A SUSTAINABILITY ANALYSIS ON THE DEVELOPMENT OF MUNICIPAL SOLID WASTE MANAGEMENT BY SANITARY LANDFILLING

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I. Future Trends of Sanitary Landfilling

“Sanitary landfilling” is commonly referred to as a landfilling technique that caters for proper control of landfill leachate and landfill gas (LFG). In the early days, serious environmental problems arose due to uncontrolled waste disposal. It was not until 1930’s that the concept of “Sanitary Landfilling” was first proposed in California of the United States. As the amount of waste is ever increasing, and it oftentimes contains toxic and hazardous substances, the potential chance of environmental pollution is hence greatly increased. This has in turn raised public concerns, leading to increasingly stringent requirements on the operation management of the landfills.

Landfilling as “fate of waste” has been playing an important role in waste management, and is still the most common technique for waste management in most countries (See *Figure 1*). This technique has the advantages of simple operation, high adaptability and flexibility. However, it is increasing difficult to locate an “ideal” landfill site. This can be generally observed in developed countries, where the proportion of waste treated in landfills has been seen decreasing since 1980’s. There are three reasons for this: (1) Old landfills are gradually reaching their design capacities; (2) Difficulties in new landfill siting; (3) Closure of some operating landfills due to their inability to satisfy the increasingly stringent environmental regulations. The United States Environmental Protection Agency (USEPA) estimated that the number of landfills in the U.S. dropped from 3,300 in 1993 to 1,654 in 2005 and forecasts a continual decline down to 1,200 in year 2010.

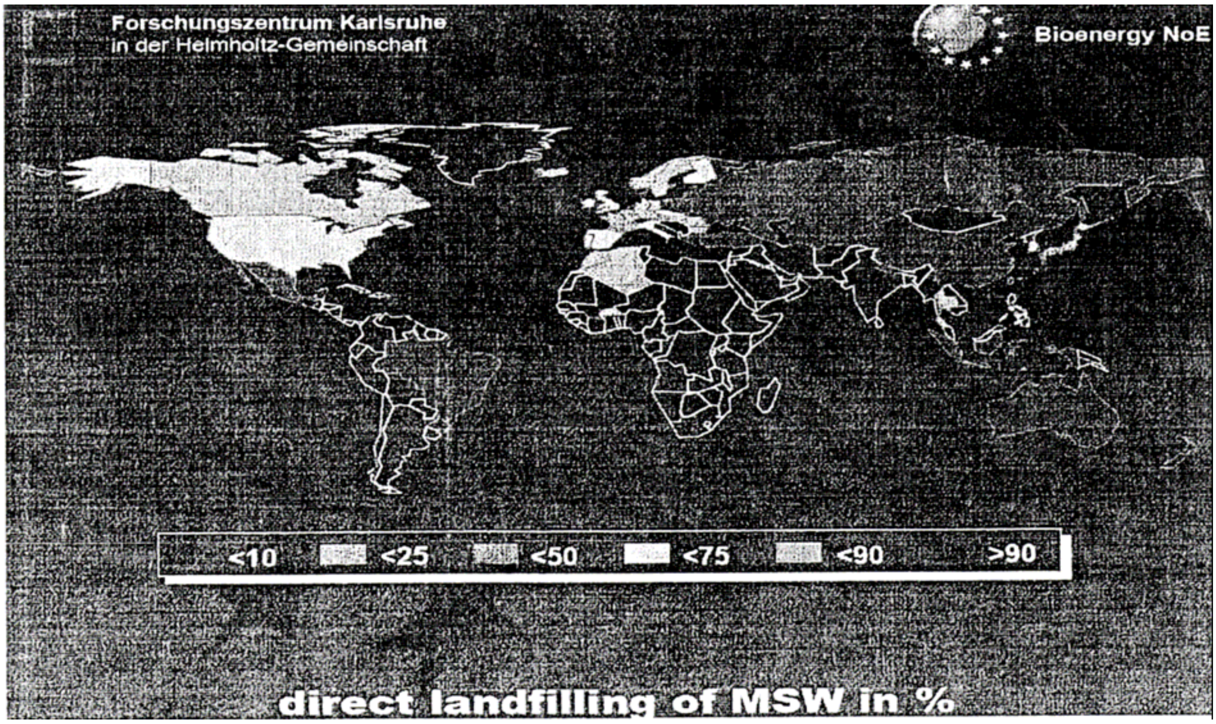

Figure 1 - % Municipal Solid Waste being handled by Direct Landfilling (Source: Philipp Schmidt-Pathmann, 2006)

