Proceedings of NAWTEC16
16th Annual North American Waste-to-Energy Conference
May 19-21, 2008, Philadelphia, Pennsylvania, USA

NAWTEC16-1930

POTENTIAL FOR THE FIRST WTE FACILITY IN MUMBAI (BOMBAY) INDIA

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ABSTRACT

The city of Mumbai (Bombay), India is facing a solid waste management crisis. The infrastructure has been unable to keep pace with economic development and population growth, resulting in insufficient collection of municipal solid waste (MSW) and over-burdened dumps. Improper disposal of solid wastes over several decades and open burning of garbage have led to serious environmental pollution and health problems. This study examined the solid waste management process in Mumbai and the potential for implementation of waste-to-energy facilities.

Mumbai's average per capita waste generation rate is 0.18 tonnes per person. Although the reported collection efficiency of MSW is 90%, almost half of the city's 12 million people live in slums, some of which do not have access to solid waste services. The most pressing problem is the acute shortage of space for landfilling. When the present waste dumps were constructed they were at the outskirts of the city, but now they are surrounded by housing colonies, thus exposing millions of people to daily inconveniences such as odors, traffic congestion, and to more serious problems associated with air, land, and water pollution and the spread of diseases from rodents and mosquitoes.

Mumbai is the financial center of India and has the highest potential for energy generation from the controlled combustion of solid wastes. The lower heating value of MSW is estimated in this study to be 9 MJ/kg, which is slightly lower than the average MSW combusted in the E.U. (10 MJ/kg). The land for the first WTE in Mumbai would be provided by the City and there is a market for the electricity generated by the WTE facility. The main problem to overcome is the source of capital since the present "tipping fees" are very low and inadequate to make the operation profitable and thus attract private investors. Therefore, the only hope is for the local government and one or more philanthropists in Mumbai to team up in financing the first WTE in India as a beacon that improves living conditions in Mumbai, reduces the City's dependence on the import of fossil fuels, and lights the way for other cities in India to follow.

1. Introduction

India is one of the fastest growing economies in the world today. The rapidly expanding economy is already putting a strain on the environment and on the availability of natural resources. Mumbai, the financial and commercial capital of India, is one of the largest cities in the world with approximately 12 million residents (2001 census).[1] [21, 17]

Mumbai has historically been a driver of economic growth not only for the state of Maharashtra, of which it is the capital, but also for the rest of India. The city contributes to approximately 5% of India's GDP. [2] However, it has been estimated that 48.9% to 54.5% of Mumbai's population lives in slums today. [18, 28] Almost six million people live in some 2,000 slums and do not have access to even the most basic services of running water, electricity, sewage disposal, and adequate housing. [34] Economic growth has slowed considerably in Mumbai, affecting the quality of life, standard of services, and the environment. According to an Economist Intelligence Unit Hardship Survey, conducted in 2002 on infrastructure, health and safety, and environment, Mumbai was ranked 124th out of 130 major cities worldwide. [6]

[1] Tokyo is the largest urban metropolitan area in the world, at over 34 million people, while Mumbai ranks fifth. [32] In terms of actual city population, Mumbai ranks first, while Tokyo comes in eighth at over 8 million. [8]

2. Solid Waste Management in Mumbai

Civic services, including the collection and disposal of solid waste, are provided by the elected local government, the Municipal Corporation of Greater Mumbai (MCGM). MCGM employs over a million people and has an annual budget of approximately Rs. 55 billion ($1.2 billion).[2] [20] The 2006-07 budget of the Solid Waste Management Department of the MCGM was Rs. 7.4 billion ($165 million), and is expected to increase to Rs. 7.8 billion ($174 million) in 2007-08. [27] The municipal corporation spends roughly Rs. 1,160 per ton ($26/ton) on collection, transport, and disposal of MSW. Collection and transport together constitute Rs. 902 ($20) or 78% of the cost, while disposal only costs Rs. 258 ($6/tonne) or 22% of the total cost of one ton of MSW. [27] In India, the average municipal expenditure on solid waste management is between Rs. 500-1,500 per ton of MSW ($11-33/ton). [11]

