FEASIBILITY ANALYSIS OF WASTE-TO-ENERGY AS A KEY COMPONENT OF INTEGRATED SOLID WASTE MANAGEMENT IN MUMBAI, INDIA

by

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EXECUTIVE SUMMARY

For a number of years, the city of Mumbai, India has been 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 the decades and open burning of garbage have led to serious environmental pollution and health problems. In order to move towards a sustainable future and achieve its goal of becoming a world-class city, Mumbai needs to adopt an integrated solid waste management approach.

The Government of India -- Ministry of Environment and Forests promulgated the Municipal Solid Wastes (Management and Handling) Rules in 2000 requiring that municipalities across India adopt sustainable and environmentally friendly means of processing MSW, including incineration. In this regard, waste-to-energy provides a solution towards both complying with the central government regulations as well as achieving integrated solid waste management. Waste-to-energy is perceived as a means to dispose municipal solid waste, produce energy, recover materials, and free up scarce land that would otherwise have been used for landfilling. Contrary to public perception, waste-to-energy can accomplish these goals in a more efficient and environmentally benign manner than landfilling.

The objective of this report is to examine the solid waste management process in Mumbai, from generation to final disposal, and determine whether waste-to-energy is a suitable method for waste disposal for the city. Various criteria are covered, such as the appropriateness of Mumbai's MSW for incineration, the environmental effects of WTE versus open dumping, the savings in availability and cost of land, and the amount of energy production from a waste-to-energy facility.

The report provides an overview of the solid waste management scenario in India. Similar to other low-income countries, India's current per capita waste generation rate of 0.46 kg/person/day is low (Section 2.2), the collection efficiency is low (Section 2.3), the MSW has a high organic content (Section 2.5), and the majority of the MSW collected is disposed in open dumps, without any lining or covering (Section 2.4). Considering that the urban growth rate in India is expected to surge in the next two decades, coupled with a high economic growth rate, India as a whole is heading towards a serious municipal solid waste disposal problem that has implications for land requirement, public health, and the environment.

Mumbai's per capita waste generation rate of 0.5 kg/person/day is higher than the national average (Section 4.4). Although the collection efficiency is reported to be as high as 90%, almost half of the city's 12 million people live in slums, some of which do not have access to solid waste services (Section 4.5). The most pressing problem for Mumbai is its acute shortage of land. When Mumbai's municipal waste dumps were constructed, they were at the outskirts of the city; today, they are surrounded by housing colonies, thus exposing millions of people to daily inconveniences, such as odor and traffic congestion, and more serious problems associated with air, land, and water pollution and the spread of diseases from rodents and mosquitoes (Section 5.4.1).

In the next ten years, the energy potential from MSW and industrial wastes in India will

increase by approximately 3,350 MW, taking into consideration rising per capita waste generation and higher proportions of non-organic materials in MSW. (Sections 3.9 and 3.8) Maharashtra, of which Mumbai is the capital, has the highest energy potential from urban wastes from all Indian states. This report finds that the heating value of MSW in Mumbai presently is 9,022 kJ/kg, which is sufficient for a waste-to-energy plant to operate without additional fuel. (Section 5.3.6.1) In addition, based on the composition of MSW, processing the waste in a WTE facility would reduce its volume by 96.74%, thus freeing up land that would otherwise have been used for landfills. (Section 5.3.6.3) From an environmental standpoint, a WTE facility would be beneficial because it would prevent the formation of leachate that contaminates groundwater, reduce emissions of toxic pollutants from burning of garbage, and prevent the production of two potent greenhouse gases, carbon dioxide and methane, both by displacing the equivalent amount of fossil fuel (coal, oil, or natural gas) that would have been used to produce the same amount of energy and by preventing the formation of methane in landfills. (Section 5.4.7)

There are over 600 waste-to-energy facilities and more are being constructed in many parts of the world today. As countries implement more stringent environmental regulations for landfills, waste-to-energy technology is quickly becoming the choice for the cost effective, energy efficient, and environmentally friendly disposal of MSW. Although at one time emissions of pollutants from WTE technology were high, pollution control technology has developed so rapidly that emissions are now well below the standards set by environmental agencies in many countries. (Section 3.5) Instead of opposition to WTE facilities, it would serve the interests of the public to compel municipalities to promote WTE in their backyards.

A number of countries have been successful in implementing WTE technology and will continue to reap the benefits for many years to come for the betterment of their citizens. Most of these countries have more stringent environmental standards and monitoring mechanisms than India. These facts should both encourage and reassure environmental groups and other stakeholders of the various benefits of implementing WTE technology in India.

Figure 1: Ragpickers, grazing cattle, and smoke from burning waste at an Indian waste dump {3}

Figure 2: A waste-to-energy facility in Brescia, Italy {15}

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I thank Mr. Dilip Shrotriya, Executive Engineer in the Office of Solid Waste Management Department, Municipal Corporation of Greater Mumbai, for his help in providing data and greatly appreciate his efforts in promoting waste-to-energy in Mumbai.

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NOMENCLATURE

BEST	Brihanmumbai Electric Supply and Transport
BOD	Biological oxygen demand
BOO	Build, own, operate
BOOT	Build, own, operate, transfer
BMC	Bombay Municipal Corporation
BSE	Bombay Stock Exchange
C&D	Construction and demolition waste
CDD	Chlorinated dibenzo-*p*-dioxins
CDF	Chlorinated dibenzofurans
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CFB	Circulating fluidized bed
C/N	Carbon/nitrogen
COD	Chemical oxygen demand
CPCB	Central Pollution Control Board
DO	Dissolved oxygen
ED	Electricity Department
ELCR	Excess lifetime cancer risk
EPA	Environmental Protection Agency
GDP	Gross domestic product
GHG	Greenhouse gas
ha	Hectare
HI	Hazard index
IL&FS	Infrastructure Leasing and Financing Services
IPCC	Intergovernmental Panel on Climate Change
JNNURM	Jawaharlal Nehru National Urban Renewable Mission
LHV	Lower heating value
MCGM	Municipal Corporation of Greater Mumbai
MEDA	Maharashtra Energy Development Agency
MERC	Maharashtra Electricity Regulatory Commission
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forests
MoP	Ministry of Power
MPCB	Maharashtra Pollution Control Board
MSEB	Maharashtra State Electricity Board
MSW	Municipal solid waste
MUD	Ministry of Urban Development
NEERI	National Environmental Engineering Research Institute
NIMBY	Not In My BackYard

NO_3/N	Nitrates
NSEI	National Stock Exchange of India
PCB	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDD/F	Polychlorinated dibenzo-p-dioxins/furans
PCDF	Polychlorinated dibenzofurans
PCG	Plasma converted gas
PO_4/P	Phosphates
PM	Particulate matter
RDF	Refuse derived fuel
REL	Reliance Energy Limited
SEB	State Electricity Board
SWM	Solid waste management
SWMD	Solid Waste Management Department
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TDS	Total dissolved solids
TEQ	Toxic Equivalents
TPC	Tata Power Company
tpd	Tons per day
TSP	Total suspended particles
VER	Voluntary Emissions Reduction
WTE	Waste-to-energy

1. INTRODUCTION

India is a vast country brimming with cultural diversity and rich in natural resources. India, along with China, has become the center of the world's attention over the last decade because of its booming economic growth, large demographic of young, English-speaking workers, and shift from an agricultural to a more service-oriented economy. What this means for millions of Indians is that they now have the ability to consume an enormous variety of goods and services that were previously either unavailable or unaffordable. From small electronic items, such as cell phones, to large consumer goods like refrigerators and cars, Indian consumption has been steadily increasing and shows no signs of abating anytime soon. The flip side of this consumption boom is that the amount of waste generated has and will continue to increase correspondingly.

Mumbai, the financial capital of India, and also its largest city, is currently facing a solid waste management crisis. Municipal solid wastes (MSW) are generated at unsustainable levels leading to a massive shortage of space for disposal. The garbage dumps that are presently in use are overfull and not properly constructed, resulting in coastal, air, and land pollution and in public health problems. Given its increasing population, rapid expansion of urban areas, and scarcity of land as it is an island, Mumbai needs a solution to its burgeoning solid waste management problem that will be sustainable, cost effective, and minimizes public health, ecological, and climate change impacts. Waste-to-energy (WTE) is a strategy that is effective, environmentally sound, and economically beneficial.

This report focuses on the use of waste-to-energy technology to mitigate the solid waste management problem in Mumbai. In several other nations waste-to-energy has been shown to be an effective, environmentally sound, and economically beneficial means for processing municipal solid wastes and recovering energy. Mumbai was selected because it is the largest city in India, with growing population and consumption trends, and has limited availability of space for waste disposal. Furthermore, Mumbai's current waste disposal options are inadequate, overburdened, and exacerbated with residential areas abutting open dumps, no provision of waste collection in slum areas, no formal programs for ragpickers or recycling, and insufficient collection and transportation mechanisms. Successful implementation of waste-to-energy as part of an overall integrated solid waste management approach may serve as an example to other urban areas in India and also to cities in other developing countries.

The first section of this report presents an overview of solid waste management in India and compares it, where appropriate, to waste management statistics and practices in other countries. The second section discusses the need for an integrated solid waste management strategy in India and why waste-to-energy is an important component in order to achieve this goal. The following section describes the current solid waste management scenario in Mumbai, and discusses garbage generation, collection, transport, and disposal methods and rates. The next section focuses on introducing WTE as an integral part of Mumbai's solid waste management policies.

2. OVERVIEW OF SOLID WASTE MANAGEMENT AND ELECTRICITY SECTORS IN INDIA

2.1 Background

India is one of the fastest growing economies in the world today. Increasing prosperity and standard of living of millions of people will increase consumption of energy and consumer goods. Concurrently, this growth will likely put a strain on the environment and on the availability of natural resources. Already, India has 16.8% of the world's population (est. 2006) and only 2.2% of the world's total land area. [13]

Figure 3: Map of India {5}

In India, as in other developing countries, solid waste management and sanitation are the least prioritized public services. These services are necessary for preventing the spread of diseases, promoting general well being, and improving the standard of living. However, due to lack of knowledge about the linkages of waste management to public health and environmental protection, unwillingness on the part of the local officials to take necessary action, and a lack of funds for implementing and maintaining best practices, waste management has not received the attention it requires.

This chapter provides an overview of waste generation, collection, disposal, and composition for India as a whole. Where appropriate, comparisons are made to other countries to show whether India has similar solid waste management practices or if it deviates from the norm. Since waste-to-energy is both an effective waste reduction strategy as well as a source of electricity and/or heat, the chapter also provides an overview of the electricity and renewable energy sectors in India.

2.2 MSW Generation in India

The amount of waste generated in a region or country is directly proportional to economic growth and consumption levels. On a per capita basis, low-income countries generally consume fewer goods and hence generate less waste than developed countries. Low-income countries also generally use less recyclable materials, especially in packaging.

2.2.1 Current MSW Generation in India

In the mid-nineties, the average waste generated per capita in urban areas in India was estimated to be approximately 0.46 kg/person/day. [119, 150] In its 2005-06 Annual Report, the Ministry of New and Renewable Energy (MNRE), formerly known as the Ministry of Nonconventional Energy Sources, estimated that approximately 42 million tons[1] of MSW are generated in urban areas of India annually. [70] Table 1 shows a direct relationship between the size of an urban area and per capita waste generation. Larger cities tend to produce higher amounts of waste per capita than smaller ones because per capita incomes and consumption are higher in urban areas. [75,150]

Table 1: Waste generation per capita in Indian cities [75]

Population range (millions)	Waste generated (kg/capita/day)
0.1 – 0.5	0.21
0.5 – 1.0	0.25
1.0 – 2.0	0.27
2.0 – 5.0	0.35
>5.0	0.50

Urban waste generation in India tends to be lower than in other developing countries and approximately one-third to half that of developed countries. [2] In low-income countries, waste generation rates range from 0.4-0.9 kg/person/day, while high-income countries tend to produce approximately 1.1-5.0 kg/person/day. At present, India's waste generation falls on the lower end of the range, as shown in Table 2. [150] This may be attributed to the fact that almost three quarters of the population still lives in rural areas. [96]

Table 2: Waste generation in selected countries (kg/person/day) [150]

Low-income countries*		High-income countries	
India	0.46	Germany	0.99
Nepal	0.50	Denmark	1.26
Vietnam	0.55	Holland	1.37
China	0.79	Australia	1.89
Sri Lanka	0.89	USA	2.00

* Waste generation rates in urban areas

2.2.2 Future MSW Generation in India

Waste generation in India is expected to increase rapidly in the future. As more people migrate to urban areas and as incomes increase, consumption levels are likely to rise, as are rates of waste generation. This has significant impacts on the amount of land that is and will be needed for disposal, economic costs of collecting and transporting the waste, and the environmental consequences of increased MSW generation levels.

It is estimated that the amount of waste generated in India will increase at a per capita rate of approximately 1-1.33% annually. [119] A World Bank publication reports that the waste generation rate in urban areas of India will be approximately 0.7 kg/person/day in 2025, which is roughly four to six times higher than it was in 1999. [150]

[1] Throughout this report, "tons" refer to metric tons. (1 metric ton = 1,000 kilograms)

Box 1: Calculation of Waste Generation Rates in India and Resulting Carbon Dioxide Emissions in 2030

Assumptions:

1. Waste generation rate in 1995 is 0.46 kg/person/day [119]
2. Urban population in 1995 is 249.1 million [150]
3. Waste generation increases at a rate of 1% per annum [119]
4. 41.4% of the population will live in urban areas by 2030 [34]
5. 75% of waste generated is either landfilled or dumped in open grounds
6. Every ton of waste landfilled releases 1.3 tons of carbon dioxide [129]

Results:

1. In 2030, over 572 million people will live in urban areas of India
2. Over 373,000 tons of waste will be generated per day (over 136 million tons/year)
3. This would result in carbon dioxide emissions of over 363,000 tons per day from landfills and open dumps

For detailed calculations, see Appendix 1.

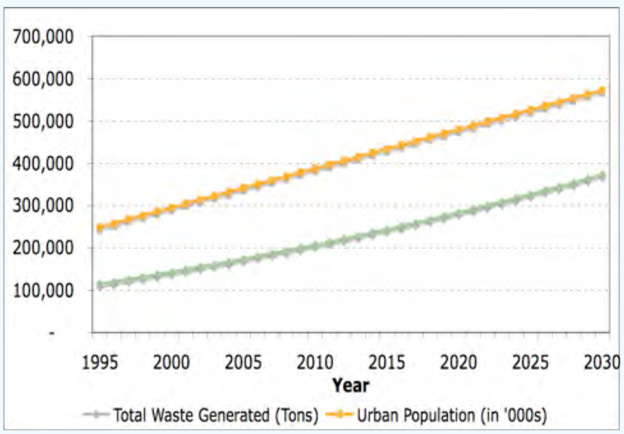

Figure 4: Urban population and waste generation in India

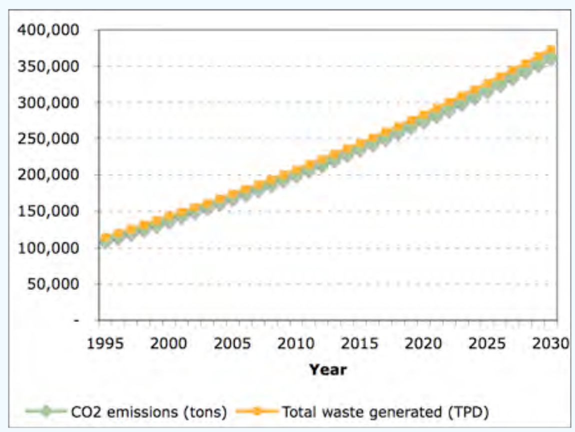

Figure 5: Waste generation and carbon dioxide emissions in India

2.3 MSW Collection in India

The Solid Waste Manual published in 2000 by the Ministry of Urban Development (MUD) states that, "In India, the system of primary collection of waste is practically non-existent…[t]hus streets are generally treated as receptacles of waste…" [75] Most cities lack primary collection systems: MSW is often left on streets or in community bins that are overflowing. House-to-house collection of MSW is carried out in only some locations in large cities in India. A large portion of the waste is collected by street sweeping, which is not done on a daily basis in some areas.

Compared to developed countries, where the majority of the waste is collected, most low-income countries have collection efficiencies ranging from 30-60%. [17] The collection efficiency in India ranges from 50-90%. A survey of Indian cities in 1989 showed that the average collection efficiency was 72.5%. However, given the results of the survey, described below, the national average must have been considerably lower than 72.5%. [39]

A study conducted by the National Institute of Urban Affairs of India in 1989 found that collection efficiencies in Indian cities were low due to two main factors: availability of labor and transportation facilities. [39] Using a benchmark of 2,800 workers/million population for an optimum manpower requirement, the survey found that less than 10% of the cities surveyed met this requirement, and that over 77% of the cities had a shortfall of at least 46%. With regard to transportation, another survey used a benchmark of 320 m^3/million population for transport volume. This survey concluded that 95% of the cities had a shortfall ranging from roughly 22-53%, and that 5% of the cities had a shortfall of over 68%. [39] A more recent study in 2006 found that 70% of urban areas in India lack proper transportation facilities to transfer MSW to disposal sites. [55]

Figure 6: Garbage being sweeped around a community waste bin in Mumbai {11}

2.4 MSW Disposal in India

In most cities and towns in India, MSW is disposed in open dumps in an unregulated and unscientific manner in low-lying areas on the outskirts of the cities.[2] Most dumps lack systems for leachate collection, landfill gas collection or monitoring, nor do they use inert materials to cover the waste. [2, 39] This results in groundwater contamination from leachate, surface water contamination from runoff and lack of covering, air pollution caused by fires, toxic gases, and odor, and public health problems due to mosquitoes and scavenging animals. [75]

Apparently, India is not alone in lack of proper waste management systems. Open dumping is commonly practiced in developing countries. It is estimated that in low-income countries, less than 25% of wastes are sent to regulated landfills. [17] Table 3 shows a comparison of disposal methods in some developing countries. These countries are the same as those shown in Table 2 on waste generation. [137]

[2] Throughout this report, the term “dump(s)” is used to describe the unregulated, unscientific method of MSW disposal used primarily in India, as opposed to “landfill(ing),” the term used for regulated disposal of MSW.

Table 3: Methods of disposal of municipal solid waste in selected countries (%) [150]

Country	Open dumping	Landfilling	Composting	Incineration	Other*
India	60	15	10	5	10
Nepal	70	10	5	-	15
Vietnam	70	-	10	-	20
China	No data available				
Sri Lanka	85	-	5	-	10

* Animal feeding, dumping in water, open burning, etc.

2.5 Composition of MSW in India

Municipal solid waste in India has a high percentage of organic matter and a low recyclable content. It also contains high amounts of ash due to the use of traditional biomass sources for fuel and heat and other inert materials.

2.5.1 General Characteristics of MSW in India

MSW in India is similar to that of other low-income countries and consists mostly of organic matter and inert materials, as Figures 7 and 8 show. Low-income countries generally have a high proportion of organic matter ranging between 40-85%. Ash and other inert materials usually range from 45-54% and make up the second largest proportion of waste due to the use of wood, charcoal, and other biomass as household fuel sources. [150]

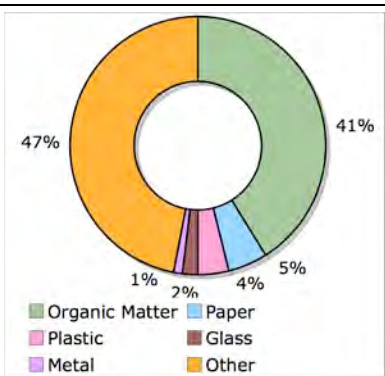

Figure 7: Characteristics of current MSW in low-income countries

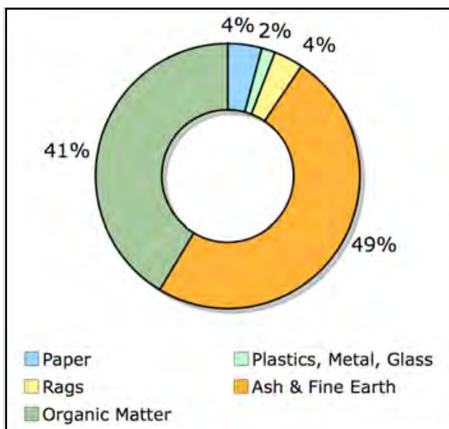

Figure 8a: Characteristics of MSW in India in 1973

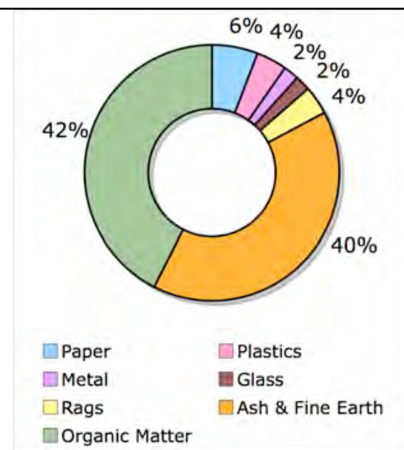

Figure 8b: Characteristics of MSW in India in 1995

As Figures 8a and 8b show, between 1973 and 1995, the biggest changes in municipal solid waste composition in India resulted from an increase in recyclable materials, such as plastics, glass, and paper, while the proportion of ash and fine earth decreased. [39, 150] The high fraction of inert materials is a result of including street sweepings, silt, and construction and demolition (C&D) waste in municipal waste dumps. [75]

2.5.2 Chemical Characteristics of MSW in India

The characteristics and composition of municipal solid waste are directly related to income levels, as is the rate of MSW generation. Developed countries tend to have much larger fractions of recyclable materials compared to low-income countries. [150] This is primarily because of different consumption patterns and much higher use of packaging materials. As a result, the moisture content is lower and the heating value of the MSW higher than in low-income countries. Table 4 shows a comparison of the moisture content, density (in trucks transporting MSW to the landfill), and the lower heating value (LHV) of the waste generated in developing and developed countries. [17] A survey of 59 cities across India conduced by the Central Pollution Control Board (CPCB) and the National Environmental Engineering Research Institute (NEERI) in 2005-06 found that the moisture content in MSW was between 30-60%, which is within the range shown in Table 4. [14] The density of municipal solid waste in urban areas is estimated to be between 500-600 kg/m^3, which is higher than the range given in Table 4. [55]

Table 4: Chemical comparison of waste in developing and developed countries [17]

	Low-income country	High-income country
Moisture Content (%)	40-80	20-35
Density (kg/m^3)	250-500	120-200
Lower heating value (kcal/kg)	800-1,100	1,500-2,700

A survey of various cities by NEERI in the mid-nineties examined the chemical composition of MSW in India. Table 5 summarizes the chemical characteristics of MSW in Indian cities. [75] In large cities with higher levels of consumption of plastics and other non-organic matter compared to small towns and cities, it would be expected that the heating value of MSW would be high. However, Table 5 shows that the larger the city, the lower is the heating value. [75] This may be attributed to two primary reasons:

- In large cities, recyclable materials are collected by ragpickers before the waste reaches the dumping ground, thus lowering the heating value of the waste; and
- In small towns, households use the organic fraction to make compost, thus increasing the heating value of the waste.