Owing to the trend of increasing rate of resource recycling from waste, and the effort to reduce potential environmental pollutions induced from landfills, it is expected that the amount of organic content in waste will gradually decrease. For example, regulations prohibiting yard waste disposal into landfills have been imposed in U.S. since 1990's. To achieve the goal of lowering the biodegradable organic content of waste into landfills, different targets in 3-stage directive was set in the European Landfill Directive (CD1999/31/EU/1999) (See *Figure 2*). Stage 1: a 25% reduction of biodegradable waste by 2005, comparing to that measured in 1995. Stage 2: a 50% reduction (compared to 1995 figures) shall be reached by 2009. Stage 3 requires a 65% reduction by 2016. Germany, Austria and Switzerland proposed even higher standards for their own nations. The total organic carbon (TOC) of landfill waste was to be controlled below 5% in Switzerland by 2000. For Austria and Germany, the corresponding years of implementation were 2004 and 2005, respectively. To achieve the above target simply implies that all waste sent to landfills will have to be basically ash. All remaining waste (or other waste, i.e. all waste collected by decentralized means) will have to be incinerated.

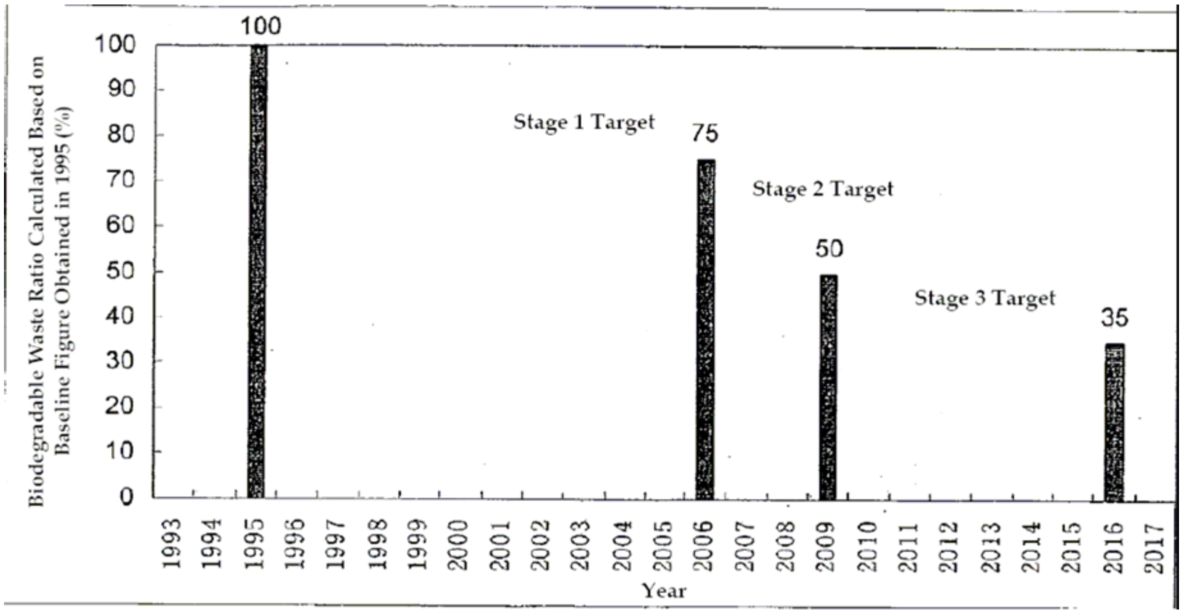

Figure 2 – 3-Stage in Reduction of Organic Content in MSW under the EU Landfill Directive

II. Characteristics of Municipal Solid Waste Sanitary Landfill Development in China

1. Severe Shortage in Number of Sanitary Landfills

According to the statistics announced in the China Urban Construction Annual Report in August 2006, 156 million tons of waste have been placed in 470 landfills (neglecting inaccurate information from some cities) of various types from 661 incorporated cities in China as at the end of 2005. Among the 470disposal faclities, there were a total 356 municipal-level landfills. An apparent drop in the number of these landfills was observed compared to a total of 484 in 2000. Currently there are 660 incorporated cities in China, yet many of them do not have their own landfills. There should reasonably be around 800 landfills by now for waste management. Hence, it is believed that the number of landfills would gradually increase after adjusting for inaccurate data.

