more includes the developing a SWM-Plan for their areas, the design, construction and operation of facilities, the documentation of related data as well as giving information to the public and administration of these duties. These duties are strongly interlinked with the technical system in place.

The technical system includes all areas of solid waste: from avoidance to disposal. Often the municipalities are responsible for the management and administration of SWM activities but they can make use of third parties (private companies) to execute some of their duties. Therefore, private companies might perform the collection or operate a solid waste facility.

The qualification and education of the personnel is an aspect seldom considered in SWM but of great importance. Lack of knowledge could result in missed planning, wrong decisions, improper operation of facilities, ending in severe damage for the environment and higher costs to repair the caused damage. Here, it would be beneficial if universities and also other education institutions like training schools would consider SWM in the curriculum for engineers, electricians and other workers needed in SWM.

Two stakeholder groups are most important for the development and implementation of an advanced SWM strategy. First the users: they are the waste producers, but also the main performers of segregation and avoidance. It is crucial to consider public information in SWM issues to gain the cooperation of the population. It has to be taken into account that public information is not a one-time issue but a periodic task, which needs substantial effort. The second stakeholder involved is the informal sector, which in many countries performs very good segregation and recycling rates, contributing to resource and climate protection. Their contribution is, however, seldom recognized and documented. When improving a SWM system, the informal sector should be considered so that people working in this sector do not lose their living income and the recyclables do not end up in the residual waste.

Furthermore, the financial and monitoring aspects should not be forgotten. A waste management system comprising collection, operation, equipment, facility construction, etc. is a costly activity. In Germany, the population, commerce and industry pay for these services. The introduction of a fees-system is however a difficult matter, since the population needs to understand the need to pay for a service that was “free” or cheap before. Therefore, when introducing a new funding system, an improvement of the service should be noticed. The monitoring of solid waste management is crucial to make sure the existing regulation is followed and therefore SWM contributes to resource and climate protection instead of further damaging the environment.

Figure 7.2 and Figure 7.3 summarize which of all the aspects above mentioned need consideration in a SWM strategy for China. The legal framework in China has been described in Chapter 3. There are already abundant legal rules related to waste management including basic laws, regulations, policy documents, standards and specifications. The legal rules consider the generation, collection and transport of municipal solid waste (MSW), the treatment of unsorted MSW, including sanitary landfills, incineration and composting as well as the co-processing in cement kilns. The separate collection of waste by now is only regulated for restaurant waste, but will be promoted in the coming 13th Five-Year

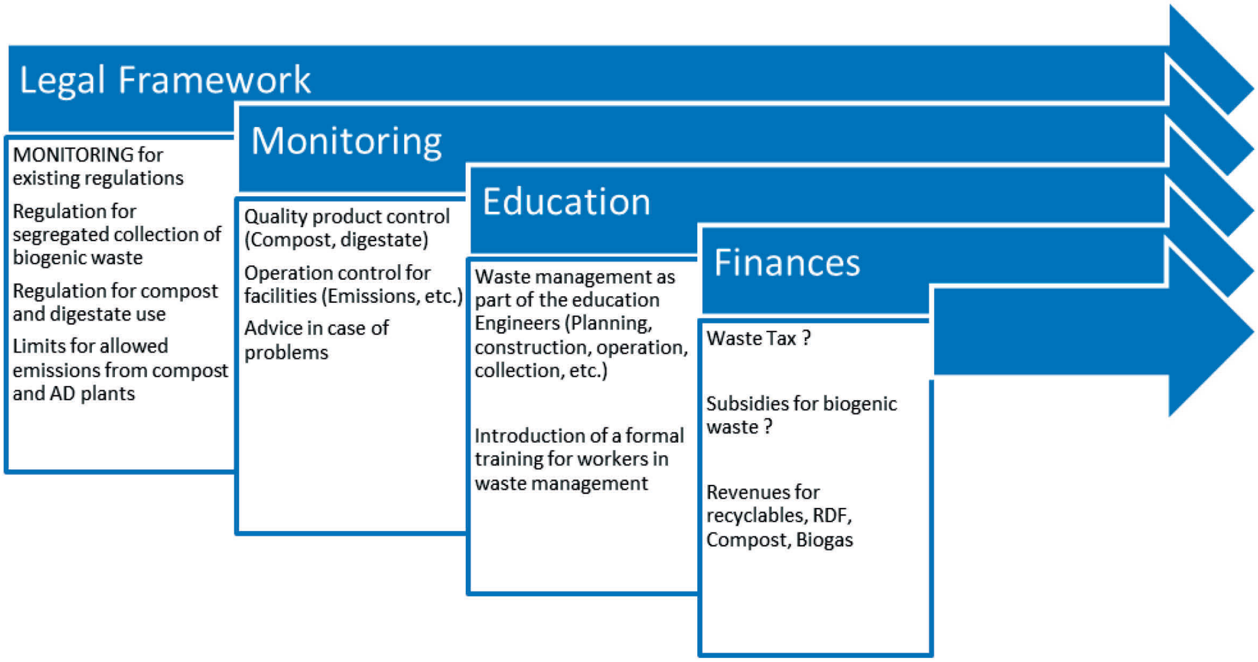


Figure 7.2: General aspects to be considered in a solid waste management strategy for China

In Germany and Europe the segregated collection and the landfill ban of untreated waste and energy-efficient WTE are the basis for sustainable waste management. Thereby, each country has found its own suitable way of implementing a sustainable waste management. But waste segregation is always an important part of it, since it lowers the cost for landfilling.

If a similar strategy were to be followed in China, the legal framework might need to be extended and the monitoring of the existing as well as new regulations should be strengthened. For the separate collection of the biogenic fraction of municipal solid waste there are no guidelines, neither are there any for the treatment of this segregated fraction as of its products. Also limits for emissions from treatment plants for biogenic waste need to be defined.

According to the experience of the German companies involved in this project, it is difficult to find skilled workers for the MSW-facilities. Therefore, new professional education with an SWM subject might need to be introduced or improved.

At present, SWM in China is financed through the national investment and support program (see Chapter 4.1). These however only consider the construction of infrastructures but not the operation costs. Therefore, for a proper operation of SWM facilities the introduction of a tax system, subsidies for biogenic waste and possible revenues from products from waste treatment should be considered.

When considering the technical aspects in SWM, avoidance should always play an important role. Waste avoidance is always a challenging matter but the most effective, although its measurement is difficult. If considering the biogenic waste stream in municipal solid waste, the introduction of a segregated collection is indispensable to truly contribute to resource and climate protection. Only when collected and treated separately can biogenic waste be transformed to high quality products.

As for the mixed waste stream, which is inevitable, the mechanical-biological Treatment (MBT) can be considered as a complementary treatment before incineration. MBT can improve the properties of this waste stream by reducing the volume, related emissions, calorific value and increasing the recovery rate of mixed waste. It should be noted that the viability of a MSW treatment technology should be evaluated in large or medium or small city-scale or county-scale.

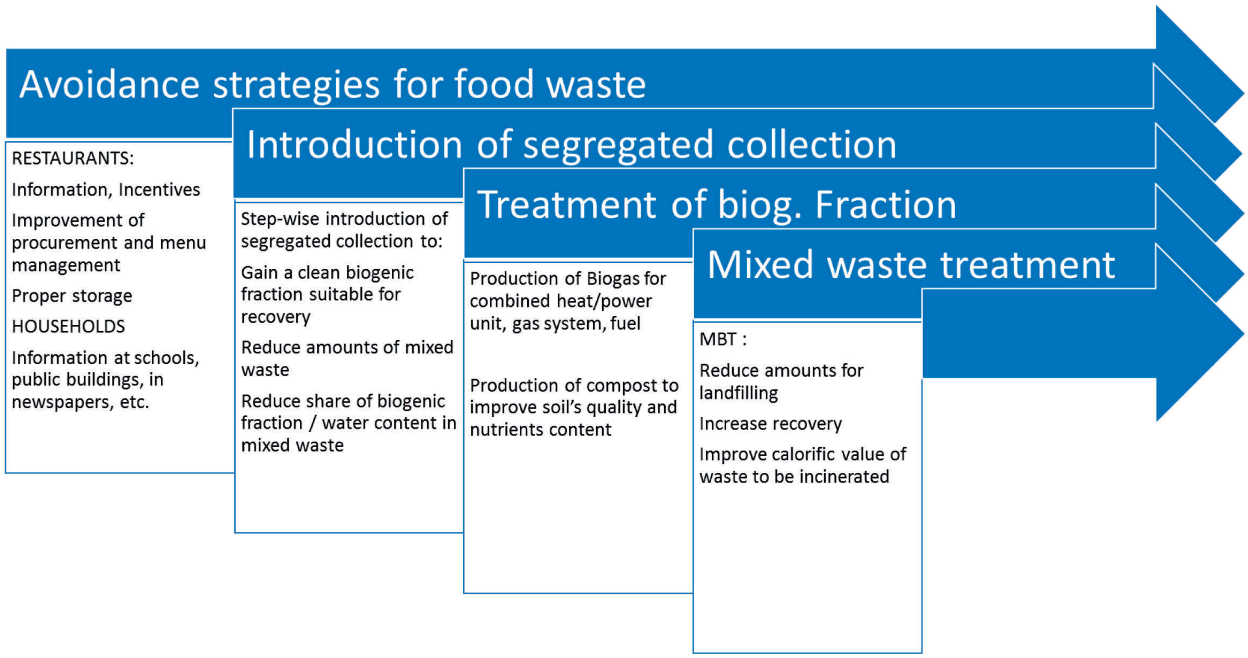


Figure 7.3: Technical aspects to be considered in the solid waste management strategy for China

The technical solutions for these two fractions, a clean segregated biogenic fraction and a mixed fraction containing biogenic waste, will be considered in detail in the following chapters and are illustrated in Figure 7.4.

7.1 Biogenic waste from segregated collection

7.1.1 Laws, regulation, management and control

If a separate collection of biogenic waste is to be introduced in China, this can be carried out step by step. Initial problems can be avoided during the expansion phase of the separate collection. New procedures are often faulty and have to be continuously revised. In Germany, biowaste has been separately collected, treated and recycled for 25 years and here still new adjustments are required from time to time.