Table 5: Composition of municipal solid waste in Indian cities [75]

Population range (millions)	Moisture content (%)	Calorific heating (kcal/kg)	C/N ratio	Organic matter (%)	Inert (%)
0.1 – 0.5	26	1,010	31	37	44
0.5 – 1.0	20	900	21	25	48
1.0 – 2.0	27	980	24	27	45
2.0 – 5.0	21	907	22	26	49
>5.0	39	800	20	39	54

2.5.3 Future Trends in MSW Composition in India

As India's economy and urban population continue to expand, it is likely that the organic fraction of MSW will increase slightly. While inert materials will decrease considerably, the recyclable fraction, consisting of plastic, paper, and glass, will increase. While it is difficult to predict how each of the components will change, a World Bank report projects the characteristics of waste of current low-income countries in Asia in 2025, shown in Figure 9. [150]

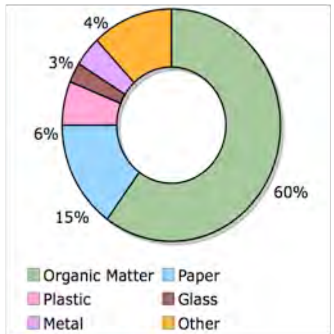

Figure 9: Characteristics of future MSW in current low-income countries in 2025

2.5.4 Recyclable Fraction of MSW in India

The survey conducted by NEERI in the mid-nineties also estimated the recyclable fraction of MSW found in urban waste. As expected, Table 6 shows that larger cities have higher fractions of paper, glass, and metal. [55] Consumption of these materials in packaging and general uses tends to be higher in urban areas than in smaller towns.

Table 6: Recyclable material in MSW in Indian cities (%) [55]

Population Range (millions)	Paper	Rubber, leather, synthetics	Glass	Metal
0.1 – 0.5	2.91	0.78	0.56	0.33
0.5 – 1.0	2.95	0.73	0.35	0.32
1.0 – 2.0	4.71	0.71	0.46	0.49
2.0 – 5.0	3.18	0.48	0.48	0.59
>5.0	6.43	0.28	0.94	0.80

2.6 The Electricity Sector in India

As mentioned earlier, one of the benefits of waste-to-energy technology is energy recovery. The process of combustion is the same as that of a fossil fuel-based plant; however, instead of coal, oil, or natural gas, municipal solid waste is combusted at high temperatures to produce steam, which powers turbines that generate power. In the United States and European Union approximately 600 kilowatt-hours (kWh) of electricity are generated per ton of MSW combusted. [128]

When looking at India as a whole, WTE would make up only a small fraction of the total energy capacity (See Section 2.6.3). It is nonetheless an effective method because it reduces the volume of MSW that would be sent to a landfill and prevents landfill-related pollution. More importantly, it is a renewable technology. (See Section 3.3 for a discussion of the renewable aspect of WTE) This section provides a brief overview of the electricity sector in India.

2.6.1 Background

One of the key infrastructure and development problems India faces is a massive shortage of electricity. This is mainly because electricity demand has outpaced the development of new power plants, transmission and distribution losses are excessive due to the use of antiquated equipment, electricity is provided free of cost to the agricultural sector, and electricity theft is common, all of which result in reduction of revenues to the electricity generators. Even large cities including India's Silicon Valley, Bangalore, face regular power cuts. As a result, businesses and residences regularly rely on diesel generators for electricity. In February 2007, peak electricity demand was 100,411 MW while the peak supply was 85,088 MW. Thus, there was a power deficit of 15,323 MW or 15.3%. [12] India's peak shortfall continues to increase over time as the population and the economy expand without a similar growth in the power sector.

State Electricity Boards (SEBs), which are state-owned entities, were responsible for power generation, transmission, and distribution until the early nineties. [78] All SEBs post negative rates of return because the average tariffs, or rates charged to consumers, are lower than the cost of electricity. [146] As a result, the SEBs are bankrupt and hence unable to invest in expanding or improving the electricity supply. Table 7 shows the average cost of generating power incurred by the SEBs and the average tariffs charged by the SEBs and Electricity Departments in 2001-02. All the SEBs and EDs incurred losses, ranging from Rs. 0.04 to Rs. 5.00 per kWh ($0.0009-0.1/kWh).[3] [106] Table 8 shows the average tariff charged to industries and households in India and some developed countries. [105] India charges the highest tariffs to industries while having the cheapest tariffs to residences as compared to these countries. Even so, the SEBs are unable to make up the shortfall for the reasons provided above.

2.6.2 Electricity Sources

The majority of India's power generation is from fossil fuels while approximately 5% comes from renewable sources other than hydroelectric power. Table 9 and Figure 10 show the current installed capacity in India, according to the Government of India Ministry of Power (MoP). [12]

2.6.3 Renewable Energy Sources

India's potential from certain renewable sources, such as solar and wind, are very high. Table 10 summarizes the potential and installed capacity of various renewable energy sources in

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

India. [55] Note that the installed capacities of renewable energy sources shown in Tables 9 and 10 are different. This can be attributed to two primary reasons:

- The data in Table 9 are more recent; and
- The data in Table 9 from the MoP may have been calculated using a different methodology than the MNRE data in Table 10.

Table 7: State-wise average cost and tarriff of electricity in 2001-02 (Rs./kWh)

State Electricity Boards and Electricity Departments	Cost	Tariff	Loss
State Electricity Boards			
Andhra Pradesh	3.61	2.22	-1.39
Assam	5.89	3.67	-2.22
Bihar	3.77	2.52	-1.25
Delhi	4.70	3.00	-1.70
Gujarat	3.65	2.43	-1.22
Haryana	4.12	2.25	-1.87
Himachal Pradesh	2.35	2.32	-0.04
Jammu & Kashmir	4.12	1.38	-2.74
Karnataka	3.75	2.46	-1.29
Kerala	3.47	2.25	-1.22
Madhya Pradesh	3.25	2.05	-1.20
Maharashtra	3.58	2.70	-0.87
Meghalaya	2.65	1.83	-0.82
Orissa	1.85	-	-
Punjab	2.85	1.84	-1.01
Rajasthan	3.68	2.21	-1.47
Tamil Nadu	3.10	2.37	-0.72
Uttar Pradesh	3.84	2.59	-1.25
West Bengal SEB	3.77	2.57	-1.20
AVERAGE	3.58	2.37	-1.30
Electricity Departments			
Arunachal Pradesh	8.00	3.00	-5.00
Goa	3.42	2.92	-0.50
Manipur	5.81	2.20	-3.61
Mizoram	5.30	1.58	-3.72
Nagaland	4.11	1.90	-2.21
Pondicherry	2.03	1.77	-0.26
Sikkim	2.81	1.15	-1.66
Tripura	3.07	1.18	-1.89
AVERAGE	4.32	1.96	-2.36
ALL-INDIA AVERAGE	3.95	2.17	-1.83

Table 8: Cost of electricity in selected countries in 2000 ($/kWh)

Country	Industry	Residential
India	0.07	0.03
Denmark	0.05	0.19
Germany	0.05	0.12
United States	0.04	0.08

Table 9: Installed capacity in India as of February 2007 [12]	
Source	MW
Total thermal	84,405
Coal	69,621
Natural Gas	13,582
Diesel	1,202
Hydroelectric	34,086
Nuclear	3,900
Renewable	6,191
Total installed capacity	**128,582**

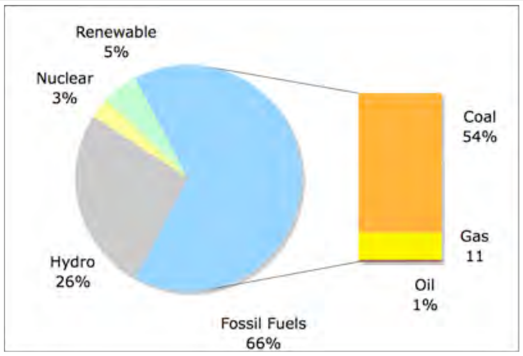

Figure 10: Graphical representation of installed capacity in India as of 2006

Table 10: India Renewable Energy Potential and Installed Capacity as of 2005 (MW) [55]		
Source	Potential	Installed Capacity
Energy from Waste		
Municipal Solid Waste	1,700	17
Industrial Waste	1,000	29.5
Wind	45,000	3,595
Small Hydro (<25 MW)	15,000	1,705.63
Biomass Power & Cogeneration	19,500	749.53
Solar Photovoltaic	--	1,566 (kWp)

3. THE CASE FOR WASTE-TO-ENERGY IN INDIA

This section discusses the various aspects of introducing waste-to-energy in India. WTE is not only an effectual method of reducing the volume of waste that is sent to landfills but also provides a supplemental source of energy that is renewable.

The need for an integrated solid waste management strategy in a city, state, or country becomes more evident as that region's economy grows and the standard of living improves. With increases in consumption, the amount of waste generated also increases. This creates stresses on the land used for disposal, can lead to environmental pollution, and can be detrimental to public health if the waste is not disposed properly. This section makes the case for waste-to-energy in India by describing the benefits of this technology as applicable to India and discusses the energy potential and funding opportunities available for WTE programs.

3.1 Background

Historically, solid waste management has been one of the most neglected public service sectors in India. A World Bank study declared that parts of India, as well as China, Indonesia, and the Philippines, are facing the "greatest waste management challenge." [150] However, initiatives at both the national level, such as the Municipal Waste Management and Handling Rules (2000) introduced by the Government of India Ministry of Environment and Forests (MoEF) and the Supreme Court directive to set up a schedule for compliance with the Rules, and at the local level, such as 100% waste segregation at source in Suryapet to Mumbai's ban on plastic bags, have resulted in a growing awareness and emphasis on solid waste management.

India faces severe deficiencies in all areas of solid waste management. For instance:

- With respect to collection, households and institutions need to segregate their wastes into wet and dry garbage and house-to-house collection needs to be implemented.
- With respect to transportation, covered vehicles need to be introduced in order to prevent odor problems and scattering of garbage along routes. [66]
- With respect to disposal, safe and effective methods need to be adopted in order to prevent pollution and health-related problems.

From an integrated solid waste management standpoint, waste-to-energy can be an effective solution to India's waste crisis for the following reasons, which are described in further detail from Section 3.3 onwards:

- Waste-to-energy is a renewable technology. It prevents the emission of greenhouse gases (GHG) from landfills, displaces fossil fuels used for power generation by creating energy from the combustion of MSW, and is an environmentally superior form of waste disposal as compared to landfills.
- Economic growth increases the amount of goods that are consumed, thus increasing the amount of waste generated. A strategy of whether this waste will be recycled or incinerated or landfilled needs to be developed, keeping in mind economic, social, and environmental costs and benefits.
- When urban areas begin to develop the space available for dumping or landfilling waste becomes scarce as the need for housing, schools, parks, and overall urban development

becomes a priority. WTE provides an effective way to reduce the volume of waste by approximately 90% and thereby lower the space needed for landfills.

- The consumption of plastics is expected to increase sharply in the future. To the extent possible, plastics should be recycled; however, not all forms of plastic are suitable for recycling. In this case, waste-to-energy is preferable to landfilling since plastics have a high heating value.

3.2 What is Integrated Solid Waste Management?

India, as well as all other developing countries, would benefit from adopting the "integrated solid waste management" approach established by the US Environmental Protection Agency (EPA) in the early nineties. [126] This approach deals effectively and efficiently with all aspects of solid waste management, starting from the generation of waste by an individual to final disposal by local government. It is based on the fact that there is not a single solution to the waste management problem, but by adopting five main approaches -- source reduction, recycling, composting, incineration, and landfills – one can effectively manage the waste generated. [126]

- *Source reduction* begins with reducing the amount of waste generated, reusing materials to prevent them from entering the waste stream, and recycling them to prevent materials from being disposed in landfills.
- *Recycling* is the method of taking used plastic, glass, metals, and paper and reprocessing them into new products. It reduces the amount of materials that need to be sent to landfills and conserves energy by lowering the amount of virgin materials that need to be used. [110]
- *Composting* is the process of converting organic material into compost through aerobic or anaerobic decomposition. Compost is used as a fertilizer or soil. [18]
- Incineration is the process of combusting waste at high temperatures and in the presence of air. The heat is then used to produce steam for electricity or district heating (cooling) or both. Incineration lowers the volume of trash to be disposed in landfills and is considered to be a renewable energy sources in many countries, including India. (See Section 3.3 for more information on WTE as a renewable technology).
- *Landfills* are used for the disposal of wastes that cannot be recycled, composted, or incinerated. Landfills have been known to cause pollution in air and water and are a major source of greenhouse gases. Hence, landfilling should be used as a last resource and only when the first four components of integrated solid waste management have been exhausted.

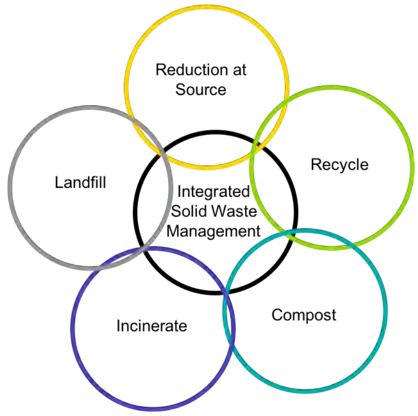

Figure 11: Graphical representation of the integrated solid waste management approach

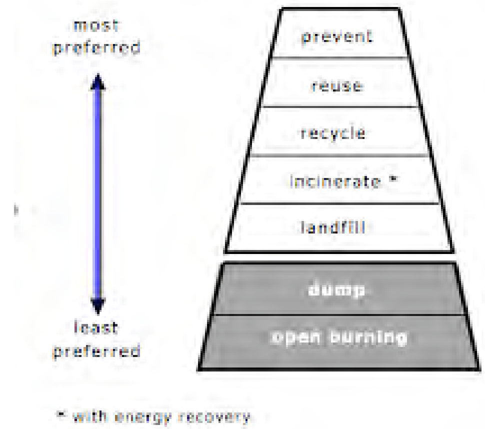

Figure 12: Waste disposal hierarchy {17}

Often a waste hierarchy is used to explain the preferred methods of waste generation and disposal. [143] Figure 12 shows that the preferred step is the prevention of waste generation. Although the goal of "zero waste" has been promoted by groups around the world, it is unlikely that as economies develop and consumption levels rise this will be achievable. Instead, reusing materials, by repairing, donating, or selling them, or recycling them into other products, are more easily achievable. If materials cannot be reused or recycled, they should be sent to waste-to-energy facilities that can recover both energy and resources through incineration. Only if products cannot be incinerated should they be landfilled. Note that incineration with energy recovery is much preferred to incineration solely to reduce the volume of waste without energy recovery. Dumping and open burning are the least preferred methods for solid waste disposal. Unfortunately, in India, both dumping and open burning are the most prevalent methods of MSW disposal today. As solid waste management policies develop and people become more aware of the consequences of open dumping and burning, it is hoped that India will switch from these methods to modern waste-to-energy and that regulated landfills will eventually be used only for disposal of non-compostable or non-combustible materials, such as WTE ash.

3.3 WTE as a Renewable Technology in India

Waste-to-energy is considered to be a renewable technology although this definition still meets with resistance from some environmental groups. The World Bank defines renewable as "[a]ble to be replaced or replenished, either by the earth's natural processes or by human action." [147] The two primary components of municipal solid waste are:

- Renewable materials, such as paper, glass and food; and
- Non-renewable materials, such as plastics and rubber, which are made from fossil fuels.

It is the renewable portion of MSW that provides a clean and sustainable source for the production of steam and electricity. In the US, approximately 64% of MSW constitutes renewable materials. [134] In India, given the high fraction of food wastes and other recyclable material, approximately 50% of MSW can be considered to be renewable.

The Government of India regards waste-to-energy as a renewable technology. The Ministry of New and Renewable Energy has developed the *National Master Plan for*

Development of Waste-to-Energy in India. [71] The MNRE lists a number of technologies for energy recovery from urban and industrial wastes that "not only reduce the quantity but also improve the quality of waste to meet the required pollution control standards, besides generating a substantial quantity of energy." [71] The four main technologies are:

- *Waste-to-energy (incineration):* See Section 3.2 for a description of incineration.
- *Landfill gas recovery:* Methane is produced in landfills by anaerobic biodegradation of organic materials. Landfill gas recovery is the method by which most of the methane is captured and used to generate electricity or heat.
- *Anaerobic digestion/biomethanation:* Anaerobic digestion is the process by which organic matter is converted primarily to methane (60-75%) and carbon dioxide (25-40%) in the presence of methanogenic bacteria and no oxygen. The biogas produced can range from 50-150 m^3/ton, depending on the type of waste.
- *Densification/pelletization:* This process, also referred to as refuse derived fuel (RDF), combines waste of high- and low-heating values waste into pellets or briquettes. They can be conveniently stored and transferred for use as fuel at a later stage. [71]

A number of developed countries also recognize WTE as a renewable technology. Box 2 provides excerpts of regulations describing WTE as a renewable technology in a few of these countries.

Box 2: Waste-to-Energy is a renewable technology in other countries

This section describes and quotes regulations from different countries that consider waste-to-energy a renewable technology.

Australia

"The following energy sources are eligible renewable energy sources: (a) hydro; (b) wave; (c) tide; (d) ocean; (e) wind; (f) solar; (g) geothermal-aquifer; (h) hot dry rock; (i) energy crops; (j) wood waste; (k) agricultural waste; (l) waste from processing of agricultural products; (m) food waste; (n) food processing waste; (o) bagasse; (p) black liquor; ***(q) biomass-based components of municipal solid waste;*** (r) landfill gas; (s) sewage gas and biomass-based components of sewage; (t) any other energy source prescribed by the regulations." (emphasis added)

- Government of Australia, Renewable (Electricity) Act, 2000, Section 17, Act No. 174 of 2000 as amended, Sept. 2006. [3]

Denmark

"Renewable energy, which includes wind power, biomass, solar power, etc. is greenhouse-neutral, i.e. it does not increase the concentration of greenhouse gases in the atmosphere. Biomass ***(including waste)*** is **the *single most important source*** of renewable energy in Denmark…" (emphasis added)

- Danish Energy Authority [20]

(contd.)

Box 2: Waste-to-Energy is a renewable technology in other countries (contd.)

Japan
The 'Law Concerning Special Measures for Promotion of the Use of New Energy' or the 'New Energy' Policy as it is commonly referred to, was created to secure a stable energy supply, address global environmental problems, and "further promot[e] good clean environmentally friendly New Energy." The New Energy Policy includes, but is not limited to, promoting the development of the following target areas: ***Waste power generation, Thermal utilization of waste,*** Waste fuel manufacturing, Biomass power generation, Thermal utilization of biomass. (emphasis added)

- Government of Japan, Agency for Natural Resources and Energy, New Energy Policy [36]

The Netherlands
"***Municipal waste is the most important renewable energy source*** for the Netherlands… Dutch policy aims at
significantly increasing the use of waste for energy purposes to 1075 ktoe by 2020." (emphasis added)

- European Renewable Energy Council, Renewable Energy Policy Review – The Netherlands, May 2004 [30]

United States
"Renewable energy resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydropower, geothermal, solar, wind, ocean thermal, wave action, and tidal action. … biomass energy is produced from non-fossilized materials derived from plants. Wood and wood waste are the largest sources of biomass energy followed by energy from ***municipal solid waste (MSW)*** and alcohol fuels. … Waste energy is the second-largest source of biomass energy. The main contributors of waste energy are ***municipal solid waste (MSW)***, manufacturing waste, and landfill gas. (emphasis added)

- Energy Information Administration, Renewables and Alternate Fuels – Biomass [28]

3.4 Greenhouse Gas Emissions from MSW in India

Waste-to-energy decreases the amount of greenhouse gas emissions in two principal ways. First, by diverting MSW to a WTE facility instead of a landfill, it prevents emissions of methane from landfills. Second, by deriving energy in the form of electricity and/or district heating (cooling) from MSW, it displaces the amount of fossil fuels it would have taken to create an equivalent amount of energy.

Landfills are one of the biggest sources of anthropogenic greenhouse gas emissions in the world. It is estimated that approximately 18% of the world's methane production is a result of waste disposal and treatment. [93] Decomposing matter produces approximately 50% methane and 50% carbon dioxide, both of which are greenhouse gases, with methane being 21 times more potent than carbon dioxide as a greenhouse gas. [47]

India is the third largest methane emitter in the world, after China and the US. Currently, it is estimated that only a fraction of its methane production comes from landfills. [62] However, precise data on landfill emissions in India are limited for a number of reasons: lack of funding and technical resources to collect data, lack of awareness, and low prioritization of waste management services. Hence, estimates on landfill emission data have a considerable margin of error associated with them and should be used with some degree of caution.