The MCGM and its private contractors constitute the formal sector of solid waste management. They are responsible for MSW collection, transport, and final disposal. The municipality of Mumbai does not have a formal recycling program or recycling facilities. However, there is a thriving informal recycling sector that is primarily made up of ragpickers. The ragpickers collect recyclables from MSW and then sell them to recyclers. This sector is considered to be 'informal' because it is not controlled by government agencies and there are no regulations for pricing of recyclable materials or to protect the health and safety of the ragpickers. Nevertheless, their work reduces MSW transportation costs, provides raw materials to recycling facilities, and helps to protect the environment. [10]

2.1 Waste Generation in Mumbai

The wastes that are generated in Mumbai can be broadly classified into four categories:

- *Municipal solid waste:* Around 5,800 tons of mixed residential waste are generated daily in Mumbai. The MCGM is responsible for the collection, transport, and disposal of MSW. [27]
- *Biomedical waste:* Approximately 25 tpd of biomedical waste are produced, but due to the lack of capacity and the improper functioning of the sole hospital waste incinerator in the city, only five tons per day are treated. [27] The rest of the waste is sent to MSW dumps, where they cause injury to ragpickers who sift through the waste and can spread diseases and infections. The Maharashtra Pollution Control Board (MPCB) is responsible for regulating the collection and disposal of biomedical wastes. [27, 14]
- *Construction and demolition (C&D) waste:* Around 2,200 tpd of construction and demolition waste are collected by the MCGM and sent to various dumps. [27] The generators of C&D waste (e.g.: construction companies, utilities) are responsible for disposal of their own waste; however, due to insufficient enforcement and monitoring, C&D waste is frequently dumped on the street or in community bins, thus becoming the responsibility of the MCGM.
- *Industrial waste:* There are no estimates as to how much industrial waste is produced in Mumbai. The Maharashtra Pollution Control Board (MPCB) estimates that there are close to 31,000 businesses and/or factories in Mumbai. [27, 21] Typically, generators of industrial waste are responsible for transportation and disposal of their own waste, as are generators of C&D waste, which falls under the purview of the MPCB, not the MCGM.

2.2 Waste Collection in Mumbai

Municipal solid waste is collected by street sweeping and by community collection, which consists of:

a) *house-to-house collection,* where residential garbage is collected by apartment buildings in private bins and then offloaded onto municipal or private vehicles that make routine stops along particular routes; and

b) *communal collection,* where residents bring their garbage to collection points such as round bins, sheds, and stationary containers, which are placed at various locations around the city. [21]

Most of the municipal solid waste is collected through communal collection areas, while only about 22% of the MSW is collected from house-to-house pick-up in three shifts, with each vehicle making roughly five trips per shift. [21, 22, 27] The collection efficiency is estimated to be between 80-90% (1997). [36]

The collected MSW is taken either to transfer stations or directly to the dump. There are three transfer stations in Mumbai with a combined capacity of 600 tpd, and three MSW dumps. The waste transfer stations are located in areas that are either very congested or where roads are too narrow to accommodate large trucks. Approximately 30% of

[2] The conversion rate used throughout this report is Rs. 45 = US $1.

the MSW collected passes through transfer stations before reaching the municipal dumps. [22] The MCGM plans to upgrade the existing transfer stations and open three new ones over the next ten years. [27]

2.3 Transportation of MSW in Mumbai

MCGM has its own fleet for garbage collection and also hires contractors to collect and transport MSW to transfer stations and dumps. The average distance from the collection points to the dumping grounds ranges from 20-28 km. [27] MCGM has entered into a contract with a private operator to add new vehicles to the existing fleet in order to expand MSW collection to slum areas and reduce the number of trips made per day. The total cost for a modernized fleet for a five-year period is estimated to be Rs. 4.76 billion ($106 million). [22]

2.4 Characteristics of MSW in Mumbai

The MSW collected in Mumbai consists primarily of wet organics (primarily food waste) (54%), dry organics (straw, wood) (15%), inert materials (sand, soil, earth) (12%), and recyclables (plastics, metal, glass, paper) (19%). [23]

The characteristics of MSW in Mumbai were determined in two different studies, one by CPCB and NEERI in 2005-06, and the other by MCGM around the same time period. It can be seen that the heating values estimated in these two studies are considerably different from each other and also from the heating value calculated in this study. This is primarily due to the high organic fraction of the waste and high moisture content. [3, 9]