The collection, treatment methods and the recovery of compost and fermentation residues must be regulated by law. The PRC is hereby well on the way!

Separate collection requires collecting containers for which the owners of the apartments have to provide storage spaces. Corresponding regulations and discussions with the owners and users of the apartments are necessary.

The transport of the bio-waste should be carried out in vehicles that are solely used for bio-waste to avoid contamination with other waste streams.

The establishment and operation of the treatment facilities will have to be regulated. Target values for permitted emissions should be defined (for example, noise, dust, odors and leachate). This minimizes influences on the environment and the local residents. Distance rules to inhabited areas reduce conflicts with local residents. Operating surface seals, enclosures for sorting and treatment units and the exhaust air purification unit have to be regulated.

The PRC is working on regulations concerning the quality of compost and fermentation residues. These will determine pollutant and contaminant concentrations and quantity restrictions for its applications. Location and use-related regulations should supplement this "Bio-waste Ordinance". Limit values for maximum soil concentrations are required. In addition to the stipulations for maximum concentrations and loads of pollutants and contaminants, the same should also be considered for nutrients.

The integration of the potential users of the compost and fermentation residues is crucial. Only when farmers and gardeners, as users of the compost and fermentation residues, recognize these as useful and financially appealing, their use will be able to prevail. The farmers and gardeners may have to be supported by recommendations for specific crops, soils and degradation conditions.

The cooperation of waste management and agricultural/horicultural authorities will be important. Production and use of compost and fermentation residues affects both areas. Areas of responsibility of the authorities and legal regulations must therefore be regulated. These regulations are very important for the efficient and as far as possible complete management and control of the production and use of compost and fermentation residues. Furthermore, administration and control includes consulting and, in case of violations of the rules, penalties.

The introduction of the separate bio-waste collection can be supported by a ban on the landfilling of non-pre-treated municipal waste. The bio-waste collection reduces the bio-waste fraction in domestic waste and improves the suitability for pre-treatment processes.

7.1.2 Collection and transport

Separate collection of the biogenic waste fractions is a pre-condition for its high quality recycling. As described in Chapter 5.3 there is at present no working segregated collection for biogenic waste in China. Therefore, to improve the environmental aspects arising from solid waste as well as to allow a high quality recycling the segregated collection of biogenic waste from household waste should be considered.

Figure 7.4 illustrates the possible solutions for the implementation of the segregated collection of the biogenic waste fraction. In institutions such as restaurants, canteens, supermarkets, food industry, etc., where large amounts of biogenic waste arise centrally, separate collection is logistically possible and already on the way, especially since these wastes have already been separately collected in the past (for feeding animals). The conventional curbside collection (collection at the generation point) in waste bins could be combined with the dehydration of the waste to reduce the volume.

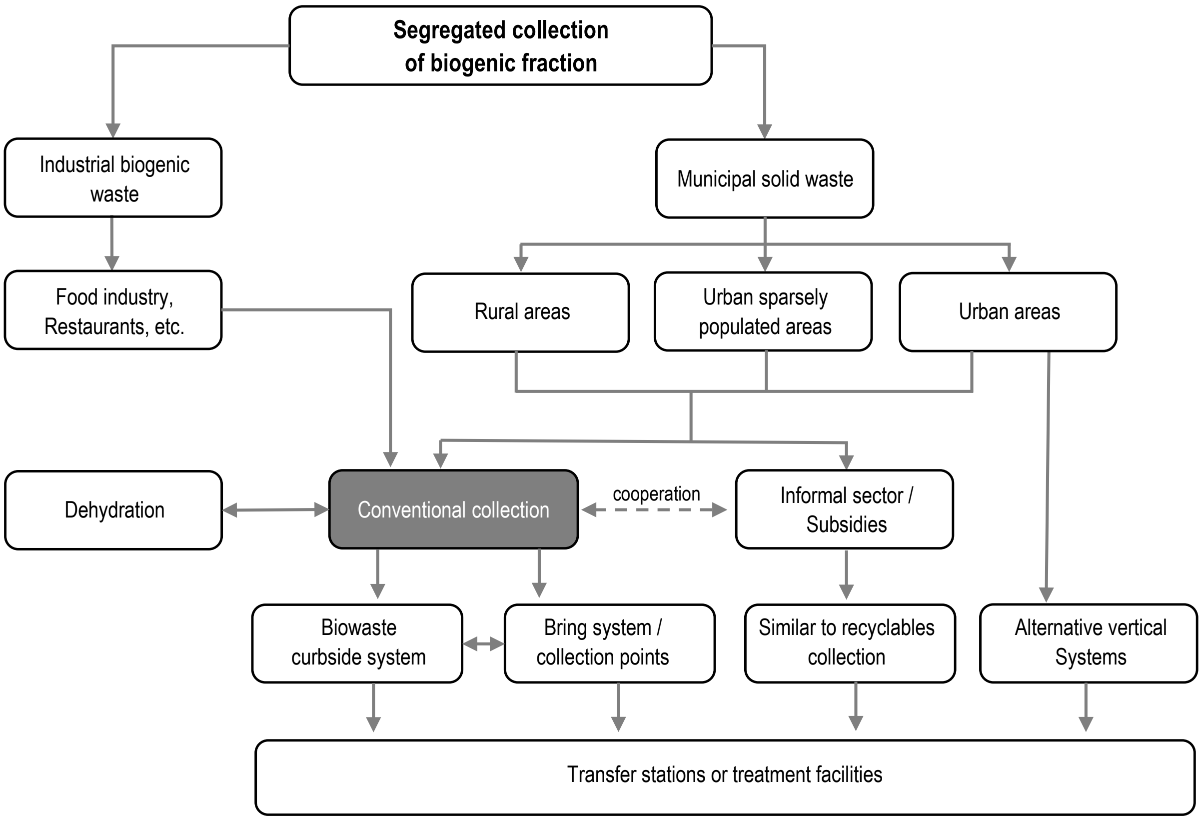


Figure 7.4: Strategy for the segregated waste collection in China

The major challenge is the introduction of a separate collection of the biogenic fraction from households. This waste stream is produced regularly/daily but in relatively small quantities (per household) and cannot be stored for a long time. For the segregated collection of this fraction, the conventional collection by a curbside system but also by a bring system seems possible.

In densely populated urban areas, alternative vertical systems for high-rise buildings might be found and developed. The conventional curbside collection in these buildings, where residents bring their waste to a big container, mostly placed in the basement, is possible. But experiences in Europe show that impurities in such systems are high.

The successful separation of biogenic waste requires an optimal design of the collection requirements for the residents more than explicit targets. With regard to the collected amounts, the container volume is of crucial importance. An analysis of existing disposal areas in Germany showed that the quantity of collected bio-waste increased with the container size (UBA, 2014).

This aspect is mainly of significance in urban, highly populated areas, where the collection takes place in high-rise buildings and space is rare. Table 7.1: Assumptions and the calculated capacities and bins needed to provide the required volume show the calculated capacities and bins needed to provide the required volume. At the same time it has to be considered that enough volume for the residual waste has to be provided as well.

Table 7.1: Assumptions and the calculated capacities and bins needed to provide the required volume.

	Organic waste separate collection from big buildings										
	daily collection					collection every 2 days					
Targeted population	1000	2000	3000	4000	5000	1000	2000	3000	4000	5000	Persons
Ge neration rate	1,0										kg/capita/day
Total daily amount	1000	2000	3000	4000	5000	2000	4000	6000	8000	10000	kg
Bio waste	60%										
Total biowaste	600	1200	1800	2400	3000	1200	2400	3600	4800	6000	kg
Collected bio waste	30%										
Collected bio waste	180	360	540	720	900	360	720	1080	1440	1800	kg
Food waste bulk density	0,5										kg/l
Required capacity	360	720	1080	1440	1800	720	1440	2160	2880	3600	l
Capacity of the containers	240										l
	1,9	3,8	5,6	7,5	9,4	3,8	7,5	11,3	15,0	18,8	Containers
No. of containers	2	4	6	8	10	4	8	12	16	19	
Capacity of the containers	660										l
	0,7	1,4	2,0	2,7	3,4	1,4	2,7	4,1	5,5	6,8	Containers
No. of containers	1	2	3	3	4	2	3	5	6	7	

Due to the low content of recyclables in the residual waste, the segregated collection of the biogenic fraction could be performed as a “wet-dry” collection system. Residents might find it more comprehensive to sort their waste in the categories “wet-dry” than in “biodegradable-residual”.

A collection system that is successful in one location cannot necessarily be easily transferred to another location without first identifying, examining and accounting for the differences in the structure of the cities. Nevertheless, experiences presented in a study (BIPRO, 2015) comparing segregated collection in Europe will be summarized in the following, as they might to some extent be applicable to China.

- Countries have introduced mandatory separate collection to achieve high municipal waste recycling levels; MBT can contribute to reach the targets of the Landfill Directive, but is not alone sufficient to achieve the 50 % recycling target.
- Countries with high rates of composting/digestion have, in most cases, implemented a separate collection of bio-waste on a door-to-door basis. Collection costs for door-to-door collection schemes might be higher; however, capture rates are also usually higher.

- The fee system combined with the municipal regulation setting the minimum standard for collection is the primary success factor for the collection of bio-waste.
- Several local instruments such as legislative instruments (landfill and incineration bans) have a clear impact on the collection rate of bio-waste.
- Involving the private sector in collection and treatment can help reduce costs and the management burden. If involving the private sector, minimum collection and treatment standards should be set and a robust reporting system for data on waste collection and treatment should be put in place.
- They have a PAYT (PAYT - Pay as You Throw) system in place based on residual waste, which cross-finances the collection of separate collected biogenic waste.
- There is a correlation between the type of charge applied (PAYT, flat rate charges or municipal taxes) and the collection rate: the cities that implemented PAYT perform much better than other cities. The worst performing cities base their funding on flat rates.
- Communication to households is very clear about what can and what cannot be placed in each bin. Properly informed citizens are vital for reducing impurities and obtaining a high quality recyclable material.