A study conducted by the US EPA in 2006 reported the estimated amount of methane emissions from MSW in India since 1990 and made projections to 2020. The study projected that methane emissions will increase by almost 80% between 1990 and 2020. (Figure 13) [139] In comparison to other developing countries that also use open dumping as the primary waste disposal method, China's rate of increase of methane emissions will be approximately one-third that of India's emissions, while Nepal's will more than quadruple that of India's. (Table 11) [139]

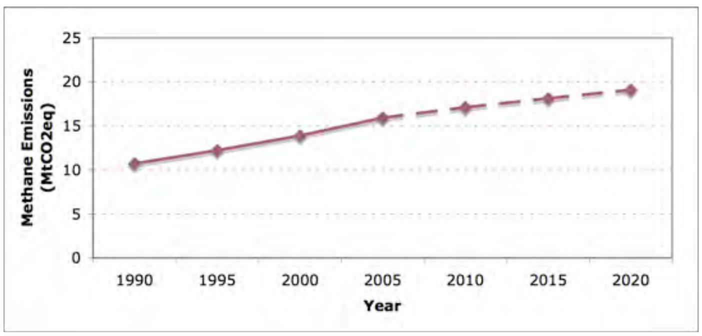

Table 11: Projected rate of increase of methane emissions from MSW between 1990 and 2020

Country	Methane Increase (%)
India	79%
Nepal	398%
Viet Nam	84%
China	23%

Figure 13: Estimated and projected methane emissions from MSW in India (EPA)

Open dump sites typically produce less methane than landfills do for the following reasons:

- Dumps tend to be shallow and do not provide enough of an anaerobic environment that is necessary for the production and accumulation of methane;
- Fires at dumps change the composition of waste thus preventing the formation of methane; and
- Ragpickers and animals often pick out food waste and paper that would normally decompose to form methane. [139, 31]

As India's MSW generation increases and sanitary landfills replace open dumps, methane emissions are likely to rise.

Using MSW instead of fossil fuels to produce energy results in fewer greenhouse gas emissions. It is estimated that one ton of MSW is equivalent to 0.25 tons of coal or 1 barrel of oil. [134] Previous calculations show that by 2030, urban areas in India will generate over 373,000 tons of MSW per day. (Box 1) Even if 50% of that amount goes towards energy recovery, it would displace 20 million tons of coal or 68 million barrels of oil a year. In addition, if this much MSW were to be landfilled instead of combusted, it would result in the creation of 88 million tons of CO_2.

Furthermore, waste-to-energy lowers the need for and thus prevents pollution from landfills, although it is hard to quantify the exact benefits. An estimate made for US sanitary landfills indicates that 10 ha of land are used up for every million tons of MSW landfilled. [128]

If 50% of the MSW generated in India in 2030 is sent to a WTE facility, it would reduce the land requirement for MSW disposal by 680 ha.

3.5 Environmental Benefits of Waste-to-Energy

Given the amount of concern over the environmental risks of waste-to-energy, this section discusses the general trend of emissions from WTE facilities, dioxin emissions from WTE facilities, and dioxin emissions from open burning, which is currently practiced in India. Waste-to-energy has historically been thought of as a major source of air pollution due to the presence of dioxins, mercury, lead, and other harmful substances. Although harmful pollutants were emitted by WTE facilities in the eighties, the technology and pollution control equipment has advanced so rapidly that the US EPA regards it as "a clean, reliable, renewable source of energy," and one that has "less environmental impact than almost any other source of electricity." [54] Today, emissions of pollutants from WTE facilities are often well below national standards, as Section 3.5.2 shows.

Contrary to many assertions made by environmental groups, waste-to-energy facilities have a number of environmental benefits. According to the Intergovernmental Panel on Climate Change,

> "Net GHG emissions from WTE facilities are usually low and comparable to those from biomass energy systems, because electricity and heat are generated largely from photosynthetically produced paper, yard waste, and organic garbage rather than from fossil fuels. Only the combustion of fossil fuel based waste such as plastics and synthetic fabrics contribute to net GHG releases, but recycling of these materials generally produces even lower emissions." [47]

In India, the environmental movement has long been opposed to WTE facilities and is misleading about actual emissions from such facilities. In fact, hazards from open burning far outweigh those from combustion of MSW, as Section 3.5.3 shows.

3.5.1 Emission Trends from Waste-to-Energy Facilities

Emissions from waste-to-energy facilities worldwide have decreased dramatically since the eighties as a result of a stricter regulatory environment and continuous improvements in technology. Tables 12 and 13 show the percentage decrease in emissions from WTE facilities within a decade for the US and Germany, respectively. Today approximately 26 million tons of MSW are diverted to waste-to-energy facilities in the US each year. [132] The waste incineration capacity in Germany increased from 9.2 million tons in 1990 to almost 14 million tons in 2000 even as emissions have decreased across the board. [35] In addition, Table 14 compares emissions per unit of heating value from coal-fired and WTE plants in the US. Emissions of sulfur dioxide, nitrogen oxides, particulate matter, and cadmium are higher from coal-fired plants than waste-to-energy facilities, while emissions of hydrogen chloride, lead, and mercury are higher from waste-to-energy facilities than coal-fired plants. [134]

Table 12: Emission Reductions from WTE facilities between 1990 – 2000 in the US [134]	
Pollutant	Reduction (%)
Dioxins/Furans	99.7
Mercury	95.1
Cadmium	93.0
Lead	90.9
Particulate matter	89.8
Sulfur dioxide	86.7

Table 13: Emission Reductions from WTE facilities between 1990 – 2001 in Germany [120]	
Pollutant	Reduction (%)
Mercury	98.7
Lead	99.8
Particulate matter	<88

Table 14: Emissions per unit of heating value of plants in the US (kg/GJ) [134]		
	Coal-fired plants	WTE facilities
Sulfur dioxide	0.452	0.013
Nitrogen oxides	0.194	0.151
Hydrogen chloride	0.017	0.087
Particulate matter	0.03	0.002
Lead	$2.6 * 10^{-6}$	$15 * 10^{-6}$
Mercury	$2.6 * 10^{-6}$	$7 * 10^{-6}$
Cadmium	$1.9 * 10^{-6}$	$1.1 * 10^{-6}$

3.5.2 Dioxins from Waste-to-Energy Facilities

Dioxins are a group of compounds that have similar chemical characteristics. Approximately 30 compounds fall into three groups: chlorinated dibenzo-*p*-dioxins (CDDs), chlorinated dibenzofurans (CDFs) and some polychlorinated biphenyls (PCBs). The term ‘dioxin’ is also used to refer to one of the most toxic of these compounds, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). The toxicity of dioxins are measured in terms of Toxic Equivalents or TEQs, which is the equivalent amount of TCDD in a mixture of dioxin compounds. Dioxins are carcinogenic and lipophilic, which means that they can easily dissolve in fats, oils, and lipids, and hence bioaccumulate in humans and wildlife, causing significant concern about the risks associated with them. [138, 64] Dioxins are commonly formed when organic material is burned in the presence of chlorine.

According to the US EPA, some of the major sources of dioxins are coal-fired plants, metal smelting plants, diesel trucks, and trash burning. However, in a span of twenty years, from 1987 to 2007, dioxin emissions from waste-to-energy facilities in the US decreased from 10,000 g/year to 12 g/year. At present, dioxins from waste incineration constitute less than 0.05% of the total US inventory. [131] In comparison, backyard burning of municipal waste in some rural areas where it is still allowed results in emissions of 580 g/year of dioxin, as shown in Figure 14. [132] In many cases, the stack gas from WTE facilities is found to be cleaner than the ambient air in some US cities. [132, 52] With regard to Germany, it is estimated that residential fireplaces emit 20 times more of dioxins than do the most modern WTE facilities in Germany. [52]

It is interesting to note that a study conducted at Oak Ridge National Laboratory, Tennessee in 1989, when WTE facilities were still considered to be 'dirty,' concluded that emissions of dioxins and furans from WTE plants ($1.2*10^{-5}$ ng TEDFs/m^3) were no greater than background levels ($1.3*10^{-5}$ ng TEDFs/m^3). [41]

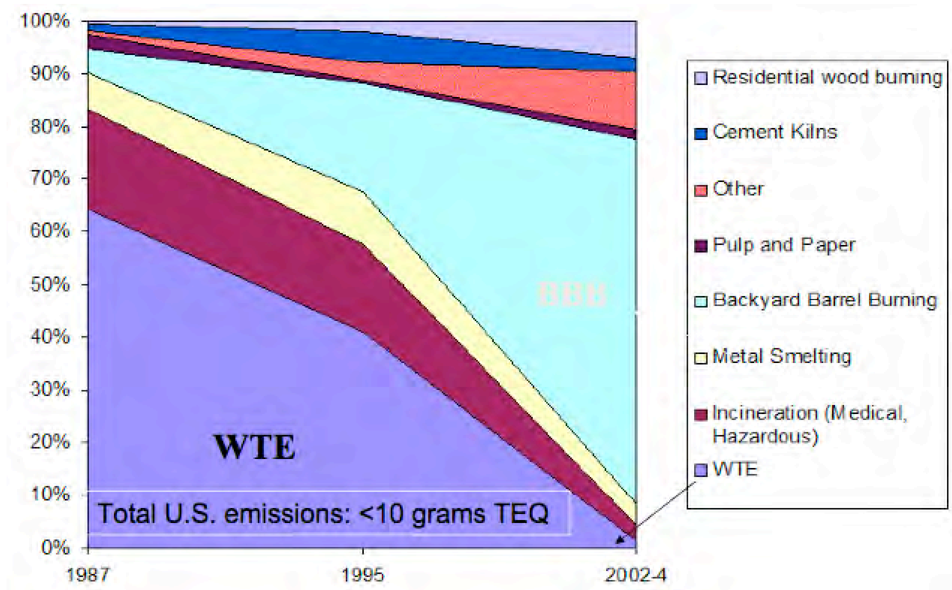

Figure 14: Dioxin emissions in the US between 1987 and 2002 {16}

In addition to measuring the decreasing trend of dioxin emissions, health risk assessments are conducted to measure the risk to human health from various industrial and manufacturing facilities. Typically the goal of these assessments is to predict the potential of excess lifetime cancer risk (ELCR), which is the probability of cancer incidence in a population, and hazard index (HI), which is the noncarcinogenic health risk. As specified by the US EPA, the ELCR for combustion facilities is 10 chances in 1 million, and the HI is 1. Independent health risk assessments of WTE facilities in the US show exceedingly low values of ELCR and HI. For example, a health risk assessment for a municipal waste resource recovery facility in Montgomery County, Maryland in 2003 showed that the worst-case ELCR scenario from TCDD TEQs was 0.5 chances in 1 million. This is 20 times less than the national standard for combustion facilities. The worst-case total HI scenario calculated for the 19 compounds selected for the study was 0.029, which is almost 35 times less than the national standard. [109]

3.5.3 Dioxins from Open Burning

Although waste-to-energy facilities have a bad reputation of producing harmful emissions, studies show that they are much less harmful than landfilling or uncontrolled burning. Studies conducted to quantify emissions from open burning of MSW show high levels of dioxins and PCBs. [53, 38, 64] One study in particular, by Minh, et al. (2003), looked at concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and PCBs at an MSW dump site in Chennai, India, among other Asian cities in the Philippines, Cambodia, and Vietnam. The results from the site in Chennai, formerly known as Madras, can be used as a proxy for Mumbai and are discussed in this section.

In general, the study found higher concentrations of dioxins and other compounds at the MSW dump site than at control sites, i.e., agricultural and urban areas located far away from the dump sites studied. Table 15 shows the concentrations of polychlorinated dibenzo-p-dioxins/ furans (PCDD/Fs) and PCBs at both the dump as well as at the control site for Chennai. The total PCDD/F concentration at the dump site was 224 times higher than at the control site. With regard to PCBs, the concentration at the dump site was 238 times higher than at the control site. The authors explain that the high levels of PCDDs and PCBs at the Chennai site, among others, resulted from uncontrolled low-temperature burning by ragpickers. [64]

The study further estimates the intake of PCDD/Fs through soil ingestion, which includes consuming small amounts of soil particles indirectly through food, as well as by inhalation. The study compared the intake of PCDD/Fs near the dump site in Chennai to an area around a waste incinerator site in Wilrijk, Belgium. The study concluded that the PCDD/F intake through soil exposure was 2.5 and 2 times higher for children and adults respectively in Chennai as compared to Wilrijk. Through dermal exposure, the PCDD/F intake at the Chennai site was found to be 2 and 5 times higher for children and adults respectively than at the incinerator site in Belgium. (Table 16) However, given that PCDD/Fs are lipophilic, the authors of the study estimate that people living in areas with high PCDD/F levels may be ingesting higher amounts of dioxins than are shown in Table 16. [64]

Table 15: Concentrations (pg/g dry wt) of PCDD/Fs and PCBs in soils from dump and control sites in Chennai, India [64]

	Dump site		Control site	
	Concentration	TEQs	Concentration	TEQs
Total PCDD/Fs	7,400	47	33	0.2
Range PCDD/Fs	2,200 – 34,000	9.9 - 200	18 - 79	0.05 – 0.34
Total PCBs	6,670	5.1	28	0.022
Range PCBs	1,300 – 20,000	2.4 - 10	12 - 52	0.015 – 0.029

Table 16: Estimated intake of PCDD/Fs from soil ingestion and dermal exposure [64]

Place	Soil ingestion		Dermal exposure	
	Child	Adult	Child	Adult
Chennai, India	0.1730	0.0152	0.0310	0.0361
Wilrijk, Belgium	0.0681	0.0079	0.0147	0.0073

Box 3: Health Effects of Uncontrolled Burning at Landfills

A number of health effects have been recorded on ragpickers and local residents who live near landfills, which are aggravated by certain factors:

- Emissions tend to be at ground level (as compared to tall stacks), which inhibits the dispersion of gases and particulate matter;
- Emissions tend to be localized and higher at certain times of the year;
- Uncontrolled burning at landfills constitute non-point sources and hence are harder to regulate than point sources. [4]

Health studies conducted on ragpickers in Bangalore and New Delhi show that ragpickers most often suffer from tuberculosis, bronchitis, asthma, pneumonia, dysentery, and parasitic diseases. A study of approximately 100 ragpickers in Mumbai quantified the medical problems faced by this community. Table 17 describes the percentage of ragpickers who reported having certain medical problems. [17] The incidence rates of these diseases are significantly higher among the ragpicker community as compared to the general public.

Table 17: Percentage of ragpickers having medical problems based on a survey conducted in Mumbai (Cointreau)

Medical condition	Ragpickers reporting ailments (%)
Eye problems	80
Respiratory problems	73
Gastrointestinal diseases	51
Skin infections/allergies	40
Decreased vision	90

3.6 Effect of Economic Growth on MSW Generation, Collection, and Disposal in India

There is a direct link between GDP and MSW generation. A number of studies have found that the higher the household income and standard of living, the higher is the amount of waste generated. [140, 150] A World Bank study summarized the progression of solid waste management practices in a country as its income increases, as shown in Table 18. [150]

As India's economic growth continues to rise, it is expected that MSW collection rates will improve significantly. This means that much more garbage will be collected and transported to landfills than what is done presently. In addition, the switch from open dumps to regulated landfills will increase the overall cost of SWM and increase emissions of methane from landfills, as described in Section 3.4. Importantly, as the composition of MSW changes to a higher fraction of non-organic materials, WTE becomes a more economic because of higher energy recovery.

Table 18: Evolution of solid waste management practices [150]		
Activity	Low income countries	High income countries
Collection	Sporadic and inefficient; service is limited to high visibility areas, the wealthy, and businesses willing to pay.	Collection rate greater than 90%. Compactor trucks and highly mechanized vehicles are common.
Recycling	Most recycling is through the informal sector and waste picking; mainly localized markets and imports of materials for recycling.	Recyclable material collection services and high technology sorting and processing facilities; increasing attention towards long-term markets.
Composting	Rarely undertaken formally even though the waste stream has a high percentage of organic material.	Becoming more popular at both backyard and large-scale facilities; waste stream has a smaller portion of compostables than low and middle income countries.
Incineration	Not common or successful because of high capital and operation costs, high moisture content in the waste, and high percentage of inerts.	Prevalent in areas with high land costs; most incinerators have some form of environmental controls and some type of energy recovery system.
Landfilling	Low-technology sites, usually open dumping of wastes.	Sanitary landfills with a combination of liners, leak detection, leachate collection systems, and gas collection and treatment systems.
Costs	Collection costs represent 80 to 90 percent of the municipal solid waste management budget; waste fees are regulated by some local governments, but the fee collection system is very inefficient.	Collection costs can represent less than 10 percent of the budget; large budget allocations to intermediate waste treatment facilities; upfront community participation reduces costs and increases options available to waste planners (e.g., recycling and composting).

3.7 Effect of Urban Population Growth on MSW Generation in India

India has historically been an agricultural economy, with the majority of people living in rural areas and engaged in the agricultural sector. However, with an expanding service- and manufacture-driven economy and various inefficiencies in the agricultural sector, coupled with an increasing population, urban areas are seeing unprecedented growth. According to the 2001 Census, around 27.8% of India's population lives in urban areas. [96] This is expected to increase to 41.4% of the total population in India by 2030. [34] This rapid urban expansion is already overextending the current infrastructure, water availability, electricity supply, public health and educational systems, and land available for housing and development.

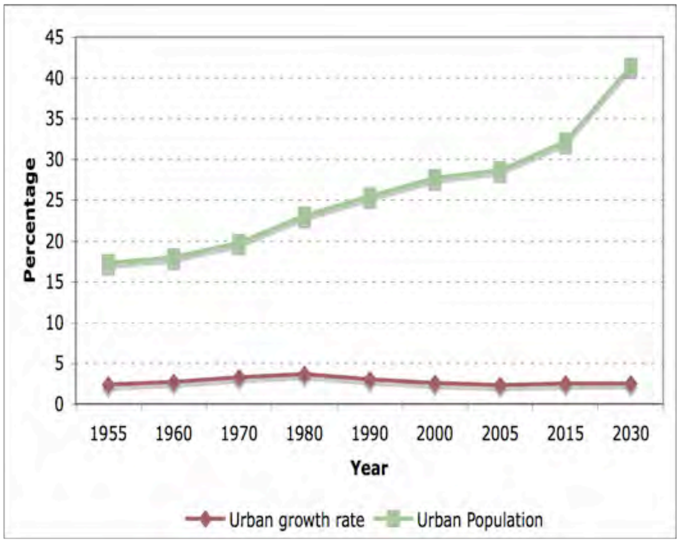

Figure 15: Actual and projected urban population and growth rates in India

A direct consequence of increasing population in and migration to urban areas is the effect on existing solid waste management practices. Urban population growth limits the capacity for waste disposal in two ways. First, the increase in demand for land needed for urban development lowers the amount of land available for MSW disposal. Second, as population increases, the total amount of waste generated also increases. As India's urban population continues to expand, space for landfills will become more costly and it will be necessary to find other means for dealing with the growing amount of MSW. It is estimated that at current rates of dumping/landfilling, by mid-century India will require approximately 1,400 km^2 of land or the equivalent of three Mumbai cities. [55] Also, as experience in Athens and Rio de Janeiro has shown, there is much resistance to locating new landfills in suburban or even rural areas. [128]

3.8 Non-organic Fraction in Indian MSW

The fraction of non-organic matter, including recyclables, in Indian municipal solid waste is expected to steadily increase as India's economic growth continues. However, depending on the composition of some types of plastics and other materials, recycling may not be an option. For example, in the US after much effort to develop collecting and processing systems, only 10% of the total plastics are recycled. [128] India's current recycling rate of plastics is reported to be between 40-80%, which is much higher than the average of 10-15% in high-income countries. [47] If India follows this trend, the recyclable fraction in MSW will increase over the coming years while the recycled fraction will decrease. Assuming that is the case, the heating value of Indian MSW will increase and thus be more suitable for waste-to-energy facilities. This section discusses the projected consumption levels of plastic and paper in India.

3.8.1 Plastics Consumption in India

Consumption of plastic materials has been increasing rapidly in India and it is expected that by 2010 India will be the third largest plastics consumer in the world. [127] Consumption of virgin plastic increased from 0.8 kg/person/year in 1990 to 3.2 kg/person/year in 2000. [90] The All India Plastics Manufacturers' Association estimates that current plastic consumption is approximately 6 kg/capita/year. [102] Although India's recycling rate for plastic is currently high, as consumption of plastic materials increases the recycling rate is expected to decrease to 35%, which will further increase pressure on the environment. [101]

Packaging is expected to account for almost half of India's total plastic consumption by 2010. [102] Since most packaging does not have a high recycling value, it tends to be disposed off as kitchen waste and hence increases the heating value of residential waste. [40] Table 19 shows the projected rate of increase of various plastic packaging materials between 2002 and 2010. [102]

Table 19: Demand for plastic packaging in India [102]

Type	2002	2010	Rate of increase(%)
Flexible packaging (million tons)	1.0	3.0	12
Multifilament packaging (million tons)	0.5	1.4	12
Rigid packaging (million tons)	0.5	1.8	14
Polypropylene (kTA)	23	135	486
Polymers (KT)	140	1,250	792

3.8.2 Paper Consumption in India

Although paper consumption in India at 4.43 kg/person/year is much lower than the world average of 55.4 kg/person/year, the amount of paper that is used is steadily increasing. Figure 16 shows that India's per capita paper consumption increased by 235% between 1961 and 2004. [151] The IPCC Third Assessment Report (2001) estimated that India's paper consumption will reach 8 kg/person/year by 2021. [47]

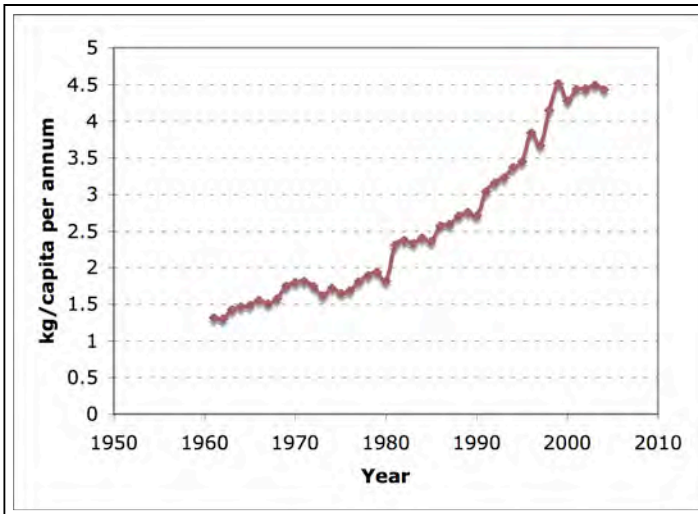

Figure 16: Paper and paperboard consumption per capita in India

3.9 Energy Potential from Urban Wastes in India

MNRE estimates that the potential to generate energy from urban wastes is approximately 1,700 MW from municipal solid waste and 1,000 MW from industrial waste, which includes paper mills and tanneries. [55, 70]

MNRE also estimated the potential power generation from solid wastes in both rural and urban areas. As Table 20 shows, the potential to generate power from municipal solid wastes is expected to more than double in the next ten years, while the potential from industrial waste is likely to increase by more than 50%. [70]

Table 20: Potential MSW and Power Generation from MSW and Industrial Waste in India [70]

Year	Projected MSW Generation (tpd)	Potential Power Generation from MSW (MW)	Potential Power Generation from Industrial Waste (MW)
2007	148,000	2,550	1,300
2012	215,000	3,650	1,600
2017	304,000	5,200	2,000

Table 21 shows the state-wise energy potential from urban wastes. Maharashtra state, the capital of which is Mumbai, has the highest potential to generate electricity from both solid and liquid wastes. [55]

Table 21: State-wise Energy Potential from Urban Wastes (MW) [55]

State	Solid Wastes	Liquid Wastes
Andhra Pradesh	107	16
Delhi	111	20
Gujarat	98	14
Karnataka	125	26
Maharashtra	**250**	**37**
Tamil Nadu	137	14
Uttar Pradesh	154	22
West Bengal	126	22
Other States	349	55

3.9.1 Funding for Waste-to-Energy Programs in India

This section provides a brief overview of funding options at the national, state, and municipal levels. Most institutions in India do not provide funding solely for environmental projects but for power generation and infrastructure projects. The financial schemes described below could be used for the development of waste-to-energy projects.