Table 1: Characterization of Mumbai Waste by two studies [9, 3]

Source	Compostable Fraction (%)	Recyclable Fraction (%)	Moisture Content (%)	C/N Ratio	Heating Value (kJ/kg)
CPCB-NEERI	62.44	16.66	54	39.04	7,477*
MCGM	54	18.6	68	25.94	3,898

* High heating value

2.5 Waste Disposal in Mumbai

As noted earlier, there are three operating dumps currently serving Mumbai. A fourth dump at Malad was closed in 2001, and a new one is scheduled to open in Kanjur in January 2008.[3] [23] Although the average lifespan of a garbage dump is said to be approximately 30 years, [1] all of the dumps have been in operation for over 30 years, with Deonar, the largest, being 80 years old. [27]

All the dumps are located in densely populated areas. [21, 13] In some instances, slum encroachment at the municipal dumping grounds has reduced the amount of land actually available for MSW disposal. [27] The trucks carrying garbage pass through residential areas to reach the dumps, thus creating noise, odor, traffic, and air pollution problems along the way. Residents living near the landfills often complain of odors, fires started by ragpickers, vermin, and scavenging animals. [33]

Table 2: Summary of MSW dumps in Mumbai [27, 23, 35]

Dump	Year opened	Area (ha)	Amount received daily (tons)	Average height of dump (m)	Quantity of MSW stored (million tons)
Deonar	1927	110	4,000	7.3	7.88
Gorai	1972	14.5	1,200	10.2	1.76
Mulund	1968	21	600	5.1	0.96
Malad (closed in 2001)	1968	19	--	--	--
Kanjur	2008 (scheduled)	141	N/A	N/A	N/A

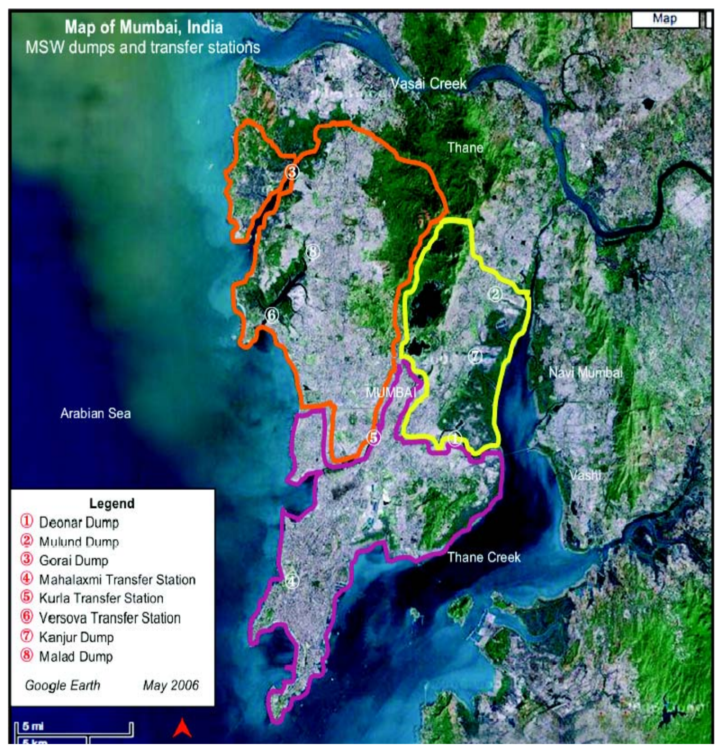

Figure 1: Map showing location of transfer stations and dumps in Mumbai

[3] As of March 2008, the Kanjur dump had yet to open.

3. Current Plan for Solid Waste Management in Mumbai

MCGM has introduced new measures as part of its solid waste management policy, partly in response to the Municipal Solid Wastes (Management and Handling) Rules established by the federal government in 2000. [16]

1. *Source segregation:* MCGM has implemented a new rule to segregate garbage into "wet" and "dry" at the household level. The method of source segregation in Mumbai, which is similar to that practiced in many developed countries, is to encourage households to separate organic waste into black or colored bags and dry, or recyclable, waste into white bags. [31] The wet waste is taken to dumps for disposal, while the dry waste is collected separately and taken to sorting centers, where trained ragpickers will sort through the waste. MCGM expects that 70-80% of Mumbai will be segregating its MSW by the end of 2007 [27]. This is an ambitious target, considering that only a small proportion of the city was practicing source segregation in mid-2007. [24]

