PART I: ANALYSIS OF THE ECONOMICS OF WASTE-TO-ENERGY PLANTS IN CHINA

PART II: MSW SORTING MODELS IN CHINA AND POTENTIAL FOR IMPROVEMENT

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Submitted in partial fulfillment of the requirements for M.S. degree in Earth Resources Engineering

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December 2012

Research sponsored by the

Earth Engineering Center

Columbia University

Executive Summary

Part I: Analysis of the Economics of Waste-to-Energy Plants in China

In a period of less than twenty years, China has become a major actor in the implementation of waste-to-energy technologies for managing municipal solid wastes (MSW); at the present time, an estimated 15% (23 million tons of MSW) are processed in over 100 WTE plants. China is also an exception to the general rule that nations with relatively low GDP per capita rely exclusively on landfilling. The objective of the first part of this thesis was to examine the technical, policy, and economic factors that have contributed to this rapid expansion of WTE capacity in China and the business models used. The study concentrated on large cities in China, in particular Shanghai, Beijing, and Guangzhou.

Despite the booming WTE market, landfilling is still the main method of waste management in Chinese cities. The landfilling rates of post-recycling MSW in Shanghai, Beijing, and Guangzhou are 75%, 85%, and 79%. An appreciable fraction goes to non-regulated waste dumps, which is called "non-harmless treatment". The current system has several problems such as low recycling efficiency, lack of landfill space, and related environmental problems. The cost for waste transportation and processing in modern sanitary landfills is high. Therefore, WTE capacity should be increased since it is an effective and, in the long-term, economical solution to the current waste crisis.

On the technical level, Chinese cities are adept to using modern WTE. Imported moving grate technology dominates the domestic WTE market. The most popular air pollution control (APC) system is the combination of semi-dry scrubber, activated carbon injection, and baghouse filter. NOx control equipment is used in some facilities. According to the field study in Shanghai and other major cities, the WTE plants have very low emissions of dioxins and mercury, far below the EU 2010 standard. NOx emission is higher than the E.U. standard but still within the Chinese National Standard. New national standards will come into effect in 2013 and will bring the limitation for Cd, Pb, etc. to the same level as the E.U. standard.

The build-operate-transfer (BOT) ownership model is currently preferred for financing and operating WTE plants in China. This model utilizes private investment, reduces government capital investment and drives the privatization of the waste management industry. A series of favorable policies are created to encourage the development of WTE in China. The most representative is the "grid electricity pricing", applying specifically to WTE power. A subsidy of US$30 per MWh of electricity will be provided for plants generating less than 280 kWh/ton of MSW.

In the course of this study, there was a critical analysis of past studies by the Earth Engineering Center and the published literature. Also, several operating WTE plants were visited in Shanghai in order to obtain first-hand data on their operation, economics and environmental performance. Design and construction documents of several WTE projects in other Chinese cities were also examined. On the basis of this information, actual local specifications and plant design documents were reviewed to provide capital and operating costs for a hypothetical WTE of 383,000-ton capacity.. A financial analysis was then carried out at different gate fee scenarios, to test the profitability of the model plant. The results showed that a plant of this capacity built in China requires an average capital investment of $74 million, i.e. $193 per ton of annual capacity, and a gate fee of $20 per ton of MSW.

This study also showed that inadequate MSW sorting in China has impeded the development of a sustainable waste management system that includes WTE. Therefore, Part II of the thesis focused on the status of the current sorting practice in China and possible improvements.

Part II: MSW Soring Models in China and Potential for Improvement

MSW sorting (i.e., separating the garbage into recyclable, compostable, etc.) is the first step of an integrated waste management system because it increases the recovery of materials and energy from the solid waste stream. This part of the study was based on an analysis of the Beijing and Guangzhou models and experience in developed countries on materials recovery from MSW. In 2000, the central government launched a campaign for MSW recycling and suggested multi-stage sorting that included some source separation by local residents and neighborhood authorities, to be followed by secondary sorting at regional waste management centers. The remainder of the MSW is disposed in landfills and waste to energy plants and Informal recycling was to be included. Different cities have modified this model according to their own situation. For example, Beijing eliminated household and neighborhood level sorting and focused on sorting at regional waste management centers (i.e., materials recovery facilities). The MSW is transported directly from curbside to these centers where the recyclables are to be sorted out while the rest of the waste is disposed to landfills or WTE plants. On the other hand, the Guangzhou model emphasized resident source separation and neighborhood sorting; waste management companies are engaged to transport the sorted materials to markets and the remainder of the wastes to landfills and waste-to-energy plants, thus eliminating the regional waste management centers.

Both models are experiencing low public participation, lack of standardized practice, insufficient economic incentives for participating companies, and poor working conditions for informal recyclers. The statistical data showed that the sorting model of Guangzhou is superior in terms of its potential to increase recycling and advance sustainable waste management. The results of this study have shown that this potential can be attained by implementing the following measures:

-There must be source separation of designated materials (.e.g., paper fiber, metals, marketable types of plastics and glass, and hazardous wastes) at residences and businesses. Public involvement should be encouraged by means of fully transparent policies, incentives, and disincentives for non-compliance. Standard sorting equipment, such as bags, cans and bins for storing designated recyclable and disposable wastes, must be provided by the municipality. The city should ensure that the sorting practice is integrated with the market for recyclables, to ensure that the sorted streams do not end up in landfills.

Non-governmental organizations (NGO) and academic institutions have a high public credibility and should be engaged in the execution of the sorting system and serve as an information channel between the public and the government. The objectives and mission of WTERT-China, an academic-industry organization, was discussed briefly in this report. This organization can help to advance sustainable waste management in China by means of its website, education programs, and bringing together universities, industry, and government agencies concerned with this major environmental issue.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor Professor Nickolas Themelis for his utmost guidance and support throughout my life in Columbia University. His invaluable expertise in the field of waste-to-energy is an inexhaustible source of power for my study. I would also like to thank Liliana Themelis for her warmth, kindness, and support throughout this study.

During the study of the thesis, I was enlightened by Brian Bahor (Covanta Energy) and David Tooley (Wheelabrator Technologies), who kindly provided me with precious practical knowledge of the industry.

I would also like to thank Professor Dezhen Chen and Professor Enke An of Tongji University, Shanghai, China and Prof. Qunxing Huang of Zhejiang University, Hangzhou, China, for their generous supports and sharing their precious experience in Chinese waste-to-energy industry.

Last, but certainly not least, I would like to give thanks to my dear parents, Ke Qiu and Pei Zhang and the rest of my family in Shanghai, who wholeheartedly supported my life and study in the U.S. Their trust and encouragements are always the supreme power in my life.

Ling Qiu, New York City, November 26, 2012

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Part I: Analysis of the Economics of Waste-to-Energy Plants in China

1. Introduction

China has the largest population (1.33 billion) on Earth and a nominal GDP of $7.3 trillion. As one of the world's fastest developing countries, China has experienced a high growth rate in economic development and urbanization. The urban population (non-agriculture population) increased from 58 million in 1949 to 670 million in 2010 (1), indicating a steady rise in material consumption of modern life style and ever growing municipal solid waste (MSW) generation. A fivefold increase in MSW generation from 31 to 156 million tons was reported between 1982 and 2004 (1). The latest national reports show that the MSW generation of the country has reached 158 million tons (1). Figure 1 show the MSW generation with the urban population growth in the recent decade.

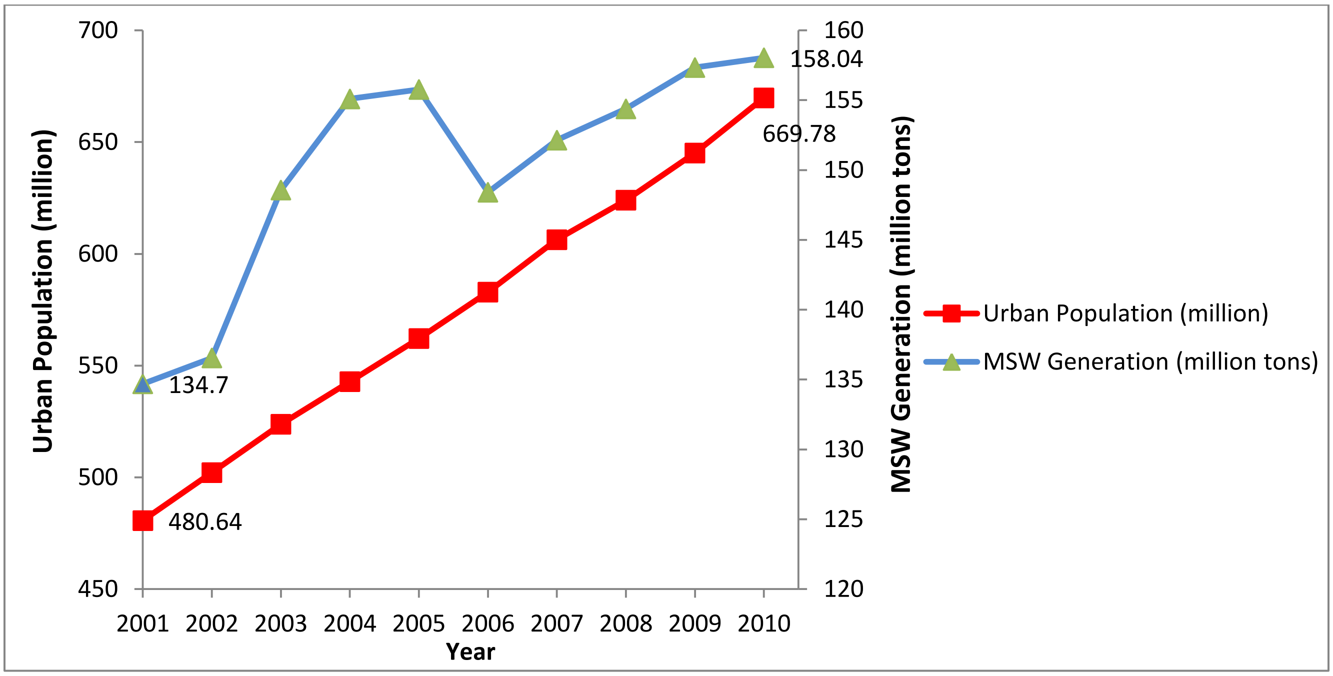


Figure 1 MSW generation with the urban population growth in the recent decade

At 2010, there were 64 cities with a population of over a million in the country, corresponding to 24.4% of China's urban population. These cities dominate the country's economy and suffer the most from the skyrocketing MSW generation because of the disparity between urban development and waste management facilities. One of the major problems is lack of landfill space. Therefore it is imperative to convert the current waste management structure of cities to a more sustainable and long-termly cost-effective one. Table 1 shows the population, economics, waste generation, and landfill percentage of three major cities. The GDP (PPP)(purchasing power parity was used to reflect the actual purchasing power compared across countries)per capita were converted from the nominal GDP per capita using China's PPP/GDP ratio, 0.6 provided by the World Bank.

Table 1 Population, economics, waste generation, and landfill percentage of top three cities

	Population (million)	GDP (nominal)* (billion USD)	GDP (nominal) per capita	GDP (PPP) per capita (USD)	MSW Generation (million tons/year)	MSW Generation per capita (ton/year)	MSW TO LANDFILLS (sanitary and non-sanitary)
Shanghai	23.0	297.2	12,922	20,545	7.3	0.3	74.8%
Beijing	19.6	251.6	12,837	20,410	6.3	0.3	85.3%
Guangzhou	12.7	158.8	12,504	19,881	6.5	0.5	79.0%
China	1,300	7,300	5,413	8,500	158	0.1	82.8%

Source: China 2011 Statistical Yearbook

From Table 1 it can be seen that the MSW generation per capita of the three cities far exceeds the national average, which is consistent with the huge discrepancy in GDP (PPP) per capita. This means the purchasing power influences the MSW generation. In terms of landfill percentage, there is no obvious difference between the three cities and the national average despite the wide gap between their GDP. This also indicates a large potential for the cities to reduce landfills, since globally landfill rates are inversely proportional to the region's economic development.

According to the hierarchy of sustainable waste management (Figure 2), waste-to-energy (WTE) is in the mid of the pyramid, moving part of the post-recycling and composting waste stream from landfill in the bottom. Table 1 indicates that waste management in Chinese cities is placed mainly in the lower part of the hierarchy. Municipalities should try every means to move up the "ladder" of waste management, in order to alleviate the current landfill space crisis. WTE, as the last step before the waste stream going to landfills is regarded internationally as an indispensable part of the solution.

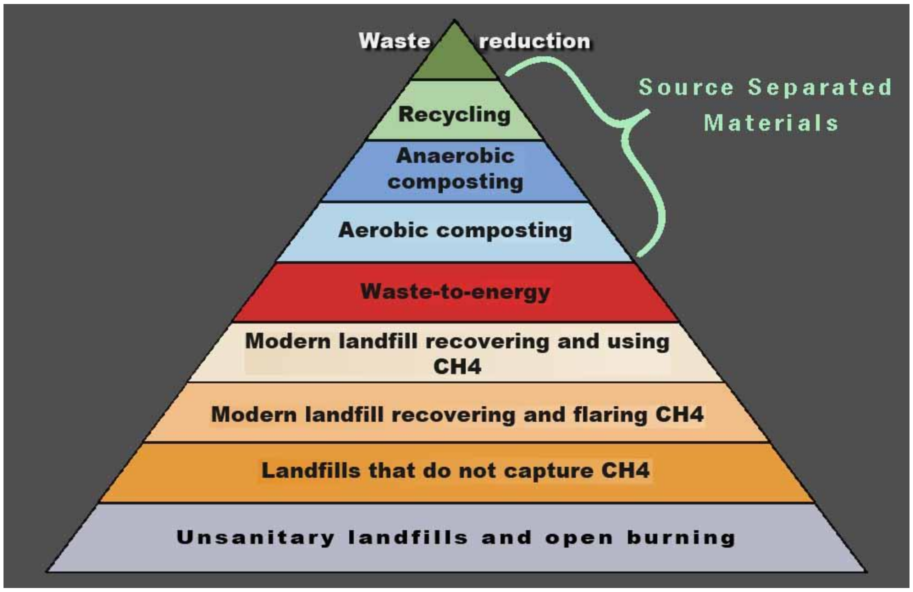


Figure 2 Hierarchy of sustainable management

By far, the largest cost item in the operation of WTE plant is the repayment of the initial capital investment of $600 to $750 per annual metric ton of capacity, which results in capital charges of $60-75 per ton of MSW processed (2). The capital cost for WTE in China is expected to be lower but the prevailing low gate fees and electricity generation per ton of waste still put the profitability of these plants under question.

The objective of this study was to compile and analyze information of the current waste management system in Chinese cities and estimate the expenditures and revenues of a 383,000 ton/year WTE plant. Different gate fee scenarios were considered and the net present value (NPV) method and internal rate of return (IRR) method were used to identify the required breakeven gate fee for such a plant, including any government subsidies for WTE projects.

2. Waste Management in Chinese Cities

2.1 MSW Characterization

Like most developing countries, the MSW in China is characterized by high moisture content and low heating value (3). The actual composition and heating value varies according to different geological and economic conditions of these cities, but the average heating value is estimated to be around 5.5 MJ/kg of MSW. Table 2 shows the MSW composition of Shanghai, Beijing, and Guangzhou.