- *National level:* At the national level, the Ministry of Environment and Forests, Ministry of New and Renewable Energy, and Ministry of Urban Development support a number of environmental projects. With regard to waste management, the ministries carry out the following tasks:
  - MoEF undertakes research projects associated with waste recycling and resource recovery from wastes, provides guidelines relating to solid waste disposal, and provides grants for waste utilization studies. [65]
  - MNRE is the nodal ministry at the national level that deals with renewable energy sources. It has developed a National Waste-to-Energy Master Plan, initiated programs on energy recovery from urban and industrial wastes, and offers subsidies for new WTE projects. [73] The MNRE provides financial incentives and basic criteria for waste-to-energy projects that would be eligible under the *National Programme on Energy Recovery from Urban & Industrial Wastes.* [73] (See Appendix 3 for details). They are as follows:
    - Interest subsidy to reduce the interest rate for lending institutions to 7.5%;
    - Provide up to 50% capital costs for demonstration projects;
    - Provide up to 50% of the incremental capital cost for generation of power from biogas;
    - Monetary incentives of up to Rs. 1,500,000 per MW ($33,333/MW) to municipalities to provide free garbage and a nominal land lease for projects, as well as financial assistance to prepare a detailed project report or economic feasibility report;
    - Financial incentives for state nodal agencies for promotion, coordination and monitoring of projects;
    - Financial assistance for resource assessment studies; and
    - Financial assistance for organization of training courses, national workshops, seminars, and creation of awareness and publicity.

    MNRE also allows foreign investment in waste-to-energy, in addition to allowing foreign investment in the manufacturing of renewable energy systems and devices for their use in India as well as to export to developing and third-world countries. [72] This provides a positive foundation particularly for the waste-to-energy market in India as any medium- to large-scale project would need to import technology and technical know-how.
  - MUD sponsors schemes for Solid Waste Management and Drainage and has set up a *Technology Advisory Group on Solid Waste Management* and an *Inter-Ministerial Task Force on Integrated Plant Nutrient Management Using City Compost*. [76] MUD has also set up an urban renewal fund, Jawaharlal Nehru National Urban Renewable Mission (JNNURM), which was created in 2005-06 to provide funding to municipalities for the development of urban infrastructure services, including solid waste management. The JNNURM provides municipalities with either soft loans or a combination of a grant and a loan. This scheme would require funding from the central government of 35%, 15% from the state government, and the rest as a contribution from the municipality or loan from a financial institution. [74]

Table 22 shows that the annual budgets of these three ministries have increased considerably in the last ten years. [67, 68, 69] This indicates that not only is the support for environmental programs and renewable energy sources increasing at the central government level, but that there is also more funding available for various programs.

Table 22: Budget Estimates of Relevant Ministries in India (million US$) [67, 68, 69]			
	1997-98	2002-03	2007-08
MoEF	120.8	220.0	300.2
MNES	140.8	244.6	224.8
MUD	505.5	1,148.2	1,148.0

- *State level:* Agencies at the state level are expected to match any funding received from the central government for environmental projects. For Mumbai, the Maharashtra Energy Development Agency (MEDA) would be the agency responsible for development of WTE projects.

- *Local level:* Municipalities receive funding from local taxes and grants from state and central governments. Most municipalities do not have the option of raising money through capital markets, nor do they have the resources to plan and operate technical projects on their own. Thus, private sector participation is necessary on a Build, Own, Operate (BOO) basis or Build, Own, Operate, Transfer (BOOT) basis. [2]

3.9.2 Cost of Waste-to-Energy in India

Energy production from waste-to-energy facilities can be in the form of electricity and/or district heating (cooling). Most WTE facilities generate electricity. Hot water is a by-product and is used in district heating (cooling). In the EU and the US, a net of about 550 kWh of electricity per ton of MSW are generated and provided to the grid. [128] In Mumbai, given the lack of infrastructure for district heating (cooling) at present, only electricity generation would be a reasonable option. However, if an industrial center were to be developed near a WTE plant, it could make use of the by-product steam for manufacturing processes, thus improving the efficiency of energy production from a WTE facility.

The Government of India published costs of electricity generation from renewable sources, as shown in Table 23. [37] In this tabulation, the cost of waste-to-energy is somewhat costlier than other renewable sources, such as bagasse cogeneration, but considerably cheaper than solar photovoltaics. It should be kept in mind that waste-to-energy facilities serve a dual role of waste disposal and conversion of MSW to a much smaller volume of inorganic ash, as well as of energy production. Although the cost per kilowatt of capacity may be more expensive for WTE than other renewable sources, the benefits of waste management, energy and metals recovery, and reduction of greenhouse gas emissions need to be factored in.

Table 23: Capital and estimated costs of generation from renewables			
Source	Capital Cost ('000 $/MW)	Estimated cost of Generation per Unit ($/kWh)	Total Installed Capacity
Wind	890-1100	0.07 - 0.09	4434
Small hydro (<25MW)	1100 - 1300	0.06 - 0.07	1748
Bagasse Cogeneration	665 - 775	0.04 - 0.07	491
Biomass	890	0.07 - 0.09	377
Biomass Gasifier	555 - 665	0.07 - 0.09	71
Energy from Waste	**1100 - 2225**	**0.09 - 0.17**	**46**
Solar Photovoltaic	5555 - 6665	0.33 - 0.44	3

4. OVERVIEW OF SOLID WASTE MANAGEMENT IN MUMBAI

4.1 Background

Mumbai is the state capital of Maharashtra and the financial and commercial capital of India. Until the 17th century, Mumbai consisted of seven islands, as shown in Figure 17a. The Portuguese, who controlled the islands for over 125 years, gave the territory as dowry to King Charles II of England when he married Catherine of Braganza. The islands were merged into a single landmass during the late 18th and early 19th centuries, when the British East India Company governed the islands. (Figure 17b) [121] Today, the island of Mumbai is separated from the rest of Maharashtra by the Thane Creek in the east, Vasai Creek in the North, and the Arabian Sea to the West. Most of the city lies at or slightly above sea level. [56]

Figure 17a: Seven islands of Mumbai {14}

Figure 17b: Mumbai islands merged into one {7}

By some accounts, Mumbai is the most populous city in the world, with approximately 12 million residents (2001 census).[4] [85, 79] The metropolitan area of greater Mumbai is home to over 16 million people. [136] Mumbai covers an area of approximately 437.71 km^2, while the metropolitan region extends to approximately 479.69 km^2. [79, 117] By 2015, it is expected that Mumbai will be the third largest city in the world, behind Tokyo and Dhaka. [136] It is estimated that 48.9% to 54.5% of Mumbai's population lives in slums today. [81, 118] 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. [149]

Mumbai has historically been a driver of economic growth not only for the state of Maharashtra but also for the rest of India. The city contributes almost $9 billion annually in taxes to the state and central governments, and to approximately 5% of India's GDP. [6] In addition, 33% of India's income tax collection, 60% of customs' duties, and 40% of foreign trade earnings come from Mumbai. [80]

[4] Tokyo is the largest urban agglomeration in the world, at over 34 million people, while Mumbai ranks fifth. [136] In terms of actual city population, Mumbai ranks first, while Tokyo comes in eighth at over 8 million. [33]

Nevertheless, economic growth has slowed considerably in Mumbai, affecting the quality of life, standard of services, and the environment. GDP growth in Mumbai fell from 7% in 1998 to 2.4% in 2002, while India's GDP increased by as much as 5.6% per year during that period. [85, 6] According to an Economist Intelligence Unit Hardship Survey conducted in 2002 on infrastructure, health and safety, and culture and environment, Mumbai ranked 124th out of 130 cities worldwide. [26]

This chapter first gives an overview of local governance in Mumbai, followed by a detailed description of the solid waste management sector in Mumbai. Where applicable, maps and calculations of future rates of increase are presented to give a complete picture of solid waste management.

Box 4: Mumbai : India :: New York : United States

Mumbai is to India what New York is to the United States. New York is the financial and commercial capital of the United States, as Mumbai is to India. New York is home to the New York Stock Exchange, while Mumbai houses the oldest stock exchange in Asia, the Bombay Stock Exchange (BSE) Limited, [7] in addition to the National Stock Exchange of India (NSEI). Mumbai also serves as the headquarters for numerous industries and multinational corporations, from the famous film industry, Bollywood, to pharmaceutical and petroleum industries. Table 24 compares the key socio-economic and solid waste management variables of Mumbai and New York City.

Table 24: Comparison of Mumbai and New York

Factor	Mumbai	New York
Population [117, 94]	11,914,335 (2001)	8,143,197 (2005)
Area [79, 94]	437.71 km^2	1,214.4 km^2
Population density [79, 94]	27,219/km^2	6,707/km^2
Population growth [136, 94]	2.3% (2000-2015)	1.7% (2001-06)
Per capita income [148, 94]	Rs. 31,922 ($709) (2000-01)	$23,389 (1999)
Average office rent in 2006 ($/$ft^2$/year) [11]	$106.09	$62.07
Garbage generation [94, 22]	8,500 tons	12,000 tons
SWM Employees [156, 22]	40,000	9,940
SWM Budget [117, 25]	$165 million	$1+ billion

4.2 Local Governance in Mumbai

4.2.1 Municipal Corporation of Greater Mumbai

The Municipal Corporation of Greater Mumbai (MCGM), formerly known as the Bombay Municipal Corporation (BMC), is the elected local government that provides civic services to Mumbai. As with other municipalities in India, it is responsible for the city's water supply, public health, education, solid waste management, and environmental monitoring. It employs over a million people and has an annual budget of approximately Rs. 55 billion ($1.2

billion). [84] The Solid Waste Management Department (SWMD) of MCGM is described in Section 4.3.1.

4.2.2 Administrative Zones

The city of Mumbai is divided into the city and the suburbs, which are further split into the western and eastern suburbs, as shown in Figure 18. For administrative purposes, Mumbai is divided up into six zones and 24 wards. These wards are shown in Figure 19. The "city" covers an area of 67.79 km^2 and comprises of wards A-G. The suburbs occupy an area of about 370 km^2 and consist of the remaining wards (H, K, L, M, P, R-T). [56] Each ward is under the charge of an Assistant Commissioner, or ward officer, who is responsible for the day-to-day management of the area, including waste management, water supply, public health, and education. [84] Table 25 shows the distribution of wards by zone, giving the area, population, and population density of each ward. In this report, wards are used to describe MSW generation, MSW collection rates, and the location of dumps.

Figure 18: Map showing the geographical area of Mumbai city {7}

Figure 19: Map showing the administrative wards in Mumbai city {8}

Table 25: Distribution of Mumbai zones, wards and ward data [21, 117]					
Area	Zone	Ward	Ward area (km^2)	Ward population	Population density
City	I	A	10.46	207514	19,839
		B	2.44	140,418	57,548
		C	1.77	190,672	107,724
		D	7.21	378,607	52,511
		E	6.79	439,393	64,712
City	II	F/N	12.46	526,839	42,282
		F/S	6.29	395,627	62,898
		G/N	7.37	590,609	80,137
		G/S	10.48	457,095	43,616
Western Suburbs	III	H/E	12.98	579,123	44,617
		H/W	6.58	336,051	51,072
		K/E	23.59	806,360	34,182
		K/W	23.64	694,151	29,363
Western Suburbs	IV	P/N	42.45	789,645	18,602
		P/S	21.22	436,907	20,589
		R/N	76.64	363,991	18,965
		R/S		579,954	
		R/C		509,503	
Eastern Suburbs	V	L	13.30	774,812	58,257
		M/E	32.66	672,767	20,599
		M/W	21.62	408,077	18,875
Eastern Suburbs	VI	N	36.58	614,945	16,811
		S	64.00	691,107	10,799
		T	45.42	330,168	7,269

4.3 Formal and Informal Sectors of SWM in Mumbai

The Municipal Corporation of Greater Mumbai (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 in Mumbai 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 regulated by government agencies, and there are no parameters for pricing of recyclable materials or regulations to protect ragpickers.

4.3.1 The Formal Sector

The formal sector responsible for solid waste management in Mumbai consists of the SWMD of the MCGM and its private contractors. The 2006-07 budget of the SWMD is Rs. 7.4 billion ($165 million), and is expected to increase to Rs. 7.8 billion ($174 million) in 2007-08. 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) or 22% of the cost of one ton of MSW. [117] In

India, the average municipal expenditure on solid waste management is between Rs. 500-1,500 per ton of MSW ($11-33/ton). [55]

The Solid Waste Management Department provides the following services, as listed on its website:

- Street sweeping
- Collection of solid wastes including temporary storage
- Removal and transportation of solid wastes
- Disposal of solid wastes
- Disposal of dead bodies of animals
- Construction, maintenance and cleansing urinals and public sanitary conveniences. (sic) [88]

4.3.2 The Informal Sector

Ragpickers are an integral part of the waste management system in Mumbai and other cities in India. [143] Ragpickers fall under the informal sector because they neither earn regular wages nor benefits nor do they get training or safety equipment from the municipal corporation. Nevertheless, they provide an essential service to the general public and the municipality by scavenging for recyclable materials, such as plastics, glass, and paper, from garbage. Their work reduces MSW transportation costs, provides raw materials to recycling facilities, and helps to protect the environment. [48]

Figure 20: Women ragpickers looking for recycable material at a dump {3}

The majority of ragpickers are migrants from the states of Maharashtra, Karnataka, and Tamil Nadu who come to the city in search of work. Most of the ragpickers are Dalits, or "untouchables," who are still discriminated against in many parts of India and have no choice but to take up menial jobs. [48] The rag pickers also have to bear a social stigma of being "unclean" because they do "dirty" work.

It is hard to quantify exactly how many ragpickers there are, how much income they earn, and what the value of the waste they collect is since there are no official records on rapgickers. Estimates on the number of ragpickers in Mumbai range from 25,000 to 100,000. [63, 145] Almost 85% of the ragpickers in Mumbai are women who earn only a few Rupees per kilogram of recyclable material collected. This waste is sold to middlemen who eventually sell it to recycling facilities at much higher prices. [48] The ragpickers are exploited because they are illiterate and not formally organized as a union or organization that can fight for their rights.

More information on recycling in Mumbai is provided in Section 4.9.

4.4 Waste Generation in Mumbai

4.4.1 Types of Waste Generated in Mumbai

The waste that is generated in Mumbai can be broadly segregated into four categories:

1. *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. [117] The following sections discuss various aspects of MSW in greater detail.

2. *Biomedical waste:* Approximately 25 tpd of biomedical waste is produced by both public and private hospitals, nursing homes, and other medical facilities in Mumbai. However, because of lack of capacity and improper functioning of the sole incinerator, only a fraction of the waste, five tons per day, is treated safely. [117] The rest of the waste is sent to MSW dumps, where they cause injury to ragpickers who sift through the waste and spread diseases and infections. The Maharashtra Pollution Control Board (MPCB) is responsible for regulating the collection and disposal of biomedical wastes; however, the MCGM is responsible for transportation and treatment of the waste. [117, 60]

3. *Construction and demolition waste:* Around 2,200 tpd of construction and demolition waste is collected by the MCGM and sent to the various dumps. [117] There are four primary generators of C&D waste, who are responsible for disposal of their own waste:
    a. Construction companies and builders;
    b. Electric and water utilities;
    c. Storm Water Drains Department, MCGM, for de-silting and clearing drains; and
    d. Domestic household repairs. [83]

    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.

Figure 21: C&D waste littering a sidewalk in Mumbai

4. *Industrial waste:* There are no estimates on how much industrial waste is produced in Mumbai, although the MPCB estimates that there are close to 31,000 businesses and/or factories in Mumbai. [117, 85] A number of these establishments are small and hence it is hard to estimate the quantity of waste generated. Typically, generators of industrial waste are responsible for transportation and disposal of their own waste, as are generators of C&D waste. The MPCB is the regulating body for industrial wastes.

4.4.2 Current MSW Generation in Mumbai

The CPCB-NEERI survey conducted in 2005-06 found that the city of Mumbai generates about 5,320 tons per day of MSW, corresponding to a waste generation rate of 0.45 kg/person/day. [14] However, using a rate of 5,800 tpd as specified by the MCGM and total population as given in the 2001 Census, the waste generate rate per person in Mumbai is 0.49 kg/person/day.

4.4.3 Future MSW Generation in Mumbai

It has been estimated that Mumbai will generate 12,000 tpd of MSW by 2010. [141] The growth of MSW generation can be calculated using the following formula [154]:

$$Domestic\ waste = PP * (1 + GR_{pp})^n * w_c * (1 + GR_{KF})^n$$

where:
PP = present population
GR_{pp} = population growth rate
w_c = 2001 capita waste generation
GR_{KF} = growth rate of waste generation
n = number of years

Table 26 shows the projected future generation of MSW in Mumbai using Equation 1. It uses as base year 2001, a population growth rate for the city of 2.26% estimated by the UN Department of Economic and Social Affairs, and a national per capita MSW growth rate of 1% per year. Hence, the figures in Table 26 are meant to give an idea of the approximate increases in MSW generation in Mumbai over time.

Table 26: Estimated growth of MSW generation in Mumbai

Year	Projected population (millions)	Projected MSW generation (tpd)	Per capita waste generation (kg/person/day)
2001	11.9	5,800	0.49
2010	14.6	7,757	0.53
2015	16.3	9,116	0.56
2020	18.2	10,713	0.59

4.5 MSW Collection in Mumbai

Municipal solid waste is collected by street sweeping and community collection. [85] Community collection is mainly conducted by:

1. *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
2. *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.

(Figure 22) An example of such a community container is shown in Figure 23a. In other areas, waste is dumped on the road for collection, as is shown in Figure 23b.

Figure 22: Number of collection spots and house-to-house collection for MSW in Mumbai

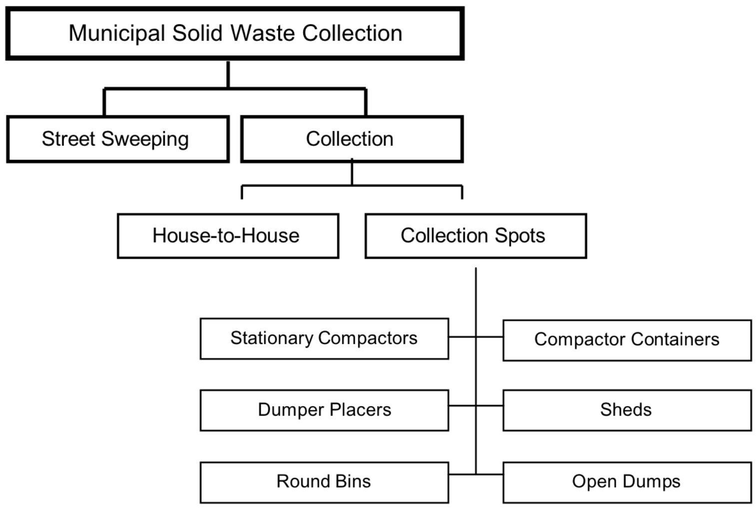

Figure 23a: Community container for garbage collection {10}

Figure 23b: Communal garbage collection area {9}

The majority of municipal solid waste is collected through communal collection areas, while only about 22% of the MSW is collected from house-to-house. [86] Most of the collection is done in three shifts, with each vehicle making roughly five trips per shift. The majority of MSW is collected during the day and approximately 10% is collected during the night shift. [85, 117] However, community bins that are $1.1m^3$ in size are slowly replacing the round bins, sheds, and open dumping in Mumbai. It is expected that by September 2007, over 6,000 community bins will be installed around the city, thus eliminating the need for round bins, sheds, and open dumping areas. [117] The distribution of community collection points currently being used for garbage collection by ward is shown in Appendix 2.