2. *Improved transportation:* MCGM is committed to improving transportation of MSW by upgrading vehicles and privatizing transfer stations. The MCGM estimates that the cost of upgrading existing transfer stations and building new ones will be approximately Rs. 210 million ($4.7 million) over 10 years. [22] Most of the MSW collected will pass through modernized transfer stations, where they will undergo compaction. This will decrease the volume of waste to be transported, decrease the number of trips needed, and hence decrease the cost and pollution generated by trucks. Compaction will also lower the moisture content of the waste by 20%, which would make it suitable for incineration (combustion) with energy recovery. [27]

3. *Treatment of MSW:* In 2008, two dumps will be closed, which would leave only two functioning dumps to receive all of Mumbai city's waste. In order to maximize the lifespan of these dumps and adopt more environmentally friendly methods of MSW disposal, MCGM hired Infrastructure Leasing & Financial Services (IL&FS), a government agency providing expertise and financing on infrastructure projects in India, to conduct a study on waste processing technologies suitable for Mumbai. As per the IL&FS recommendations, the MCGM has decided to pursue a combination of composting, biomethanation, and processing of the rest of the MSW to a refuse-derived fuel (RDF) that will be combusted to generate electricity. Table 3 shows the assumed disposition of the 5,800 tpd of MSW currently being generated. [27]

Table 3: Generation and assumed disposition in Mumbai MSW. [27]

Treatment method	Amount of MSW treated (tpd)	Dump Location
Composting	3,000	Kanjur
Composting	1,500	Deonar
Biomethanation	500	Mulund
Refuse derived fuel	300	Deonar

4. Proposed Improvements of Waste Management in Mumbai

4.1 Integrate Waste Streams

MCGM is not formally responsible for collection and disposal of C&D and industrial wastes. Yet, because of lack of monitoring and enforcement by regulatory agencies, this agency is forced to also collect these wastes from the streets of Mumbai. This overburdens the capacity of the municipality to collect and dispose of waste in an effective manner. If the MCGM were assigned the responsibility for managing C&D and industrial wastes, it would receive funding for and be better able to manage them. In addition, the responsibility for all types of waste generated would be under the purview of the MCGM, which would make it easier to enforce regulations.

4.2 Separation of Waste and Recycling

Instead of creating sorting centers at the ward level as MCGM plans to do [22], the existing transfer stations can be retrofitted with sorting areas, where the recyclable fraction is separated from the organic and inorganic fractions. This would provide centralized areas where the waste is separated before it is sent to various treatment facilities, utilize the same transport routes, and employ ragpickers. Any recyclable material collected at the sorting centers could be sold directly by the MCGM to scrap collectors and/or wholesalers. This would provide a significant revenue source for the MCGM, which could be used to pay ragpickers' salaries.

4.3 Treatment of Waste

Once the waste has been sorted according to the type of downstream treatment that it is suited for, it will be compacted and transported from the transfer stations to the waste treatment sites. Appropriate waste treatment technologies should be adopted depending on the types of waste generated. For example, composting could be used for organic waste and incineration (combustion) with energy recovery for non-recyclable waste.

4.4 Implementation of a Waste-to-Energy Facility

Initially, an 800-ton-per-daily-capacity facility should be built to accept waste suitable for incineration. This facility can be built at the site of the new landfill at Kanjur, scheduled to open in 2008. Part of the landfill can also be used for disposing the ash formed during the combustion process. However, the bottom ash that at the most would amount to about 200 tons per day could be used beneficially for road and other construction purposes. This would minimize transportation costs of the ash. Combining MSW with industrial waste and the combustible fraction of C&D wastes would increase the heating value of the waste and result in higher energy recovery.