Table 2 MSW composition of Shanghai , Beijing, and Guangzhou

Composition	Mass distribution (% wet weight)		
	Shanghai (Eastern China)[a]	Beijing (Northern China)[b]	Guangzhou (southern China)[c]
Paper	22.2	14.3	6.9
Plastic and rubber	20.9	13.6	17.2
Wood	3.3	7.5	2.8
Textiles	6.0	9.6	5.9
Organic waste	21.7	44.2	56.3
Metals	0.8	1.2	0.3
Glass & stone	8.3	7.2	4.6
Small waste residues	14.6	2.5	6.0
Average Moisture content %	51.66		

a. *Source: Field research at Shanghai Jiangqiao WTE plant by Prof. Dezhen Chen of Tongji University, 2008*
b. *Source: Rong Bo et al. Composition Analysis of Beijing's Domestic Refuse and Corresponding Treatment Countermeasure, Environmental Protection, Oct. 2004*
c. *Source: Guidebook of MSW Sorting in Guangzhou*

According to EEC previous research, southern cities have more organic waste while northern cities have more dry ash in the MSW, especially in winter. The heating value varies in a very short range despite the changing moisture content.

2.2 Waste Management Infrastructure

Waste management in Chinese cities is based mainly on landfilling and WTE. Landfilling is still the dominant method of MSW disposal, although many cities are now running out of land. The percentages of post-recycling MSW sanitary landfilling, composting, WTE, and unregulated landfilling (aka "non-harmless treatment" in China) for Shanghai, Beijing, and Guangzhou till the end of 2010 are listed in Table 3.

Due to inadequate waste sorting, the portion of composting in the whole waste management system in China remains low (1% of the Chinese total)(1). For large cities, which usually have much less portion of food waste in the MSW stream than smaller ones, the development of composting is limited and therefore must turn to WTE to diminish landfill. Table 4 shows the comparison between different waste management methods and their status in China.

Table 3 Post-recycling waste management structure in Shanghai, Beijing, and Guangzhou

City/Treatment	Sanitary Landfill%	Composting%	WTE%	"Non-harmless" treatment
Beijing	70.4	12.5	10.5	1.8
Shanghai	56.8	2.9	14.8	25.5
Guangzhou	83.6	0	8.3	8.1

**Source: China 2011 Statistical Yearbook*

Table 4 Comparison between different waste management methods and their status in China

	Non-Sanitary Landfill	Sanitary Landfill	Composting	WTE
Land consumption	Large	Large	Large	Small
Harmfulness	Severe secondary pollution	Light secondary pollution	Some secondary pollution	No secondary pollution
Volume reduction	No	No	Not obvious	90% volume reduction
Weight reduction	No	No	No	75% weight reduction
Resource recovery	No	Landfill gas collection to some extent	Fertilizer	Electricity
Water contamination	Severe	Nearly no pollution	Heavy	No pollution
Soil contamination	Severe	Little	Heavy	No pollution
Air pollution	Severe	Little	Heavy	No pollution if under control
Life span	Short, generally 10 to 20 years	Short, generally 10 to 20 years	Long	Long
Capital investment	Low	High	High	High
Operational cost	Low	High	High	High
Domestic usage	Many, but not adopted in developed areas	Little	Very little, and not successful	Adopted by developed areas and cities
National policy	Not encouraged, restricted in some regions	Not encouraged	Not encouraged	Encouraged, and enjoys favorable policies
Future trend	Gradually eliminate	Adopted by some regions	Hard to spread in the short-term	Increased with economic development

The current waste management systems in Chinese cities are facing the following problems:

a) High rate of disorganized informal recycling with low efficiency

Due to the lack of public awareness and relevant infrastructure, organized formal recycling in Chinese cities has a very high cost. Even though a few cities have been assigned to implement formal recycling strategy by the central government since 1998, an overwhelming portion of the waste stream still goes to untraceable, disorganized, and low efficiency individual recyclers. A number of cities have tried various methods to enhance formal recycling, such as curbside waste separation, charging disposition fee for per kilogram of household waste, and penalty for dumping main recyclables. However, little effect was seen in the past few years.

b) Lack of landfill space

A number of cities in China are now running out of landfill space due to the booming waste generation and the slow development of alternative strategies. Not having sufficient budget for long distance transportation and disposition, most of the cities are now besieged by an enlarging ring of landfill. This problem is too severe for recycling alone to solve. Guangzhou city boasts its national No. 1 33% of waste recycling rate, claiming that it recovers 5,800 tons of MSW per day. However, one of the local landfills, which has a designed capacity of 2,500 tons per day, now receives 7,000 tons daily (4). Actually, the city is expected to use up all its landfill space if no more aggressive strategy is taken.

c) Environmental problems of composting and landfilling

With the expanding urban boundary, many residential and developing areas in Chinese cities are located near, or even on the previous landfills. Composting and landfilling odors can affect as far as 15 km in the worst case, degrading the land value and investment attraction of surrounding areas. The Shanghai Laogang Landfill, the largest landfill in the city, is only 40 km from Lujiazui, China's major financial center. Surrounding neighborhoods have never stopped complaining about the landfill and the neighboring composting project. One composting plant in that area near Caoluzhen, a 2,000 ton per day facility, has caused significant social instability because of its heavy odor and suspected health risk. Foreign investments are severely prohibited due to the unfavorable environment. The same thing happens to other cities and property values in these areas suffer heavily. Figure 3 shows a wild burning of garbage on a landfill right near a new residential area in Beijing (5).

Figure 3 A snapshot of the film Beijing Besieged by Waste by Wang Jiuliang

2.3 Post-recycling MSW Management Cost for City Government

The cost for post-recycling MSW management is mainly composed of three parts: collection cost, transportation cost, and terminal processing cost. Collection and transportation are done by governmental agencies such as the local Environmental Protection Bureau and neighborhood authority and the costs are calculated according to operational expenses, while the terminal processing is practiced by authorized partner companies and the government expenses is calculated by fixed subsidies (gate fee) for per ton of MSW received by the facility. This section includes only sanitary landfilling as the terminal processing method, for WTE processing cost will be discussed in detail later in this study.

This part of study is based on the price and environmental protection information available for some of the average cities in China. The information and data include the economic effect of vehicle, material, power, maintenance, equipment depreciation, personnel, and tax throughout a certain process. Actual cost varies case by case due to unbalanced economic development of these cities. Usually megacities like Shanghai and Beijing have a much higher cost than average.

2.3.1 Collection cost

The collection cost is mainly composed of the personnel expenses for frontline labors and managing positions as well as the transportation, vehicle, and material involved in the process. The average cost for MSW collection is calculated to be $10.27 per ton of MSW. 31.4% of the expense is paid by municipal environmental protection bureau and the rest is paid by neighborhood authorities (6).

2.3.2. Transportation cost

The transportation cost mainly consists of the personnel expenses of truck drivers, technicians and fuel expenses. The average transportation cost is calculated to be $6.92 per ton of MSW, in which 41.5% is associated with vehicle fuel and maintenance (6). The municipal environmental protection bureau is responsible for all of the transportation processes.

2.3.3 Landfilling gate fee

Gate fee is the fixed governmental subsidy paid to terminal processing facility owners for per ton of MSW received. The average gate fee for sanitary landfill facilities is around $9.52 per ton of MSW (7). Part of this fund is collected by the government from local residents and enterprises as waste disposal fee. However, the amount is far from enough compared with the whole gate fee without governmental financial subsidies.

2.3.4 Landfilling processing cost

"Waste disposition cost (in the landfill) should be contained under governmental subsidies (gate fee), therefore we have very little profitability", said Zhou Xiaohua, general manager of Veolia Environment China, owner of the Shanghai Laogang Landfill, the largest sanitary landfill in China (7). Compared with the relatively fixed gate fee, the ever increasing personnel and fuel costs continue to fill the gap between processing costs and gate fee. The processing costs for a sanitary landfill is around $8.41 (8). Table 5 shows the breakdown of the landfill processing cost.

Table 5 Breakdown of landfill processing cost 2010 (8)

Item	Percentage %
Leachate processing	38.98
Personnel	32.74
Fuel	4.02
Equipment maintenance	2.90
Office expense	8.83
Auxiliary materials	3.79
Others	8.75
Total	100

3. WTE in Chinese Cities

3.1 WTE Technologies in Chinese Cities

Generally speaking, a 200-ton per day capacity is the minimum amount for a WTE line to be commercially viable and the fluctuation of MSW supply should be maintained within 20% (9). An average lower heating value above 5 MJ/kg is required for combustion without auxiliary fuel (9). The MSW generation and characterization in Chinese cities have fulfilled the prerequisites mentioned above therefore it is technically feasible to practice WTE in these cities.

Between the two main WTE technologies in China, moving grate combustion of as-received MSW and circulated fluidized bed (CFB), the former is favored over the latter in cities. Almost all of the existing moving grate combustion technologies are imported from Europe, U.S.A., and Japan in these cities while CFB is mainly from domestic Zhejiang University (ZJU) and Chinese Academy of Science and the market is much smaller and immature. Three reasons account for this preference:

a) CFB technology is mainly designed for low-grade MSW characterized with high moisture and low lower heating value as well as relatively low investment per ton for domestically designed and constructed CFB plants (generally 70% of the moving grate combustion plant investment) (10). Large Chinese cities usually have much higher quality MSW and more severe problem of waste crisis than less urbanized cities, therefore imported technologies that have been proved effective in developed countries are preferred even with a higher investment.

b) CFB technology needs waste pretreatment before combustion such as shredding, which complicates the operation and maintenance of the facility. Much simpler technology is preferred in cities in order to maintain a high availability of the plant.

c) CFB technology produces more fly ash than moving grate combustion (10), which lays heavy burden on post-combustion processes and environmental impacts. Large cities have more strict environmental assessment mechanism and monitoring system, therefore any possible risk is avoided by these cities.

Table 6 shows the statistics of WTE plants in major cities.

Table 6 WTE plants in major cities

Plant Name	City	Capacity (tons/year)	Combustion Technology	Electricity Generation Capacity (MW)	Investment (million USD)	Investment/ton of annual capacity (USD/ton)
Imported technologies						
Shanghai Pudong Yuqiao WTE Plant	Shanghai	346,500	Alstom, France, CITY 2000 grate furnace	2*8.5	100.00	289
Shanghai Jiangqiao WTE Plant	Shanghai	495,000	Steinmuller, Germany, grate furnace	2*12	139.68	282

Ningbo Fenglin WTE Plant	Ningbo	346,500	Noell-KRC, Germsny ladder type pushing grate furnace	2*6	63.33	183
Hangzhou Lvneng WTE Plant	Hangzhou	148,500	Japan Mitsubishi Heavy Industry Martin grate furnace	7	34.13	230
Shenzhen Longgang Pinghu WTE Plant (Phase I)	Shenzhen	363,000	Mitsubishi Heavy Industry, Japan, Martin grate furnace	12	45.40	125
Shenzhen Baoan Baigehu WTE Plant	Shenzhen	396,000	Seghers SHA, Belgium, multistage grate furnace	9	63.49	160
Shenzhen Yantian WTE Plant	Shenzhen	148,500	Seghers SHA, Belgium, multistage grate furnace	6	36.51	246
Shenzhen Nanshan WTE Plant	Shenzhen	264,000	Seghers SHA, Belgium multistage grate furnace	12	68.57	260
Shenzhen Baoan Laohukeng WTE Plant	Shenzhen	198,000	Seghers SHA, Belgium multistage grate furnace	N/A	99.68	503
Chongqing Tongxing WTE Plant	Chongqing	396,000	Alstom, France, CITY 2000 grate furnace	2*12	50.00	126
Tianjin Shuanggang WTE Plant	Tianjin	396,000	TAKUMA SN, Japan, grate furnace	2*12	85.71	216
Taiyuan WTE Plant	Taiyuan	330,000	Japan EBARA CFB	2*12	57.78	175
Guangzhou Likeng WTE Plant	Guangzhou	330,000	Mitsubishi Heavy Industry, Japan, Martin grate furnace	2*7.5	100.00	303
Guangzhou Likeng WTE Plant (Phase II)	Guangzhou	660,000	Mitsubishi Heavy Industry, Japan, Martin grate furnace	40	153.49	233

Suzhou Suneng WTE Plant	Suzhou	330,000	Seghers SHA, Belgium multistage grate furnace	N/A	79.37	241
Dalian WTE Plant	Dalian	495,000	EBARA, Japan, CFB reactot	N/A	99.21	200
Xiamen WTE Plant	Xiamen	132,000	Von Roll, Switzerland, multi-stage grate furnace	6	31.75	241
Fuzhou Hongmiaoling WTE Plant	Fuzhou	330,000	Mitsubishi Heavy Industry, Japan, Martin grate furnace	2*8	57.94	176
Beijing Gaoantun WTE	Beijing	528,000	TAKUMA SN, Japan, grate furnace	2*15	119.05	225
Chengdu Luodai WTE Plant	Chengdu	396,000	Grate furnace	2*12	76.19	192
Changzhou WTE Plant	Changzhou	264,000	TAKUMA SN, Japan, grate furnace	3*9	52.38	198
Wuhan Guanshan WTE Plant	Wuhan	330,000	Grate furnace	N/A	68.25	207
Foshan Nanhai WTE Plant	Foshan	462,000	BASIC Model 1000 , U.S.A., pulsed type grate furnace	12	55.56	120
Foshan Shunde Xingtan Youtan WTE Plant	Foshan	198,000	BASIC Model 1000 , U.S.A., pulsed type grate furnace	12	31.75	160
Shenyang Daxin WTE Plant	Shenyang	313,500	Richway CAO, Canada, Pyrolysis furnace	2*7.5	46.03	147
Huizhou WTE Plant	Huizhou	264,000	Richway CAO, Canada, Pyrolysis furnace	2*6	28.57	108
Domestic technologies						
Changchun Xinxiang WTE Plant	Changchun	171,600	N/A	6	25.40	148

Shijiazhuang Qili WTE Plant	Shijiazhuang	165,000	CFB	2*15	21.59	131
Harbin WTE Plant	Harbin	66,000	CFB	3	22.70	344
Hangzhou Jinjiang WTE Plant	Hangzhou	264,000	ZJU Differential Density CFB	N/A	N/A	N/A
Zhengzhou WTE Plant	Zhengzhou	330,000	ZJU Differential Density CFB	N/A	N/A	N/A
Wuhu WTE Plant	Wuhu	198,000	ZJU Differential Density CFB	2*6	32.22	163
Wuxi WTE Plant	Wuxi	372,900	Chinese Academy of Science CFB	2*18	36.51	98
Shenzhen Pinghu WTE Plant	Shenzhen	222,750	Chinese Academy of Science CFB	N/A	36.51	164

Source: Statistics for the National Tenth Five-year plan period Existing and Planning WTE Plants

Some plants use a squeezing press to decrease the moisture content of the MSW. At one of the plants visited by the author in Shanghai, this practice was reported to increase the Lower Heating Value of the MSW by as much as 2 MJ/kg. However, the tradeoff is the unbalanced density distribution of the feedstock entering the combustion chamber, which causes unstable temperature zones on the grate.

The leachate collected in the waste bunker in some plants is used in anaerobic digestion facilities to form biogas, which is then injected into the combustion chamber to enhance combustion.

The most common Air Pollution Control system used in these WTE plants is the combination of semi-dry scrubber, activated carbon injection device and fabric filter baghouse. Also, in some WTE plants, SNCR technology is incorporated in the air pollution control system, for example in the WTE plants planned for Guangzhou and Chongqing. Due to the relatively loose national standard for NOx emission and people’s less awareness of its harmfulness, most plants reserved room for NOx control equipment while not implement the control method to avoid additional cost. Temperature control technology is also widely utilized in the combustion chamber to keep the flue gas temperature above the decomposition temperature of dioxin for an adequate period of time. Therefore the complete air pollution control process is called “seven-stage controlling method” in China. Figure 4 shows the flowchart for the “seven-stage controlling method”.