The collection efficiency is estimated to be between 80-90% (1997). [156] The garbage is collected by the formal sector, consisting of municipal employees and private collection companies contracted by the municipality, and the informal sector, consisting of ragpickers. It is estimated that ragpickers collect 25% of the total waste generated, mainly in the form of recyclable material that is then sold. [156]

Figure 25: MSW being offloaded onto larger vehicles at a transfer station {3}

The collected MSW is taken either to transfer stations or directly to the dump. There are three transfer stations in Mumbai at Mahalaxmi, Kurla, and Versova, with a combined capacity of 600 tpd, and three MSW dumps at Deonar, Gorai, and Mulund. [86] (See Section 4.8 for detailed information on waste disposal in Mumbai) The transfer stations service areas that are either very congested or where roads are too narrow to accommodate large trucks. Approximately 30% of the MSW collected passes through transfer stations before reaching the municipal dumps, as shown in Figure 25. For areas that are near dumps or that can accommodate larger vehicles, the MSW collected in larger vehicles and taken directly to the dump. [86] Table 27 lists the wards that send their MSW to a transfer station before it is sent to the dump. [117] Figure 24 shows the locations of the transfer stations and dumps in Mumbai. Note that the locations are approximate. The area outlined in purple sends its MSW to the Deonar dump, the area marked in orange to Gorai, and the area in yellow to Mulund. MCGM plans to upgrade the existing transfer stations and open three new ones in Gorai, Versova, and a third undetermined location.

Table 27: Wards serviced by transfer stations in Mumbai

Transfer Station	Wards
Mahalaxmi	A, B, C, D, E, F/S, F/N, G/S, G/N
Kurla	G/N, L, H/E
Versova	K/W

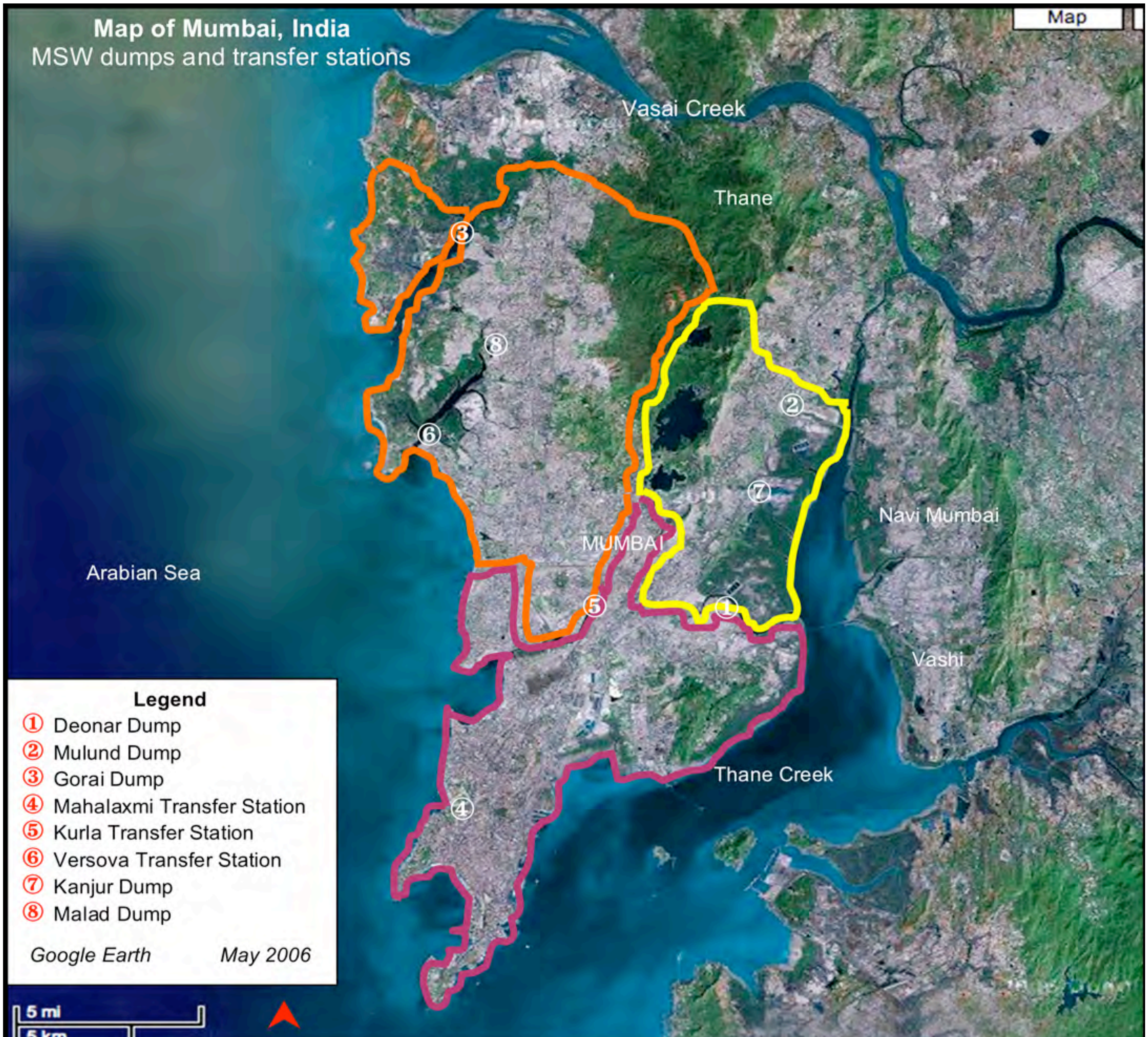

Figure 24: Map of Mumbai depicting MSW transfer stations and dumps

4.6 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 municipality and private contractors use compactors, dumper placers, trucks, and other refuse vehicles for garbage collection. (Figures 26 and 28) Based on data made available by MCGM, the municipal corporation uses approximately 420 vehicles per day for garbage collection, while the private contractors have about 560 vehicles. [86] Figure 27 shows the total number of both municipal and private contractor vehicles used.

The average distance from collection points to the dumping grounds ranges from 20-28 km. [117] As mentioned above, the collection vehicles make multiple stops along the route to the dump or refuse transfer station, and multiple trips to the dump each day.

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). [86] Small one-ton vehicles will be used in slum areas to navigate the narrow alleys. They will be unloaded into large six-ton compactors that will go directly to the dump, as shown in Figure 26c. ‘Mini’ compactors, having a capacity of 2.5 tons, will be used to transport MSW to transfer stations, and will haul garbage a distance of approximately 5-10 km. From the transfer station, large six-ton compactors will then transport the compacted MSW to the dump. [117]

Figure 26a: Dumper placer {3}

Figure 26b: Dumper {3}

Figure 26c: One-ton vehicle unloading MSW into large compactor {9}

Figure 26d: Open truck {3}

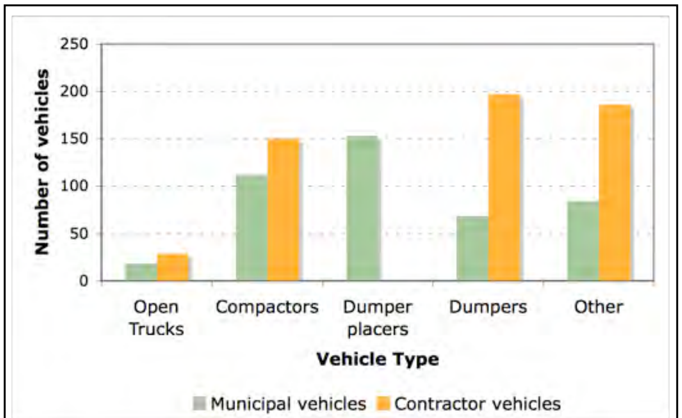

Figure 27: Number of municipal and contractor vehicles used for garbage collection

Figure 28: Waste transported by truck in Mumbai {11}

4.7 Characteristics of MSW in Mumbai

4.7.1 Typical Composition of MSW in Mumbai

The MSW collected in Mumbai consists of wet organics (primarily food waste), dry organics (straw, wood), inert materials (sand, soil, earth), and recyclables (plastics, metal, glass, paper), as shown in Figure 29. [87]

A detailed analysis of the MSW received at the Deonar dump was conducted. The average values are based on seven-day samples of a total of 100 kg. The MSW received at Deonar is similar to that of Gorai and Mulund. [87]

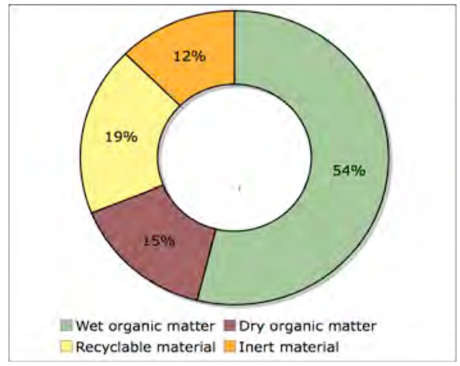

Figure 29: Composition of waste in Mumbai as of 2006

4.7.1.1 Organic Component

Organic matter can be divided into wet and dry organic matter. Wet organic matter consists of kitchen wastes, fruit wastes, flower wastes, green grass, and other small organic material that is less than 1" in size. With regard to wet organic wastes, kitchen wastes constitute the majority of the waste, while green grass and flower waste make up less than 1% of organic waste. The largest components of dry organic wastes include dry grass and cotton waste, which together make up 89% of the total dry organic material found in the MSW in Mumbai. [87]

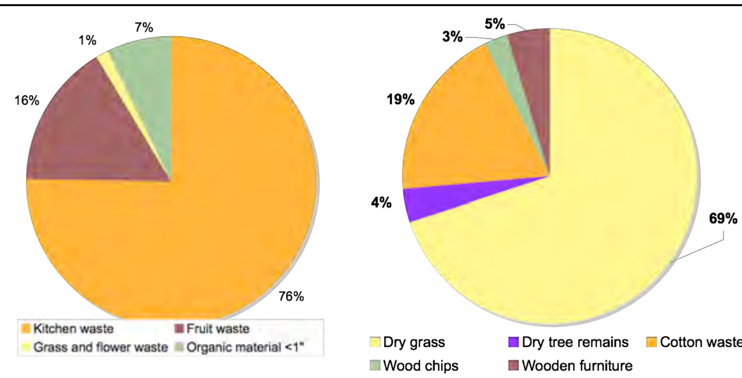

Figure 30a: Composition of wet organic wastes in Mumbai MSW

Figure 30b: Composition of organic wastes in Mumbai MSW

4.7.1.2 Recyclable Component

The recyclable fraction of MSW in Mumbai consists of plastic, paper, glass, rubber, leather, and a very small amount of Styrofoam and metals, as shown in Figure 31. Metals are removed by ragpickers for their high re-sale value, hence the metal fraction in MSW is very small. Plastics, on the other hand, make up approximately 50% of recyclable material found in MSW. [87]

4.7.1.3 Inert Materials in Mumbai MSW

The inert materials found in Mumbai MSW are sand, stone, silt, and bricks. A large proportion of this comes from street sweeping and illegal dumping of construction and demolition waste, as discussed in Section 4.4.1. [87]

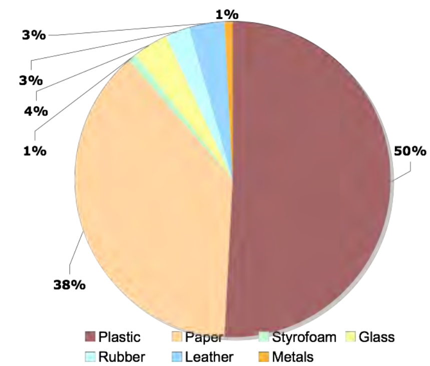

Figure 31: Recyclable materials found in Mumbai MSW

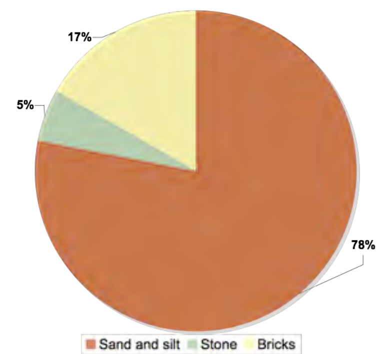

Figure 32: Composition of inert materials in Mumbai MSW

4.7.2 Chemical Characteristics

The chemical characteristics of MSW in Mumbai were determined by two different studies, one by CPCB and NEERI in 2005-06, and the other by MCGM around the same time period. Note that the moisture content and heating value differ significantly between the two studies. [14, 44] (See Section 5.3.6.1 for more information on the heating value of MSW in Mumbai)

Table 28: Comparison of Chemical Composition of Mumbai Waste [44, 14]

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

4.7.3 Comparison of MSW in Mumbai to Other Indian Cities

A comparison of the waste characteristics of the seven smallest (population < 100,000) and largest metro cities (population > 1,000,000) surveyed in India in the CPCB-NEERI study is made in this section. The compostable fraction and moisture content found in Mumbai waste is comparable to the other large cities in India. The smaller cities tend to have a slightly higher compostable fraction and moisture content than the larger cities. The recycling fraction in both groups seems to vary, with the smallest city in the survey, Kavaratti, in the Lakshadweep Islands, having the highest percentage of recyclables at 27%. [14]

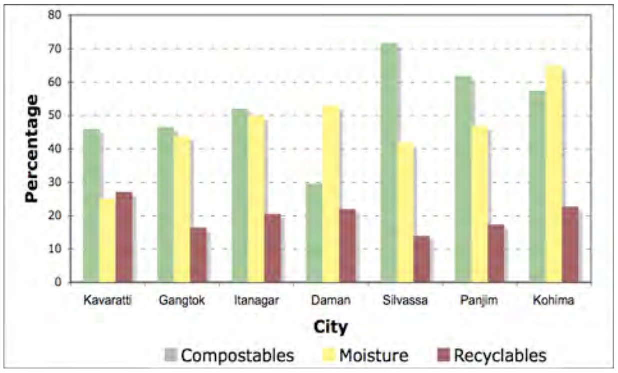

Figure 33a: Waste characteristics of the seven smallest cities included in the CPCB-NEERI report

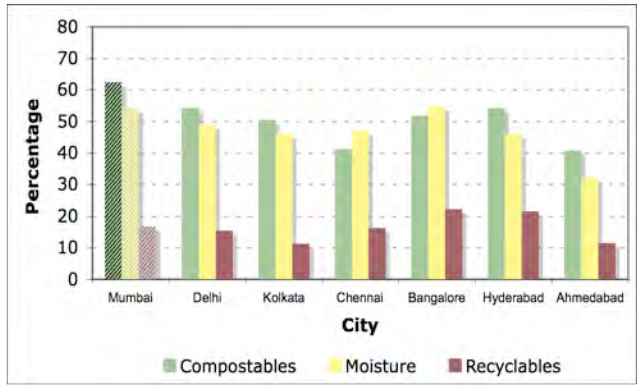

Figure 33b: Waste characteristics of the seven largest cities included in the CPCB-NEERI report

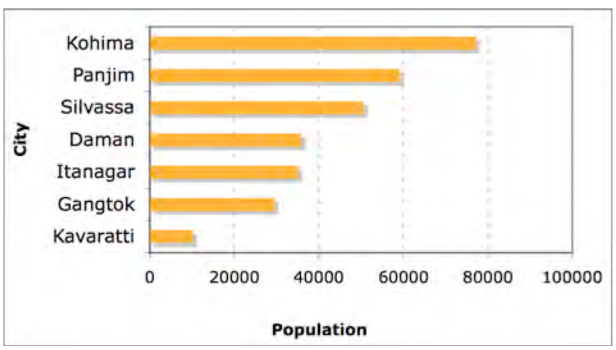

Figure 34a: Population of the seven smallest cities included in the CPCB-NEERI report

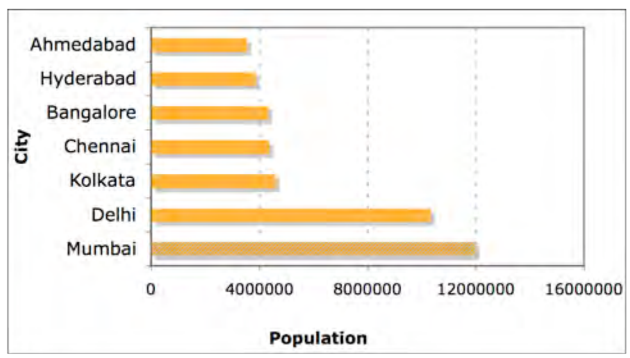

Figure 34b: Population of the seven largest cities included in the CPCB-NEERI report

4.8 Waste Disposal in Mumbai

4.8.1 Background

As noted earlier, there are three operating dumps currently serving Mumbai. They are located in Deonar, Gorai, and Mulund. A fourth dump at Malad was closed in 2001, and a new one is scheduled to open at Kanjur in January 2008. [87] Figure 24 shows the relative locations of the dumps in Mumbai. Although the average life of a garbage dump is said to be approximately 30 years, [5] all of the dumps have been in operation for over 30 years, with Deonar, the largest, being 80 years old. [117] Figure 35 shows the lifespan of the Mumbai landfills.

All the dumps are located in densely populated areas. [85, 59] In some instances, slum encroachment at the municipal dumping grounds has reduced the amount of land actually available for MSW disposal. [117] 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. [141] To combat these problems, the municipality sometimes sprays disinfectants on the waste. It has also planted about 7,000 trees around the Gorai dump to create a buffer between the dump and residential areas. [85] Table 29 shows a summary of the dumps in Mumbai.

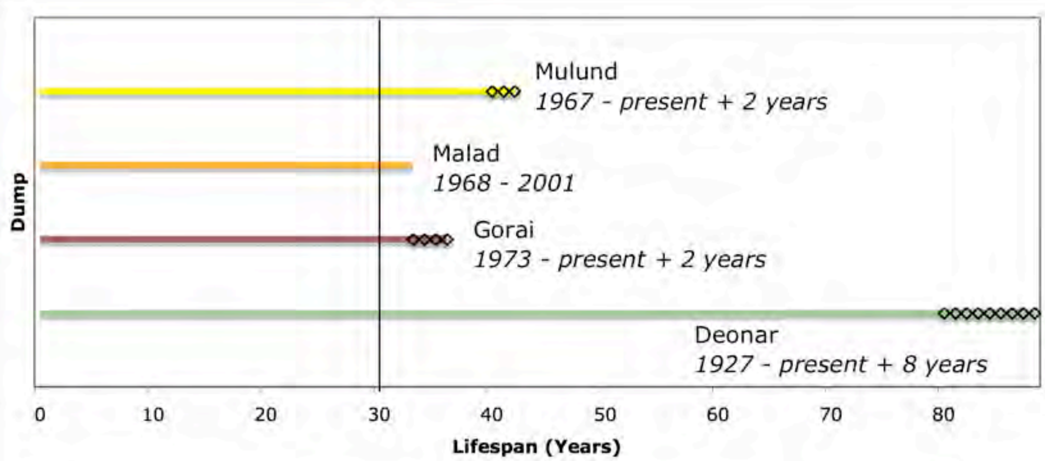

Figure 35: Graphical representation of the lifespan of MSW dumps in Mumbai

Table 29: Summary of MSW dumps in Mumbai [117, 87, 155]					
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

4.8.2 Deonar Dump

The dump at Deonar was opened in 1927 and is the oldest dump in Mumbai. [117] It is located in the eastern suburbs of the city and is adjacent to Thane Creek, as shown in Figure 24. Although the official area of the Deonar dump is 132 ha (1.32 km^2), the amount of land available for disposal is 110 ha (1.1 km^2) due to slum encroachment. As the map of Deonar in Figure 36 shows, slums and residential buildings surround the disposal site, leaving no buffer zone. Figures 37a and 37b clearly show how close both residential buildings and hutments are to the dumping ground.

At present, Deonar receives approximately 4,000 tpd of MSW and 1,000 tpd of C&D waste, [117, 44] and is scheduled to shut down partially with the next two to three years. MCGM plans to convert approximately 75 ha (0.75 km^2) into a waste processing facility to compost 1,500 tons of MSW. It is expected that three composting units, each having a capacity of 500 tpd, will be built to process the entire amount of MSW received. At the time of closure of the landfill, MCGM also plans to set up a facility for the collection and treatment of leachate. [87]

Figure 36: Map showing a bird’s eye view of Deonar Dump in Mumbai

Figure 37a: Ragpickers working at the Deonar dump with residential areas in the background {9}

Figure 37b: Slum dwellings adjacent to MSW at the Deonar dump {9}

Figure 38a: Ragpickers at the Gorai dump, with the MSW abutting the coast without a buffer zone {9}

Figure 38b: MSW disposal at Gorai near residences and coastal habitat {9}

4.8.3 Gorai Dump

The Gorai dump opened in 1973 and is the only dump located in the western suburbs of the city, as shown in Figure 24. It is bordered by Gorai Creek and residential areas that are approximately 750 feet from the landfill perimeter, as shown in Figure 39. An estimated 80,000 people live near the Gorai dump. [141, 87]

The Gorai dump receives approximately 1,200 tpd of MSW and 1,000 tpd of C&D waste from the western suburbs of Mumbai. [117] The road leading to the dump sometimes becomes inaccessible during the monsoons, so the garbage that litters the streets is sometimes dumped into the creek nearby. [141] Figure 38a and 38b show the proximity of the dump to Gorai Creek. This dump is scheduled to close in January 2008. After closure, landfill gas collection facilities, barriers to prevent tidal intrusion into the landfill, and leachate collection and transportation systems are scheduled to be constructed at the site. [87]

Figure 39: Map showing a bird’s eye view of Gorai Dump in Mumbai

4.8.4 Mulund Dump

The Mulund dump was opened in 1967 and is located north of Deonar, as shown in Figure 24. It located in the eastern suburbs, along the Eastern Express Highway. The total area of the dump is approximately 25 ha (0.25 km^2), although only about 21 ha (0.21 km^2) are used for actual waste disposal. Some of the closest buildings to the dump are less than 200 feet from the boundary, but the majority of the buildings are roughly 1,200 feet from the main dumping area, as shown in Figure 40.

At present, the Mulund dump receives around 600 tpd of MSW and 200 tpd of C&D waste. [117, 44] MCGM intends to close about 10 ha (0.1 km^2) of this dump and install landfill gas collection mechanisms in 2008. The Mulund dump will continue to receive primarily bio-degradable waste from commercial entities and process up to 500 tpd by biomethanation. Approximately 4 ha (0.04 km^2) of the dump will be converted into other treatment facilities. [87]

Figure 40: Map showing a bird's eye view of Mulund Dump in Mumbai

Figure 41a: MSW disposal at the Mulund dump with residential buildings in the background {6}

Figure 41b: MSW disposal and leachate at the Mulund dump {6}

4.8.5 Kanjur Dump

A new dump at Kanjur Village in the eastern part of the city, also beside the Eastern Express Highway, is scheduled to open in 2008 on old saltpan land. The Kanjur dump occupies an area of approximately 141.8 ha (1.42 km^2). [117] As Figure 42 shows, there are a number of residential areas near the dump.