4.4.1 Suitability of Mumbai MSW for a WTE Facility

1. *Heating value:* Although the MCGM reports that the average heating value is 3,898 kJ/kg, this report calculated that the average lower heating value is 9,022 kJ/kg, based on the values of energy content of MSW components given in Tchobanoglous (1993). Also, as noted above, another possibility for the first waste-to-energy facility in Mumbai is to design the plant so it can utilize a mix of MSW and combustible commercial, industrial and C&D wastes that are generated in the area (e.g., plastic and rubber remnants that cannot be recycled in the primary manufacturing process).
2. *Moisture content:* The moisture content of MSW in Mumbai is approximately 50% during the dry season and 65% during the monsoons. [3, 22] Generally, MSW with a moisture content greater than 50% is not suitable for incineration. [15] However, the compaction of MSW that will take place at transfer stations after they are modernized will decrease the moisture content of the MSW by approximately 20%. [27]. This will result in a moisture content of approximately 30% during the dry season and 45% during the monsoons, which will increase the heating value of the MSW and make it suitable for incineration (combustion). In this regard, the experience gained by modern WTEs in China where the MSW collected is also very wet (for example, the Sanfeng-Covanta WTE facility in the City of Chongqing) will be invaluable. [30]
3. *Volume reduction:* Based on the characteristics of MSW in Mumbai, the volume reduction through combustion would be around over 90%. This was calculated based on the fact that the density of the waste prior to landfilling or combustion in low-income countries is 375kg/m^3 and that the density of waste after it is combusted is 600 kg/m^3. [5]

4.4.2. Costs and Revenues

Capital Costs

Experience in China has shown that by using native manufacturing resources the cost of a WTE facility in China can be as low as $40,000 per daily ton of capacity. Furthermore, new alternative processes, such as the Zhejiang Circulating Fluidized Bed process, being developed in China are apparently even less costly. [37, 30] On the basis of the Chinese experience, this report assumes a capital cost of $50,000 per daily ton of capacity for Mumbai. Therefore, the first WTE facility of 800 tons per day capacity that is proposed for Mumbai would have a capital cost of approximately $40 million.

Operating Costs

The main operating costs considered here are maintenance and labor costs. Maintenance costs are assumed to be $5 million per year, based on maintenance costs of the Covanta Energy WTE Facility in Essex, New Jersey.[4] [25] Furthermore, it is assumed that maintenance costs will increase by 3% per year during the life of the Mumbai WTE facility.

Labor costs were calculated assuming a plant personnel of 60. It is assumed that labor costs for the first year will be $400,000 and increase annually by 3%.

All other expenses are estimated to start at $1 million per year and increase by 3% per year.

Revenues

The waste-to-energy facility in Mumbai would derive revenues from tipping fees and by selling the electricity produced by the facility to the electricity grid. For the purposes of this analysis, it is assumed that MCGM would pay the WTE operator tipping fees starting at $9 per ton and increase it by 3% per year during the 25-year write-off period of the plant. It should be noted that these tipping fees are one-third to one-half of the tipping fees charged by WTEs in China. [30]

A tariff rate of $0.08/kWh was used based on a petition filed by a company that wanted to start an MSW-based power generation plant in Mumbai. [12] Taking the average efficiency of a WTE facility and the internal requirements of the facility for electricity, it is estimated that one ton of municipal solid waste would provide 500 kWh to the grid for a revenue of $40 per ton of MSW combusted. This source of revenue was assumed to increase by 3% per year during the life of the project.

Economic Analysis of a WTE Facility in Mumbai

On the basis of the assumed operating costs and plant revenues detailed above, a cash flow analysis was conducted for a potential WTE facility in Mumbai. The cash flow was based on the assumption that the project would be financed by a Private-Public-Partnership (PPP) as follows:

- 15% interest on capital investment on $8 million (i.e. 20%) of capital investment by private investors;
- 6.5% interest on $32 million (i.e. 80%) of capital investment by municipality;
- Straight-line depreciation of capital investment over a 25-year write-off period, as specified by MCGM for waste treatment technologies [22];
- Any net annual income from the operation of the plant would be returned to the municipality of Mumbai, thus lowering their tipping fees. Consequently, there would be no taxes to be paid by the WTE facility.