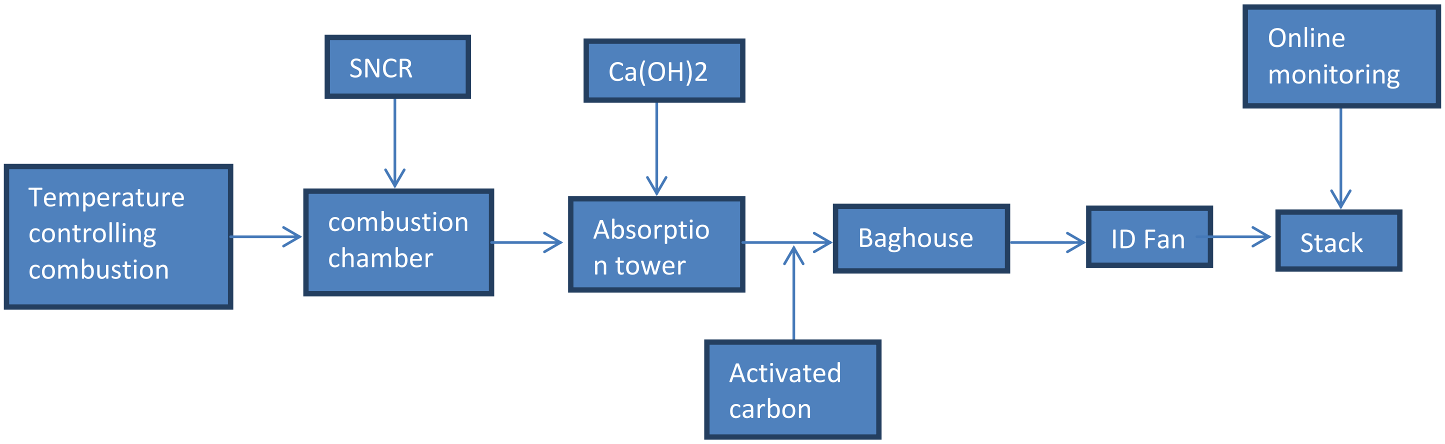


Figure 4 Flowchart of the "seven-stage controlling method"

3.2 Plant Emissions

One WTE plant in an eastern China city was investigated by the author and the emission data was acquired. The plant investigated has three CITY2000 moving grate lines and the total actual daily capacity is 1350 tons. It has two 8.5 MW electricity generation units. The APC system consists of semi-dry scrubber, activated carbon injection, and baghouse. No SNCR technology is implemented. The ten-year-old plant has a decent environmental performance and is representative of Chinese city plants of the same capacity in terms of APC system and grate technology. The average value of the environmental performance of the three lines is presented in this paper as agreed with the plant operator to protect confidentiality. The average plant availability was 92.8% in 2011.

Table 7 shows the air emission for the plant (by local Environmental Monitoring Station).

Table 7 Air emission for the plant

Pollutant	Average	Chinese National Standard (GB 18485-2001)	EU Standard (2010)
HCL (mg/m3)	5.42	75	10
SO2 (mg/Nm3)	27	260	50
Nox (mg/Nm3)	286	400	200
CO (Nmg/m3)	<1	150	50
Particulate matter (Nmg/m3)	3.33	80	10
Hg (mg/Nm3)	7.3 E -7	0.2	0.05
Cd (mg/Nm3)	<0.0006	0.1	0.05
Pb (mg/Nm3)	<0.0006	1.6	0.5
Dioxin TEQ ng/m3	0.0085	1	0.1

From table 7 it obvious that the Dioxin and heavy metal emission of the plant is far below the EU standard, which indicates a perfect performance of the APC system. The acid emission (SO2 and HCL) is also within the EU Standard. When it comes to NOx emission, the plant's emission data shows a good performance according to the Chinese National Standard, while exceeds the EU Standard. This is because of the omission of NOx reduction strategy in compliance with the looser national standard. The new national standard starting from 2013 for existing plants will bring the NOx emission standard a step lower to 250 mg/m3 and mercury as well as Cadmium emission standard to as low as that of EU (11).

Table 8 shows the fugitive emissions of the plant (by local Environmental Monitoring Station).

Table 8 Fugitive emissions

	Average Testing Results	**Local Emission Standard**
Odor Concentration	**10**	**20**
NH3 (mg/m3)	**0.07**	**1.5**
H2S (mg/m3)	**0.001**	**0.06**

Table 9 shows the water emission of the plant (by local Environmental Monitoring Station)

Table 9 Water emission

	Average Testing Results	Local Sewage Standard
COD_{Cr} (mg/l)	144	500
5 days BOD (mg/l)	43.9	300
NH3-N (mg/l)	5.68	40
Oil (mg/l)	2.6	100
Suspended Solid (mg/l)	87	400
pH	6.3	6-9

From Table 8 and Table 9 it can be seen that the plant's odor and water emission meet the local standard for environmental safety therefore no health risk is taken by surrounding communities. The water emitted shows a feature of weak acid but is within the local sewage standard.

In 2011, the plant generated 80,875 tons of bottom ash (0.19 ton per ton of MSW processed) and 12,540 tons of fly ash (0.03 ton per ton of MSW processed). The bottom ash of the plant was used as roadbed material after recycling heavy metals while the fly ash was sent to the nearby hazardous waste monofill.

3.3 Features of WTE in Chinese Cities

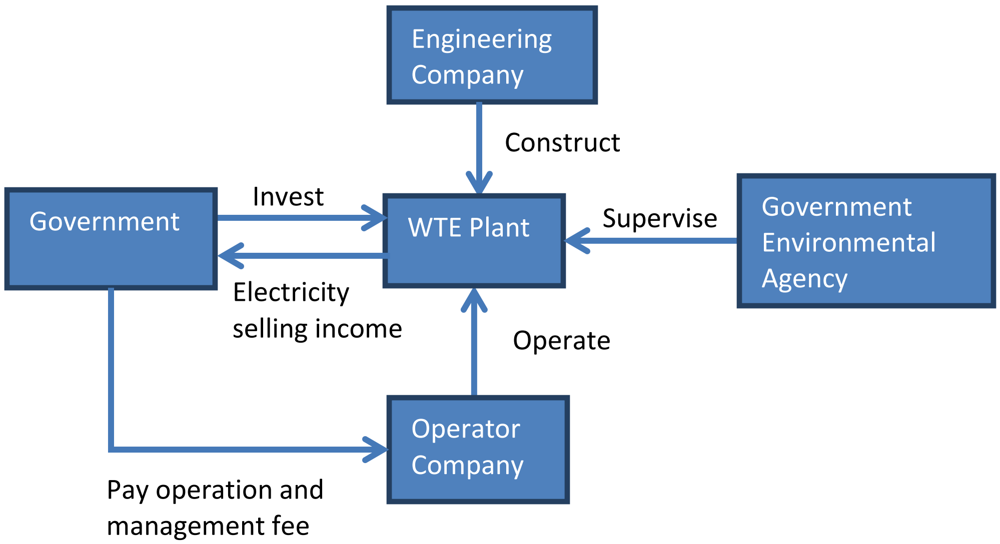
3.3.1 Ownership Model

Like many developed countries, most WTE plants in China are now practicing commercialized models rather than governmental non-profit service. There are two major ownership models for WTE plants in China--government owned model and build-operate-transfer (BOT) model. The latter model, also known as BOT model, is practiced more in cities.

a) Government owned model

In this model, the government utilizes its annual budget or national government loans to invest in the WTE project and then hire, through tendering, professional operator companies to manage and operate the project. The government pays the operator for management and operation and at the meantime supervises the environmental performance of the plant. The model can be sub-divided into two cooperation methods according to different ways of payment for management and operation by the government. Figure 5 (a) and (b) show the difference between the two methods.

(a) Method A



(b) Method B

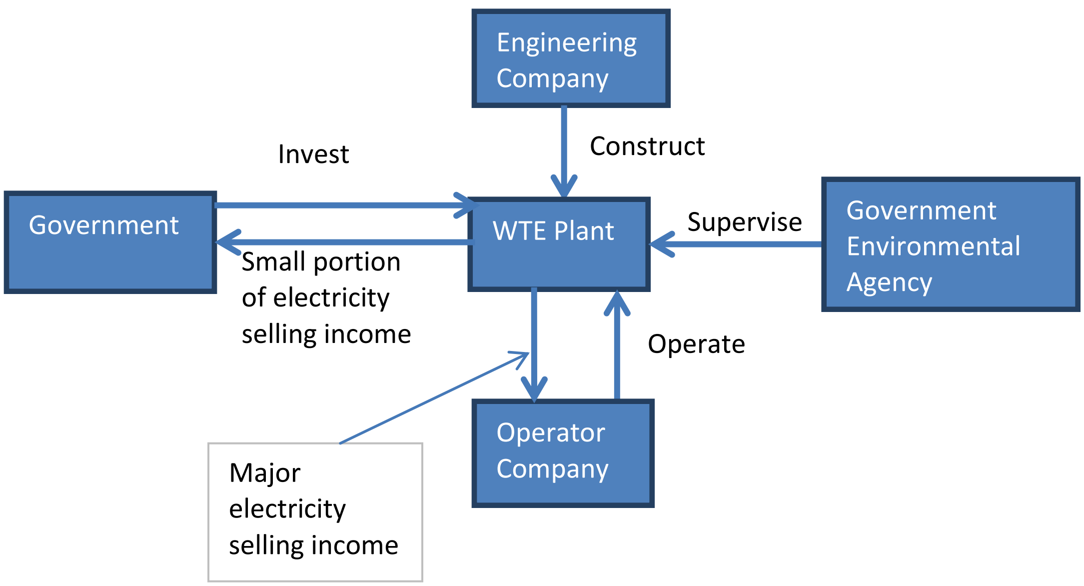


Figure 5 Two different cooperation methods for government investment-enterprise operation model

In both methods the local government is the investor of the project and wholly owns the plant. The difference is how the operator company makes a profit. In method A all of the electricity selling income is turned over to the government, which, in return, pays the operator for plant operation and management according to the contract. In method B, the operator company has more degree of freedom than in method A in adjusting its operational strategy to make profit. It can be easily understood that method B is more preferred by plant operators who have high quality and sufficient supply of MSW so decent and stable electricity selling income is guaranteed with lower processing cost.

The government investment-enterprise operation model is still characterized by strong governmental interference, in which the WTE facility is still a governmental infrastructure. No gate fee is involved in the model. Heavy financial burden is laid on the local government by capital investment and payment to the operator company. Long-term development of the industry is compromised. Therefore in recent years Chinese cities have shifted their WTE ownership model to the new BOT model.

b) Build-operate-transfer model (BOT)

The build-operate-transfer (BOT) model is now widely used among Chinese cities for WTE projects. It is a form of project financing, wherein a private entity receives a concession from the government to finance, design, construct, and operate a facility stated in the concession contract. This enables the project proponent to recover its investment, operating and maintenance expenses in the project. The economic analysis in this study was based on the BOT model.

BOT model finds extensive application in the infrastructure projects and in public–private partnership. In the BOT framework a third party, the local government, delegates to a private sector entity to design and build infrastructure and to operate and maintain these facilities for a certain period. The period for WTE projects is usually 20 to 30 years. During this period the private entity has the responsibility to raise the finance for the project and is entitled to retain all revenues generated by the project and is the owner of the regarded facility. One source of revenue specific to WTE plants is the governmental subsidy for per ton of waste received by the facility, which is called gate fee. The facility will be then transferred to the government at the end of the concession agreement (12), without any remuneration of the private entity involved. The following parties are involved in the WTE BOT project:

a) Local government: The local government is the initiator of the WTE project and decides if the BOT model is appropriate to meet its needs. The government provides normally support for the project in some form (provision of the land and favorable policies). In addition, the government is responsible for a stable supply of the fuel (MSW) to the plant with adequate amount of gate fee to guarantee the profitability of the project. Higher purchasing price is also given by the government to the plant’s electricity generation. The Environmental Agency of the government serves to supervise the performance of the plant.
b) The concessionaire: The project sponsors who act as concessionaire create a special purpose entity which is capitalized through their financial contributions.
c) Lending banks: Most WTE BOT projects are funded to a big extent by commercial debt. The bank will be expected to finance the project on “non-recourse” basis meaning that it has recourse to the special purpose entity and all its assets for the repayment of the debt.
d) Other lenders: The special purpose entity might have other lenders such as national or regional development banks and foreign funds.

Figure 6 shows the relationship between different parties in the BOT model.

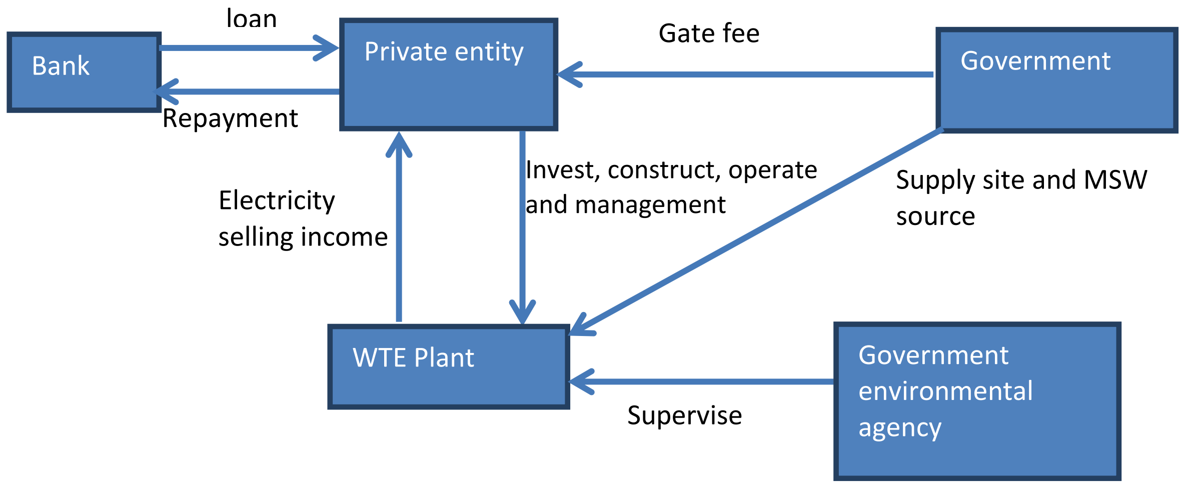


Figure 6 Relationship between different parties in BOT model

The BOT model exempts the local government from raising huge amount of fund itself to deal with the emerging waste management crisis, therefore solves the problem of heavy financial burden of WTE on local economy. On the meantime, the concession contract between the government and the private entity serves as a guarantee for profitability, which helps the entity get easy bank loan of huge amount.

3.3.2 Strong Government Support

In order to help the BOT model perform smoothly, Chinese government has launched a series of favorable policies and subsidies apart from gate fees to ensure the profitability of the WTE project. The most representative is the latest "Announcement of Improving WTE Electricity Purchasing Price Policy" (13) (the announcement, in the rest of the thesis) issued in March, 2012 by National Development and Reform Commission for WTE projects approved after January 1st, 2006.

The announcement designed a specific pricing mechanism according to the low heating value characteristic of Chinese MSW so as to maximize the subsidy to adequate facilities while preventing operators from adding unpermitted amount of auxiliary fossil fuel during combustion to generate excessive subsidized electricity.