It is estimated that the Kanjur dump will process 3,500 tpd of MSW at its composting facility. In addition, a scientific landfill will be constructed for waste not suitable for composting and for inert materials. [117, 87] There has been considerable opposition to the construction of this dump by residents in the area because a disproportionately large amount of land in the eastern suburbs has been diverted for waste disposal over the decades.

Figure 42: Map showing a bird's eye view of the new MSW dump at Kanjur in Mumbai that is scheduled to open in 2008

4.8.6 Malad Dump

The Malad dump, located in the western suburbs, was closed in 2001 by order of the Supreme Court of India. [91] Although according to the Municipal Solid Wastes (Management and Handling) Rules 2000 "post-closure care of landfill" should be conducted for at least fifteen years after closure, development at this site began only two years after it was shut down. [66, 91] Offices, residential buildings, and a mall were built on the site, which was not closed in a scientific manner. No provision for leachate collection was made and only a superficial soil cover with grass was constructed. Consequently, gases have begun to escape causing corrosion problems with electronic equipment in these buildings. Instead of standard failure rates of electronic equipment between 2-5%, repair companies are seeing rates as high as 80%. [92] Environmental testing of air quality found high levels of sulfur dioxide, nitrogen oxides, carbon monoxide, hydrogen sulfide, methane and mercaptans. [91]

4.9 Recycling in Mumbai

Like most cities in developing countries, Mumbai does not have a formal recycling program. This is because, at present, the waste is not segregated at source, which makes it more expensive and cumbersome to remove the recyclables. In addition, as in most low-income countries, the majority of the solid waste management budget is directed towards collection and transportation, thus decreasing the funding available for recycling programs. [143] (See Section 4.3.1 for cost of MSW disposal in Mumbai) The recyclable material is removed from household waste by ragpickers and sold to recyclers. Although there are a number of drawbacks to this method of collection, such as lack of protective gear for ragpickers and no controls on price, it nevertheless provides employment to roughly 100,000 thousand people in Mumbai itself. [145] Because collecting and selling recyclable material from MSW is the only source of income for ragpickers, the removal efficiency is very high.

Since the recycling industry is an unregulated market, there are no official estimates on what the value or the amount of the collected recyclables is. MCGM estimates that the value of the recyclables ranges from Rs. 550-750 million per year ($12-16 million/year) and the amount of recyclables collected is 1050 tpd, which is roughly 19% of MSW generated daily. (See Section 4.7 for characteristics of MSW in Mumbai) [86, 87] However, these numbers should be used with caution, as it is unclear how these figures were calculated.

Figure 43 shows the process of recovering and selling recyclable material in the informal sector. Most of the households and institutions collect items for re-sale, such as glass bottles, plastic containers, cans, newspapers, and magazines, which are then either sold to itinerant waste buyers, who go from house-to-house collecting these goods, or are taken to waste dealers, or *radiwallas*. Smaller recyclables, such as waste paper and plastic packaging, are disposed off in MSW, which is then collected by the MCGM from house-to-house collection or community bins. Ragpickers then sort through the MSW at community bins or the waste dumps, collecting any recyclable material they can find. Figures 44a, 44b, and 44c show various plastic items that are collected for recycling by ragpickers. Ragpickers then sell the recyclables to waste dealers, who collect and segregate the materials, and then sell them to the wholesaler, as shown in Figure 45. The wholesaler then sells it to the recycler. [143, 102]

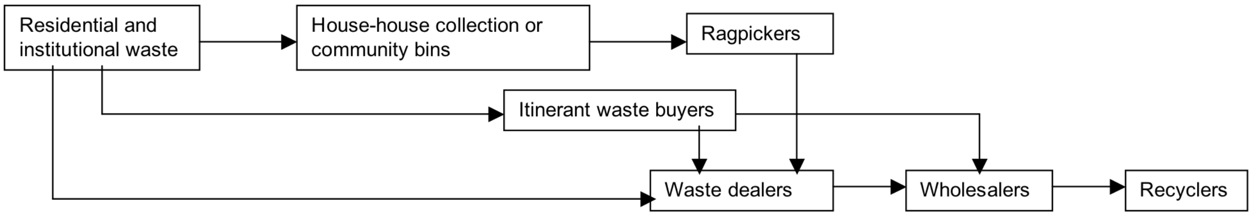

Figure 43: Flow of recyclable material recovery and reuse in the informal sector

Figure 44a: Milk pouches collected for recycling {12}

Figure 44b: PVC sandals that will be recycled into new footwear {12}

Figure 44c: Plastic packaging used for food products {12}

Figure 45: Waste dealer weighing and packaging recyclable material for re-sale in Mumbai

5. THE CASE FOR WASTE-TO-ENERGY IN MUMBAI

5.1 Background

There are over 600 waste-to-energy facilities worldwide that convert around 155 million tons of MSW per year to electricity or district heating (cooling). [130] Over the last two decades, the waste-to-energy industry has been highly effective in reducing the volume of waste being sent to landfills, decreasing the amount of air pollution generated by WTE facilities, and increasing the efficiency of energy recovery from MSW. Waste-to-energy is highly beneficial for areas that are very populated and short on space (such as islands), as well as to provide a renewable source of energy and decrease the amount of fossil fuels used for the same.

This chapter first describes the MCGM's current plan for managing solid waste in Mumbai. MCGM is in the process of introducing source segregation of MSW in Mumbai, upgrading its collection and transportation services, and promoting waste treatment technologies, such as composting, biomethanation, and RDF. Section 5.3 lays out a proposal for an integrated solid waste management strategy for Mumbai, by combining elements of the MCGM's plan and including a waste-to-energy facility. The proposal considers the cost and revenue streams to build and operate a WTE facility in Mumbai, examines the suitability of Mumbai MSW for WTE, and discusses the land requirements for such a project. Section 5.4 presents reasons why waste-to-energy is necessary, and would be successful for, Mumbai city.

5.2 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, 2000. These initiatives are briefly discussed in this section.

5.2.1 Source Segregation

MCGM has implemented a new rule to segregate garbage into "wet" and "dry" at the household level. Source segregation has been introduced through pilot schemes in Mumbai, such as the Slum Adoption Scheme and the Advanced Locality Management system; however it has yet to be implemented on a large scale. [117] The method of source segregation in Mumbai, which is practiced in many developed countries around the world, is to encourage households would separate organic waste into black or colored bags and dry, or recyclable, waste into white bags. [135] The wet waste is taken to dumps for treatment, 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, [117] which is a lofty target given that only a small proportion of the city is currently practicing source segregation. [107] An important drawback of segregation at source is that there is no way to monitor whether households are, in fact, separating their waste, especially in a populous city like Mumbai.

5.2.2 Improved Transportation

MCGM is committed to improving transportation of MSW by upgrading vehicles and privatizing transfer stations. As discussed in Section 4.5, three new transfer stations will be constructed in order to improve the efficiency of transporting MSW to the dumps. 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. [86] 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, which will lower the number of trips needed, and hence the cost and pollution generated by trucks, from the transfer stations to the dumps. Compaction will also decrease the moisture content of the waste by 20%. [117]

5.2.3 Treatment of MSW

Once both dumps at Gorai and Mulund are closed in 2008, Deonar and Kanjur will be the only remaining dumps. In order to maximize the lifespan of the two dumps and adopt more environmentally friendly methods of MSW disposal, MCGM hired Infrastructure Leasing & Financial Services (IL&FS) Ecosmart to conduct a study on waste processing technologies suitable for Mumbai. Per IL&FS Ecosmart's recommendations, the MCGM has decided to pursue composting, biomethanation, and RDF at Deonar, Kanjur, and Mulund.

As discussed in Section 4.8, all 5,800 tons of MSW generated daily will be treated before final disposal, as shown in Table 30. [117]

Table 30: Methods and amount of Mumbai MSW to be treated [117]

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

IL&FS estimated that the total cost of introducing composting, biomethanation, and RDF into Mumbai's solid waste strategy would be approximately Rs. 4.96 billion ($110 million). It is expected that the private sector will finance slightly more than 50% (Rs. 2.54 billion or $56 million), central and state government funding will contribute 35% (Rs. 1.72 billion or $38 million) and the rest will be covered by the MCGM (Rs. 700 million or $15 million). In comparison, the cost of upgrading the fleet to transport MSW is Rs. 4.76 billion ($105 million) according to the MCGM. Hence, it is likely that the costs for MSW treatment will be significantly higher than projected by IL&FS.

Revenues from these treatment methods will be earned through tipping fees paid by the MCGM to the promoter, as well as through the sale of compost and energy produced through biomethanation and RDF. However, the analysis conducted by IL&FS shows that the assumptions made for tipping fees are very low and for the price of compost are very high. For example, assuming that 100% of the compost is sold at Rs. 1,800 per ton ($40/ton), the tipping fee at Kanjur would be Rs. 90 per ton ($2/ton). [117, 44] Although IL&FS does perform a sensitivity analysis, the range of compost prices used is still too high.

Moreover, composting and biomethanation are generally slow processes, which means that if Mumbai plans to treat 5,000 tpd by these methods, the land requirement will be very large. In addition, for both processes, the MSW used must be free of contaminants and inert materials in order to maintain the quality of the compost or the gas. The compost will be sold to fertilizer manufacturers and would need to be transported to Pune city approximately 200 km from Mumbai. [117] This would significantly increase the overall cost of the compost.

5.3 A Proposal for Waste-to-Energy in Mumbai

This section recommends a strategy for implementing an integrated solid waste management plan for Mumbai and how WTE can be successfully incorporated into the plan. Various aspects of introducing waste-to-energy in Mumbai, such as appropriate technology, costs, suitability of waste, and land requirement are discussed in detail. Where appropriate, comparisons have been made to landfilling MSW.

5.3.1 Components of the Proposal

5.3.1.1 Integrate Waste Streams

As described in Section 4.4.1, the MCGM is not responsible for collection and disposal of C&D and industrial waste, yet because of lack of monitoring and enforcement by regulatory agencies, the MCGM is forced to collect these wastes. This overburdens the capacity of the municipality to collect and dispose of waste in an effective manner. If the MCGM took on 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.

5.3.1.2 Separation of Waste and Recycling

Source segregation is an important part of integrated solid waste management and must be encouraged. However, it is unlikely that Mumbai will switch from not segregating their waste to segregating all of it within a span of a few months. Not only does the infrastructure need to be developed in the form of separate community bins and trucks for collecting and transporting wet and dry garbage, but people also need to be educated through public campaigns on the benefits of source segregation. Instead of creating sorting centers at the ward level as MCGM plans to do, [86] 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 it could utilize to pay ragpickers' salaries.

5.3.1.3 Treatment of Waste

Once the waste has been sorted according to the type of treatment 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 for non-recyclable waste.

5.3.1.4 Starting 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 Kanjur site, which can also be used for the final disposal of ash formed during the combustion process. This would minimize transportation costs of the ash. Combining MSW with industrial waste would increase the heating value of the waste and act as a better fuel source. The following sub-sections discuss these aspects in greater detail.

5.3.1.5 Expanding WTE facilities in the future

After a WTE facility in Mumbai successfully showcases the benefits of WTE, a larger facility can be constructed, which would accept waste from surrounding municipalities. This would ensure that suitable waste with the highest heating value is used as a fuel. As has been proposed for New York City, Mumbai can utilize its waterways such as the Thane and Vasai Creeks, to transport waste to WTE facilities in neighboring areas. This would significantly decrease transportation costs, emissions from trucks, and traffic in Mumbai.

5.3.2 Technology Options for MSW

Appropriate waste treatment technology should be selected based on the characteristics of the waste generated. Waste processing technologies can be broadly divided into two categories: thermal treatment and chemical conversion. Figure 46 shows the various technologies that fall under each category. Given that this report focuses on combustion technology for MSW treatment, only thermal processing technologies are described briefly in this section.

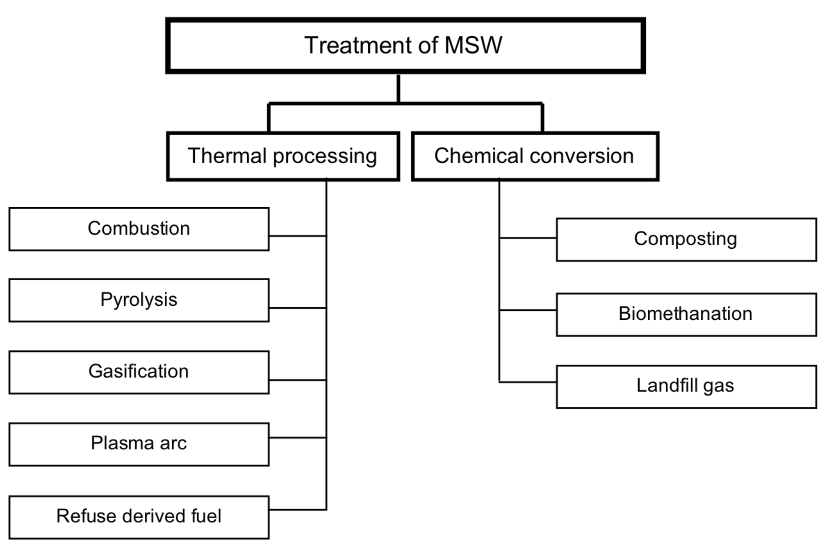

Figure 46: Treatment options for municipal solid wastes

1. *Combustion:* Combustion, or mass burn, is the process of burning materials, in this case MSW, in the presence of air, to convert chemical energy into heat or electricity at temperatures around 800-1000ºC. Generally, combustion works best when the MSW has a moisture content of <50%. [61] Figure 47 shows a schematic of a typical MSW mass burn plant. Mass burn plants are the simplest and most common of WTE technologies.

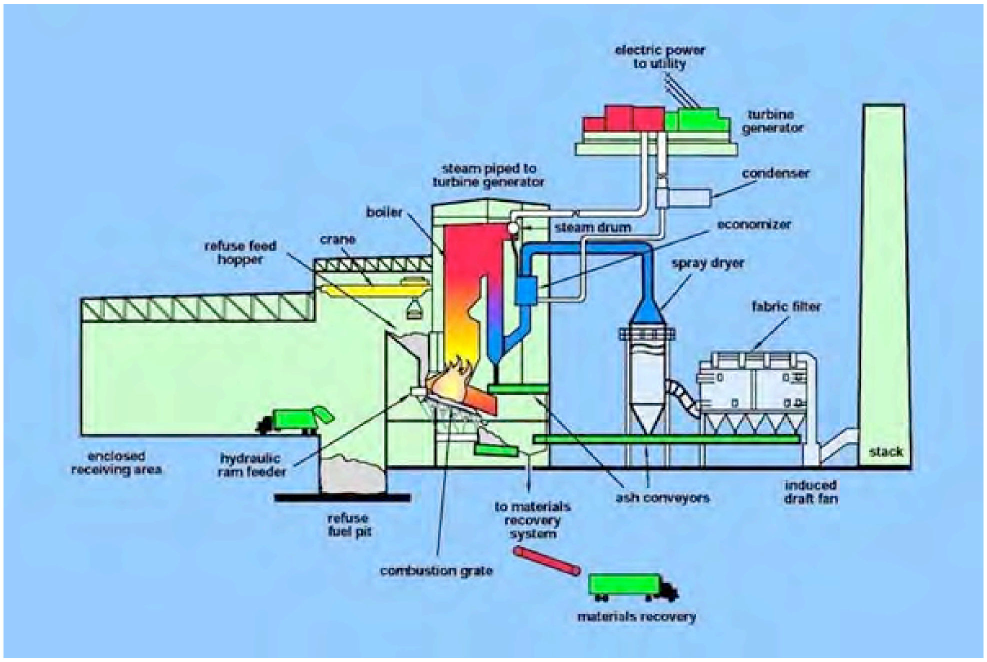

Figure 47: General schematic of a WTE facility {4}

Mechanical grate and circulating fluidized bed (CFB) are two common methods of mass burn. In a mechanical grate, the MSW is placed on a moving grate and is combusted as it moves along the grate. Figure 48 shows the MSW on a grate being fired in a boiler. In a CFB, MSW is suspended by upward-blowing jets of air during the combustion process, as shown in Figure 49. The turbulent action results in more efficient reactions and heat transfer. CFB technology has been developed and is used more commonly in China at much lower capital costs than grate technology. [157, 128] Given the low capital costs for CFB, this technology would be suitable for Mumbai. Section 5.3.3 discusses the investment costs for a WTE facility in Mumbai.

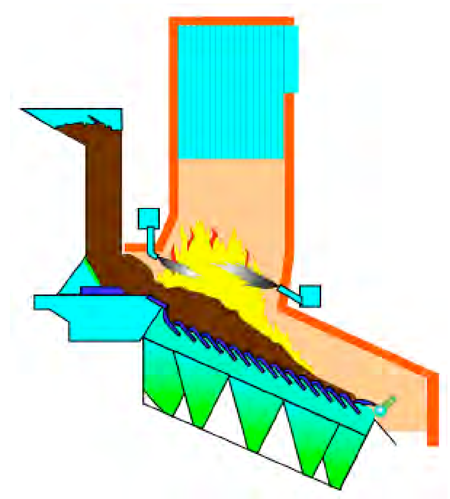

Figure 48: Moving grate technology used in WTE facilities {18}

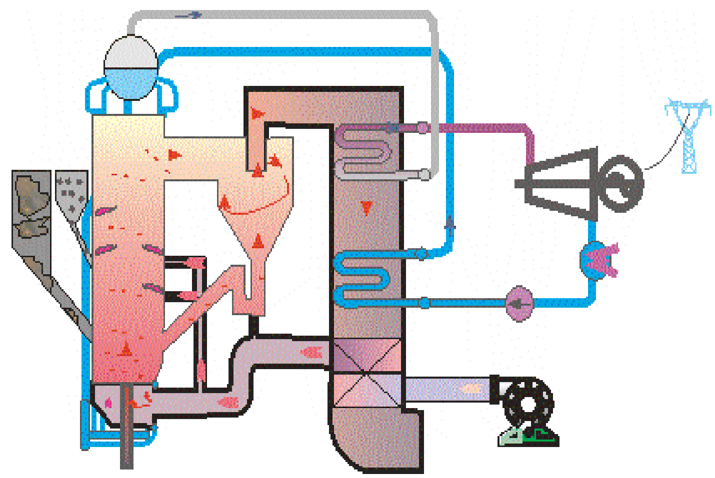

Figure 49: Circulating fluidized bed process for WTE facilities {19}

2. *Pyrolysis:* In pyrolysis, the organic fraction of MSW is degraded under pressure and in the absence of oxygen at temperatures ranging from 500-1000ºC. This process produces solid (char), liquid (pyrolysis oil), and gaseous (syngas) products. [104]

3. *Gasification:* Gasification is the process of converting MSW at higher temperatures than that of pyrolysis and in the presence of limited oxgyen to produce syngas (*syn*thetic *gas*, consists of hydrogen and carbon monoxide). [32]

   Pyrolysis and gasification are similar thermal processes of treating MSW. They differ from incineration because they limit the conversion of MSW to form intermediates, instead of combusting the MSW directly, that are then used for energy recovery. [103] Pyrolysis and gasification are more expensive than combustion.

4. *Plasma arc:* Plasma arc technology uses an electrical arc, created between two electrodes, to decompose MSW into its elements (carbon, hydrogen, oxygen, and so on). The resultant products are hydrogen-rich plasma converted gas (PCG) and slag from inorganic products. It operates at temperatures as high as 13,000ºC, thus preventing the formation of dioxins and other pollutants. Hence, it is useful for treating hazardous and bio-medical waste. However, it is considerably more expensive than combustion and would not be suitable for MSW treatment in Mumbai until it becomes more economical. [99, 100]

5. *Refuse Derived Fuel:* In an RDF system, MSW is processed, most commonly by shredding, prior to combustion. Noncombustible materials, such as glass and metals, are removed before the MSW is converted into pellets or briquettes by densification or compression. The RDF can be used on its own or combined with other fuels to produce energy. [111] Although this process creates a uniform fuel, a considerable amount of energy is used in the creation of RDF, and hence the energy benefits derived from it need to be analyzed in detail before this method is chosen as a waste processing option. [114]

5.3.3 Potential Costs of a WTE Facility in Mumbai

The capital and operating costs to set up a WTE facility in Mumbai are discussed in this section. All assumptions are clearly stated.

5.3.3.1 Capital Costs

One of the main deterrents for setting up waste-to-energy facilities is the high capital cost. In the EU and the US, the capital costs range from $110,000 to $140,000 per daily ton of capacity. [152] However, as stated in Section 5.3.2, 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. [157, 128] On the basis of the China experience, this report assumes a capital cost of $50,000 per daily ton of capacity for Mumbai. If a WTE facility were set up in Mumbai using CFB technology to treat 800 tpd of MSW, the capital cost would be approximately $40 million. It is assumed that the total capital expenditure takes place in first year, i.e., Year 0.

It is estimated that the land required for a WTE facility in Mumbai would be 6 ha (0.06 km^2). [29] Based on government regulations explained in Section 5.3.4.1, it is assumed that the annual rent paid for the land would be Rs. 60,000 ($1,200/year) and would not increase for the lifespan of the plant.

5.3.3.2 Operating Costs

The main operating costs considered here are maintenance and labor costs. Maintenance costs are assumed to be $6 million per year, based on maintenance costs of a Covanta Energy WTE Facility in Essex, New Jersey.[5] [115] It is assumed that maintenance costs increase by $1 million every 10 years for the WTE facility in Mumbai.

Labor costs are calculated for a team of 50 workers, as shown in Table 31. It is assumed that labor costs for the first year are $170,000, and increase annually by 5%.