Considering the socialist new rural construction and the concept of new integrated city-town construction in China, the demand for construction of new landfills is high. Assuming there is at least one landfill in each county, over 1,600 new landfills should be constructed. Likewise, over 3,000 new landfills would be required if there are two landfills on average in each county.

Analyses of the number of landfills in Germany and the U.S. (See *Tables 1, 2 and 3*) show that in every 1,000 km^2, there would be 0.18 and 0.85 landfills in the U.S. and Germany, respectively. The results also reveal an average of 0.56 and 0.4 landfill is available for every 100,000 population in the U.S. and Germany. As the population distribution and economic development in China are quite different from those in developed countries, landfill density in China at this time cannot be as high as those in the developed countries. However, based on the analyses on the land resources and landfill construction standards in China, the percentage of waste managed via centralized management in China should be similar to those in the developed countries.

Table 1 – Change in Number of MSWLF in Germany between 1990 and 2004

Year	1990	1993	1995	1997	1999	2004	2010[1]
No. of Landfills	8,273	562	472	372	376	297	27–111

(Note 1: Based on EMU/UBA projection.)

Table 2 –Change in Number of MSWLF in U.S. between 1988 and 2005

Year	1988	1990	1995	2000	2005
No. of Landfills	7,924	6,326	3,97	1,967	1,654

(Source: USEPA)

Table 3 – Statistics on Number of Landfills per Unit Area and per Capita

Year	**1988**	**2005**
No. of Municipal Solid Waste Landfills in the United States	7,924	1,654
No. of Landfills Per 1,000 km^2 Area	0.87	0.18
No. of Landfills Per 100,000 Population	2.7	0.56
Year	**1993**	**2004**
No. of Municipal Solid Waste Landfills in Germany	560	297
No. of Landfills Per 1,000 km^2 Area	1.60	0.85
No. of Landfills Per 100,000 Population	0.7	0.4

2. Improved Construction Standards for Sanitary Landfill Construction

A number of landfills with liner systems have been commissioned with the steady development of landfills in China, especially with the support of funds from the state bonds. Based on a casual survey, over 30 million m^2 HDPE geomembrane has been used in construction of landfill base liner. Standard in liner design and construction in China are on par with international standards (See *Table 4*). For example, the construction standard for impermeable liner in China is close to that in Germany, and is more stringent than those adopted in the U.S. and the E.U.

Table 4 – Comparison of Basic Requirements for Bottom Liners in MSW Sanitary Landfills

Liner System Requirement	**USEPA Standard (40CFR258)**	**EU Landfill Directive (1999/31/EC)**	**German Standard (TASI, 1993)**	**Chinese Standard (CJJ 113-2007)**
Leachate Drainage Layer	$K > 1x10^{-4}$ m/s Thickness: 0.3m	Thickness: 0.5m	$K \geq 1x10^{-3}$ m/s Thickness ≥ 0.3m	$K \geq 1x10^{-3}$ m/s Thickness: 0.3m
Geomembrane liner	Thickness≥ 0.75mm (Recommended : 1.5mm HDPE)	Not Specified. Yet liner thickness should be 100cm ($K \leq 1x10^{-9}$ m/s)	Thickness ≥ 2.5mm HDPE	Thickness ≥ 1.5mm HDPE
Compacted Clay Layer	$K \leq 1x10^{-9}$ m/s Thickness:~ 60cm	With HDPE liner, thickness of Clay layer > 50cm	$K \leq 5x10^{-10}$ m/s Thickness3x25cm	$K \leq 1x10^{-9}$ m/s Thickness: 75cm

In 2006, China's Ministry of Construction initiated an inspection exercise on the status of landfill operations, and the classification of landfills according to their level of "sanitation". Based on the inspection and assessment, there were 372 active landfills in China as of the end of 2005, with the waste intake capacity of 194,700 tons per day. Among the 372 landfills, there were 190 landfills classified as Class II, or higher. Their daily waste intake capacities were 127,500 tons. HDPE liners were constructed in most of the above mentioned Class II landfills.