In the announcement, the price for WTE electricity was set as 65 cents CNY ($10 cents), 20 cents CNY ($3.2 cents) higher than fossil fuel electricity. The 20 cents CNY subsidy was paid collaboratively by local grid companies, terminal customers, and national budget renewable energy. However, not all of the electricity sold by WTE plants was entitled with such a higher price. The mechanism was based on the difference between the baseline electricity generation per ton of MSW, which was set by the central government, and the actual electricity generation per ton by the plant. The announcement assumed, according to domestic condition, that the baseline unit electricity generation for WTE is 280 kWh/ton of MSW. And the assumed baseline grid electricity is the actual tonnage of the MSW processed by the plant multiplied by the baseline unit, 280 kWh/ton of MSW. Three scenarios may occur according to the announcement. Table 10 shows the three different conditions and the relevant electricity selling income according to the subsidy.

Table 10 Three different scenarios and the relevant electricity selling income (13)

Condition	High Electricity Generation	Moderate Electricity Generation	Low Electricity Generation
Actual Grid Electricity	Higher than two times the baseline	Higher than baseline but lower than two times the baseline	Lower than baseline
Electricity Selling Income (including tax)	Counted as fossil electricity, no subsidy	Baseline amount of grid electricity × benchmark price (65 cents); excess amount counted as fossil electricity;	Actual amount of grid electricity × benchmark price (65 cents);

The pricing mechanism takes into to consideration the low heating value nature of Chinese MSW and encourages MSW sorting in order to reasonably raise the heating value of the waste as close to the baseline unit electricity generation ability (280 kWh/ton of MSW) as possible for the WTE operators to make more profit. Other favorable policies, apart from the grid electricity pricing subsidy, also help stimulate the industry. The most used practices are: local income tax relief, easy bank loan policy, favorable land usage policy, etc. to name but a few.

3.3.3 High Social Cost

On the contrary to the firm governmental support, local residents and environmentalists have never given up their right of opposition. Cities are usually the frontline of public opposition because the opponents there are generally more informed, organized, and financed. A number of WTE projects in cities like Shanghai and Guangzhou were postponed or even forever crippled by the public opposition. One representative case is the Panyu WTE Project in Guangzhou. The project was initially proposed to be built in 2009, but was postponed till 2012 due to strong public opposition. According to a public poll for the project done in 2009, 97.1% of the 1,550 respondents were against building the project on the proposed site, driving the local government to hold the project for fear of social instability.

During previous researches, WTERT has identified several possible reasons for continuing public opposition to WTE projects in China:

a. Inadequate information to public as to benefits of WTE by Chinese academia;
b. Need for transparency of WTE emission data by government;
c. Fear that new WTE project will lower surrounding property values;
d. Odor emissions from the plant and related infrastructures; and
e. Inadequate operating control of emissions by some WTE plants.

To address the problems, a few suggestions are put forward in this study:

a. Establish academic organizations that combines the regional efforts on WTE to popularize the unbiased knowledge of WTE through easy-understanding online sources and brochures rather than confusing technical parameters and convoluted academic terms;
b. Establish regular report mechanism for local WTE facility online and on newspaper, improve the public opinion channel to the relevant governmental agency to understand the most desired information from the public;
c. Organize education programs for local stakeholders;
d. Use sealed garbage truck and enhanced air extraction strategy in order to maintain the negative pressure in the tipping floor even when the combustion load is decreased by maintenance, operational fault, etc.; and
e. Enhance governmental regulation and punishment method for improper operation.

4. China WTE Project Economics

4.1 Model Plant

To build the model, the study surveyed engineering documents of the WTE projects in several cities. The model is based on the information from these documents as well as field surveys done by the author. An average level WTE plant is built in the model, which uses widely accepted technologies and economic output in China. The capital cost of the model is mainly based on a series of national standards and regulations for WTE and power industry as well as estimations according to existing plants of the similar capacity and technologies. The operation cost analysis is based on local documents and field survey. Table 11 shows the basic technical information of the model plant.

Table 11 Basic technical information of the model plant

Item	Unit	Value
Processing Capacity	t/d	3×350
Processing Capacity per Line	t/h	14.58
Annual Capacity	t/a	382,500
Boiler Evaporation Capacity	t/h	30.5
Steam Parameters		400 °C, 4.0 MPa
Electricity Capacity	MW	18
Plant Availability	h/a	8000
Total Power Output	MWh/a	117,000
Grid Electricity	MWh/a	97,700
Plant Electricity Consumption Rate	%	16
Life	Year	28
Construction Period	Year	2
Project Boundary Area	m2	60,000
Total Personnel		70

Table 12 shows the major equipment of the model plant.

Table 12 Major equipment of the model plant

Item	Technology	Number	Import/Domestic
Furnace	Martin Reverse Grate	3	Imported technology & domestic manufacturing
APC System	Semi-dry Scrubber	3	Imported Equipment
	Activated Carbon Injection		
	SNCR		
	Baghouse		
Online Flue Gas Monitoring System		3	Imported Equipment
Leachate Processing System	MBR+NF	1	Domestic Equipment
Boiler		3	Domestic Equipment
Turbine	Condensing Steam Turbine	2	Domestic Equipment
Generator		2	Domestic Equipment
Controlling System	DSC	1	Domestic Equipment

With the development of domestic manufacturing level, more and more cities are now using a combination of imported technology with domestic manufacturing for grate furnace. This reduces the capital cost of WTE in China to a large extent. However, for APC systems, imported equipment is thought to be more adequate by city investors.

4.2 Capital Costs

The capital costs include all of the economic expenses within the project boundary for construction and equipment purchase. Land using expenses and local residents relocation fee are paid by the government therefore is not included in the study.

The project capital costs are based on estimations according to similar existing plants and the following regulations:

Table 13 Chinese National Regulations for WTE Project

Regulation	Application in the Study
Budgeting and Calculation Standard for Coal Fired Power Plant, 2006	Allocation of project investment
The Electricity Industry Construction Project Fixed Budget, China Electricity Industry Association, 2006	Project cost estimation, construction labor wage estimation
China Mechanical and Electrical Product Pricing Content, 2009	Equipment pricing estimation

The model project uses the prevailing BOT model and is invested and operated by a local company. The construction period is set to be two years in which the first year accounts for 60% of the capital investment while the second year uses up the rest 40%. For fund raising, 30% of the capital investment is from the company itself while the rest 70% is from bank loan at an interest rate of 5.94%. The bank repayment period is 13 years and the investor is allowed to start the repayment at the beginning of the third year of the project (the first year of operation).

The detail of the capital investment is shown in table 14.

Table 14 Capital investment detail

Capital Investment Detail of the Model Plant (million USD)					
	Construction Period		Operation Period		
Item	1	2	3	Total	Percentage of Total Investment
Investor Funding	21.2	0.0	0.3	21.4	29.0%
Bank Loan	22.4	29.9	0.0	52.3	71.0%
Total Investment	43.6	29.9	0.3	73.7	100.0%
Investment/annual ton of capacity (USD/ton)				193	

Since capital costs are very dependent on world steel price indices and various local factors such as economy and tax, the estimate is expected to be within +/- 25% accuracy whereas huge cities such as Beijing and Shanghai may have even higher costs.

Compared with the capital costs for WTE in the U.S., which is usually $600 to $750 per annual metric ton of capacity (2), the around $200 per annual metric ton capital investment in an average Chinese WTE plant is impressively low. The study identified three possible reasons for the low costs.

a) Low construction labor cost

The labor cost for the model plant construction is based on The 2006 Electricity Industry Construction Project Fixed Budget, which standardized the baseline daily salary for construction labor is 26 CNY ($4.13)/person•day, and 31 CNY ($4)/person•day for equipment installation skilled worker. Cities usually have a much higher payment—100 CNY ($15) for skilled worker per day and 70 CNY ($11) for labor per day. Managing positions on the construction site can have a monthly salary of 5,000 to 7,000 CNY ($462-770). Despite the regional differences in labor cost, generally it is much lower than that in the U.S., which significantly reduces the construction cost of the plant. The construction labor plan of the model plant is based on the plan for an existing WTE plant of similar design (14). The two-year construction period has a peak time personnel of as many as 680 people, with an average of 422 people on the construction site. Table 15 shows the composition of the 442 on-site personnel.

Table 15 Average on-site personnel during construction

Managing	33
Logistic	41
Skilled workers	216
Labors	132
Sum	422

b) Localization of equipment and technologies

There is a trend that Chinese WTE projects are now trying to maximize the localized portion in the plant equipment and technology. Domestic manufacturing of major equipment such as Martin grate furnace cuts down the investment to a large extent. Furthermore, the model plant uses domestic technologies in leachate processing and automation systems to further reduce the costs. With the domestic technologies and manufacturing industry getting more and more mature, the capital investment of Chinese WTE plants is expected to become even lower due to the lower local labor and material cost.

c) Favorable tax policy

According to Chinese laws regarding equipment import, environmental protection industry related equipment is waived off tariff and value-added tax (VAT). Only sea transportation fees and other procedure fees are charged.

The country's low national price level may partly contribute to the low costs listed above. According to The World Bank, the national price level is the ratio of PPP (purchasing power parity) to GDP, which “tells how many dollars are needed to buy a dollar’s worth of goods in the country as compared to the United States.” The national price level for developing countries like China are usually low (0.6), however, it can be quite high for developed countries (.e.g., U.K.: 1.1, France: 1.2, and Japan: 1.3) (The World Bank Database). Therefore, the $193 per annual ton capacity capital costs can be converted to $322 per annual ton capacity using the PPP/GDP ratio if the plant was built in the U.S.

4.3 Operating Period Economic Output

The economic output during the operating period can be divided into two parts: MSW processing costs and bank loan repayment from the beginning of the third year of to the end of the 13^{th} year of the project.

4.3.1 MSW Processing Cost

The MSW processing cost estimation for the model plant is based on local market price and industrial internal price. The costs for core WTE plant materials are: lime powder--300 CNY/ton ($48), activated carbon powder--7000 CNY/ton ($1111), and urea--1800 CNY/ton ($285). The fabric filter in the baghouse is designed to be changed every 2.5 years, with an average annual cost of 280,000CNY ($44,444). The fly ash is sent to hazardous waste monofill and the operator is responsible for 100 CNY/ton of fly ash ($16). The bottom ash is reused as roadbed material therefore no cost and income is included in this study. The total personnel for the plant operation are estimated to be 70, with an average annual salary of 25,000 CNY ($3968). The personnel expenses are the salary plus the welfare at a rate of 33% and coordination fee at a rate of 22%. Table 16 shows the composition of MSW processing costs.

Table 16 Composition of MSW processing costs

	Cost (million USD/year)
Raw Material Purchase	0.76
Fuel and Water Purchase	0.07
Leachate Processing	0.49
Fly Ash Disposition	0.22
Personnel	0.45
Maintenance	0.99
Depreciation Charges	4.37
Other Fees	3.88
Total	11.23
Costs/ton of MSW (USD)	29.36

4.3.2 Bank Loan Repayment

The bank loan principal and interest in the study is paid by uniform annual repayment during the 12-year period. The repayment starts from the beginning of the third year and stops at the end of the 13th year. The annual repayment is calculated according to the uniform series capital recovery equation (15):

$$A = P\frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

A is the uniform annual repayment;

P is the present value of the loan at the beginning of the repayment period;

i is the interest rate;

n is the repayment period.

According to this calculation, the uniform repayment amount is decided to be $6.4 million.

4.3.3 Total Operating Period Economic Output

The operating period economic output can be divided into two stages: before and after the bank debt is cleared. Therefore before the beginning of the 14th year of the project, the total economic output is $17.6 million while after that, the annual economic output is $11.2 million. During the repayment period, the economic output per ton of MSW processed can be as high as $46.

4.4 Plant Revenues

Three main sources of WTE plant revenues are considered in this study—electricity sale, gate fee, and value-added tax (VAT) return. Metal recycling is not included in the study because of the low metal content in the MSW.

4.4.1 Electricity Sale

According to the national announcement for WTE electricity sale (13), the model plant's grid electricity generation is within the "low electricity generation" scenario in table 9. Therefore all of the electricity the plant sells is covered by the $10 cents/kWh subsidized price. According to table 10, the estimated annual grid electricity sale is 97,700 MWh, so the annual electricity sale revenue is estimated to be $9.8 million.

4.4.2 Gate Fee

Gate fee is the payment that the landfills or WTE plants earns per ton of waste received from the local government. The source of this part of subsidy is mainly from governmental budget and waste disposition fee charged from local residents. It is a very important source of revenue which dominates the profitability of the WTE project. The fee is a very case sensitive index, depending heavily on the local economy, waste management structure, and plant condition. Generally the gate fee for WTE is higher than that for sanitary landfill due to the high capital cost for WTE plant. The highest gate fee in Chinese cities is $39 for one WTE plant in Shanghai, while the lowest can be around $10 for a plant of the similar capacity. Gate fee for CFB plants is even lower due to the low capital cost of them. The financial analysis in the following section gave a thorough understanding of the relationship between gate fee and plant profitability in these cities. Table 17 shows the gate fee for some of the WTE projects in China.

Table 17 Gate fees for some of the WTE plants in China

Plant Name	City	Capacity (t/day)	Combustion Technology	Investment (million USD)	Gate Fee (USD)
Shanghai Pudong Yuqiao WTE Plant	Shanghai	3*365	Moving grate	100	39.2
Shanghai Jiangqiao WTE Plant	Shanghai	3*500	Moving grate	139.68	29
Tianjin Shuanggang WTE Plant	Tianjin	3*400	Moving grate	85.71	26.5
Shenzhen Baoan Baigehu WTE Plant	Shenzhen	1000	Moving grate	63.49	20.3
Ningbo Fenglin WTE Plant	Ningbo	3*350	Moving grate	63.33	15.9
Changzhou WTE Plant	Changzhou	2*400	Moving grate	52.38	15.4
Hangzhou Lvneng WTE Plant	Hangzhou	3*150	Moving grate	34.13	13.5
Chengdu Luodai WTE Plant	Chengdu	3*400	Moving grate	76.19	11.3

Foshan Nanhai WTE Plant	Foshan	4*350	Moving grate	55.56	7.9
Foshan Shunde Xingtan Youtan WTE Plant	Foshan	600	Moving grate	31.75	4.8
Hangzhou Jinjiang WTE Plant	Hangzhou	800	CFB	N/A	4

4.4.3 Value-added Tax Return

WTE plant is categorized as an environmental protection facility. According to Chinese National Finance and Taxation (2000) 198 Document, MSW WTE plants are subject to the value-added tax return policy. The tax is returned at the point of imposition, which causes a 5 million CNY ($0.8 million) tax return income. This tax policy is made by the central government to stimulate the investment of WTE in China. However, with the WTE market in China getting more and more mature and commercialized, the grant is expected to be reduced and later totally omitted in the future according to some market analysis.

5. Financial Analysis

The financial analysis in the study is based on the prevailing BOT model for WTE projects in China. The government grants the right of developing and operating the WTE plant with a series of favorable policies and supporting infrastructures to the concessionaire for a 30-year period of time (two years of construction plus 28 years of operation). And the latter is responsible for the financing, loan repayment, and profit making from the project in the agreed time period.

Two scenarios were investigated in the study: with VAT return and without the return to see the project's dependence on governmental participation. For both scenarios, a range of gate fees are fitted into the analysis to check the profitability as well as the feasibility of the project.