Table 31: Salary assumptions for labor at a WTE facility in Mumbai

Position	Number	Monthly salary (Rs.)	Monthly salary ($)	Total monthly salary ($)
Manager	1	45,000	1,000	1,000
Assistant Manager	1	45,000	1,000	1,000
Foreman	4	33,750	750	3,000
Administrative Assistants	4	13,500	300	1,200
Facility Worker	40	9,000	200	8,000

[5] Covanta Energy is a leading owner and operator of waste-to-energy plants in the US. The Covanta plant in New Jersey includes a state-of-the-art control room to monitor boiler operations and emissions, air pollution control equipment to remove pollutants, mechanisms to recover both ferrous and non-ferrous materials, and two 35 MW turbines to generate electricity that is sold to the grid and one 6.5 MW turbine that provides power to the facility itself.

Other expenses are estimated to start at $1 million per year and increase by $500,000 every 5 years.

5.3.4 Potential Revenues of a WTE Facility in Mumbai

A WTE facility earns revenues by two primary means. First, by collecting a tipping fee from the municipality for the MSW that the municipality sends to the WTE facility for treatment; and second, by selling the electricity produced by the facility to the electricity grid. In Mumbai, the WTE facility would be required to sell the electricity produced to Tata Power Company (TPC), Reliance Energy Ltd. (REL), or Brihanmumbai Electric Supply and Transport (BEST). (See Section 5.4.5.1 for more information on Mumbai's electricity supply)

5.3.4.1 Revenues from Sale of Electricity

The heating value per ton of MSW in Mumbai is approximately 9,022 MJ or 2,508 kWh/ton of MSW. (See Section 5.3.6.1 for a discussion of the heating value of Mumbai MSW) Assuming that the average efficiency of a waste-to-energy plant is 25%, approximately 627 kWh of energy can be produced per ton of municipal solid waste combusted. If the plant uses 15%, or 94 kWh, of the electricity produced internally, each ton of MSW combusted could contribute 533 kWh to the grid. At the rate of $0.08/kWh, one ton of municipal solid waste could generate about $43.

The Maharashtra Electricity Regulatory Commission (MERC), which is the state agency responsible for setting tariffs related to power purchase, transmission, and distribution, determined the tariff, or electricity rate, for power purchased from MSW-based plants in 2004. [57] This was done in response to a petition filed by a company that wanted to start an MSW-based power generation plant in Mumbai. Although the project did not materialize for a number of reasons, the tariff would have been Rs.3.5 per kWh ($0.08/kWh) in 2007 and would have gradually increased to Rs. 5 per kWh ($0.11/kWh) by 2015.[6] MERC also provided the following guidelines [58]:

- The municipal corporation, i.e., MCGM, would provide land for the waste-to-energy plant at Rs. $1/m^2$/year ($\$0.02/m^2$/year). Given the high value of land and high rental costs in Mumbai, this provision determines that the land would be provided virtually free of cost to a waste-to-energy operator.
- The operator will receive a sales tax benefit of no more than 50% of the total investment cost.
- Any octroi, or a local tax on goods brought into a district, on machinery will be refunded in full.

[6] As described in Section 5.4.5.1, Tata Power Company and Reliance Energy Ltd. are the two primary generators of electricity to Mumbai. Their tariffs are determined by MERC, as was the power tariff for the waste-to-energy proposal described in Section 5.3.4.1. As of 2004, TPC supplies power to BEST for Rs. 1.41-1.95 per kWh ($0.03-0.04/kWh), to REL for Rs. 1.45-2.00 per kWh ($0.03-0.04/kWh), to the railways for Rs. 2.57 per kWh ($0.06/kWh), and between Rs. 3.30-4.00 per kWh ($0.07-0.09/kWh) for industrial consumers. [124] REL's tariff charges range from Rs. 1.15 per kWh ($0.02/kWh) for residential customers to Rs. 5.50 per kWh ($0.12/kWh) for commercial institutions. [113] Hence, the tariff determined for the waste-to-energy facility in Mumbai seems to be reasonable.

According to MERC, the WTE facility could increase its tariff by 5% per year for the first 10 years, then keep it constant for three years, after which it could once again increase the tariff by 5% per year. [58] A similar methodology has been used to calculate the tariff for a WTE facility in Mumbai, starting at a rate of $0.08/kWh. Detailed calculations for estimates of annual revenues from sale of electricity to the grid are shown in Appendix 6.

5.3.4.2 Revenues from Tipping Fees

A tipping fee is a fee charged to unload waste at a transfer station, landfill, or treatment facility. For the purposes of this analysis, it is assumed that MCGM would pay the WTE operator Rs. 225 per ton ($5/ton) for the first 10 years, Rs. 360 per ton ($8/ton) for years 11-20, and Rs. 405 per ton ($9/ton) for the remaining five years. It should be noted that these tipping fees are hugely underpriced compared to other countries. For example, the average tipping fee at incinerators in the US was $61.64 in 2004. [114] In the EU, tipping fees at landfills tend to be much higher than at incinerators given the environmental benefits of WTE over landfilling. Detailed calculations for estimates of annual revenues from tipping fees are shown in Appendix 7.

5.3.4.3 Revenues from Greenhouse Gas Emission Credits

A potential source of revenue for a WTE facility is through the Clean Development Mechanism (CDM) of the Kyoto Protocol. CDM is a mechanism set up by the Kyoto Protocol by which developed nations can help developing countries, such as India, reduce their greenhouse gas emissions. This can either be done through Certified Emission Reductions (CERs), projects registered under the UN Framework Convention on Climate Change, or Voluntary Emission Reductions (VERs), projects that do not fall under CDM for technical reasons. Each CER or VER refers to a reduction of 1 ton of carbon dioxide that would have been emitted had the project not been implemented. According to the MCGM, the prevailing market rate for an emissions reduction project in Mumbai is $7 per CER and $5 per VER. [86] (See Section 5.4.7 for how many tons of carbon dioxide would be omitted if Mumbai had a WTE facility) At present, there are no approved methodologies for waste-to-energy combustion technologies, and hence this revenue stream has not been included in the cash flow analysis. However, new methodologies are added frequently and hence CDM credits for a WTE facility in Mumbai are a potential source of revenue in the future.

5.3.5 Economic Analysis of a Potential WTE Facility in Mumbai

Given the various costs and revenues detailed in Sections 5.3.3 and 5.3.4, a cash flow analysis was conducted for a potential WTE facility in Mumbai, as shown in Appendix 8. Assumptions and results for the cash flow are as follows:

- A time period of 25 years was used, as specified by the MCGM for waste treatment technologies; [86]
- Straight-line depreciation was employed to calculate depreciation of capital investments;
- A tax rate of 35% was used; and
- A discount rate of 10% was used, which resulted in an NPV of around $19 million; and
- The payback period for the investment is 13 years.

5.3.6 Suitability of Mumbai MSW for a WTE Facility

This section discusses the suitability of MSW in Mumbai for waste-to-energy technology. The heating value, moisture content, and volume reduction of MSW are discussed.

5.3.6.1 Heating Value of MSW in Mumbai

It is important to calculate the potential energy production from a waste-to-energy facility in order to assess how much energy, in the form of electricity and/or heating, can be created and sold. Although the MCGM reports that the average heating value is 3,898 kJ/kg, this report calculated that the average LHV is 9,022 kJ/kg, based on the values of energy content of MSW components given in Tchobanoglous (1993).

A compositional analysis was conducted to calculate the heating value of Mumbai MSW. The composition of the waste was taken from a study conducted by MCGM on the average MSW reaching the Deonar dump in 2006. (See Section 4.7 for detailed breakdown of MSW components in Mumbai) [87] Based on these data, the heating value of municipal solid waste in Mumbai is estimated to be approximately 9,022 kJ/kg. Table 32 details the composition and heating values for the various components found in MSW in Mumbai. Based on this calculation, the waste is appropriate as a feedstock for MSW. According to the World Bank, a minimum heating value of 7,000 kJ/kg is necessary in order to operate a waste-to-energy facility without additional fuel sources. [108]

Another possibility for the waste-to-energy facility in Mumbai is to design the plant so it can utilize a mix of MSW and combustible industrial or commercial wastes that are generated in the area (e.g., plastic and rubber remnants that cannot be recycled in the primary manufacturing process).

Table 32: Calculation of heating value of Mumbai MSW

Component	Fraction of component (%)	Energy content (kJ/kg)	Heating value of component fraction (kJ)
Kitchen waste	39.24	4,180	1,640
Fruit waste	8.33	3,970	331
Flower waste	0.14	6,050	8
Green grass	0.62	6,050	38
Dry grass/tree	9.58	15,445	1,480
Other organic material	3.79	4,180	158
Cotton waste	2.48	15,445	383
Wood chips/furniture	0.95	15,445	147
Plastic	10.14	32,799	3,326
Paper	7.52	15,814	1,189
Thermocol	0.19	38,191	73
Glass	0.71	195	1
Rubber	0.52	25,330	132
Leather	0.67	17,445	117
Metals	0.19	-	-
Inerts	14.93	-	-
TOTAL	100		9,022

5.3.6.2 Moisture Content of MSW in Mumbai

The moisture content of MSW in Mumbai is approximately 50% during the dry season and 65% during the monsoons. [14, 86] Generally, MSW with a moisture content greater than 50% is not suitable for incineration. [61] 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%. [117] This will result in a moisture content of approximately 30% during the dry season and 45% during the monsoons, which makes the MSW suitable for combustion.

5.3.6.3 Volume Reduction of MSW using WTE Technology

The combustion process in waste-to-energy facilities results in a volume reduction of about 90%. [152] The remainder is in the form of either bottom ash, formed during the combustion of MSW, or fly ash, which is the leftover ash after the flue gas has been processed by air pollution control equipment. Based on the characteristics of MSW in Mumbai, the volume reduction through combustion would be around 96.7%. The approximate reduction in the volume of waste and the volume of the residue after combustion for Mumbai's waste are calculated in Box 5.

Box 5: Calculations of Volume Reduction of MSW Disposal in Mumbai using WTE Technology

The original and residue volumes before and after combustion can be calculated using the following formulas [125]:

Original volume = Amount of waste prior to combustion ÷ Density of waste prior to landfilling/combustion

Residue volume = Amount of waste after combustion ÷ Density of waste after combustion

Assumptions:

1. The components and their relative concentrations in Mumbai waste are based on a study conducted by MCGM in the Deonar dumping ground. (See Section 4.7) The amount of inert residue (%) is based on ultimate analysis of combustible materials by weight on a dry basis. [125] Certain substitutions were made for components that did not have inert residues:

Table 33: Substitutions for MSW components to calculate volume reduction

Component	Substitute
Flower wastes, green grass	Yard wastes
Dry grass/tree, cotton waste, wood chips/furniture	Wood (mixed)
Other organic material	Food wastes (mixed)
Thermocol	Polystyrene

2. The density of waste before it is either combusted or landfilled is 375kg/m^3 (see Table 4)
3. The density of waste after it is combusted is 600 kg/m^3

Results

1. Original volume = 100 kg ÷ 375kg/m^3 = 0.27 m^3
2. Residue volume = 5.26 kg ÷ 600 kg/m^3 = 0.0087 m^3

Therefore, the total volume reduction is ((0.27 – 0.0087) ÷ 0.27) * 100 = 96.7%

5.3.6.4 Beneficial Use of Bottom Ash from WTE Facilities

The ash from waste-to-energy facilities consists of “bottom ash,” about 20% of the weight of MSW in the US, and fly ash (2-3% of the weight of MSW in the US). [128] After recovering ferrous and non-ferrous metals, the bottom ash has various beneficial uses, such as in road construction (in place of stone aggregate), to form concrete blocks (mixed with a small amount of cement) that are used for shore protection and artificial reefs, as fill material, and as a daily and final cover for landfills. [46, 77] In some cases, up to 90% of the ash can be used, thus drastically reducing the total amount that needs to be landfilled. [77]

The WTE fly ash contains mercury, cadmium, lead, and other heavy metals. After stabilization with phosphate addition, the fly ash is safely disposed in MSW landfills. [128]

5.3.7 Land Requirements and Siting of a WTE Facility in Mumbai

For the purposes of this study, an area of 6 ha (0.06 km^2) is estimated for a WTE facility in Mumbai. This value was chosen based on a survey of approximately 20 WTE facilities and their daily capacities around the world. [29]

The siting of a WTE plant is a key component of the overall waste-to-energy strategy. The location should be such that garbage transportation costs and times do not increase substantially, i.e., the plant should be located near areas that generate the maximum amounts of waste. However, the plant should be at a sufficient distance from residential areas to minimize public opposition to its construction and reduce the impact of dump truck traffic, noise, and emissions through these areas.

Given the shortage of space in Mumbai, there are limited options for building a WTE facility. At first thought, building a facility at a closed landfill, such as Malad (Section 4.8.6), or one that is scheduled to be closed in 2008, i.e., Gorai, would minimize the need to develop new land for waste treatment and would be able to use the existing infrastructure to transport MSW. However, construction over dumps is unsuitable for a number of reasons:

- The high organic content and varying degrees of strength of the old landfill ground would make foundations unstable;
- Production of leachate over time may weaken and wear out the building’s foundation; and
- The continued decomposition of garbage produces methane and other toxic gases, which maybe flammable or cause corrosion problems. [16, 140]

In fact, a number of buildings constructed over old dumps in Mumbai have had to be evacuated or demolished because they were deemed unsafe. [16] The Municipal Solid Wastes (Management and Handling) Rules, 2000, state that no construction should be allowed on landfills for at least 15 years after they have been shut down. [66] Furthermore, as discussed in Section 4.8.6, the construction of buildings on the old Malad dump in Mumbai has led to a number of problems, such as corrosion of electronic equipment, odors, and so on.

A suitable site for a WTE facility would be the area demarcated for the new dump to be started in early 2008 at Kanjur. The Government of Maharashtra has allocated approximately

142 ha (1.42 km^2) to the MCGM for the development of the new dump, of which the MCGM has earmarked 86 ha (0.86 km^2) for a waste processing facility and sanitary landfill. [85, 87]

5.3.7.1 Land Required for MSW Disposal in Open Dumps

Mumbai has been unable to maintain proper disposal of waste due to the severe shortage of land. With millions of people living in slums or whole families often having to live in one room, the priority has been to develop areas for housing and development. Based on the assumptions made and calculations show in Box 6, between 2001 and 2010, an additional 35 ha (0.35 km^2) of land will be required each year (or a total of 315 ha (3.15 km^2) for the nine-year period) for waste disposal. If the US average of 10 tons of MSW/m^2 is used, the annual land requirement between 2001 and 2010 is 20.5 ha (0.21 km^2), or 185 ha (1.85 km^2) for the nine-year period. These calculations do not take into consideration a buffer zone needed between the dump and housing and office developments, utility roads, etc. An extra 20-40% should be added to the required dumping area for such a buffer zone. [125] For the last forty years, Mumbai has used a total of 170 ha (1.7 km^2) to dump its waste on. In comparison, a WTE facility would have a footprint of only 6 ha (0.06 km^2).

5.3.7.2 Price of Land Used for MSW Disposal in Open Dumps

One of the main concerns regarding solid waste management in Mumbai where to send the large amount of wastes that are generated. Land is already at a premium given that Mumbai is an island and hence has very limited space to develop laterally. Mumbai's real estate prices are amongst the highest in the world. Section 5.3.7.1 shows the amount of land that would be required if most of the waste is landfilled. This section estimates the monetary value of the land.

It is assumed that one square foot of land costs Rs. 600 ($13.33/$ft^2$). This is based on the current price of a piece of land in Malad, which is where an MSW dump was closed down in 2001. [43] Although this amount may seem high, Kanjur and its surrounding areas are rapidly developing. [50] In fact, in its report on "Transforming Mumbai into a world-class city," McKinsey & Company suggests that areas like Kanjur be developed for low-income housing. [6] In light of this, the amount of Rs.600/ft^2 seems reasonable.

Box 6: Calculations of Land Required for MSW Disposal in Open Dumps in Mumbai

The area required for MSW disposal can be calculated using the following formulas (based on Tchobanoglous):

$$Vol_{req} = G_w \div \rho_w$$

$$Area\ required/year = (Vol_{req} * 365\ days/year) \div D_w$$

Where:
G_w = Amount of MSW sent to landfill per day
ρ_w = Density of MSW
D_w = Depth of compacted MSW
Vol_{req} = Volume of space required per day

Assumptions:
1. Amount of MSW generated per day taken from calculations in Table 26
2. In 2001, ragpickers removed approximately 25% of the waste before it was landfilled. [154] As consumption of recyclable material increases, the amount of waste that is recycled or removed by ragpickers increases by roughly 5% every 10 years.
3. Amount of waste destined for dump G_w = Amount of waste generated per day * (1 – amount removed by ragpickers)
4. Various sources have different estimates of waste density at the landfill, ranging from 260 kg/m^3 [154] to 1 ton/m^3. A density of 650 kg/m^3 was chosen for the calculation.
5. The all-India average depth of dumps is given as 4 m [39, 140, 154]; however, the MCGM reports a range of 5.1 m (Mulund) to 10.2 m (Gorai) for the dumps in Mumbai. Hence, an average of 7 m is used here.

Results:

Table 34: Calculations for future land required for MSW disposal in open dumps in Mumbai

Year	Waste generated (tpd)	Amount removed by ragpickers (%)	Waste sent to dump (tpd)	Volume of space required (m^3/day)	Area required for waste disposal (ha/year)
2001	5,800	25	4,350	6,692	35
2010	7,757	30	5,430	8,354	44
2015	9,116	32.5	6,153	9,467	49
2020	10,713	35	6,963	10,713	56

5.4 Direct Benefits of a WTE Facility to Mumbai

Sections 3.3-3.9 describes the benefits of adopting waste-to-energy technology in India. This section focuses on the advantages of having a WTE facility in Mumbai's backyard. Contrary to public opinion and environmental opposition in Mumbai, introducing a WTE facility would decrease pollution from waste that would otherwise have been landfilled, free up land so that it is available for housing and development, promote recycling, decrease costs and pollution associated with transport of MSW, provide a supplemental energy source to meet some of Mumbai's electricity demand, provide a source of renewable energy to meet the state government's requirement to obtain a portion of the total energy demand from alternative sources, and displace a significant amount of greenhouse gas emissions from fossil fuels.

5.4.1 Decreases Environmental Pollution Related to MSW Disposal in Mumbai

5.4.1.1 Background

The MSW dumps in Mumbai are a significant source of air, surface, and groundwater pollution in the city and surrounding areas. The Mumbai Metropolitan Region Development Authority (MMRDA) prepared a matrix of environmental concerns for various land use activities in the Greater Mumbai Region, and ranked the various problems in one of three stages, if applicable: 'requires attention,' 'potential to cause concern,' and 'likely to cause significant concern.' Table 35 shows that environmental problems related to solid waste disposal in and around Mumbai are likely to cause a significant amount of concern. [82] Since emissions from WTE facilities have been discussed in great detail in Section 3.5.1, the following sections highlight the various forms of environmental pollution from landfills. Needless to say, a WTE facility in Mumbai would decrease or eliminate many of these problems. It is important to note that European countries with more stringent environmental regulations than most other countries in the world commonly use WTE technology to treat their waste and are phasing out the use of landfills.

Table 35: MMRDA environmental concerns regarding solid waste disposal in Mumbai [82]

Environmental problem	Degree of concern
Air Emissions	
Particulate smoke	Likely to cause significant concern
Gases	Likely to cause significant concern
Odor	Likely to cause significant concern
Liquid generation	Likely to cause significant concern
Hazardous and toxic waste generation	Potential to cause concern
Noise generation	Potential to cause concern
Traffic congestion	Potential to cause concern

5.4.1.2 Air Pollution

Air pollution is primarily caused by odor, methane emissions, and landfill fires. MSW in Mumbai is deposited without any soil cover, thus allowing odors to permeate to nearby housing complexes. In addition, ragpickers often start fires in order to retrieve metals and glass. This not only harms their health but also causes significant air pollution, including emissions of dioxins and furans.

Refuse burning at the dumps causes a significant increase in air pollution. Extremely high emissions from the Deonar, Gorai, Malad (while it was still open), and Mulund dumps were estimated by two consultants, AES, Ltd. and NEERI, and are shown in Table 36. These estimates were based on data collected by the MCGM in 1997 (Figure 50 and Table 37). [116] Figure 50 and Table 37 also show the city-wide averages for the same pollutants during 1997. It can be seen that the emission levels from burning garbage at the dumps are significantly higher than the average for the city, and are at dangerously high levels for public health as shown by the national ambient standards. Interviews with residents in surrounding areas and NGOs confirmed that the smoke is felt up to the third or fourth floor of nearby buildings and to a downwind distance of as much as 4 km from the landfill. The predominant wind direction is north/north-east in the winter, thus causing high levels of pollution in the city.[7] [148, 85]

Table 36: Emissions of pollutants estimated at MSW dumps in Mumbai in 1997 (kg/hr) [116]

Source	Total suspended particulates	SO_2	NO_x
AES	54.3	3.4	20.4
NEERI	39.6	3.0	7.3

Table 37: Emissions of pollutants at MSW dumps in Mumbai as estimated by MCGM in 1997 ($\mu g/m^3$) [116]

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

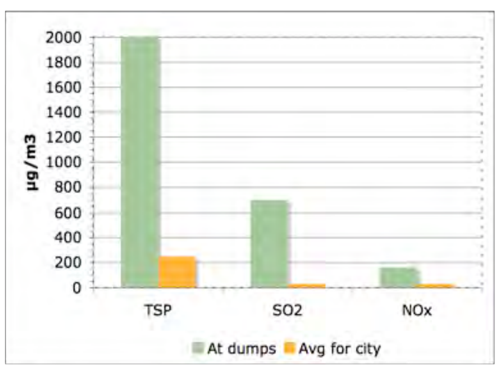

Figure 50: Graphical representation of emissions from MSW dumps in Mumbai in 1997

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[7] Note: The average values for the city are for industrial areas because the majority of the dumps as well as the industries are concentrated in the north/north-eastern part of the city; the average TSP for the city is substituted by the average SPM for the same period; the national ambient standards shown in the table apply to residential areas.

In addition to this study in the mid-nineties, the MPCB estimated the emissions from refuse burning in 2004-05, as shown in Table 38. [60] It is shown that a total of about 9 tons of these major pollutants are emitted per day, i.e., 3,300 tons /year of these pollutants.