3. Operational Weaknesses: Leachate Treatment and LFG Recovery/Utilization

Currently, leachate treatment is one of the weaker links in China's construction and management of landfills. Due to the wide fluctuation in quantity and quality of leachate and the high concentration of contaminants, in-situ treatment with complex treatment design, sophisticated management, and a relatively high capital investment is typically required to meet discharge requirements.

To ensure reliability, the capacity of leachate treatment plant is usually over-designed. Many of the leachate treatment facilities in small- and medium-sized landfills are over-designed by a factor of 0.5 higher compared to the practical design criteria; while some even exceed by over 0.8. However due to limited funding and technology in real life, most of the leachate treatment plants do not attain their design capacities, hence not meeting the actual requirements of daily landfilling needs. From a technology point of view, there would be a significant increase in the operation costs to meet the Class 2 standard (or higher) according to the <Standard for Pollution Control on the Landfill Site of Municipal Solid Waste> (GB16889-1997), which requires membrane treatment technology; at the same time, it would be necessary to achieve the highest practical level of rainwater/leachate segregation. Otherwise, a huge amount of leachate would be generated, leading to unbearable operation costs in leachate treatment.

LFG recovery and utilization benefits the environment by reducing its pollution and lowering greenhouse gas emission. LFG could also be used for electricity generation or other purposes if sufficient amount is generated. In China, there are operating landfill gas-to-electricity projects in Hangzhou, Guangzhou, Nanjing, Xian, Beijing, Changsha, Wuxi and Jinan. According to investigation, there are 18 LFG utilization projects completed and commissioned by the end of 2007. 15 of these contain facilities for electrical power generation using landfill gas, with a total capacity of 30MW.

Development of and application for CDM projects have been quite active. As of 16th January 2008, 21 MSW treatment projects (See *Table 5*) have been approved by the NDRC (with 18 projects for LFG utilization). Most of the larger landfills have signed agreements in place for LFG utilization with foreign companies. Progress of implementation of these LFG utilization projects, however, tends to be slow overall and some projects are still stalled at the agreement stage.

Table 5 – Approved MSW Treatment CDM Projects

No.	Project Name	Project Owner	CER Buyer	Est. Emission Reduction (tCO_2e/yr)
1	Nanjing Tianjinwa Landfill Gas to Electricity Project	Nanjing Green Waste Recovery Engineering Co., Ltd.	EcoSecurities Group Ltd. (UK)	265,032

2	Meizhou Landfill Gas Recovery and Utilization Project	Shenzhen PhasCon Technology Co., Ltd.	Austrian JI/CDM Programme, Kommunalkredit Public Consulting GmbH (Austria)	278,000
3	Beijing Anding Landfill Gas Recovery and Utilization Project	Beijing Erqing Environment Engineering Group	Energy Systems International B.V. (Holland)	90,000
4	Shenzhen Xiaping Landfill Gas Collection and Utilization Project	Shenzhen Lisai Development Co., Ltd.	Climate Change Capital Carbon Fund s.a.r.l. (UK)	749,186
5	Nanjing Jiaozishan Landfill Gas Recovery and Utilisation Project	Nanjing Yunsheng New Energy Development Co., Ltd.	CAMCO International Limited (UK)	147,880
6	Wuxi Taohuashan Landfill Gas to Electricity Project	Wuxi Tianshun Environmental Technology Co., Ltd.	Toyota Tsusho Corporation (Japan)	75,316
7	Guangzhou Xingfeng Landfill Gas Recovery and Electricity Generation Project	Guangzhou Huijing Environment Protection Technology Co., Ltd.	ICECAP (UK)	626,834
8	Shandong Jinan Landfill Gas to Energy Project	Shandong Shifang New Energy Ltd.	EcoSecurities Ltd. (UK)	150,158
9	Nanning Landfill Gas to Energy Project	Guangxi Gettop Science & Technology Co.,Ltd.	Biogas Technology Ltd. (UK)	195,208
10	Kunming Wuhua Landfill Gas to Energy Project in Yunnan Province	Kunming Huan Ye Environmental Protection Engineering Development Co., Ltd.	Biogas Technology Ltd. (UK)	201,586
11	Hunan Changsha Qiaoyi Landfill Gas Recovery and Electricity Generation Project	Changsha Huiming Environment Energy Co.,Ltd.	Trading Emissions PLC (UK)	238,319
12	Fuzhou Hongmiaoling Landfill Gas to Electricity Project	Fujian Tianyi Renewable Energy Technology & Utilization Co.,Ltd.	Eco Bank Ltd. (Japan)	181,234