Two financial indicators are used in the study to do the analysis: Net Present Value (NPV) and Internal Rate of Return (IRR). NPV is an indicator of how much value an investment or project adds to the firm. It can be described as the “difference amount” between the sums of discounted cash inflows and cash outflows in a certain time period. It compares the present value of money today to the present value of money in the future, taking inflation and returns into account. Appropriately risked projects with a positive NPV could be accepted. In financial theory, if there is a choice between two mutually exclusive alternatives, the one yielding the higher NPV should be selected (15). The IRR on an investment or project is the "annualized effective compounded return rate" or "rate of return" that makes the NPV of all cash flows (both positive and negative) from a particular investment equal to zero. An investment is considered acceptable if its IRR is greater than an established minimum acceptable rate of return (MARR). A typical value for MARR is the interest rate for bank loans (16), which is used in the study. Thus, the MARR equals to 5.94%.

5.1 Scenario I

This scenario assumes that there is no tax return for the project.

The cash flow of the project within the BOT period is listed in table 18. The bank loan cash flows do not have numerical impact during construction period (the first and second year of the project) therefore they were not shown in the table.

Table 18 Cash flow for Scenario I

At the beginning of the year	Item	Amount (million USD)
1	Investment (without bank loan)	-21.2
2	Investment (without bank loan)	0
3	Investment (without bank loan)	-0.3
	Bank loan repayment	-6.4
4-14	Operating expenses	-11.2
	Bank loan repayment	-6.4
	Electricity sale	9.8
	Gate fee	To be determined
15-31	Operating expenses	-11.2
	Electricity sale	9.8
	Gate fee	To be determined

From table 18 it can be seen that bank repayment lays a large burden on the project’s operating finance. Actually in low gate fee situations in the study, the net cash flow for the equity in the 13-year bank repayment period remains negative, indicating a deficit during its operation. A group of gate fees ranging from $0 to $40 is fitted into the cash flow context to check the profitability of the project. Table 19 and Figure 7 show the relationship between the gate fee and NPV without VAT return.

Table 19 Relationship between the gate fee and NPV without VAT return

Gate fee (USD)	NPV without VAT return(million USD)	Net cash flow during bank repayment period (million USD)
0	-84.2	-7.8
5	-62.5	-5.9
10	-40.8	-4
15	-19.1	-2.1
20	2.6	-0.2
25	24.3	1.8
30	46	3.7
35	67.7	5.6
40	89.4	7.5

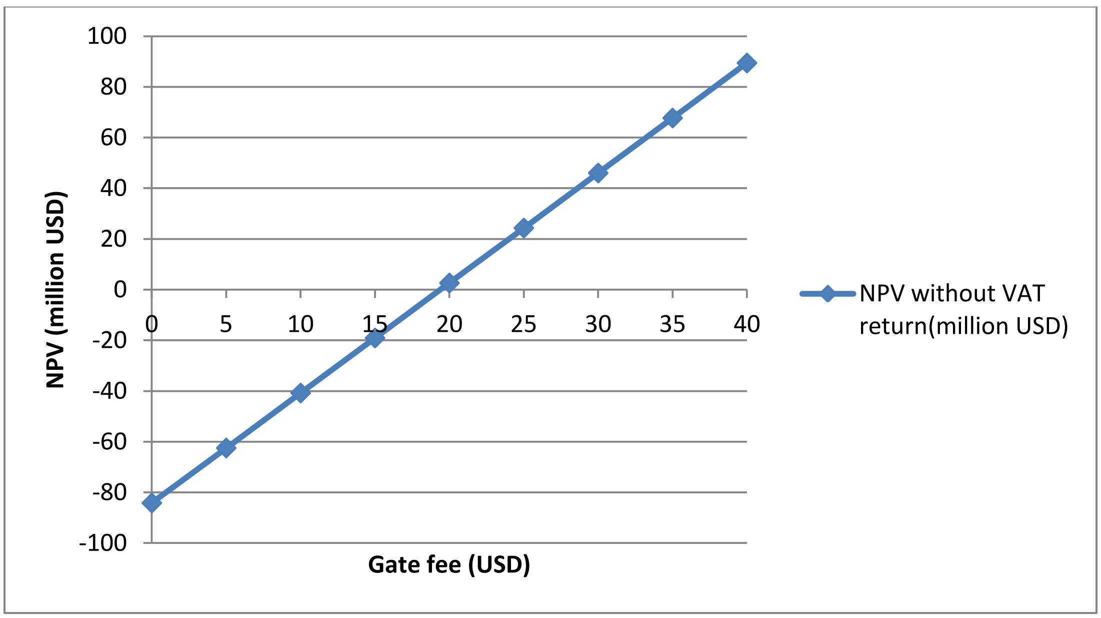


Figure 7 Relationship between gate fee and NPC without VAT return

From the table and the chart it is obvious that gate fee has a significant impact on the profitability of the project. The horizontal axis intercept for Figure 7 is $19.4; therefore the project reaches the breakeven point at that rate of gate fee. To ensure the profitability of the project, a gate fee of $20/ton of MSW or more is required. From table 16, most of the existing WTE plants whose capital investment is close to or higher than the model plant have a gate fee higher than $20, indicating a positive economic condition of the plants. For cities that can afford less than the amount of gate fee, proper strategies to lower the capital and operating costs are urged in order not to compromise the adequate operation of the plant.

During the bank repayment period, the net cash flow remains negative until the gate fee reaches $20.4. Therefore an actual gate higher than that amount is preferred to guarantee the equity's healthy capital chain.

Table 20 and Figure 8 show the results of IRR analysis for the project.

Table 20 Relationship between gate fee and IRR without VAT return

Gate fee (USD)	IRR without VAT return
5	-13.6%
10	-3.3%
15	2.07%
20	6.4%
25	10.5%
30	14.3%
35	18%
40	21.6%

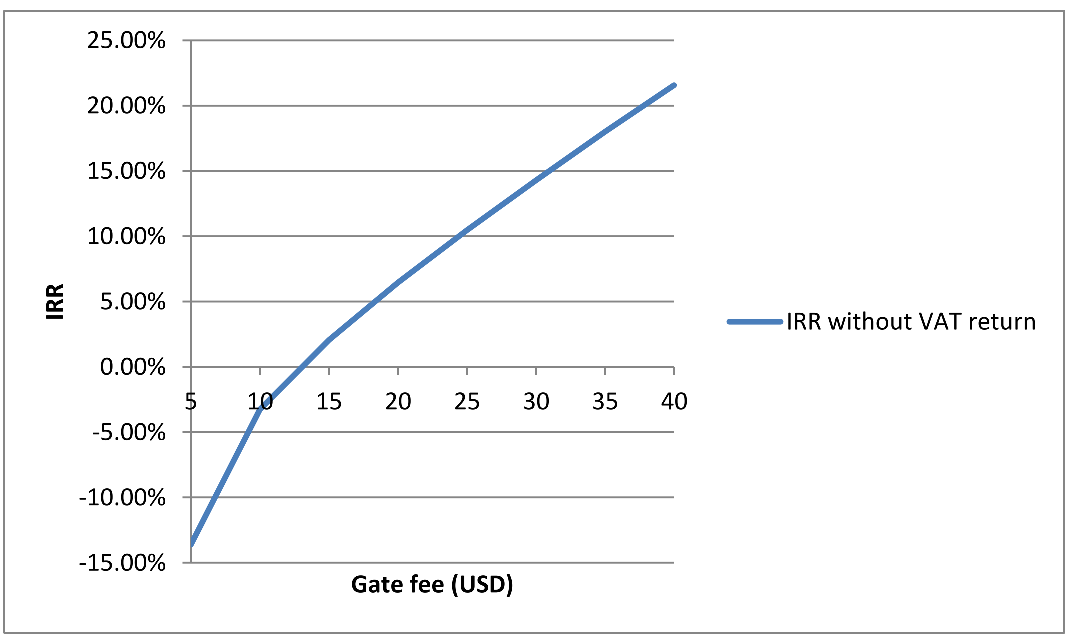


Figure 8 Relationship between gate fee and IRR without VAT return

From table 20 and Figure 8 it can be seen that the IRR remains under the MARR (5.94%) until the gate fee approaches $20, which is consistent with the result for NPV analysis. A higher gate fee around $25 that can bring the IRR to 10.5% is desired to prevent the project from practical economic risks such as the fast growing inflation rate in economic downturn.

The study also investigated the investment payback period of the suggested gate fee. The result shows that with a $25/ton MSW gate fee, the investment of the equity is paid back at the 16th year of operation (18th year of the project).

5.2 Scenario II

This scenario assumes that there is VAT return for the project.

The cash flow of the project within the BOT period is listed in table 21. The bank loan cash flows do not have numerical impact during construction period (first and second year of the project) therefore they were not shown in the table.

Table 21 Cash flow for Scenario II

At the beginning of the year	Item	Amount (million USD)
1	Investment (without bank loan)	-21.2
2	Investment (without bank loan)	0
3	Investment (without bank loan)	-0.3
	Bank loan repayment	-6.4
4-14	Operating expenses	-11.2
	Bank loan repayment	-6.4
	Electricity sale	9.8
	Gate fee	To be determined
	Added-value tax return	0.8
15-31	Operating expenses	-11.2
	Electricity sale	9.8
	Gate fee	To be determined
	Added-value tax return	0.8

Compared with electricity sale, the annual added-value tax return revenue is much less in amount. However, its impact on financial indicators is still worth to investigate. A group of gate fees ranging from $0 to $40 is fitted into the cash flow context to check the profitability of the project in this scenario. Table 22 shows the relationship between the gate fee and NPV with VAT return.

Table 22 Relationship between gate fee and NPV with VAT return

Gate fee (USD)	NPV with VAT return(million USD)	Net cash flow during bank repayment period (million USD)
0	-75.1	-7
5	-53.4	-5.1
10	-31.7	-3.2
15	-10	-1.3
20	11.7	0.6
25	33.4	2.6
30	55.1	4.5
35	76.8	6.4
40	98.5	8.3

Figure 9 shows a comparison of the gate fee-NPV relationship between the two scenarios.

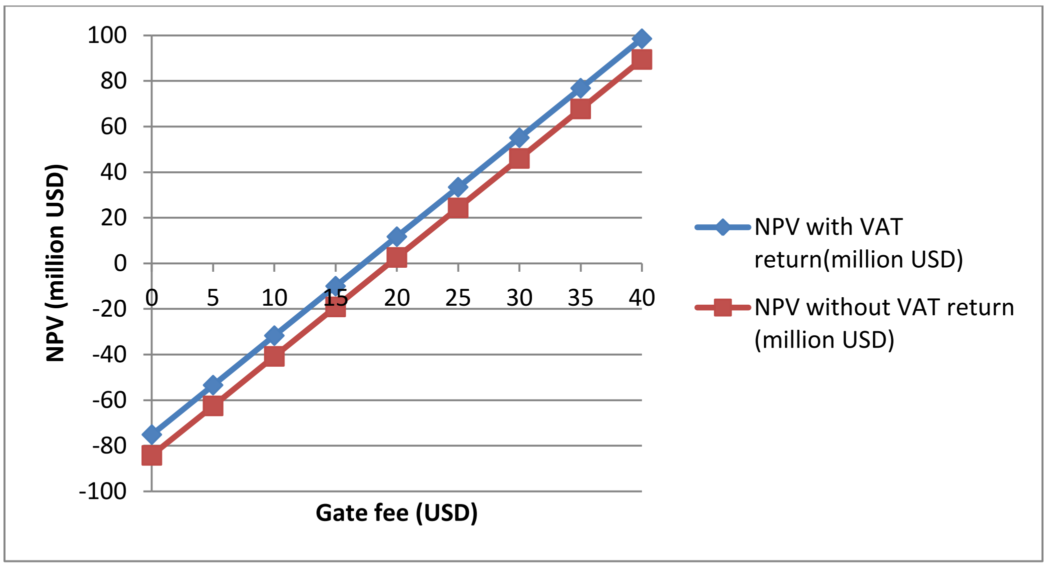


Figure 9 Relationship between gate fee and NPV with and without VAR return

From Figure 9 it can be seen that the VAT return raises the NPV to a certain extent for the same amount of gate fee and brings the breakeven point leftward on the horizontal axis from $19.4 to $17.3. This means the tax preferential by the central government can help alleviate the financial burden of WTE on the local government by at least $0.8 million of budget for the model plant in terms of gate fee expense to reach the breakeven. It stimulates less developed cities to involve WTE in their waste management system.

During the bank repayment period, the net cash flow starts to be positive when the gate fee reaches $18.3. This alleviates the financial burden and possible economic risks during the repayment period.

Table 23 shows the results of IRR analysis for the project with VAT return.

Table 23 IRR with VAT return

Gate fee (USD)	IRR with VAT return
5	-7.8%
10	-0.8%
15	4.0%
20	8.1%
25	12.1%
30	15.9%
35	20.0%
40	23.0%

Figure 10 shows a comparison of the gate fee-IRR relationship between the two scenarios.

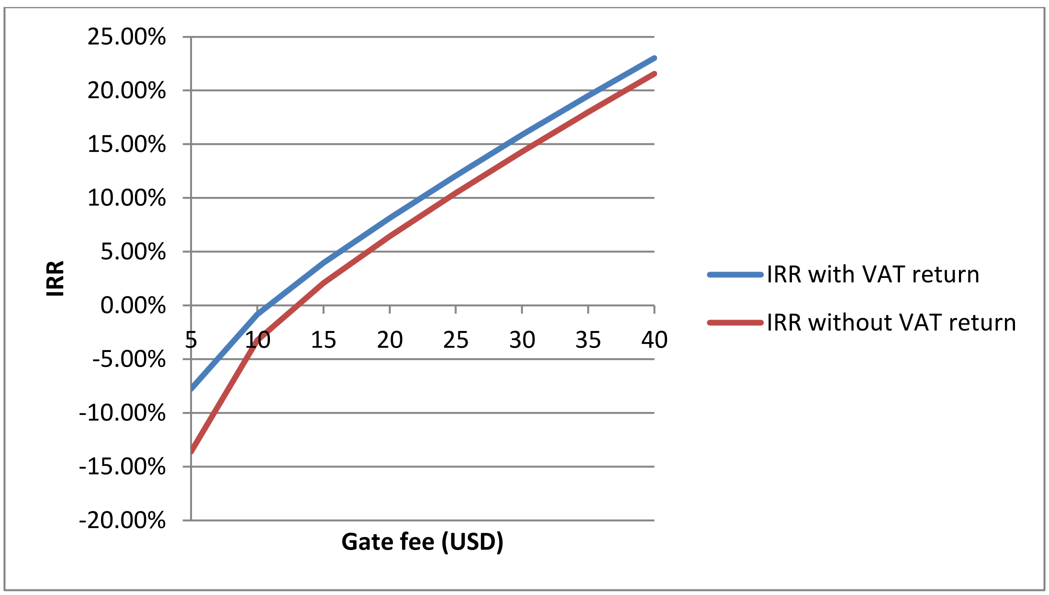


Figure 10 Relationship between gate fee and IRR with and without VAT return

The gate fee for IRR to reach the MARR in scenario II is $17.3, meaning the investor can gain more profit with lower gate fee. A gate fee of $20 in this scenario is adequate for the project to be financially feasible. However, the IRR without VAT return grows faster than that with VAT return when gate fee increases, diminishing the advantage of VAT return in profitability in high gate fee conditions. Table 24 shows the difference of IRR between two scenarios.

Table 24 Difference of IRR between two scenarios

Gate fee (USD)	IRR (II) - IRR (I)
5	5.85%
10	2.43%
15	1.90%
20	1.70%
25	1.62%
30	1.57%
35	1.51%
40	1.45%

According to table 21, IRR difference between the two scenarios decreases with the increase of gate fee, which means that the tax preferential does more help for profitability in low gate fee conditions. This reflects the central government's intension to assist cities with weaker economic development to launch WTE projects. Since projects in rich cities with high gate fee benefit less from the tax subsidy, their dependence on the policy is getting far less with the maturation of the market. It can be expected that the nationwide VAT return policy will gradually become a regional one.