In PAYT schemes households are charged according to the amount of waste they generate. Some of the PAYT schemes include a combination of flat rate fees or taxes (e.g. certain annual amount) and a variable element linked to container sizes (volume-based schemes), number of sacks (sack-based scheme), frequency of collection (frequency-based scheme) or the weight collected (weight-based scheme) or a combination of these elements. PAYT is usually used for mixed residual waste. The intention is that the separate collection of bio-waste is (partly or completely) cross-financed by a higher charge for residual waste.

7.1.3 Mechanical treatment

Mechanical processes prepare the input of waste treatment plants for the biological processes and improve their efficiency. Finally, mechanical processes are needed for the condition of the end products to make it marketable.

Separately collected waste fractions also contain impurities referred to as contaminants. If the contaminants release substances which directly influence the biological process, this can be disturbed or inhibited. Metal ions contained in the impurities may among other things enter the product of the biological treatment, thus reducing its quality and limiting its marketing potential. Contaminants and impurities can damage or even destroy equipment. If they remain in the compost or fermentation residue, the product cannot be sold because the impurities would then contaminate the farmland.

Impurities in separately collected bio-waste are other waste fractions that citizens have mistakenly thrown into the biodegradable waste containers. They often include glass and metal packaging, plastics and, above all, plastic bags in which citizens collect and dispose their bio-waste.

Various impurities have different effects on treatment and product quality:

- Natural mineral fractions (sand, gravel, stones) - sedimentation in fermentation processes, abrasive wear on many treatment appliances, deterioration of product quality,
- Oversized degradable debris, e.g. wood - clogging of aggregates and parts,
- Degradable but potentially contaminated components, e.g. treated or coated wood - contamination of the products,
- Metals, e.g. metal packaging and cutlery parts - wear or clogging of treatment parts; potential contamination of products with metal ions,
- Glass, mainly packaging glass – risk of injury while manual sorting; sedimentation in fermentation processes, abrasive wear on treatment equipment, deterioration of product quality,
- Plastics and plastic films, mainly packaging material – clogging of conveyor belts, screens and pumps; contamination of products,
- Cardboard, paper – not/hardly fermentable; potential contamination of products when printed or coated.

Bio-waste is broadly contaminated with impurities. The separation of the contaminants must be carried out to ensure the required product quality of the biological treatment and/or the avoidance of mechanical disturbances in the process sequence.

For the removal of contaminants, the bio-waste treatment plants have to make considerable expenditures. The bio-waste, composts or fermentation residues are freed from contaminants by various technologies. This is almost always incomplete and is technically and financially complex.

Prior to the biological treatment, raw materials (biogenic waste) are comminuted to disintegrate them for biodegradation, to increase the surface area and the degradation rate. Contaminants lead to an increased wear of the crushing units.

Crushing units are also used for the mechanical unpacking of the bio-waste from the plastic bags. Slowly running shredders crush the plastic bags into larger parts, which can be removed from the product before or after the biological treatment.

Prior to the biological treatment, metals have to be separated with a magnetic separator. The metal fraction should be removed prior to comminution so that the crushing units are not damaged.

The sorting of impurities can also be performed manually. In particular, plastics and glass can also be removed before the comminution and biological treatment. The removal of glass is particularly important if the compost and fermentation residues are used for gardening. Special protection measures must be taken into account when manually sorting impurities from bio-waste.

After the biological treatment, the product is conditioned for use in agriculture and horticulture, i.e. a final treatment removes remaining contaminants and foreign substances and optimizes the properties of the compost and fermentation residues for further use. Sieving (20 - 10 mm) is the most important step of conditioning. Hard material separation or drying can be used as required. One problem must not be underestimated during conditioning: Finely crushed plastic bags and glass flakes can hardly be removed from the compost or fermentation residue. They remain on the agricultural land.

The mechanical treatment is of great importance for the biological process, the plant and machine technology as well as the product quality.

7.1.4 Biological technologies

As already discussed in the introduction to this chapter, there are two options when dealing with biogenic waste from municipal waste: a clean fraction collected separately and a mixed fraction with a share of biogenic waste. Figure 7.5 summarizes the technical treatment options of both these fractions. For the mixed waste MBT is a good complement to incineration or landfilling. This solution will be described in detail in chapter 7.2.2.

The segregated collection of biogenic waste could include food waste from restaurants and food industry, bio-waste (mainly kitchen waste) from households and green waste mainly from parks and public green areas. As described in Chapter 5, only households in Chinese villages generate green waste. For counties and cities there was no data regarding green waste. Nevertheless, this stream will be also considered since for a final strategy in a certain city, county or village a detailed analysis of the local situation has to be performed and be taken into account and this might include a green fraction.

As described in Chapter 6.1.3 the state-of-the-art technologies for separated collected biogenic waste are composting and anaerobic digestion. Which of these technologies is the most suitable for a certain city, county or village depends on many factors and mainly on the **waste characteristics**. The moisture content is one important parameter to be considered, since its optimal range is different for the three technologies. Table 7.2 shows the optimal range for the three technologies and compares them with the average moisture content of waste in cities, counties and villages already discussed in chapter 5.1.2. Since the moisture content of the waste is dependent on the biogenic fraction, it is assumed that biogenic waste collected separately will have similar moisture content. It can be seen that the average moisture content of waste from cities and counties is very similar. Considering only the moisture content of the waste, biogenic waste from both origins seems to be suitable either for dry-anaerobic digestion or composting. If no other wet materials or liquid are added the moisture content is not suitable for wet digestion.

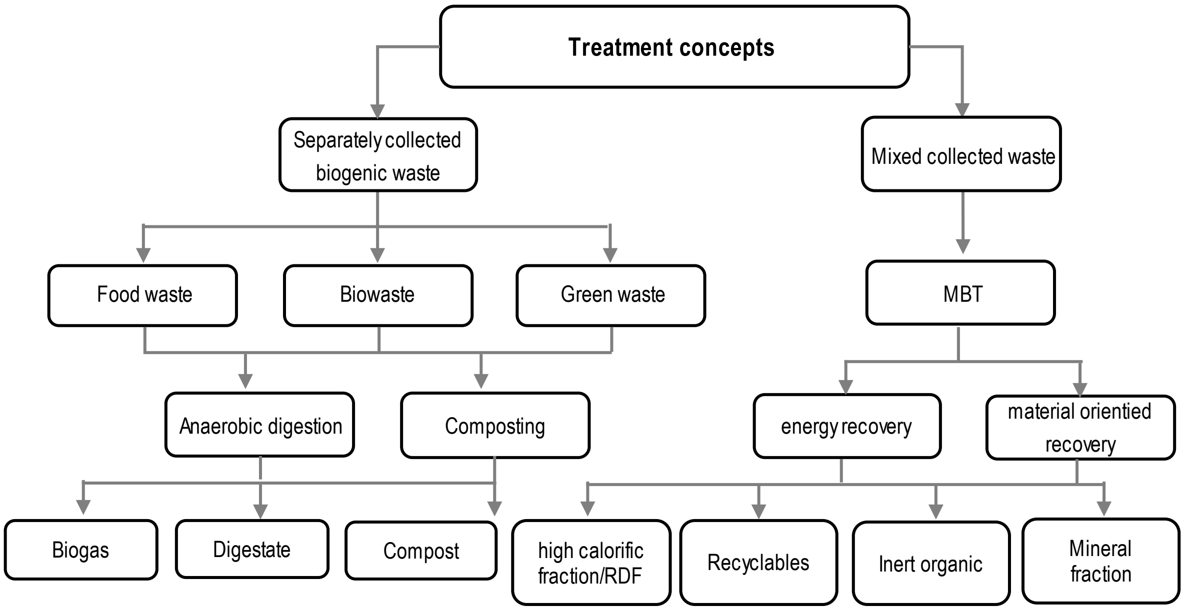


Figure 7.5: Treatment concepts for biogenic waste streams in China

The available data for the composition of waste from villages did not state the moisture content, but in contrast to the other data, it considered green waste in addition to kitchen waste. For this reason, it is assumed that due to the content of green waste the biogenic waste from villages will have proper characteristics for composting, but also for dry anaerobic digestion.

Table 7.2: Comparison of the average moisture content of waste in cities, counties and villages (compare chapter 5.2.1) with the optimal range for the different technologies

Moisture content	Optimal range	Cities $x_{0,75}$-$x_{0,25}$ (x_{max}...x_{min})	Counties $x_{0,75}$-$x_{0,25}$ (x_{max}...x_{min})	Villages
Wet anaerobic digestion	97 – 85 %	60 – 50% (62…46%)	58 – 50% (68…44%)	No data
Dry anaerobic digestion	85 – 55 %			
Composting	65 – 50 %			

To make a final decision on the most suitable technology, other parameters aside from the moisture content have to be considered. Other important parameters which could be taken into account are for example the structure of the material, the C:N-ratio, the pH-value, etc. Important parameters for composting are summarized in Figure 7.6. The structure of the waste is important for the aeration of the waste material and of special importance if passive aeration is taken into account. Due to the high moisture content, it can be assumed that the structure of the biogenic waste is low. Therefore, composting systems with active aeration are recommended. The structure of the waste material is also for the anaerobic digestion with percolation technology important since the percolate has to be able to pass through the waste body.

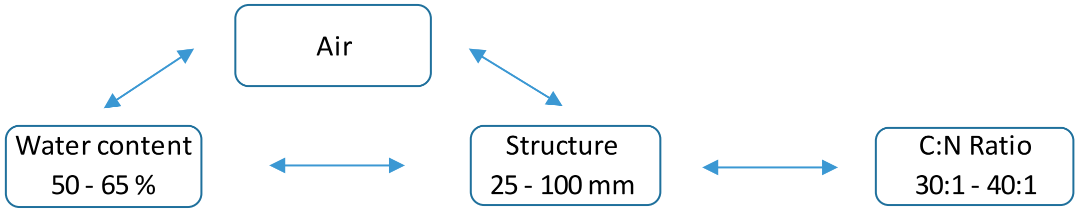


Figure 7.6: Important parameters for the composting

Also the waste **amounts** in China play an important role in the consideration of the suitable technology for an area. The population number and waste amounts mainly in Chinese urban areas are considerably higher and not comparable to numbers and amounts in Europe. In densely populated areas, the waste amounts generated and collected separately have to be estimated carefully to plan the capacity of facilities.