13	Tianjin Shuangkou Landfill Gas Recovery and Electricity Generation Project	Tianjin Clean Energy and Environmental Engineering Co.,Ltd.	International Bank for Reconstruction and Development (Spanish Carbon Fund)	155,823
14	Kunming Dongjiao Baishuitang LFG Treatment and Power Generation Project	Kunming Huan Ye Project Development Co.,Ltd.	Asja Ambiente Italia S.P.A(Italy)	64,302
15	Shenyang Laohuchong LFG Power Generation Project	Shenyang Laohuchong Municipal Solid Waste Treatment	Asja Ambiente Italia S.p .A (Italy)	126,179
16	Jilin Municipal Solid Waste Incineration for Grid-connected Electricity Generation Project	Shuangjia Environmental Protection and Energy Utilization Co.,Ltd.	EcoSecurities Group Plc. (UK)	176,751
17	Fuzhou Hongmiaoling MSW Incineration Power Plant	Fuzhou Hongmiaoling Waste to Energy Co., Ltd.	Green Hercules Trading Limited (UK)	174,616.7
18	Mianyang Landfill Gas Utilization Project	Mianyang Taidu Environment Energy Technical Development	Sindicatum Carbon Capital Ltd.	103,204
19	Nanchang Maiyuan Landfill Gas Recovery and Utilization Project	Nanchang Xinguan Energy Development Co.,Ltd.	One Carbon B.V. (Netherlands)	150,599
20	Shenyang Daxin Landfill Gas to Electricity Project	Shenyang Xinxin Tomorrow Renewable Co.,Ltd.	Danish Ministry of Foreign Affairs(Denmark Carbon Fund)	195,436
21	Municipal Solid Waste Composting Project in Urumqi, China	Xinjiang Urban Construction & Environmental Protection Co.,Ltd.	RWE Power Aktiengesellshaft (Germany)	51,712

(Source: China NDRC Website, as of 16th January 2008)

A relatively high proportion of China's MSW is food waste, while the proportion of fiber, wood and other slowly biodegradable organics is relatively low. Food waste exhibits the fastest biological decomposition among all waste types, which leads to rapid gas generation and hence limiting its collection efficiency. The recovery and utilization rate of landfill gas is generally less than 60% in developed countries; whereas to achieve a 20% gas recovery in China appears to be difficult (Bernhard Raninger, 2007). Analyses of operating landfill gas-to-electricity projects in China show that electricity generated through LFG recovery and utilization is approximately 30kWh per ton of waste. There is an obvious difference compared to the 250-300kWh per ton of waste via incineration. Hence, the energy recovered from disposed waste in landfills and LFG is fairly limited.

III. Is There A Need for Developing “Recyclable” Sanitary Landfills?

From an environmental protection standpoint and an economics point of view, small-scale sanitary landfills (landfills with waste intake capacity of below 200 tons/day, representing most landfills on a county level) in China are not rational choices. Taking the Three Gorges District as an example, for a 120 tons/day landfill, the capital investment would amount to a cost of over RMB50/ton of waste, while for a 5 tons/day landfill, the cost would be over RMB100/ton. Considering the additional costs of operation and the fact that the actual waste intake is less than the design capacity, the cost of such a small-scale landfill could be as high as RMB100 - 200/ton of waste (not even including the cost of land usage), which is double that of landfill operations in urban areas. The overall budget for developing a small-scale landfill is relatively high and economically unattractive if stringent national construction specifications are to be met, especially with the difficulties in landfill siting. Even though the construction of landfills could be guaranteed by financial support from the Chinese government, due to the limited funds for landfill operation, developing of small-scale landfills would lead to some other environmental pollution problems because of the low quality in treatment.

Leachate from these small scale sanitary landfills is difficult to be treated properly. Very often the leachate is directly discharged into a small sewage treatment plant leading to obvious adverse impacts (it is hard for these small sewage treatment plants to take up the shock-load in a short duration), or it is just diluted in these plants and discharged into the nearby rivers. The capacity of these small-scale landfills to reduce overall pollution impacts is very limited, but they use up land resources and partly induce land contamination issues.