The investment payback period of the suggested gate fee ($20) for the scenario is calculated. The result shows that the investment of the equity can be paid back at the 15th year of operation (17th year of the project). The VAT return policy reduces the payback time at the meantime of alleviating the gate fee burden on local government.

6. Conclusions to Part I

The current waste management in Chinese cities relies heavily on landfilling. The system is confronted with low recycling efficiency, lack of landfill space, and severe environmental problems of composting and landfilling. Therefore WTE should be developed in the system to move up the "ladder" of sustainable waste management.

On the technical level, Chinese cities are adept to using modern WTE. Imported moving grate technology dominates the domestic WTE market. The domestic technology—CFB technology, has much lower capital cost but more complicated processing procedures and environmental problems. The most common air pollution control system is the combination of semi-dry scrubber, activated carbon injection, and baghouse filter.

One existing WTE plant was investigated in the study for its emission data. It shows that most of the pollutant emissions of the plant are within the EU 2010 standard. The dioxin emission reaches 0.0085 TEQ ng/m3 against the 0.1 TEQ ng/m3 for EU standard. NOx emission is higher than the EU standard value but within the Chinese national standard. A new national standard to be launched in 2013 will be more strict and closer to the EU standard especially in mercury and Cadmium emission.

WTE industry is now commercialized in China. BOT model is the prevalent model for WTE project financing and operating. The model alleviates the economic burden of high capital cost on the government, which, in return, ensures the profitability of the plant owner through the concession contract.

The overwhelming support through both the central and local government to WTE stimulates the rapid development of the industry and guarantees the profitability of the BOT model. The most important policy supporting WTE is the "grid electricity pricing", applying specifically to WTE power by the National Development and Reform Commission. For situations in which actual electricity generation rate is lower than the 280 kWh/ton of MSW benchmark, the grid purchasing price is counted as 65 cents CNY ($10 cents) per kWh.

A model plant with 1050 ton/day capacity is considered in the economic analysis. The capital cost for the plant is $193 annual metric ton of capacity. 70% of the total capital cost is from bank loan with a repayment period of 13 years.

Several gate fees are tested in the study to see the profitability of the model in two scenarios. In scenario I (no VAT return), a gate fee of $19.4 breaks even the project finance. A less risky IRR of 10.5% is reached when the gate fee is $25. In such situation, the total investment can be paid back at the 16th year of the operation. In scenario II (VAT return), a gate fee of $17.3 breaks even the project. And an IRR of 8.1% is reached when the gate fee is $20. The study shows that the VAT return policy reduces the budget burden on local government and the economic risk on the investors, especially local economy is not developed enough to support a high gate fee.

Part II: MSW Sorting Models in China and Potential for Improvement

1. Introduction

MSW sorting is the first step of an integrated waste management system. It increases the recovery of materials and energy from the solid waste stream. As noted in Part I of this thesis, inadequate MSW sorting in Chinese cities affects recycling and also has impeded the development of composting and anaerobic digestion, resulting in high moisture food and other organic wastes going to WTE; this reduces the heating value of the feedstock and increases the processing cost of the plant. Therefore, better sorting systems can benefit a municipality in three ways:

a) Reduce landfill space: Due to the lower economic level there is less packaging material in the MSW and a large fraction consists of food wastes and other biodegradable materials. Diverting this material to composting or anaerobic digestion facilities will conserve landfill space.

b) Environmental protection: Hazardous waste, e.g., batteries and thermometers contain hazardous materials such as mercury and cadmium. Since some of the Chinese MSW is disposed in non-sanitary landfills, these materials can contaminate the local soil and water. Also, if unsorted MSW goes to WTE plants, the burden on the Air Pollution Control (APC) system is increased.

c) Resource recovery: According to local newspapers and media, China as a whole generates around four billion fast food containers, 500 to 700 million instant noodle boxes, and billions of other disposables, all of which account up to 15% of the MSW. These materials are made from petrochemicals or paper fiber and have a relatively high heating value. Disposing these wastes in landfills represents a loss of a valuable resource.

Although governments at all levels have been aware of the importance of MSW recycling and composting and have launched a series of policies for more than a decade, the implementation and effectiveness of these policies are still inadequate due to low budgets and public cooperation. As early as 2000, the National Ministry of Housing and Urban-Rural Development, from now on referred to as the Ministry, requested Beijing, Shanghai, Guangzhou and five other cities to practice MSW sorting, i.e., attempt to separate paper, plastics, and hazardous wastes from the waste stream at the collection point. However, as discussed in the following sections, twelve years after implementation. This nationwide campaign has been hampered by several practical problems.

As an issue that requires strong public engagement, MSW sorting is more policy-oriented than technical. Due to different regional economic development and other conditions, the MSW sorting models vary from city to city. This study concentrated on the waste sorting policies and present status of the sorting models used in the megacities of Beijing (urban population: 17 million) and Guangzhou (urban population: 7 million).

2. MSW Sorting Models of Beijing and Guangzhou

2.1 MSW Composition from a Sorting Perspective

The MSW composition of Guangzhou City (population: 8 million) is representative of Chinese megacities. Table 25 shows the composition of Guangzhou MSW in 2009, from a sorting perspective.

Table 25 MSW composition of Guangzhou in 2009

	Composition	Mass Distribution %	
Non-combustible	Metal	0.33	Recyclable
	Glass	1.34	
Combustible (for energy recovery)	Paper	8.39	
	Plastics	19.19	
	Wood	1.12	Compostable
	Organics	54.66	
	Rubber & Leather	0.77	Non-recyclable/compostable
	Fabric	10.28	
Non-combustible	Brick & Ceramics	1.69	
	Mixture <10mm	2.20	
	Batteries	0.03	Hazardous

Source: Guangzhou MSW Sorting Guidebook; Chart by the author;

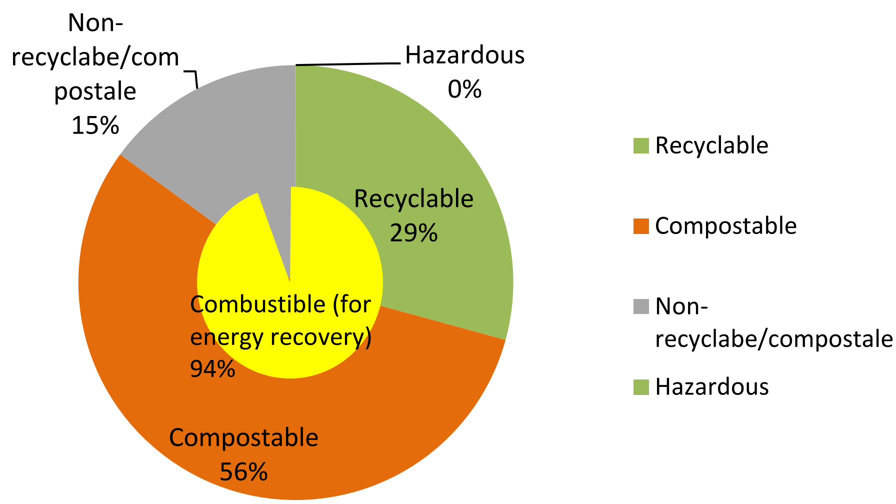


Figure 11 Grouping of Guangzhou MSW components in terms of their potential for material and energy recovery

Figure 11 groups the various components of the Guangzhou MSW in terms of their potential for theoretical recovery for materials and energy by means of recycling, composting, and WTE. It can be seen that by separating compostable waste, which accounts for over 56% of the total, from the waste stream, the efficiency of recycling can be raised and less wet waste will be in the WTE stream, thus increasing the heating value of the feedstock. The structure of the MSW composition indicates that with a better sorting and waste management system, the need for landfill space in these cities can be significantly decreased.

2.2 MSW Sorting Model in Beijing and Guangzhou

In 2000, Beijing and Guangzhou, plus another six cities, were requested by the National Ministry of Housing and Urban-Rural Development to practice official MSW sorting, which included some source separation by local residents and neighborhood authorities, followed by secondary sorting at regional waste management centers; the remainder of the MSW is disposed in landfills and waste to energy plants. Informal recycling was to be included. The municipal environmental protection bureau is in charge of collection, transportation, and disposition of the MSW. Figure 12 shows the theoretical model and the stakeholders of MSW sorting, as suggested by the Ministry.

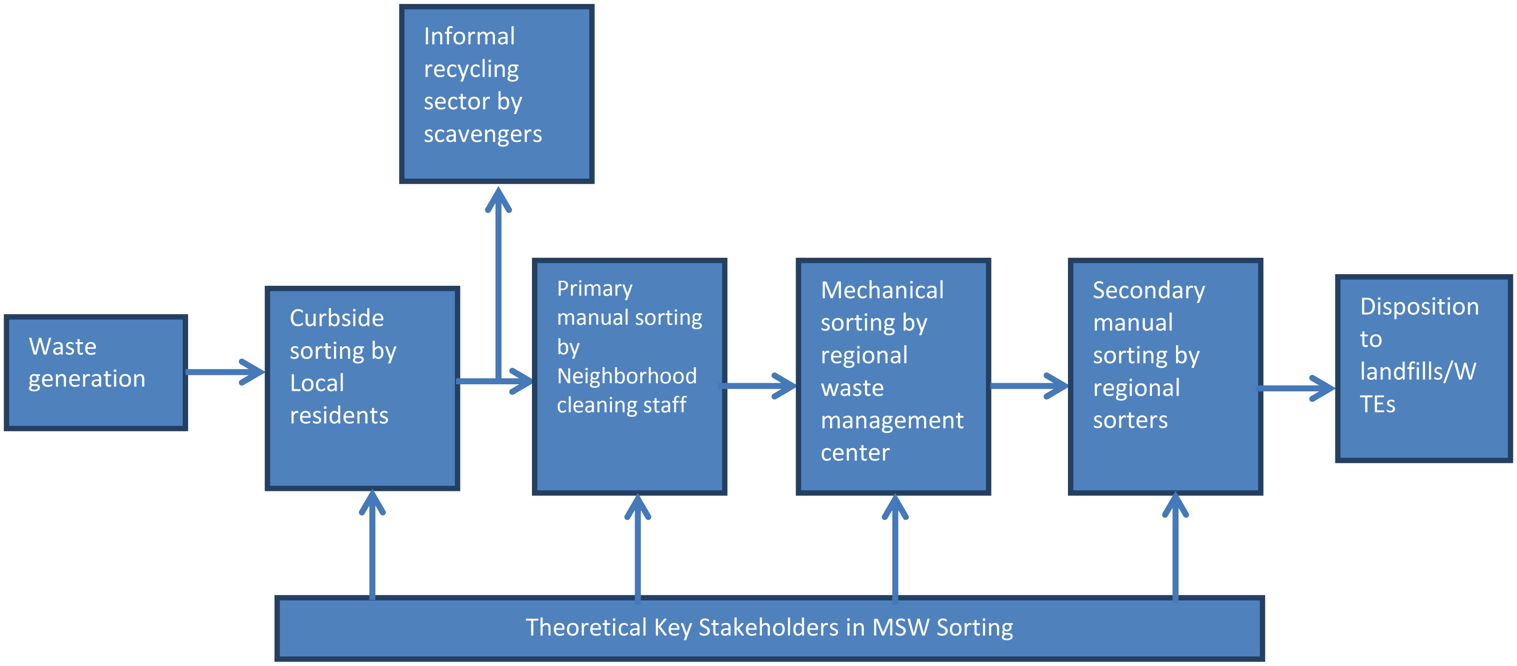


Figure 12 Theoretical process and stakeholders of MSW sorting, as recommended by the Ministry

As shown in Figure 12, the key stakeholders are designated to be the local residents and regional/neighborhood infrastructures. Mechanical technologies are to be introduced into the process to improve the efficiency of sorting.

Since 2000, the municipal governments of the two cities under study have spent a huge amount of money in purchasing collection trucks, sorting trash bins, sorting trash bags, and food waste processing equipment. A series of regulations and compulsory measures were also put in place to support this practice. However, the actual models practiced in different cities are different from the "ideal" model for various reasons. This section discusses the sorting models used in Beijing and Guangzhou. The remaining problems are discussed in Section 3.

2.2.1 The Beijing MSW Sorting Model

Since 2000, the Beijing municipal government has launched a series of various means and expenditures to support MSW sorting. During 2007 to 2009, the focus of MSW sorting was shifted from residents to waste management companies, thus relying more on concentrated processing downstream the curbside collection: The curbside sorting streams were reduced from four (plastics, metals, paper, and "trash") to three (food waste, recyclables, and "trash"). Since 2009, the curbside sorting by citizens was simplified to two streams: wet and dry waste. However, in practice, there is little source separation at curbside, with the exception of informal recycling. The principal actors in the present sorting system in Beijing are informal sector Recyclers (scavengers) and regional waste management stations that receive most of the city's MSW before any sorting is done. Figure 13 shows the overall sorting system currently in practice.

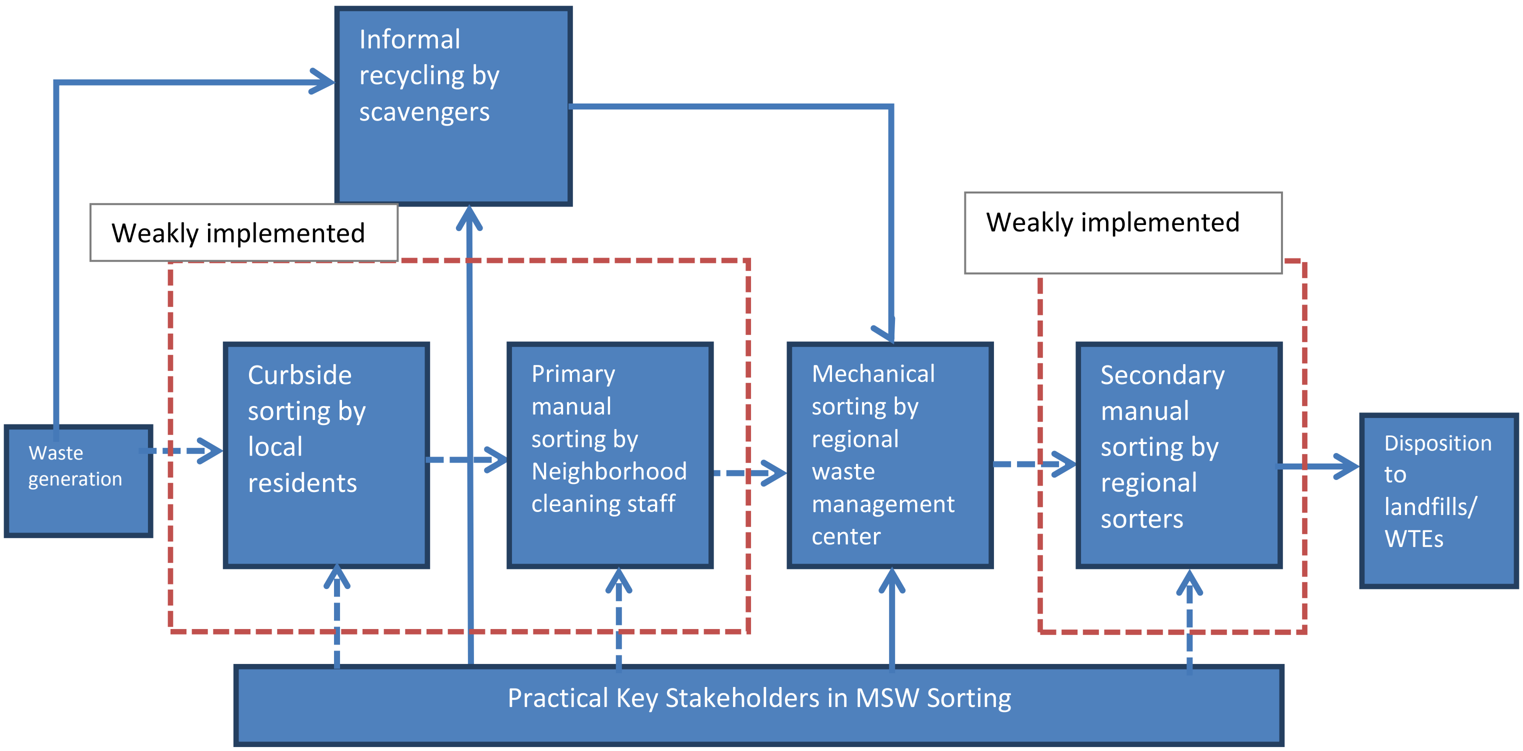


Figure 13 Practical process and stakeholders of MSW sorting in Beijing

The blue dashed arrow in the chart denotes a loose bonding between two stakeholders and the red dashed boxes denotes weakly implemented items. Informal recyclers and regional waste management centers are the main stakeholders in such a system. The regional waste management center is designed to further sort recyclables from the incoming MSW and then send the rest to landfills and waste-to-energy plants. However, due to the practical difficulties in sorting mixed MSW, in practice the centers are now only acting only as a transition center between curbside and terminal processing facilities.