Table 7.3 shows the estimated amounts of waste generated and collected separately based on different collection rates. For the estimation the average waste generation of 1.1 kg/cap/d and the average waste content of biogenic waste in household waste of 60% (compare chapter 5.1) were used.

Table 7.3: Estimated biogenic waste amounts for different collection rates and population number

Population		100.000	250.000	500.000	750.000	1.000.000	2.000.000
total waste generated	Mg/d	110	275	550	825	1.100	2.200
total bio generated	Mg/d	66	165	330	495	660	1.320
collected bio-10	Mg/d	7	17	33	50	66	132
collected bio-20	Mg/d	13	33	66	99	132	264
collected bio-30	Mg/d	20	50	99	149	198	396
collected bio-40	Mg/d	26	66	132	198	264	528
collected bio-50	Mg/d	33	83	165	248	330	660
collected bio-60	Mg/d	40	99	198	297	396	792

These estimated amounts of biogenic waste collected separately for different population numbers in Table 7.3 are compared with the capacities of two operating dry digestion facilities from two different German companies: the plug-flow digestion plant has a capacity of 219 Mg/d while the percolation digester has a capacity of 356 Mg/d. These are not the typical capacities for each technology but the highest technology operating from these companies.

It can be seen that the green area in the table marks amounts of waste collected, which are in the range of conventional capacities of the German facilities. The two orange areas show amounts slightly higher than the conventional capacities and it is assumed that also these higher amounts can be handled in dry digestion facilities. The amounts collected listed in the remaining red areas are significantly higher than the conventional capacities.

According to one of the companies (oral communication), increasing the capacity is not a technical problem, as dry digestion technologies are built in modular design and adding a higher number of fermenters is not a problem. But the logistics are challenging for the transport of the waste, the finished product, and the feeding of the fermenters is performed with conventional equipment like trucks and wheel-loaders.

With regard to composting technologies and the amounts to be treated, the area requirement for the technologies differ and might be challenging in highly populated areas with high waste amounts and lack of space. Here mainly box- and/or container-composting are the technologies, which are not best suitable for high amounts.

Food / Restaurant waste is an important waste stream due to the huge amounts generated. A study on food waste in Hong-Kong (EPD, 2009) suggested that comparatively pure organic waste could be found in some markets, food-processing factories, hotels and restaurants, and is therefore easy to be separated out at source. Moreover, due to its high moisture content it is suitable as feedstock for anaerobic digestion. Table 7.4 compares different parameters with the optimal range for anaerobic digestion.

Table 7.4: Characteristics of Chinese food waste and comparison with optima for AD [EPD, 2009]

Parameter	Optimal range	All samples	
		Range	Median
pH value	6.0 - 7.4	3.2 – 6.1	4.4
Moisture content (%)	Dry AD >70% Wet AD >85%	28.6 – 94.4	74.15
C:N ratio	25 – 30	6.2 - 126	12.35
Sodium content	<16,700 mg/kg	85.6 – 53,600	6,025

In general, the analysed food wastes have enough moisture to allow wet AD, but dry AD also seems possible. If wet AD is to be adopted, a controlled pre-treatment mixing would be beneficial to optimize the feedstock characteristics. For example high-moisture food waste (e.g. restaurant wastes) could be used to increase the moisture content of dryer waste.

The analyzed food waste was mostly more acidic than suitable for a typical AD process and might hinder the biodegradation. Optimizing the pH level might be necessary. For highly acidic feedstock, lime may buffer the pH level.

The C/N ratios of the food waste samples generally fall below the optimal range of 25-30 but may vary greatly among the sources. It should be noted that a high C/N ratio could mean insufficient nitrogen for the building-up of bacterial mass, while a low C/N ratio would lead to ammonia formulation, thus inhibiting bacteria activity. In view of the high variability of C/N ratio between sources of waste, it is advisable to allow a controlled pre-treatment feedstock mixing, adding sources of carbon to increase the C/N ratio in certain cases.

The majority of the food waste samples showed a significantly lower sodium content than the limit of 16,700 mg/kg. The result indicates that the risk of salt toxicity to AD process is not significant, but it has to be monitored for sources with potentially high sodium load as the maximum value shows

7.1.5 Utilization and disposal of output streams

As described in Chapter 6.1.3, compost can be utilized in agriculture and further landscaping purposes. Compost returns organic matter and nutrients to soils, making it one of the best ways of recycling biogenic matter. Usually only minor amounts of impurities such as plastic bags, glasses and stones sorted out before and after the process need to be disposed of.

To achieve a safe recycling of organic matter and nutrients, high quality standards need to be set for the product. Table 7.2 compares the limits for compost in China and Germany.

Biogas, as one of the products from anaerobic digestion (compare Chapter 6.1.3), will surely find applications in China. The situation for digestate might need to be clarified.

In both cases, composting and anaerobic digestion, the market for the products might need to arise, so that a certain transition period should be considered.

Table 7.5: Comparison of Chinese and German limits for compost

Control standard for urban wastes for agricultural use (GB8172-87)			**German standards (BioAbfV and DüMV)**			
Parameter	Unit	Limit	Limits		Unit	Parameter
			A	B	Mg DM/ha	Max. application rate in years
			20	30		
			< 2		per litre FM	Germinating seeds
Particle size	%	≤ 12	0		%	Impurities > 20mm
Impurities	%	≤ 3				
			0,1		%	Non-degraded plastic films > 2mm
			0,4		%	Other impurities > 2 mm
			5		%	Stones > 5 mm
Moisture	%	25 - 35	< 45		%	Moisture
Organic matter	(C, %)	10	15 - 40		%	Organic matter
Total Pb	mg/kg	100	150	100	mg/kg	Total Pb
Total Cd	mg/kg	3	1,5	1	mg/kg	Total Cd
Total Cr	mg/kg	300	100	70	mg/kg	Total Cr
Cr (VI)	mg/kg		2	2	mg/kg	Cr (VI)
Total Hg	mg/kg	5	1	0,7	mg/kg	Total Hg
Total Ni	mg/kg		50	35	mg/kg	Total Ni
Total Zn	mg/kg		400	300	mg/kg	Total Zn
Total Cu	mg/kg		100	70	mg/kg	Total Cu
Total Tl	mg/kg		1	1	mg/kg	Total Tl
Total As	mg/kg	30	40	40	mg/kg	Total As
Perfluorinated Tensides (PFTs)	mg/kg		0,1	0,1	mg/kg	Perfluorinated Tensides (PFTs)
Dioxins / Furans (PCDD/PCDF)	ng WHO-TEQ/kg		Σ 30	Σ 30	ng WHO-TEQ/kg	Dioxins / Furans (PCDD/PCDF)
dl-PCB	ng WHO-TEQ/kg				ng WHO-TEQ/kg	dl-PCB
Total N	(N, %)	0,5				
Total P	(P_2O_5, %)	0,3				
Total K	(K_2O, %)	1				
Mortality of ascarid eggs		95 - 100				
Coliform values		0,01 - 0,1				
pH		6,5 - 8,5				

* Note: The Chinese standard is now under revision, and will be replaced by a new National standard called “National Standard on the Pollution Control of Biomass Composting” (MEP No. 2015-4).

7.1.6 Recommendations

To increase the resource efficiency and climate protection from solid waste management, the following measures are recommended for China:

- Consider legal amendments and/or new regulations to ensure a proper handling of the waste and quality of the product (for example landfill ban of untreated waste)
- Introduction of segregated collection for biogenic waste to divert waste from landfills and reduce volume and emissions
- Consider a step-wise introduction of waste segregation with a strong information campaign
- Treatment of segregated biogenic waste to recycle organic matter (and produce energy as e.g. biogas)
- Establish an educational training on solid waste management
- Financing system for biogenic waste

No technology is especially recommended since composting and anaerobic digestion are both suitable for the average Chinese biogenic waste. For each city/county/village a detailed waste analysis of composition and amounts will be necessary to make the final decision. Due to the moisture content of restaurant waste, wet anaerobic digestion appears to be the best solution. But also here a detailed waste analysis is always necessary for the final decision.

As described in Chapter 6.1.4 (operation of facilities) as well as explained in the introduction of Chapter 7, for the proper operation of facilities skilled and experienced personnel is inevitable. Practical experience mainly for the biological process is essential; theoretical knowledge is insufficient. It would be therefore advisable to establish an educational training for different professional groups (technicians, electricians, etc.) in order to attract trained personnel for the operation of waste treatment plants. Skilled workers should learn and be able to:

- Accept, identify, analyse and declare waste
- Operate, monitor, inspect, maintain and repair waste treatment plants
- Control and monitor biological processes
- Detect operation faults/breakdowns and (let) remedy them independently
- Document and evaluate workflows and operational procedures
- Advise and inform clients, e.g. in matters of waste segregation and disposal

Since biogenic waste is not as valuable as metals or paper its segregated collection cannot be organized identically to these recyclables, but a similar system could be set in place. Subsidies might be possible or the pay-as-you-throw model. In any case the environmental benefits from the segregated collection (volume reduction at landfills, emissions reductions, etc.) need to be taken into account. The environmental costs of not segregating waste might be higher on the long term.

7.2 Biogenic waste from the mixed collection

7.2.1 Laws, regulations, management and control

The residual waste, which is discharged as municipal waste, still contains usable waste fractions. Depending on how intensively these recoverable waste fractions are collected, they are more or less contained in the residual waste. In the PRC, many recyclable wastes are collected separately, often by the informal sector. The municipal waste is thus enriched with bio-waste; up to 75% of organic components can be measured (compare Chapter 5.2).

The introduction of the separate bio-waste collections would reduce this share.

The use of biogenic waste contained in municipal waste is only possible to a very limited extent.

The products from the treatment of the organic fraction of the mechanical-biological treatment of residual waste (municipal waste, mixed waste) are called compost-like output (CLO). In many countries, CLO is used on agricultural land. The PRC should establish rules on whether the products (CLO) resulting from the treatment of mixed waste can be used in and on soils (limit values for pollutants and foreign substances and soils, degree of degradation).