Land Requirements and Siting of a WTE Facility in Mumbai

For the purposes of this study, the required area of the Mumbai WTE facility was estimated at 6 ha, on the basis of a survey of approximately 20 WTE facilities of various daily capacities around the world. [7]

A suitable site for the proposed WTE facility would be the area at Kanjur, which has been demarcated for the new dump to be started in early 2008. The Government of Maharashtra has allocated approximately 142 ha to the MCGM for the development of the new dump, of which the MCGM has earmarked 86 ha for a waste processing facility and sanitary landfill. [21, 23]

4.4.3. Direct Benefits of a WTE Facility in Mumbai

Contrary to public opinion and some past environmental opposition in Mumbai, implementation of a WTE facility would have a number of benefits for the residents of Mumbai and the local and global environment. These benefits are summarized below:

1. *Decrease in environmental pollution caused by landfills:* The MSW dumps in Mumbai are a significant source of air, surface, and groundwater pollution in the city and surrounding areas. Air pollution is primarily caused by odor, methane emissions, and landfill fires that are started by ragpickers in order to retrieve metals and glass. Extremely high levels of Total Suspended Solids, SO_2, and NO_x were found at the dumps in studies conducted. [26] In addition, the dumps are located near creeks, and industrial and municipal solid wastes are regularly dumped in these waterways, causing flooding during the monsoons, as well as hazardous pollution to aquatic life and humans. [19] Although few studies have been conducted on how much leachate is produced and what the composition of the leachate is, given that MSW is being dumped in low-lying areas without any lining or protection, it is highly likely that the dumps are a significant source of pollution in the groundwater and land. [13]

Table 4: Emissions of pollutants at MSW dumps in Mumbai as estimated by MCGM in 1997 (µg/m3) [26]

	Total suspended particulates	SO_2	NO_x
At dumps	2011	702	164
Avg for city	250	30	30
National ambient standard	140	60	60

2. *Decrease in land surface required for MSW disposal:* Mumbai is one of the most highly populated cities of the world. In the early- to mid-part of the 20th century, areas that housed the dumps were deemed suitable for landfilling because they were much less populated than the city area in the southern part of the island. However, with increased migration to and population growth in Mumbai, these areas can no longer be considered to be on the outskirts of the city. Introducing a WTE facility in Mumbai would take up considerably less space than landfilling. In the assumed 25-year period, the WTE would combust 800 tpd * 330 days * 25 years = 6,600,000 tons of MSW. Modern landfills require a total surface area of one square meter for every ton of MSW landfilled. Therefore, the 6.6 million tons of MSW would require 660,000 square meters of a landfill, i.e., 66 ha. In comparison, the WTE would require 6 ha of plant surface plus an additional **maximum**

of 7 ha for landfilling the ash, in the worst case that none of the bottom ash is used beneficially.

3. *Decrease in costs and emissions related to transportation of MSW:* If part of the Kanjur dump, which is scheduled to be opened in 2008, is set aside for the creation of a waste-to-energy facility, the trucking costs and emissions of sending waste there would be lower.

4. *Creation of a supplemental and renewable source of electricity:* Mumbai has historically been shielded from electricity shortages that plague the rest of the country and many other large cities. However, electricity consumption has been increasing rapidly, and the City currently faces a peak shortfall of 400 MW. [4] A waste-to-energy facility would provide a supplemental source of renewable energy. In addition, it would help the city meet regulations to get a certain percentage of its electricity from renewable sources. By 2010, a minimum of 6% of Mumbai's electricity should be met through renewable energy sources. An additional consideration is that the WTE facility would result in a decrease of carbon emissions amounting to between 0.5-1 ton of carbon dioxide per ton of MSW combusted rather than landfilled. This will result in reducing global carbon emissions and may, in the near future, bring additional revenues to the WTE facility in the form of carbon credits.

5. Conclusions

Mumbai faces significant solid waste management challenges. These challenges present numerous opportunities to improve methods in waste collection, transport, and disposal. Given that solid waste management directly affects public health, land use, and the environment, stringent waste management regulations need to be formulated, enforced, and monitored. This paper shows that a waste-to-energy facility is not only possible but necessary in order to meet the demands of a growing city, improve environmental conditions, and be an example for cities in India as well as in other developing countries. Despite the assumed very low tipping fee, a WTE facility of 800 tpd of assumed capital cost of $40 million (based on recent WTEs in China) would earn appreciable electricity revenues and be economically feasible. It would provide a much cleaner environment for the City's residents by reducing environmental pollution from open dumping and decreasing the amount of emissions from transporting the waste; and positively impact the global environment by reducing the amount of greenhouse gas emissions that are generated through open dumping.

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