In addition to the national initiatives, the local municipality has implemented a number of policies and regulations attempting to strengthen the city's MSW sorting. These policies have been changed over the years and reflect the evolving trend for MSW sorting during that period. Table 26 shows the local policies and regulations and their functions regarding MSW sorting.

Table 26 Beijing policies regarding MSW sorting

Policy/Regulation	Year	Function
The Announcement for Implementation of MSW Sorting in Collection and Disposition (18)	2003	Regulated that MSW in residential areas be roughly sorted into four categories and food waste be composted in-situ;
Implementation Proposal for the Pilot Plan for Industrialization of Beijing Renewable Resource Recovery System (19)	2006	To enhance the cooperation between government environmental protection resources and social recycling resources;
Implementation Proposal for Beijing Eleventh Fifth year MSW Treatment Infrastructure Construction Plan (20)	2007	To increase the promotion of source separation of MSW; Install sorting equipment in regional waste management center to shift from dispersed source separation to concentrated regional sorting;
Suggestions for a Complete Improvement of MSW Treatment (21)	2009	Set a clear goal for MSW source reduction and sorting: a 50% sorting adequacy rate in 2012 and a 65% sorting adequacy rate in 2015; a zero increase in MSW generation in 2015;

A review of the policies implemented in Beijing showed that special attention was paid to food waste. In fact, the city's MSW sorting strategy was designed to maximize the recovery of food waste. District government was encouraged to set aside specific budgets to subsidize composting facilities in various neighborhoods to dispose food waste on site (18). The trend was consistent with the city's initiative to shift its waste management system from landfilling to a WTE dependent model with the assistance of composting and some landfilling. The ratio of MSW to WTE, composting, and landfilling is expected to change from 2:3:5 in 2012 to 4:3:3 in 2015 (21).

Various social resources are expected to be involved in the MSW sorting process. The main social resources are informal recyclers and waste management companies. In one of the pilot neighborhoods, waste management companies were encouraged to integrate local informal recyclers (scavengers) into their recycling business.

The actual result of the model for the city's waste management is a high rate of harmless treatment (97%), which includes sanitary landfill, composting, and WTE, but low rate of recycling. The harmless treatment stream is dominated by sanitary landfill (73%) (1), because of the poor source separation. Table 27 shows the city's capacity for harmless treatment.

Table 27 Beijing harmless treatment capacity (1)

Treatment	Number of facilities	Capacity (ton/day)
Composting	3	2,400
WTE	2	2,200
Sanitary landfill	15	12,080
Total	20	16,680

Table 28 shows the waste management in Beijing.

Table 28 Beijing waste management

	Beijing City	Central (Urban) Beijing	Percent of Beijing City generation
Population	19.6 million	16.9	
MSW generation, million tons	6.3	4.3	68%
MSW generation per capita	0.3	0.25	
Composting, million tons	0.8	N/A	13%
WTE, million tons	0.9	N/A	14%
Sanitary/regulated landfills, million tons	4.5	N/A	71%
Others	0.1	N/A	2%
Total, million tons	6.3		100%

Source: 1. China 2011 Statistical Yearbook, Chapter 12: Resources and Environment;
2. 2010 Beijing Solid Waste Prevention and Control Information, Beijing Environmental Protection Bureau;

The item "others" in Table 28 stands for untraceable disposition methods such as unregulated landfilling (dumping) and informal recycling. A large portion of informal recycling and dumping occurs out of the government statistical system for MSW collection; therefore the actual tonnage for this item is expected to be greater than the official number. The amount of formal recycling is negligible due to the low source separation nature of the model.

2.2.2 Guangzhou MSW Sorting Model

Guangzhou is the first city in China to make MSW sorting mandatory. The Temporary MSW Sorting Management Regulation, issued in February 2011, imposes a fine of at least 50 RMB (7.9 USD) on each violator, and at least 500 RMB (79 USD) per cubic meter of MSW, on each organization. This regulation came into effect in April, 2011 and aims to building up a comprehensive waste sorting system. As of now, the only step that residents are expected to do is to separate their MSW into "dry" and "wet"; the municipal sanitation staff is responsible for collecting these two streams and sorting the dry stream into recyclable materials using the appropriate equipment (22). As the campaign goes on, according to the Guide Book of MSW Sorting in Guangzhou, residents are expected to sort the MSW into four streams: Recyclable, non-recyclable, hazardous waste, and "trash". Compared to Beijing, Guangzhou emphasizes more on curbside/resident MSW sorting than concentrated processing facilities. Figure 14 shows the practical process and stakeholders of MSW sorting in Guangzhou.

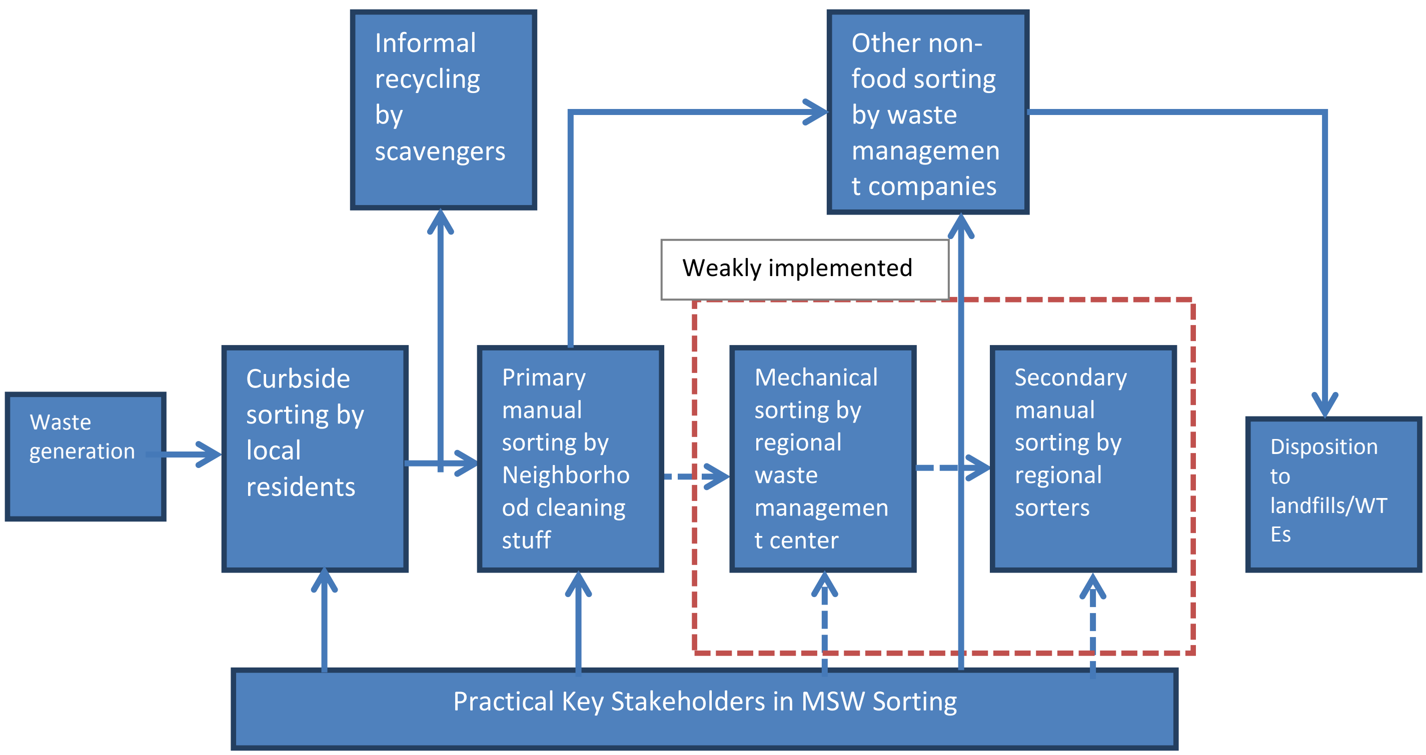


Figure 14 Practical process and stakeholders of MSW sorting in Guangzhou

Figure 14 shows that apart from local residents and the neighborhood cleaning service, waste management companies play a key role between the neighborhood and the landfills and waste-to-energy.. Unlike the Beijing model, where waste management companies have an auxiliary role, the Guangzhou model embeds these companies in the sorting system. Informal recyclers (scavengers) are not considered to be stakeholders in this model, since better management is applied to curbside/neighborhood collection.

On the policy level, Guangzhou's sorting policies and regulations are stricter with individual and organization non-compliance. Table 27 shows the policies and regulations regarding MSW sorting in Guangzhou.

Table 29 Guangzhou policies regarding MSW sorting

Policy & Regulation	Year	Function
MSW Sorting Evaluation Standard (23)	2004	Categorized and defined MSW into six streams: recyclable, bulk waste, compostable, combustible, hazardous waste, and others; standardized the MSW sorting collection bin; Gave mathematical methods to quantify sorting efficiency;
Working Plan for MSW Sorting and Collection	2004	Gave a more applicable way of categorization in residential areas, which includes recyclable, bulk waste, hazardous waste, food waste, and others;
Temporary MSW Sorting Management Regulation (24)	2011	Made MSW sorting mandatory and applied economic punishment against violation;

Apart from the policies and regulations listed in table 24, the city has a series of auxiliary standards and regulations for the sorting containers, encouraging resident participation, etc.. The most thorough and practical guide is the Guidebook of MSW Sorting in Guangzhou. All of these policies intend to enhance the source separation of the MSW, which can facilitate the downstream processes.

Social resources such as waste management companies in Guangzhou usually work closely with neighborhood authorities and customize sorting strategies according to the features of the service area. These companies are responsible for purchasing sorting equipment and providing collecting/sorting staff who work with the local neighborhood office. The companies gain profit from the management fees paid by the neighborhood and by selling the sorted recyclables. The model reduces direct investment into the sorting facilities and labor by the neighborhood and builds an easy channel between curbside recyclables and the recyclable demanding market.

The model's emphasis on public involvement and commercialization results in a high recycling rate (33%), as reported in official statistics (29). The "harmless treatment" rate (92%) is not as high as that of Beijing (97%) Table 30 shows how the means of Guangzhou's harmless treatment system (22).

Table 30 Guangzhou harmless treatment capacity (22)

Treatment	Number of facilities	Capacity (ton/day)
Composting	0	0
WTE	1	1040
Sanitary landfill	5	9800
Total	6	10840

Table 31 shows the waste management in Guangzhou (22). The data of Beijing was also included in order to compare the waste management system of both cities.

Table 31 Guangzhou waste management (22)

	Guangzhou City	Beijing City	Central (Urban) Guangzhou	Percent of Guangzhou City generation	Percent of Beijing City generation
Population	12.7 million	19.6 million	7.7 million		
MSW generation, million tons	6.5	6.3	3.6	55%	68%
MSW generation tons per capita	0.5	0.3	0.5		
Recycling	2.1	Negligible	NA*	33%	0%
Composting, million tons	0	0.8	NA	0%	13%
WTE, million tons	0.4	0.9	NA	6%	14%
Sanitary/regulated landfills, million tons	3.6	4.5	NA	55%	71%
Others	0.4	0.1	NA	6%	2%
Total, million tons	6.5	6.3		100%	100%

Source: 1. Guangzhou Statistical Bureau: Guangzhou 2011 Statistical Yearbook
2. Bulletin of Sixth Guangzhou Census, 2010
3. Guidebook for Guangzhou MSW Sorting **NA: Not available*

The item "Others" in Table 31 consists of illegal dumping and a small amount of informal recycling. The high rate of recycling (2.1 million tons or 33% of the MSW)reported by Guangzhou results in calculating a lower rate of landfilling (55%) than Beijing (71%). However, Table 25 showed that all the potential recyclable materials (metal, glass, paper, and plastics) amount to a total of 29.25%. It was not possible in this study to verify the "2.1 millions of recycling" by tracing the actual tonnages of sorted materials that reached the recycling market. Nevertheless, the recycling program of Guangzhou is indeed impressive and could be improved further, as discussed in the following section.

3. Existing Problems

Generally speaking, the whole process of MSW treatment is characterized by overwhelming government involvement—other stakeholders, such as the public and waste management companies, play a much smaller role in planning, implementing, and managing the system than the local environmental protection bureau.. This lack of stakeholder interaction results in passive condition throughout the whole chain of waste management. Local residents accept the unilateral policy and sorting guidance passively, while the governmental agency adjusts the collecting manner according to the negative reaction from the residents, and the initial plan is compromised. Therefore, most MSW sorting programs in Chinese cities suffer from low efficiency. Four main problems of MSW sorting are discussed in this section.

3.1 Poor Public Participation

Since a large portion of regulations and policies are made from the government's point of view, public awareness of MSW sorting and participation are underdeveloped. Despite the wide media coverage of waste sorting and punitive measures, residents are still not used to practicing sorting in their daily life. Since people seldom separate the household garbage in their home, curbside and neighborhood sorting bins are just belated actions. Figure 15 is a picture taken in one neighborhood that suffers from poor public participation.

Figure 15 Picture of sorting bin (left side for non-recyclables and right for recyclables)

Although Guangzhou model has made it mandatory for MSW sorting and fines are imposed on violation, the implementation of such an aggressive is still under question due to the lack of monitoring mechanism. It is impossible for neighborhood offices to check the garbage sorting practice for every single household, so actually only organizations and companies have been fined for unsorted garbage disposal.

3.2 Lack of Standardized Practice

Although guidance such as the MSW Sorting Evaluation Standard (23) has been issued for a couple of years, sorting categorization and facilities still vary from block to block. Even in the same neighborhood, sorting collection bins can have various combinations and styles in different residential areas. This imposes huge pressure and labor on waste collection and downstream sorting. Due to different sorting standards in various areas, waste content in different category bins varies from area to area. On the other hand, in many cities only one agency, the local environmental protection bureau, is responsible for the collection and processing of MSW with uniformed vehicles and facilities. Therefore, many times it is nearly impossible for the agency to sort waste from a number of combinations of categories. The result for that confusion is poor sorting efficiency. The Beijing model described earlier is the main victim of this kind of problem. On the contrary, the Guangzhou model can solve part of the problem because of its stronger company involvement. In order to maximize the profit, companies are more likely to customize the sorting and collecting style according to different areas. However, the Guangzhou model is not flawless. The following problem is usually discovered in the sorting systems of other cities.