If CLO is to be deposited, regulations are required that formulate landfill requirements. This way, permitted emissions (gas formation rate, eluate concentrations) can be limited.

Furthermore, treatment plants which handle residual waste (municipal waste, mixed waste) are also subject to legal requirements. Requirements on the location of the plant should include distance regulations for residential buildings and protective nature.

Further regulations should cover the emissions from the plants (limit values for emitted dusts, odours, exhaust air and exhaust gas, both as concentration and load).

One option to use mixed municipal waste is the fermentation in an anaerobic MBA process. The resulting biogas can then be directly used or upgraded to bio-methane. For this, regulations should specify the quality of the gases, especially when bio-methane is to be introduced into the natural gas network.

The government can also financially promote the production of energy from waste and thereby create incentives.

When laws and regulations are enacted, there must also be a controlling authority. A corresponding authority should be established and equipped with the necessary competences. The authority should also be able to impose sanctions.

7.2.2 Mechanical-biological treatment

The experience in Germany and Europe show that even if the segregated collection of biogenic waste is introduced, not all residents follow or understand how to segregate and an important share of biogenic waste is still found in residual waste. To reduce the environmental impacts of mixed waste there are mainly two state-of-the-art treatment technologies: incineration and MBT-Technologies (compare chapter 6.2.2 and figure 6.15).

In China, due to its high moisture content and low caloric value, the incineration of mixed waste does not contribute to resource conservation [Dorn, 2015] and thus will not be discussed in this study. However, the treatment of mixed waste in an MBT prior to incineration would considerable improve its calorific value making energy recovery possible.

As already described in Chapter 6, MBT allows the separation of resources for recycling or energy recovery before the remaining waste is combusted or landfilled. A further advantage is that after the MBT-treatment the remaining residual waste causes significantly lower emissions when landfilled.

MBT-technologies are very flexible and can be adapted to the specific requirements and targets of an area. Therefore, considering the needs of the city or county in question, two options can be chosen regarding the specific sorting fractions:

- Mechanical-biological waste treatment (MBT) for resources recovery
- Mechanical-biological stabilisation (MBS) or biological drying for energy recovery

The simplified process flow of both options is illustrated in Figure 6.15. The differences between the options are first whether material or energy recovery is the main target. Second, whether the material splitting takes place before or after the biological step. This last aspect affects the quantity of waste to be treated biologically as well as the sorting characteristics of the waste.

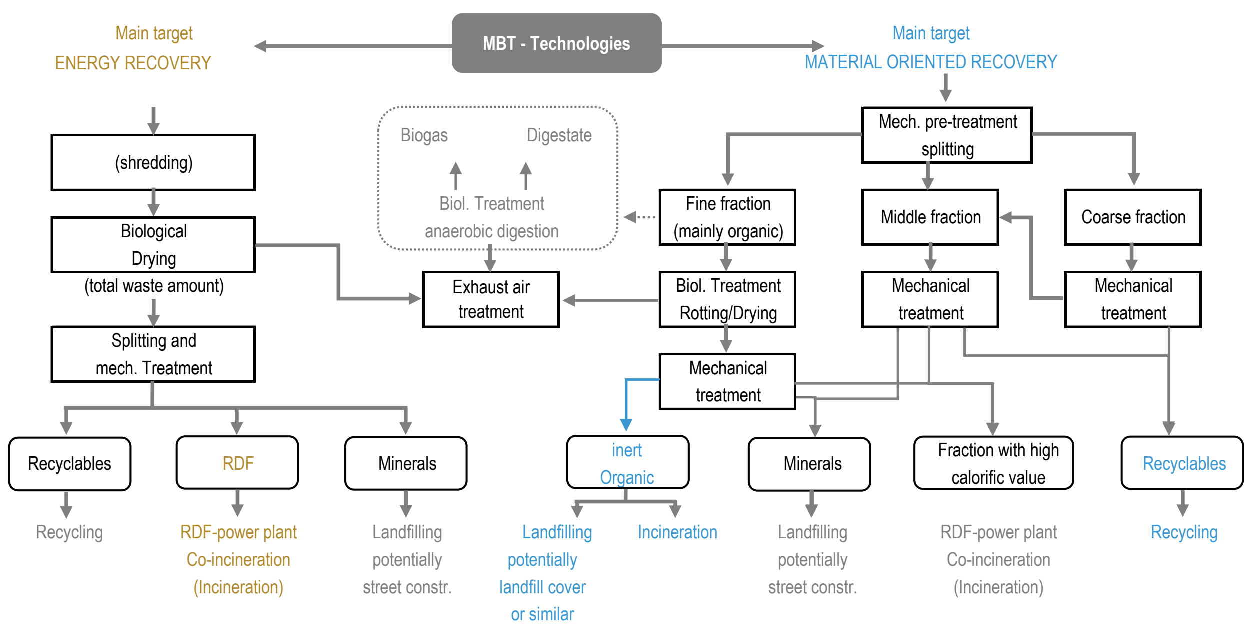


Figure 7.7: Simplified process flows for MBT and MBS

The resources recovery approach (MBT) combines the biological treatment (anaerobic digestion and/or rotting or biological drying) with mechanical processing steps to separate products from the waste prior or/and after the biological treatment. In this approach the waste splitting takes place at the beginning of the process. Most of the biogenic material is contained in the fine fraction and therefore only this fraction is treated biologically.

The main purpose of the biological – rotting - part of the process is to degrade the biogenic fraction of the waste to gain an inert fraction, which causes almost no emissions when landfilled. Due to the mass loss during the biological process the volume of the fraction has to be reduced, saving landfill space.

Instead of rotting, also biological drying or anaerobic digestion can be applied as biological treatment. The AD aims to gain biogas and recover energy out of the biogenic fraction. The main purpose of the biological – drying - part of the process is to produce heat to remove the moisture from the waste and divert some biogenic material for energy recovery (as part of the RDF/high calorific fraction).

The scope of the energy recovery (MBS) approach is to use heat produced in the aerobic process to remove water from the waste and hence dry the waste (biological drying). In this approach the waste splitting takes place after the biological treatment of the entire waste amount.

The main purpose of the biological – drying - part of the process is to produce heat to remove the moisture from the waste in order to enable easier and more efficient mechanical separation. In this case the mechanical separation is performed after the biological treatment, and waste is only shredded before the biological treatment. Most of the biogenic material in the waste and in the high calorific fraction /RDF for energy recovery.

Which of both options is best for a certain region will depend among other things on other industrial facilities nearby, which could make use of the outputs. A study on MBT treatment for China advised against the physical drying in MBT due to the higher costs for this option. For this reason this technology was not further considered in this study [Nelles et.al, 2014].

7.2.3 Utilization and disposal of output streams

MBT will contribute to the solution of a China specific problem, where municipal solid waste has a very high moisture content and thus low heating value. After the final mechanical treatment in both approaches of the MBT, a stabilized organic material will be produced, and recyclable fractions like ferrous and non-ferrous metals are recovered from the dry matter. Also, incombustible, inert contraries like glass, sand and stones are separated, Figure 7.8. In addition to the recyclables a RDF material is also produced, which consist of all combustible waste components like plastics, wood, paper, cardboard and also includes the dried organic fraction with a sufficient heating value.

Stabilized organic waste fraction (CLO)

MBT and composting processes both use very similar techniques. However, the two processes have to be distinguished in terms of input material and proper utilization of the output. Composting of organic material is to obtain high-quality compost; it requires “pure” organic material as input, such as source separated bio-waste. Whilst MBT aims at the reduction of the organic material in waste, the input is mixed municipal waste, which is pre-treated prior to disposal. A utilization of the pre-treated waste may be possible; however, it is subject to certain restrictions. If “Compost like Output” or “Stabilized MBT Output” is produced from mixed solid wastes in a MBT, the quality criteria and requirements for proper land application have to be met according to the requirements of approved standards.

Composts intended as growing media should meet more stringent quality criteria compared to (CLO) that will be used as landfill cover. The difference in the MSW collection service level will affect the criteria that set the quality limits of the compost as product.

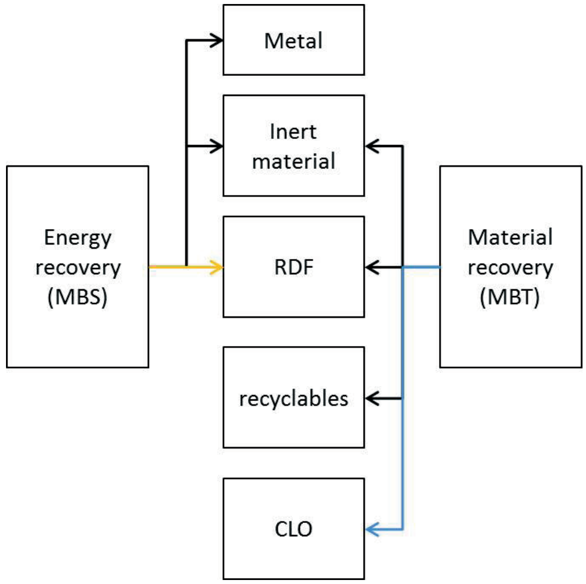


Figure 7.8: Outputs from MBT treatment of mixed MSW.

A number of characteristics determine compost quality, such as moisture, organic matter and carbon content, heavy metals, salinity, inert contaminants and state of maturity or stability etc. are shown previously in Table (7.5).

Recyclables

Recyclables derived from the various MBT processes are typically of a lower quality than those derived from a separate collection system from households or at recycling centers and therefore have a lower potential for high value markets. However, these plants may enhance overall recycling levels and enable recovery of certain constituent items that may otherwise not be efficiently collected in household systems. Recyclable components in MSW include paper and board, plastics, glass, metal and putrescible materials.

Refuse Derived Fuel (RDF)

After adequate (pre-) treatment in different processing plants and applying strictly defined quality assurance measures, various non-hazardous and/or hazardous waste materials from households, commerce, and industry can be used as RDF in co-incineration plants

The main application of RDF is its utilization as a fuel in the industrial and energy sectors. It is utilized to supply energy for a production process in co-incineration plants. Solid recovered fuels (SRF) are also a subgroup of RDF; it refers only to solid waste fuels that are prepared from non-hazardous, sorted or mixed solid wastes.