A large portion of the capital investment for landfills is used for site development and construction of landfill base liner system. Capital investment costs could be significantly lowered if the design and construction of liner system can be simplified and the amount of land reduced. The operation costs can also be decreased substantially if the amount of leachate is minimized and the treatment process simplified. The aerobic digester landfill from the U.S. is a worthwhile experiment (See *Figure 3*). Simply put, its principle is to perform composting in a landfill, or constructing a composting facility in the form of a landfill.

Formerly the main goal in composting facilities was also to shorten the fermentation period. The so-called Active Rapid Composting System is capable of shortening the fermentation period to within 1 week. If the landfill is constructed as a passive composting system, complete fermentation can take as long as a year.

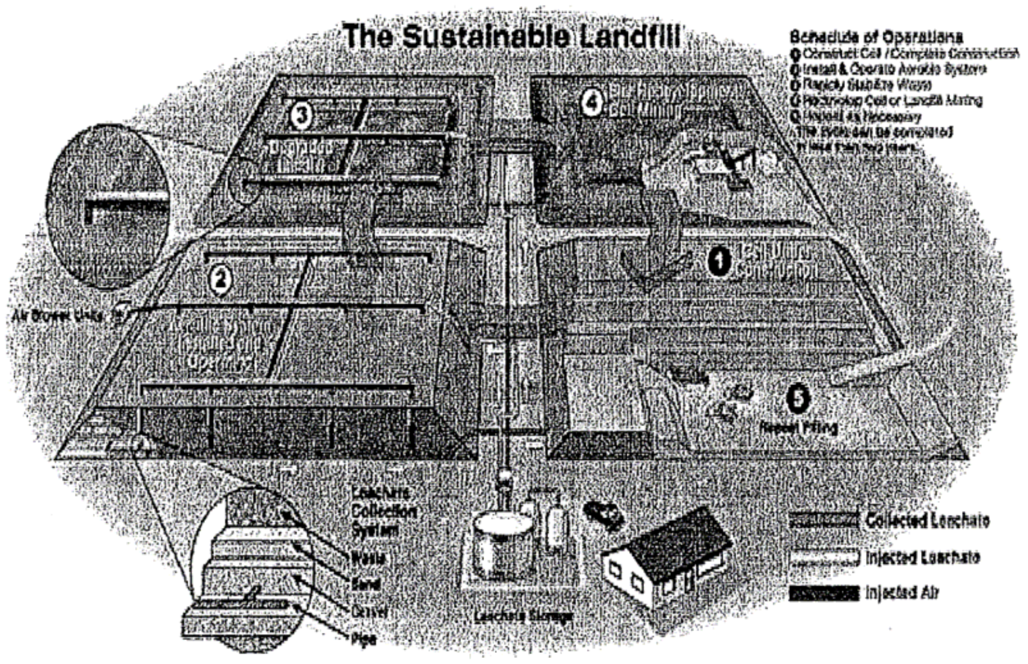

Figure 3 – Illustrative Diagram of Aerobic Digester Landfill in U.S.

Residuals after fermentation could be used as compost or as backfill into the landfill; while the combustible materials retained on the sieve could be gathered and used as fuel. Such a landfill occupies minimal space, materials can be recycled, and maximum diversion of rainwater from leachate can be achieved (membrane cover will be applied when raining); no sophisticated leachate treatment facilities will be required, and both the construction and operation costs will be significantly reduced.

Taken a landfill with daily waste intake of 100 tons as an example,
Space required: 15,000 – 20,000 m^2;
Land and site development costs: within RMB 5 million;
Facilities cost: RMB 3 million;
Operation cost can be controlled to below RMB 50/ton of waste.

IV. Conclusions

Recapping the history of development in municipal solid waste management on a waste collection standpoint, waste collection progresses from incomplete collection, to complete collection, and finally to collection with separation into different waste streams. Waste treatment progresses from decentralized disposal to sanitary landfilling, to waste reduction and ultimately control to waste input to landfills. In developed countries, the whole development occurred over 30 – 40 years. Although the Chinese economy is growing rapidly, a huge economic gap still exists between the developed countries and China. The overall status of MSW treatment in China is still in the developing stages, with waste collection going from incomplete to complete collection, and waste treatment going from decentralized disposal to sanitary landfilling. The development of treatment of MSW should adhere to stringent standards, but it should also be pragmatic and innovative.