3.3 Low Profitability

Profitability is the driving force to involve social resources in MSW sorting. However, high processing cost and low economic return has made sorting less attractive. For example, In general, companies are required to purchase equipment such as food waste shredders; however, due to the currently low composting capacity and lack of market for the compost product, the equipment is operating under low load. Furthermore, because of the inadequate curbside/resident sorting mentioned above, the quality of the feedstock to this equipment varies widely.. This increases the labor and maintenance cost for the sorting facility. As a result, the recycling service industry is actually shrinking in some cities in China. For example, in 1965, there were more than 2,000 recycling centers in Beijing; however, now there are less than 16 (26).

3.4 Poor Working Conditions for Informal Recyclers

The informal recycling sector in Chinese cities plays a very important role in diverting the MSW from landfill and recover valuable content. It has also provided working positions for a number of jobless people. For example, there are over 50,000 informal recyclers in Beijing; an estimated 30,000 recycle plastics, paper, and metals, while 20,000 deal with food waste. Through a rough calculation, this garbage-picking army can save the municipal government almost a billion CNY in MSW disposal costs per year (26). However, along with its impressive digesting ability, the Chinese informal recycling sector has also caused a number of human health and urban sanitation problems. The disorganized garbage pickers are distributed through the whole MSW treatment process, from curbside/neighborhood garbage bin to landfill sites. In order to get valuable materials from the neighborhood garbage bins, the scavengers sometimes tear the sealed trash bags or even break the trash bins, which cause severe odor and leachate problems.

The garbage pickers around regional MSW centers and landfills work in miserable hygiene conditions and without adequate health protection equipment.. On the food waste side, due to the lack of official or regulated agency to accept the waste from the informal sector, usually the recovered food waste is used to produce swill oil and sold to some restaurants at a much lower price than clean oil. The dregs are then dumped at illegal sites. Therefore, the informal recycling sector in China, if not regulated and organized, will continue to be a contributor to the city's sanitation troubles. The Beijing theoretical model may be improved by integrating these disorganized "garbage pickers" into the formal recycling system and providing them with much better e working and living conditions. Figure 16 shows a group of garbage pickers waiting for the waste to be discharged from a collection truck at a landfill.

Figure 16 Garbage pickers in a landfill Source: HDWIKI Image, http://tupian.hudong.com/11249/4.html?prd=zutu_thumbs

4. MSW Sorting Experience of Developed Countries

MSW sorting is a case-by-case issue that depends on the community's waste composition, population density, waste management budget, etc. Countries and regions successful in waste sorting have customized the sorting strategy according to their particular condition. Table 28 shows the MSW sorting strategy of some developed countries and regions.

Table 32 MSW sorting strategy for some developed countries (27)

Country	Strategy & Highlights
U.K.	1. Every household has three garbage bins for food and yard waste, cans and bottles, and others; 2. Different trucks come to the household weekly to transport three kinds of garbage to local sorting centers separately; 3. Local sorting centers further sort the garbage into 42 kinds of recyclables;
South Korea	1. Specific trash bags are applied to different kinds of garbage; 2. Particular time and place is determined for household trash collection;
Japan	1. Every household has to sort the garbage into more than 10 categories according to standard sorting table; 2. Government assigned trash bags are used to place different garbage; 3. Different weekdays are assigned for different kinds of garbage;
France	1. Strict law for waste sorting; 2. Special attention is paid to waste packaging materials, which results in a 80% recycling rate for packaging;
Australia	1. Every household has three garbage bins in red, yellow, and green for yard waste, recyclables, and others respectively; 2. Garbage should be sent to designated

	places in a special multi-layer trash bag provided by the neighborhood; 3. High fine for not sorting the garbage;
Finland	1. Households bring recyclables to public sorting bins or directly to recycling center; 2. The recycling center further sort the recyclables for different use; 3. Special trucks are used twice every year to collect hazardous waste such as acid, battery, and pharmaceutical waste;
Sweden	1. Aluminum cans and glass bottles can be sold for money via automatic recycling machine; 2. Three non-governmental organizations are responsible for the country's waste collection, who collect recyclables once every month and non-recyclables once every week;

Table 28 shows that source-separation at households and businesses are the basis for all kinds of advanced MSW sorting models. The recyclables in MSW are all treated separately from the collection point. Furthermore, strict regulations are applied to garbage disposal in terms of placing, timing, and sorting. Public participation in the separation practice is an international task. NGOs and academic institutions play a vital role in developed countries in promoting MSW sorting. As a branch of the Global WTERT Council (GWC), WTERT-China was introduced as an example of how these organizations can help in the campaign.

In terms of collection and separation method, over the past decade communities and municipalities in developed countries such as the U.S. have been increasingly switching their recycling systems from multi-stream (MS) to single stream (SS), in order to increase the rate of recycling. In MS collection, residents source-separate their recyclables, such as paper fiber, glass, plastics, and metals into several bins. These streams are collected in separate trucks or in separate compartments of the same truck. The streams are separated independent from one another. In SS collection, all designated materials are combined in a single cart, collected in a single truck, and separated with a single, unified process. SS recycling results in increased MSW diversion rates for participating communities and decreased costs of MSW collecting and transporting (30).

5. Discussion and Conclusions

As noted in the previous sections of this Report, both the Beijing and Guangzhou models are experiencing low public participation, lack of standardized practice, insufficient economic incentives for participating companies, and poor working conditions for informal recyclers. The statistical data show that the sorting model of Guangzhou is superior in terms of its potential to increase recycling and advance sustainable waste management. The results of this study have shown that this potential can be attained by implementing the following measures:

5.1 Enforcing Source Separation

Based on the foreign and the author's study, there must be source separation of designated materials (.e.g., paper fiber, metals, marketable types of plastics and glass, and hazardous wastes) at residences and business. Whenever the recyclables are mixed with the trash in households, it is almost impossible to separate them in later processes. Single stream collection and separation, which requires the residents only to separate the MSW into recyclables and non-recyclables, was suggested by the author, because it increases diversion rates of MSW in households and simplifies MSW collection and transportation. Furthermore, China's inexpensive labor costs reduce the expenses in sorting recyclables in materials recovery facilities (MRF).

5.2 Enhancing Public Participation

5.2.1 Improve the Communication Channel

A large portion of inadequate implementation results from poor public-government communication. In order to boost MSW sorting, a lot of municipal governments in China take a very aggressive measure or simply duplicate successful experience from developed countries, without taking into account the level of public awareness, economic conditions, , etc. This can result in public unwillingness to do household sorting. Residents have no initiative to spend extra effort and money on separating their daily output when imposed a series of to-dos by the local government. Therefore it is suggested that each neighborhood should hold hearings when designing the area's MSW sorting policy. Online feedback section should be established during the practice of the policy to improve it iteratively. On the meanwhile, every building should have a resident sorting observer to timely report the sorting condition to the neighborhood authorities.

5.2.2 Establishing Incentives and Disincentives

Reward should go along with punishment in a mature system. In China's current condition, punishment without adequate monitoring will only result in illegal avoidance. The study suggests that local government link the monthly waste disposal fee with the household's level of sorting adequacy. The Swedish experience for cans and bottles recycling can be introduced after modification. Each neighborhood can have a recycling center which accepts major recyclables from households, which, in return, get certain credits for the amount they provide and later apply them to the waste disposal fee.

5.3 Providing Standard Sorting Equipment

According to the experience from developed countries, the most effective way for household to have adequate waste sorting is to provide them with standard garbage bins and trash bags. The increase in the budget can be offset by the decrease in sorting labor in regional MSW processing centers and the sorting efficiency can be significantly increased.

5.4 Integrating Sorting and Recycling Market

The sorting, collecting, recycling, and terminal treatment of the MSW stream should be an integrated system. An adequate sorting mechanism is to be supported by a well-shaped recovery market to digest the sorted materials. Government should play an important role in forming the market, since under-regulated companies and informal sector are only extracting commodities with immediate value in the MSW stream while dumping the rest because of the high disposal cost. Several suggestions are put forward in the study:

a) Set Separate Collection and Transportation Strategy for Sorted MSW
Local environmental authority should be responsible for organizing different governmental agencies and waste management companies to deal with various kinds of sorted waste. Sorted MSW should be transported with separate vehicle in different times.

b) Setup Special Place for Secondary Sorting
According to the current condition in Chinese cities, it is nearly impossible to have as detailed a household MSW sorting level as Japan do. Therefore secondary sorting is necessary in every neighborhood to further separate roughly sorted MSW from households. The secondary sorting center should be co-managed by environmental protection agency, recycling agencies, and waste management companies. The environmental protection agency or other MSW collection entities are responsible for the input to the center while the waste management companies are dedicated to the output of the center.

5.5 Developing NGOs and Academic Institutions

NGOs and academic institutions play a vital role in issues which involve both the government and companies. They help monitor the decision-making process and transfer the opinion from the bottom to the top and vice versa. By education programs and online publications, third-party organizations improve the public awareness for MSW sorting and visualize the result of sorting.

Due to their better public credibility, third-party organizations have already been active in all kinds of environmental issues by conducting public opinion polls and organizing education activities. Generally speaking, third-party organizations can facilitate MSW sorting in two ways: convey public opinions to the policy-makers so as to enhance a public-oriented strategy; and popularizing MSW sorting knowledge so as to improve public acceptance and initiative.

5.6 WTERT-China as Part of the Sorting Campaign

As a non-governmental, non-profit organization, WTERT's mission is to identify the best available technologies for dealing with various waste materials, conduct additional academic research as required, and disseminate this information by means of publications, the WTERT webpages, and periodic meetings (28). The Global WTERT Council consists of several national organizations. WTERT-China is devoted to upgrading the country in the hierarchy of sustainable waste management, by increasing recycling, composting and waste to energy and ensuring that the rest of the MSW is deposited in sanitary landfills.

5.6.1 WTERT-China Organization

Due to the country's vast territory and varied regional economic development, WTERT-China at this time does not have a single base of operations. The two academic groups involved in WTERT-China are Zhejiang University (ZJU) in the city of Hangzhou and Chongqing University of Science and Technology (CQUST) in Chongqing City. ZJU is the top research institution in China on thermal treatment technologies and is home to one of the National Dioxin Laboratories. CQUST is closer to industry and has a cooperation relationship with Covanta, a major U.S. WTE company. Meanwhile, Tongji University (TJU) in Shanghai is also in contact with WTERT in areas of sustainable waste management. TJU is the leading university of waste management in Shanghai and has contributed a lot to the regular testing, assessment, and improvements to the existing two WTE plants in Shanghai.

At this stage, WTERT-China is still in its starting period and a network needs to be built connecting as many as possible academic groups who are engaged in waste management research in China. The ZJU WTERT website has been built and there are plans to improve it (http://wtert.zju.edu.cn/cn/index.asp). Figure 17 shows the homepage of WTERT-China Website (ZJU Sector).

Figure 17 WTERT-China (ZJU Sector)

5.6.2 WTERT-China Sorting Consideration

As mentioned in the introduction section of Part II, MSW sorting is the very basis of adequate WTE and recycling. Therefore WTERT-China should also try every possible means for improving the upstream conditions, before the post-recycling MSW reaches the WTE plants.

5.6.3 WTERT-China Website Improvement

Currently, WTERT-China's website focuses only on WTE rather than the whole hierarchy of sustainable waste management. It is necessary that the website expands its coverage to other waste management technologies and setup a special section of MSW sorting knowledge for public education. According to the current condition in China, the public has much higher acceptance of recycling than the other means of waste management, while they are not aware of the complementary role that WTE plays in developed countries, thus reducing landfilling. Therefore, the WTERT-China websites can contribute much in explaining the hierarchy of sustainable waste management and emphasize the importance of MSW sorting to all kinds of technologies, including WTE.

For example, It is important for the public to know where the sorted streams are going. Therefore, it is suggested that the WTERT-China websites provide a flow chart for all kinds of sorted MSW, from curbside collection to terminal facility and keep it updated according to new policies and measures. Figure 18 shows a snapshot from WTERT-US website about resource recirculation.

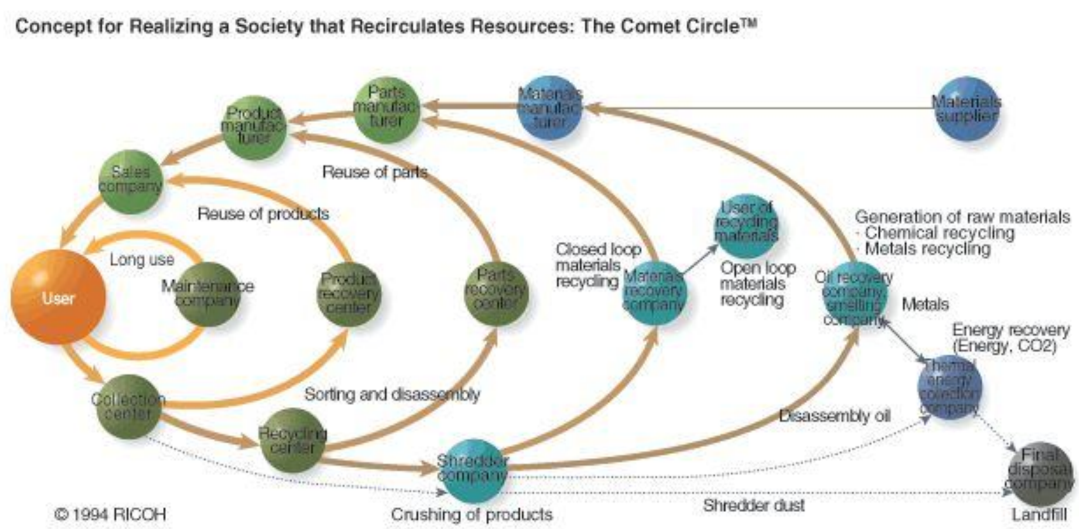


Figure 18 Resource recirculation from WTERT website

5.6.4 Public Education Program

Since it is based at top academic institutions working on waste management issues, WTERT-China can take full advantage of the academic resource it has and the high credibility of non-governmental organizations to conduct education campaigns that popularize waste management technologies with an emphasis on the role sorting plays in them. For example, the various parts of WTERT-China can cooperate with local government in setting up sorting knowledge lectures in neighborhoods and help design and distribute instructive brochures for residential waste management. University students can be involved in designing the waste management strategy under professors' instruction to convert the fruits of academic research to practical use. Outstanding design and neighborhood performance in waste management can be rewarded by means of an annual prize.

Currently, most neighborhood lectures about sorting are hosted by sub-district or neighborhood offices. The instructors are usually office staff who have just gained the relevant knowledge from upper level meetings. This prevents the instructors from conveying the very essence of the knowledge to the residents since they themselves are new learners. WTERT-China can take the responsibility of co-hosting the neighborhood lectures and have experts and outstanding students be lecturers.

5.6.5 Organizing Nationwide Academic Efforts

Successful experience of other WTERT branches shows that it is of great significance to integrate the existing academic efforts in the country so as to provide advice to policy-makers from a scientific perspective. A network of Chinese waste management academic institutes can be built to facilitate contact and cooperation. ZJU, as a top academic institution in waste management technologies, can take advantage of its nationwide influence to start the network. A nationwide waste management summit can be organized on a regular basis to exchange ideas.

According to the author's review, there is no professional waste management magazine in China currently. It is suggested that WTERT-China try to coordinate national academic resources to form an editor group and publish the latest waste management technology and progress. Such a journal could be called "Waste Management and Research in China".

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