Solid Recovered Fuel (SRF) has been defined in compliance with CEN/TC 343 as a sub-category of waste derived solid fuels.

The produced RDF/SRF can be described in accordance with the European List of Waste and classified by two waste codes:

- 19_12_10: (quality assured) combustible waste (SRF)
- 19_12_12: other wastes from mechanical treatment of wastes (RDF).

Waste is not a regular fuel and during incineration it can deliberate or/and form pollutants that may harm the environment and to minimize its negative impacts on environment, a legal control regime is required for WtE-plants.

The RDF/SRF producers, potential customers, and the respective authorities are responsible for setting its characteristics and quality standards associated with waste processing for fuel production. This must ensure the protection of the combustion facilities as well as the final product.

Although many European countries and organizations have already set specifications and quality criteria for the chemical characteristics of RDF, limited work exists on actual measurements of chemical parameters on RDF samples.

Biogas

An MBT plant that uses Anaerobic Digestion (AD) as its biological process will produce biogas. Biogas can be used in a number of ways. It can be used as a natural gas substitute (distributed into the natural gas supply) or converted into fuel for use in vehicles and engines. More commonly it is used to fuel boilers to produce heat (hot water and steam), or to fuel generators in combined heat and power (CHP) applications to generate electricity, as well as heat.

7.2.4 Recommendations

Considering the high biogenic share and moisture content in Chinese mixed waste, Figure 7.9, the pre-treatment in MBTs prior to landfilling or incineration, seems to be a good option to reduce the environmental constrains arising from waste management. MBT can be used to recover resources and minimize the emissions from landfills, but it can be also used prior to incineration to enhance the calorific value of the waste and make energy recovery possible.

MBT-technologies are very flexible and can and should be adapted to the local requirements and targets. Therefore, no special technology is recommended. Each city/county/village has to describe their local necessities as well as targets to develop their own suitable solution.

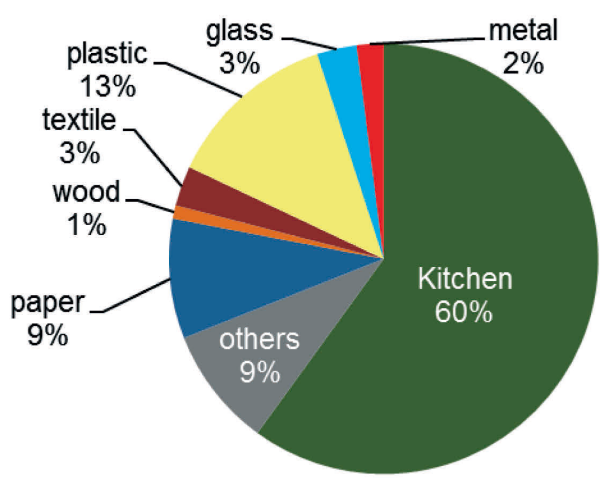


Figure 7.9: Typical Chinese mixed waste composition for urban areas.

The next figure, Figure 7.10, shows the waste composition of German residual waste and the outputs achieved with the two different MBT approaches. Considering the average waste composition, the following estimations regarding the outputs after the processes can be made:

- The mass loss could be higher due more to high organic fraction and high water content
- The energy recovery could be lower
- The material recovery could be the same or less depending on the type and quality of recoverable material
- Material for landfilling could be more or the same

The market for MBT-outputs is not yet installed, therefore a certain transition time to let the market develop should be considered. At the same time other industrial facilities in the area, which could make use of the outputs, should be considered.

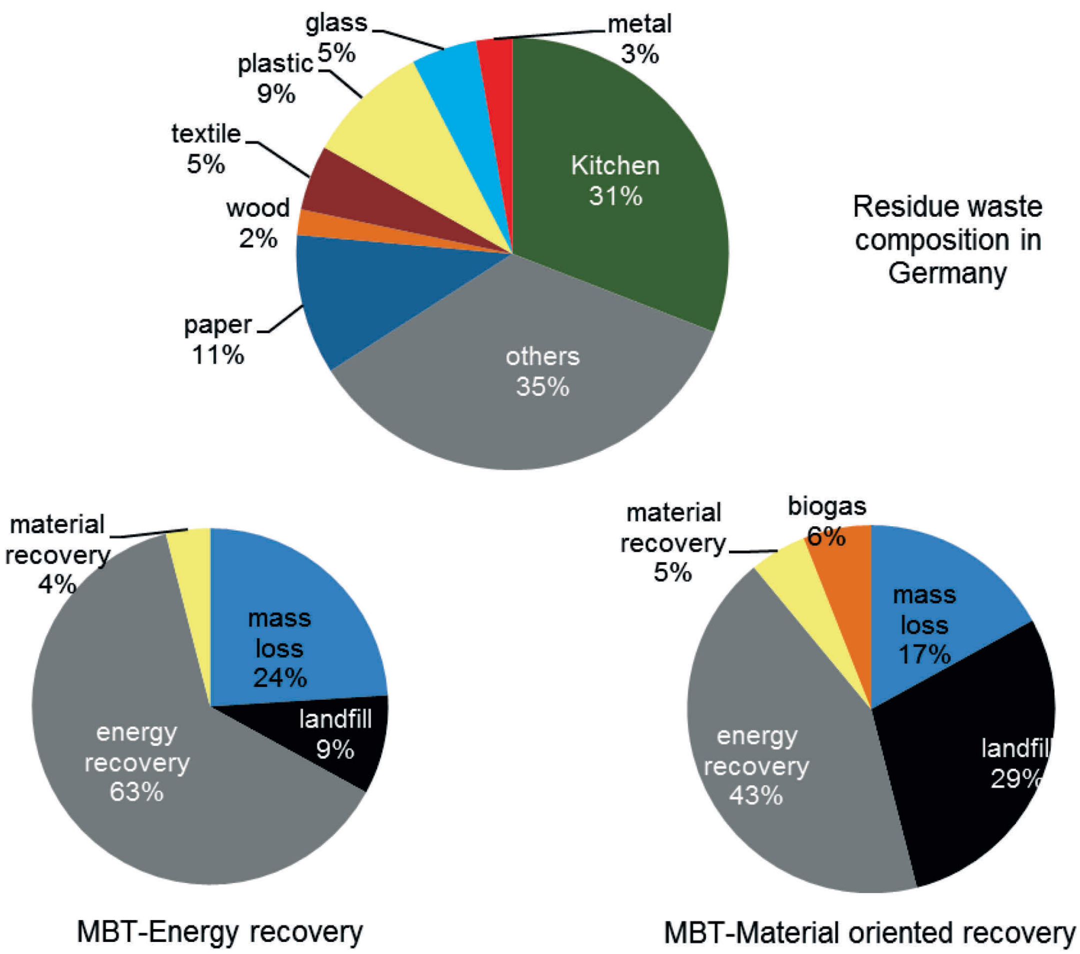


Figure 7.10: Waste composition of German residual waste and the outputs achieved with the two different MBT approaches

8. Summary

Biogenic waste is the key fraction for a sustainable solid waste management (SWM) as it is responsible for many environmental constraints if not treated properly: generation of climate relevant emissions, leachate production and low calorific value of waste are the main problems caused. There are two main fractions of biogenic waste in municipal solid waste (MSW): a clean fraction if segregated collection if practised and a mixed fraction in residual waste. Therefore, if these two fractions are managed with state-of-the-art solutions, important resource and climate protection measures can be achieved.

The segregated collection of biogenic waste is a precondition to recycle biogenic waste and produce high-quality composts and therefore recirculate organic matter and nutrients. It further reduces the amount of residual waste to be disposed or incinerated and lowers the water content in residual waste for a more effective incineration.

Composting and anaerobic digestion (AD) are the main state-of-the-art technologies to recycle separately collected biogenic waste. Both make use of natural degradation processes, but while composting is an aerobic process, anaerobic digestion works under the absence of oxygen. Composting allows the recycling of the waste, turning the organic matter into compost. In the anaerobic digestion process the organic matter is turned into biogas and digestate, allowing the energetic use combined with the subsequent material use of the digestate (multiple use). Both the replacing of artificial fertilizers by compost and digestate on soil and the energetic utilization contribute to the protection of the climate and resources. Which technology is the most suitable, depends on the biogenic waste composition. For wet biogenic waste as well as for food waste, anaerobic digestion is a good option. For lignin and cellulosic plant material in green and biowaste, composting is the best option.

In Germany, the landfill ban on untreated waste was the main reason for the success of the segregated collection and treatment of biogenic waste. Furthermore, the energy-efficient WTE and the mandatory nationwide segregated collection, which has been newly implemented, were the basis for sustainable waste management.

At present, only waste incineration and MBT-technologies are the available state-of-the-art technologies as pre-treatment options for mixed MSW before landfilling. Incineration is already practised in China and will not be discussed further. An MBT system is a waste processing facility that combines a waste sorting facility with biological treatment methods (anaerobic digestion and/or composting). It is designed to process mixed household waste to convert and segregate the waste into suitable outputs and marketable products.

Typical outputs are: a stabilized fraction for disposal, materials for recycling, Refuse Derived Fuels (RDF)/Solid Recovered Fuels (SRF) to be used as alternative fuel but also a minor fraction of contaminated solid rejects, as well as, controlled water and gas emissions. Therefore, MBT facilities achieve material and energy recovery of waste contributing to a sustainable resource management and reduction of greenhouse gases.

In China, waste management has made great progress in the last years. The collection and treatment of municipal waste is wide-ranging at city and county level and is gradually increasing at village level. Waste treatment is however limited to incineration or landfilling (landfilling is considered a waste treatment in China), wasting energy and material resources and resulting in environmental problems. Furthermore, there are abundant legal rules ranging from basic laws, regulations, policy documents, standards and specifications considering different waste management aspects. The separate collection of waste is, however, only regulated for restaurant waste. All in all, there are technically and legally very good conditions to introduce a sustainable waste management.

To increase the resource and climate protection from solid waste management in China considering the biogenic waste stream, several aspects and measures could be considered. The following figure illustrates and compares the waste streams for the actual waste system implemented in China and the advanced proposed system (estimation). It can be clearly seen that the advanced system would significantly reduce the waste to be landfilled. Further benefits are summarized in the figure.

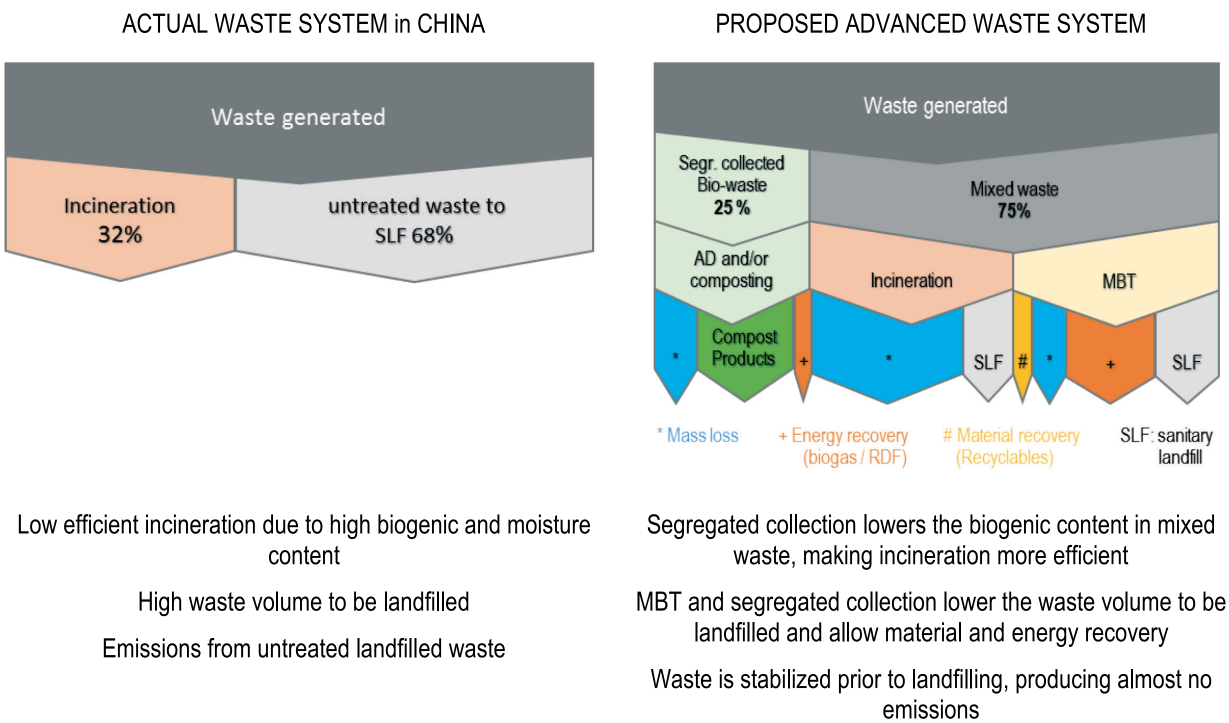


Figure 8.1: Comparison of the waste flows for the actual and proposed SWM system in China

LEGAL FRAMEWORK: Consider legal amendments and/or new regulations to ensure a proper handling of the waste and quality of the product (for example landfill ban of untreated waste). Furthermore the implementation and motoring of the existing as well as new regulations should be strengthened.

SEGREGATED COLLECTION: the introduction of a segregated collection is indispensable to truly contribute to resource and climate protection. Only collected and separately treated biogenic waste can be transformed to high quality products. Furthermore, the segregated collection reduces the amounts of waste to be landfilled or incinerated. Pilot projects on separate collection should be introduced step-wise, be accompanied by a strong public information campaign and run for at least 5 years to obtain significant results. For the collection in high-rise buildings innovative solutions for vertical systems are needed.

COMPOSTING/ANAEROBIC DIGESTION: to recycle separately collected biogenic waste both technologies seem to be suitable for the average Chinese waste composition. For each region a detailed analysis of the waste situation will be necessary to make a final decision. Marketing for high quality compost is available. The use of digestate as fertilizer needs to be advised and supported.

MECHANICAL-BIOLOGICAL TREATMENT: For the mixed waste stream, the MBT has potential as a decentralized solution and as a complementary treatment before incineration and/or landfilling. MBT can be used to recover resources and to minimize the emissions from landfills, but it can be also used before incineration to enhance the calorific value of the waste and make energy recovery possible (and to reduce the number of incineration plants needed).

The market for MBT-outputs is not yet installed therefore a certain transition time for the market development should be considered. At the same time industrial facilities in the area such as cement plants, which could make use of the outputs, should be considered.

RESTAURANT WASTE: There is a trend towards a solution for restaurant waste in Chinese cities. Due to the moisture content of restaurant waste wet anaerobic digestion appears to be a suitable approach. Recovery/disposal of digestate must be part of the solution.

OPERATION and PERSONNEL: For the proper operation of facilities, skilled and experienced personnel are crucial. An educational training for different professional groups on SWM could help find appropriate personnel.

FINANCING: SWM in China is financed through the national investment and support program, which mainly considers the construction of facilities. For a proper operation of SWM the introduction of a tax system, subsidies for biogenic waste and possible revenues from products from waste treatment should be considered. Also the environmental benefits from the MBT-treatment and the segregated collection need to be taken into account, since their operation costs are usually lower than the remediation costs for climate change and a polluted environment.

COOPERATION: A close cooperation between Chinese and German actors sharing knowledge and experiences can help to achieve a sustainable waste management.

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annex A: List of laws and regulation in China

Production, collection, and transportation of MSW		
Basic Laws and Regulations		Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste released in 1995 as PD No.58, revised quartic in 2004, 2013, 2015 and 2016
Policy Documents		The regulation of urban city appearance and environmental sanitation management released in 1992 as Decree of State Council (SC) No.101; revised in 2011
		Notice on the application of charge system to promote industrialization of MSW treatment released in 2002 by the State Development Planning Commission(SDPC), Ministry of Finance (MoF), MoC, and StateEnvironmentalProtectionAdministration (SEPA) as SDPC-Price [2012] No.872
		Notice on opinions about further improvement of MSW treatment released in 2011 by SC as Document of SC [2011] No.9
		Letter on public review of "compulsory waste classification system (exposure draft)" released in 2016 by General Office of the NDRC and MOHURD as Document No. [2016]1467 of Department of Resource Conservation and Environmental Protection (DRCEP), NDRC
Standards and specifications	Waste production and facility planning	The method of calculate and forecast about municipal domestic refuse output(CJ/T106-2016, alternative version of CJ/T 106-1999)
		Standard for terminology of city appearance and environmental sanitation (CJJ/T 65-2004)
		Standard for figure symbols of environmental sanitation(CJJ/T 125-2008)
		Standard for setting of environmental sanitation facilities (CJJ 27-2012)
		Technical specifications of domestic pollution control for town and village (HJ574-2010)
	Waste classification	Classification and evaluation standard of municipal solid waste (CJJ/T 102-2004)
		The classification signs for municipal solid waste (GB/T 19095-2008)
		Classification of municipal solid waste generation source and discharge (CJ/T 368-2011)
		Sampling and analysis methods for domestic waste (CJ/T313-2009,alternative version of CJ/T3039-1995)
		General detecting methods for the chemical characteristic of domestic refuse(CJ/T96-2013, alternative version of CJ/T96-1999, CJ/T97-1999, CJ/T98-1999, CJ/T99-1999, CJ/T100-1999, CJ/T101-1999, CJ/T102-1999, CJ/T103-1999, CJ/T104-1999, and CJ/T105-1999)
	Product standards for waste collection containers and devices	Specific equipment for municipal environmental sanitation (CJ/T 16-1999)
		Plastic refuse sack (GB/T 24454-2009)
		Biodegradable plastic refuse sack (GB/T 28018-2011)
		General technical specifications for plastic waste container (CJ/T 280-2008)

		Indoor plastic trash bin(GB/T 28797-2012)
		Buried garbage collection device (CJ/T 483-2015)
		Metal trash bin (QB/T 4902-2016)
		Waste container-Five-ton truck used freight container (CJ/T 5025-1997)
		Compression refuse collector (CJ/T 127-2000)
		Plate waste conveyor (CJ/T 390-2012)
		Compact electric refuse collecting vehicle (CJ/T 419-2012)
		Kitchen garbage vehicle (QC/T 935-2013)
		Detachable container garbage collector (QC/T 936-2013)
		Refuse collection vehicle (QC/T 52-2015)
		Refuse transfer station facilities (JB/T 10855-2008)
		Compactor for refuse transfer station (CJ/T 338-2010)
		Compactor for refuse collection station (CJ/T391-2012)
	Technical specification for MSW collection and transportation	Technical specification for collection and transportation of municipal solid waste (CJJ205-2013)
		Technical specification for operation and maintenance of municipal solid waste transfer station (CJJ 109-2006)
		Technical specification for municipal solid waste collecting station (CJJ 179-2012)
	Construction standards for MSW collection and transportation facilities	Construction standards for refuse transfer station (Project construction standard117-2009)
		Construction standards for refuse collection station (Project construction standard 154-2011)
	Evaluation standards for MSW collection and transportation facilities	Evaluation standards for refuse transfer station (CJJ/T 156-2010)

Unsorted MSW treatment

Policy documents	
	Policy on MSW treatment and pollution prevention/control technologies (released in 2000 by MOC, SEPA, and Ministry of Science and Technology (MoST) as Jiancheng No. [2000]120)
	Guidelines for MSW treatment technologies (released in 2010 by MOHURD, NDRC, and Ministry of Environmental Protection (MEP) as Document No. [2010]61ofDepartment of Urban Construction, MOHURD)
	Opinions on improving co-processing of municipal and industrial waste in production processes (released in 2014 by NDRC, MoST, Ministry of Industry and Information Technology (MIIT), and so on as Document No. [2014]884 of DRCEP, NDRC）
	Notice on carrying out pilot work in co-processing of MSW by cement kiln (released in 2015 by General Office of MITT, General Office of MOHURD, and NDRC as Document No. [2015]28 of General Office, MITT)

Sanitary landfill	
Standard for project construction	Project construction standard for MSW sanitary landfill site (Project construction standard 124-2009)
	Project construction standard for closure of MSW sanitary landfill site (Project construction standard 140-2010)
Standard for pollution control	Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (GB 16889-2008)
Technical Specification for Project Design	Technical Guideline for Projects of Municipal Solid Waste Sanitary Landfills (RISN-TG014-2012)
	Technical code for municipal solid waste sanitary landfill (GB 50869-2013,alternative version of CJJ17-2004)
	Technical code for liner system of municipal solid waste landfill (CJJ 113-2007)
	Technical code for geotechnical engineering of municipal solid waste sanitary landfill (CJJ 176-2012)
	Leachate treatment project technical specification of municipal solid waste landfill(HJ564-2010)
	Technical code for ecological restoration technologies of old municipal solid waste landfill (under preparation)
Technical specification for operation and mainte-nance	Technical specification for operation and maintenance of municipal solid waste sanitary landfill (CJJ 93-2011)
	Technical code for municipal solid waste sanitary landfill closure (CJJ 112-2007)
	Technical specification for operation and maintenance of landfill gas collection, treatment and utilization projects (CJJ 175-2012)
	Technical requirements for site utilization after stabilization in municipal solid waste landfill (GB/T 25179-2010)
Evaluation standard	Standard of assessment on municipal solid waste landfill (CJJ/T 107-2005)
	Monitoring and testing in municipal solid waste landfill degradation treatment (GB/T 23857-2009)

	Technical specification for soil test of landfilled municipal solid waste (CJJ/T 204-2013)
	Technical specification for leak location surveys of geomembrane in municipal solid waste landfill (CJJ/T 214-2016)
	Technical requirement for environmental monitor on sanitary landfill site of domestic refuse (GB/T 18772-2008)
Product Standard	Specific equipments for municipal environmental sanitation-Sanitary landfill of refuse (CJ/T 18-1999)
	Sanitary landfill compactor (JB/T 10668-2006)
	Technical requirements of compactor for landfill (CJ/T 301-2008)
	Sanitary landfill compactor (GB/T 27871-2011)
	High density polyethylene geomembrane used for landfills (CJ/T 234-2006)
	Liner low density polyethylene geomembrane used for landfills (CJ/T 276-2008)
	High density polyethylene pipe used for landfills (CJ/T 371-2011)
	Nonwoven geotextiles used for landfills (CJ/T 430-2013)
	Geomats for landfills (CJ/T 436-2013)
	Geofiltration fabrics for landfills (CJ/T 437-2013)
	Geonets Drain for Landfills (CJ/T 452-2014)
	Disc-tube reverse osmosis equipment for domestic waste leachate treatment (CJ/T 279-2008)
	Spiral-wound reverse osmosis equipment for municipal solid waste leachate treatment (CJ/T 485-2015)
	Equipment for Renewing the Plant Cover for Sanitary Landfills Closure (GB/T 29150-2012)

Incineration	
Standards for project construction	Construction standard for Municipal solid incineration treatment plant (Jianbiao 142-2010)
Standard for pollution control	Standard for pollution control on municipal solid waste incineration GB18485-2014 (replace of GB 18485-2001)
Technical Specification for Project Design	Technical Code for Municipal Solid waste incineration projects (CJJ 90-2009)
	Technical specifications for bag filters of municipal solid waste incineration (HJ 2012-2012)
Technical Specification for Operation & Maintenance	Technical specification for operation maintenance and safety of municipal solid waste (CJJ 128-2009)
	Specification for maintenance of municipal solid waste incineration plant (CJJ 231-2015)
	Standard for supervision on operation of municipal solid waste incineration plants (CJJ/T 212-2015)
Evaluation Standard	Standard for assessment on municipal solid waste incineration plant (CJJ/T137-2010)
Product Standard	Specific equipment for municipal environmental sanitation - incineration, gasification, pyrolysis of refuse (CJ/T 20-1999)
	Technical requirements of waste grab cranes in domestic waste incineration plant (CJ/T 432-2013)
	Specification of MSW incineration boilers (JB/T 10249-2001)
	Municipal solid waste incinerator and boiler (GB/T 18750-2008)
	Technical requirements for grate of huge type MSW incinerator (JB/T 12121-2015)
	MSW incineration exhaust gas treatment equipment (GB/T 29152-2012)
	Fabric for bag filter of exhaust gas treatment in solid waste incinerator (JB/T 11310-2012)
Standard for Product (Residue) Utilization	Municipal solid waste incineration bottom ash aggregate (GB/T 25032-2010)
Composting	
Standards for project construction	Construction standard for waste composting treatment plant (Construction standard 141-2010)
Standard for pollution control	Pollutant control standard of bioorganic waste composting (under preparation, plan to publish on 2018)
Technical Specification for Project Design	Technical code for the composting of municipal solid waste CJJ 52-2014 (replace of CJJ/T52-93)
Technical Specification for Operation & Maintenance	Technical specification for operation and maintenance of municipal solid waste composting plant CJJ 86-2014 (replace of CJJ/T86-2000)
Evaluation Standard	Technical evaluation targets on municipal solid waste composting plant (CJ/T 3059-1996)
	Standard for assessment on municipal solid waste compost plant (CJJ/T 172-2011)
Product Standard	Specific equipment for municipal environmental sanitation – compost of refuse (CJ/T 19-1999)

	Bio-chemical processor for organic waste (CJ/T 227-2006)
	Equipment for automatic monitoring and control of composting (CJ/T 369-2011)
	Automatic equipment of oxygen monitoring for aerobic composting (CJ/T408-2012)
	Real-time on-line detection equipment for odor from municipal solid waste (CJ/T465-2015)
	Pile turning machine for composting (under preparation)
	Integrated aerobic composting equipment (under preparation)
Standard for Product (Residue) Utilization	Control standards for urban wastes for agricultural use (GB 8172-1987)
	Organic fertilizer (NY 525-2002)
	Organic-inorganic compound fertilizer (NY481-2002)
	Organic-inorganic compound fertilizer (GB18877-2002)
	Microbial organic fertilizers (NY884-2004)
	Compound microbial fertilizers (NY/T798-2015)
	Organic media for greening use (LY/T1970-2011)
	Quality of sludge from municipal wastewater treatment plant (GB24188-2009)
	Disposal of sludge from municipal wastewater treatment plant – quality of sludge used in garden or parks (GB/T 23486-2009)
	Disposal of sludge from municipal wastewater treatment plant –sludge quality for land improvement (GB/T 24600-2009)
co-processing of solid waste in cement kiln	
	Technology policy of pollution prevention and control on co-processing of solid waste in cement kiln (released in 2016 by Ministry of Environmental Protection No.72) Standard for pollution control on co-processing of solid waste in cement kiln (GB 30485-2013) Standard for technology on co-processing of solid waste in cement kiln (GB30760-2014) Standard for engineering design on co-processing of waste in cement kiln (GB50954-2014) Standard for design on co-processing of industrial waste in cement kiln (GB50634—2010) Standard for environmental protection technology on co-processing of solid waste in cement kiln (HJ662-2013)

Separated collected MSW

Restaurant Waste		
Policies		General Office of State Council: Opinions on Strengthen Management of Waste Cooking Oil and Restaurant Waste (released in 2010 as No. [2010]36 of General Office of State Council)
		Restaurant Waste Management Regulations of Local Cities
Standard & Specificati-on	Technical specifica-tions and procedures	Technical code for food waste treatment (CJJ 184-2012)
		Technical standard for waste cooking oil recycling and processing (exposure draft)
	Product standard	Kitchen Waste Treatment and Utilization Equipment in Catering Service (GB/T 28739-2012) (actually refers to the restaurant waste)
		Automatic oil-water separation equipment of restaurant waste (CJ/T 478-2015)
		Food waste disposal machines (JB/T 12342-2015)
		The norm of energy consumption from the biochemical treatment of food waste (DB 11/T 1119-2014)
Bulky Waste		
		Technical requirements for collection and recycling of bulky waste (GB/T 25175-2010)

National investment and support program
General Office of NDRC: National Plan on Municipal Solid Waste Harmless Treatment Facilities Construction in the 13th Five-Year (released in 2016 by General Office of the NDRC as Document No. [2016]2851 of DRCEP, NDRC)
General Office of State Council: National Plan on Municipal Solid Waste Harmless Treatment Facilities Construction in the 12th Five-Year. (released in 2012 by General Office of the State Council as Document No. [2012]23)
MOHUDR, NDRC, MOF, etc: Notice on Carrying Out the Work on Municipal Solid Waste Separation Demonstration Cities (Districts) (released in 2014 by MOHURD, NDRC and MOF, etc.; as Document No. [2014]39 of MOHURD)

Catalogue of Advanced Applicable Technologies for Comprehensive Renewable Resources Utilization (the second batch)(Ministry of industry and information technology, No.5, 2014)
NDRC: Notice on the Proposed Circular Economy Demonstration Key Projects in 2013 (2013)
NDRC: Decision on Amending Some Related Clauses of <Industrial Structure Adjustment Guidance Catalogue (2011)> (released in 2011 by NDRC as Decree of NDRC No.21)
NDRC: Notice on Agreement of Restaurant Waste Utilization and Harmless Treatment Implementation Plan of 33 Cities (Districts) and Set These Cities as Pilot Cities (2011) (released in 2011 as Document No. [2011]1669 of DRCEP, NDRC)
From 2011 to 2015, a total of 100 pilot cities were established.
NDRC: Notice on Issuing Circular Economy Development Special Fund to Support the Construction & Implementation Plan of Restaurant Waste Utilization and Harmless Treatment Pilot Cities. (released in 2011 as Document No. [2011]1111 of DRCEP, NDRC)
NDRC: Notice on Printing the "12th Five-Year" Guideline of Resources Comprehensive Utilization and Implementation Plan of Solid Waste Comprehensive Utilization. (released in 2011 as Document No. [2011]2919 of DRCEP, NDRC)
NDRC, etc.: Notice on Carrying Out the Pilot Work on Restaurant Waste Utilization and Harmless Treatment. (released in 2010 as Document No. [2010]1020 of DRCEP, NDRC)