Table 38: Estimated emissions from refuse burning (tpd) [60]

Pollutant	Emissions
Sulfur dioxide	0.11
Particulate matter	1.37
Nitrogen oxides	0.25
Carbon monoxide	5.42
HC	1.92

Thus, the total amount of particulate matter (PM) from refuse burning is approximately 500 tons/year. In the early nineties, it was estimated that power plants in Mumbai release about 1,500 tons/year of PM_{10}, [116] which means that burning garbage produces one-third the amount of particulate matter as do power plants, even though these power plants meet almost all of Mumbai's electricity needs.

It should be noted that there have been no formal studies or surveys on the amount of refuse that is burnt, the rate of burning, or continuous monitoring of emissions from the dumps. Hence, it is hard to know precisely how much waste dumps and open burning are contributing to air pollution. [116]

5.4.1.3 Surface Water Pollution

The creeks and coastal waters in Mumbai are so polluted that they are unfit for any recreational activity. [82] Industrial and municipal solid wastes are regularly dumped in these waterways, causing flooding during the monsoons, not to mention hazardous pollution to aquatic life and humans. The existing landfills border the coastal areas of Mumbai: Gorai is adjacent to the Gorai creek and Deonar and Mulund are both near the Thane creek. Lack of proper MSW disposal facilities have considerably degraded the coastal marine water quality and fisheries. For example, the MMRDA reports that MSW is deposited below the high-tide level, thus coming into direct contact with the water. [82] Thane creek is estimated to be one of the most polluted waterways in the Mumbai area, with high levels of nitrogen and phosphorus and very low levels of dissolved oxygen. [89] The chemical parameters for Thane and Vasai creeks are shown in Table 39. [82]

Table 39: Chemical parameters of Thane and Vasai Creeks (mg/L) [82]

Thane Creek			Vasai Creek		
Parameter	1986	1991	Parameter	1986	1991
BOD	0.66	3.20	BOD	1.00	1.98
DO	4.45	3.90	DO	3.70	2.16
NO3/N	10.25	781.00	NO3/N	42.00	630.00
PO4/P	64.45	306.00	PO4/P	11.69	39.00

5.4.1.4 Groundwater Pollution

Although most of the city's water supply comes from six lakes, [122] groundwater is an "important supplementary source in certain parts" of Mumbai. [82] The coastal regions, in particular, rely on wells for domestic and irrigation needs. [82] Table 41 shows the number of wells in the wards where MSW landfills are located. The MPCB conducted a study on the composition of leachate at the three existing dumps. The results are shown in Table 40. [59]

Table 40: Composition of leachate at MSW dumps in Mumbai [59]

Dump	pH	BOD	COD	TDS
Deonar	7.9	310	928	-
Gorai	7.8	600	1150	-
Mulund	8.2	119	1264	6942
Mature landfill average [125]	6.6-7.5	100-200	100-500	--

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. [59]

5.4.2 Decreases Amount of Land Required for MSW Disposal in Mumbai

As Mumbai's population continues to expand rapidly, more space is needed for housing, schools, parks, and so on. As mentioned earlier, Mumbai is one of the most crowded cities in the world. Introducing a WTE facility in Mumbai has a direct benefit to the amount of land required because it takes up considerably less space when compared to landfilling, composting, or biomethanation.

More people are shifting from central and south Mumbai to the suburbs in the north. The graphs below show the historical and projected populations for Mumbai. Until 1971, the city population exceeded that of the suburbs; since then, the suburban population has increased substantially while the city population has remained fairly constant, as shown in Figures 51a and 51b. This increasing trend is expected to continue into the future with the suburban population, but the city population is projected to decrease by almost 18% between 2001 and 2031. [81, 85]

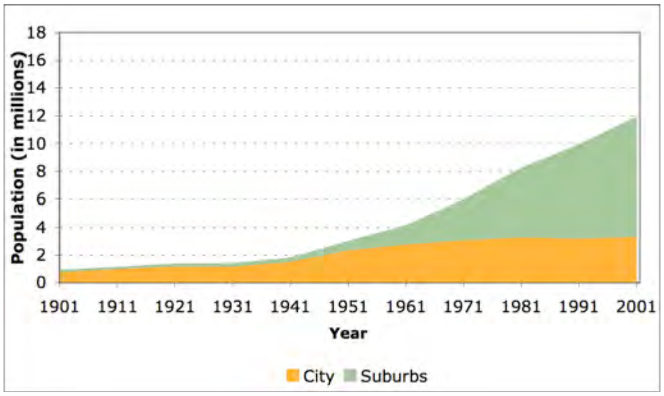

Figure 51a: Population distribution in Mumbai

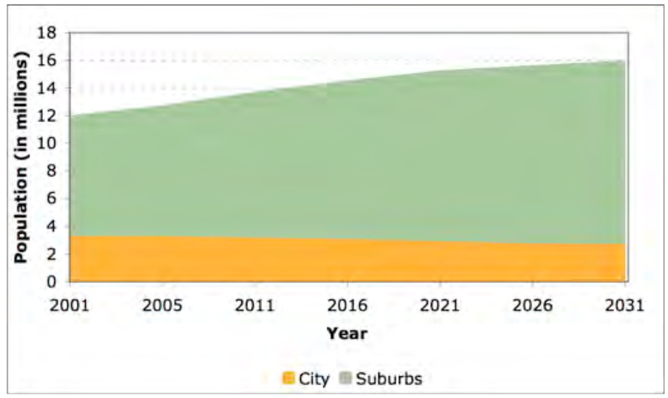

Figure 51b: Projected population distribution in Mumbai

With regard to the wards that house the city's garbage dumps, the population growth and population density has increased considerably. Table 41 gives a summary of these wards. In the early- to mid-part of the 20th century, these areas were deemed suitable for waste dumps 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. Figures 52a and 52b show a sharp increase in population in the wards that have dumps. [85] On average, the population in these wards increased by 287% between 1971 and 2001. Except for the R/North and T wards that have the Gorai and Mulund dumps respectively, more than 50% of the residents in these areas live in slums. S Ward, which is where the new Kanjur dump is situated, has a slum population of approximately 85%.

Table 41: Summary of wards that house Mumbai's dumps [87, 117, 118, 155]

Factor	Deonar	Gorai	Mulund	Malad	Kanjur
Ward	M/East	R/North	T	P/North	S
Area of Ward (km^2)	32.50	68.61	45.42	19.13	64
Total area of Dump (km^2)	1.32	0.19	0.25	0.19***	1.41
Population increase from 1971-2001 (%)	241	516	164	229	
Slum Population (%)	68.48	46.63	35.20	63.65	85.83
Open wells in ward[8]	84	5	169	339	259

[8] The wells in Mumbai do not supply water for drinking, but for washing and industrial use. (shrotriya)

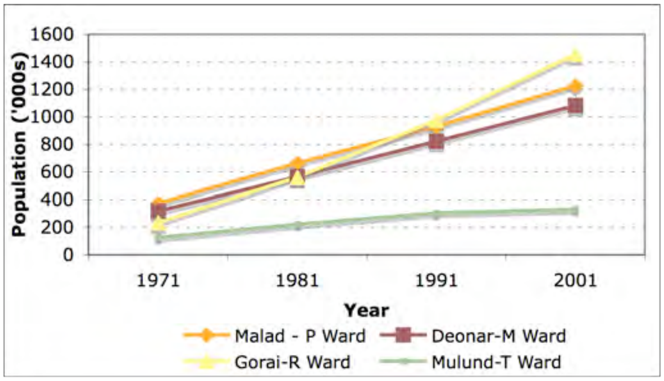

Figure 52a: Population growth in the wards where landfills are located

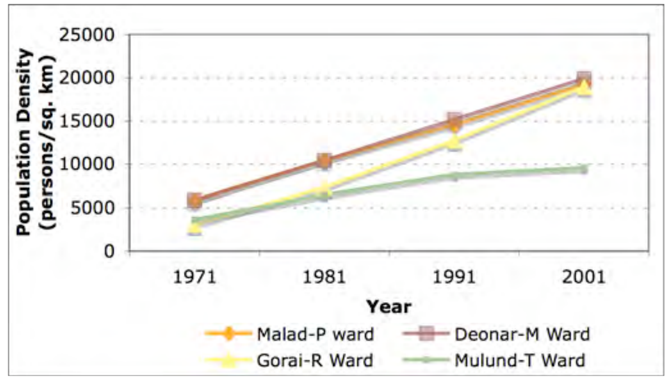

Figure 52b: Change in population density in wards housing landfills

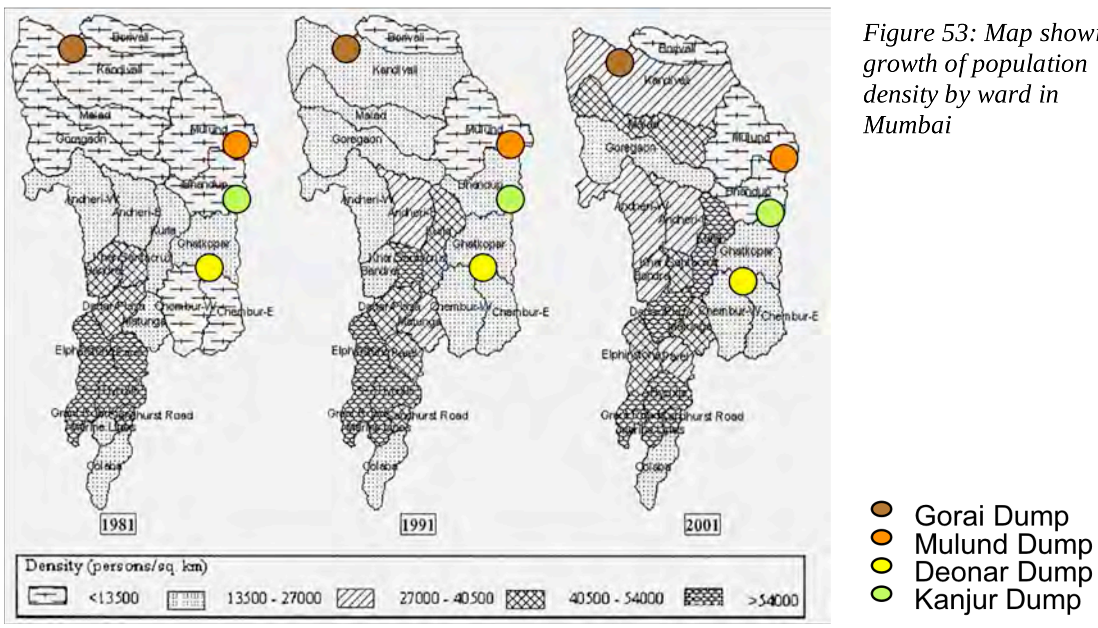

Figure 53: Map showing growth of population density by ward in Mumbai

Figure 53 shows the change in population density in the various wards where landfills are located in the period 1971 to 2001. [5] The locations of the dumps shown in Figure 53 are very approximate. In the north, the population density near the Gorai dump increased from less than 13,500 people/km^2 to over 54,000 people/km^2 in twenty years. Around the Deonar dump in the south-east, by far the biggest dump in the city, the population density has increased from less than 13,500 people/km^2 to up to 27,000 people/km^2 during the same time period. The Malad dump, which was closed in 2001, [117] registered a growth in population density from less than 1,500 people/km^2 to 40,500-54,000 people/km^2. In the Mulund landfill ward, in the north-east of the city, population growth leveled after 1991. [5] In comparison to the above numbers, the population density in the Bronx, New York, where the Pelham Bay landfill is located, is 12,242 people/km^2 (2000 census). [10]

5.4.3 Recycling

A common misconception about waste-to-energy is that it diverts materials that would otherwise have been recycled to waste incinerators. This is categorically untrue and can be proven by Figure 54, which shows that countries in the EU with high levels of incineration also tend to have high recycling rates. [45] In Germany, as with many other countries, government regulations, such as TA-Siedlungsabfall, mandate that only waste that cannot be reused or recycled will be treated. [77] For other specific examples of how much countries recycle their waste instead of either landfiling or incinerating them, see Appendix 5.

In fact, in many instances, WTE plant operators do not want recyclable material in the MSW because it tends to raise the heating value of the waste. High temperatures can cause problems in the boiler and also decreases the amount of waste that can be fed into a boiler at any given time, thus slowing down the process of treating the waste that comes in. [115]

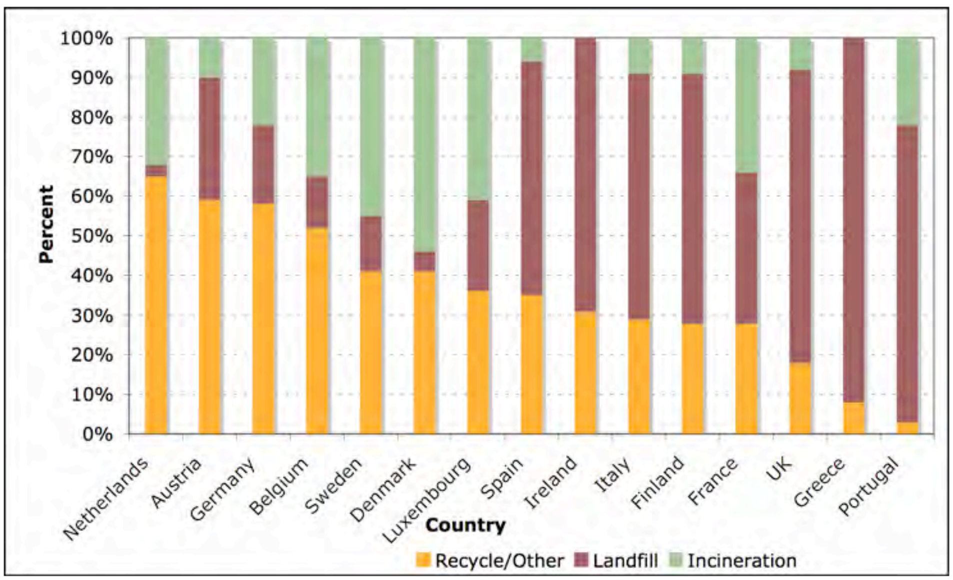

Figure 54: Graph showing the proportion of recycling, landfilling, and incineration in EU countries

5.4.4 Decreases Costs and Emissions Related to Transportation of MSW in Mumbai

Diesel emissions from trucks and other vehicles can be particularly harmful to public health because they emit dioxins, polycyclic aromatic hydrocarbons, and particulate matter. In fact, it is estimated that diesel trucks emit five times more particulate matter per ton of waste than waste-to-energy plants. [52] These emissions worsen asthma and other respiratory diseases because they are a major source of fine particles and cause high smog levels. [19]

If Mumbai does not adopt stringent policies to reduce the amount of waste sent for final disposal, it will exacerbate an already dire scenario. If the city chooses to continue landfilling the majority of the waste generated, it will need to transport the waste longer distances to neighboring towns that will accept the waste for disposal. This would not only increase the costs of trucking the waste, but also increase air pollution from vehicle emissions.

When the Kanjur dump opens in 2008, vehicles that are currently transporting waste to the Gorai dump will travel 2-3 km less per route than before. [117] Assuming that part of the Kanjur dump was set aside for the creation of a waste-to-energy facility, the trucking costs and emissions of sending waste there would be lower. It would also minimize the costs of transporting the residual ash for disposal if the ash could be landfilled at the Kanjur dump itself.

5.4.5 Provides a Supplemental Source of Electricity in Mumbai

Mumbai is unique when it comes to electricity supply because it is one of the only cities in India that does not experience periodic blackouts or brownouts. However, electricity consumption in Mumbai has been increasing so rapidly that power suppliers and the Government of Maharashtra are trying to increase production and reduce electricity consumption respectively, and are warning consumers of power shortages, especially in the summer months. This section provides a general overview of power supply in Mumbai and discusses the electricity shortages experienced by the city.

5.4.5.1 Mumbai Electricity Supply

Mumbai has historically been shielded from electricity shortages that plague the rest of the country and many other large cities. This is primarily because its power supply comes from private sources and it is “islanded” from the rest of the grid that connects to Maharashtra state and beyond. Further, during power outages, suburban areas are more likely to lose power than the city area.

The network of power suppliers and distributors in Mumbai is complicated. TPC, REL, and BEST, and to a certain extent the Maharashtra State Electricity Board (MSEB) are the key players in the power sector related to Mumbai.

- Tata Power Company: TPC is India’s oldest private sector power company, and has been supplying electricity to Mumbai since the 1920s. It generates approximately 1700 MW of electricity for Mumbai through a mix of thermal and hydro power plants. It also sells part of its production to REL and BEST. Its main distribution customers are the railways, ports, and large industrial and commercial consumers in Mumbai. [123]
- Reliance Energy Ltd.: REL acquired the suburban distribution company, Brihanmumbai Suburban Electric Supply (BSES), in 2003. In addition to being primarily responsible for distribution to Mumbai suburbs, REL also generates 500 MW of electricity from thermal power plants. [112] It purchases power from TPC to cover its shortfall.
- Brihanmumbai Electric Supply and Transport Undertaking: BEST is a distributor of electricity and covers residential and commercial areas that are not serviced by REL and TPC. It purchases its power from TPC. [8]

- Maharashtra State Electricity Board: The MSEB is the generator and distribution licensee for two wards, S and T, in Mumbai. The Mulund and Kanjur dumps are situated in these wards. In addition, during times of power shortfalls in Mumbai, REL and TPC draw power from the MSEB grid, which supplies power to the rest of the state.

Although REL is a customer of TPC, since it does not have adequate generation capacity, the two companies are also competitors to supply power to large industrial and commercial clients. As a result, this causes a number of regulatory and legal issues between the two companies.

5.4.5.2 Mumbai Electricity Shortage

Mumbai currently faces a peak shortfall of 400 MW. [15] The total power supplied is 2,200 MW, of which 1,700 MW is generated by TPC and the remaining 500 MW from REL, [51] while the peak demand is 2,600 MW. Suburban areas tend to experience the majority of power failures, when they do occur, than the city. This is because the government has mandated that south Mumbai, which is home to a number of financial institutions and the state government, should be shielded from power cuts. In addition, if TPC is facing a shortfall, it will cut its power supply to REL, which distributes electricity to the suburbs.

Table 42 shows the actual and projected amounts of electricity consumption in Mumbai. The industrial sector comprises only 8% of total consumption, while residential and commercial sectors make up the bulk of the consumption. [9]

Table 42: Energy consumption in Mumbai by sector (million kWh) [9]

Sector	2005-06	2006-07	2007-08	2008-09	2009-10
Residential	1651	1684	1744	1810	1885
Commercial	1590	1665	1724	1787	1853
Industrial	321	321	324	329	333
Other	52	53	58	64	72
Total	3,614	3,723	3,850	3,990	4,143

5.4.6 Provides a Source of Renewable Energy

MERC has introduced regulation whereby power distributors (for Mumbai, they are TPC, REL, and BEST) must purchase a certain percentage of their power from renewable sources. Table 43 shows the minimum fraction of renewable energy required from 2006 to 2010. [9] TPC produces approximately 450 MW from hydropower, [123] which is sufficient to meet the requirements set by MERC. However, as TPC and REL add capacity to their thermal plants in order to cover the power shortages faced in Mumbai and MERC revises its regulation for future years, it may be necessary for TPC and REL to supplement their thermal power generation with renewable sources. Moreover, waste-to-energy is more readily available than most other renewable sources, as shown in Figure 55. [24] WTE is available over 90% of the time in a year, compared to less than 40% for wind and less than 10% for solar energy. Thus, WTE can help Mumbai meet its renewable energy requirements in the future.

Table 43: *Minimum fraction of power required from renewable energy sources as ordered by MERC (%)*	
Year	Minimum fraction of renewable energy (%)
2006-07	3
2007-08	4
2008-09	5
2009-10	6

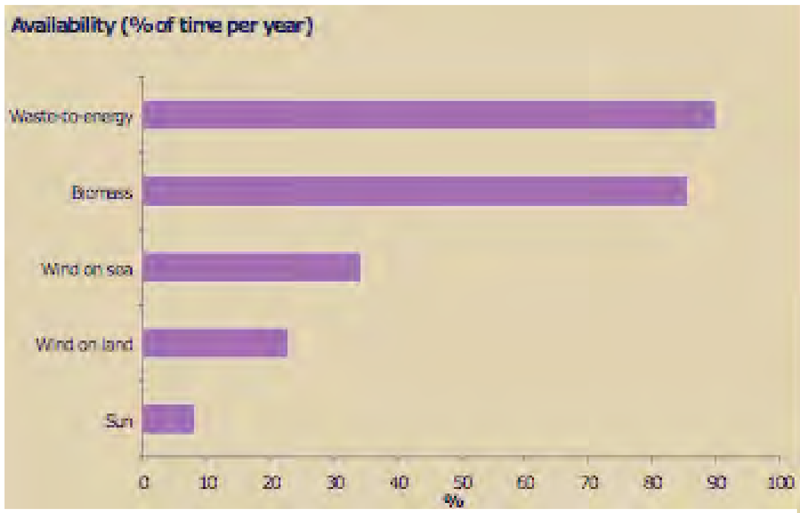

Figure 55: Graph showing availability of WTE as compared to other renewable energy sources. (Hendrick)

5.4.7 Displaces Coal and Oil, and Prevents Greenhouse Gas Emissions

Switching from open dumping to waste-to-energy will have numerous environmental benefits for Mumbai. First, Table 44 shows the equivalent amount of coal or oil it would take to produce the same amount of electricity from MSW, assuming that only 50% of MSW is incinerated, based on calculations from Table 26. Since most of the coal in India is sub-bituminous, it is estimated that 1 ton of MSW is equivalent to 0.25 tons of coal or 1 barrel of oil. [97, 134] Table 44 also shows the amount of carbon dioxide emissions that would be averted because 50% of the waste would be combusted at the WTE facility instead of landfilled.

Table 44: Amount of coal and oil displaced and prevented CO_2 emissions by incineration of Mumbai MSW				
Year	Amount of MSW processed in WTE (million tons/year)	Equivalent amount of coal replaced (‘000 tons/year)	Equivalent amount of oil replaced (million barrels/year)	CO_2 emissions prevented (million tons)
2001	0.8	198	0.8	1.04
2010	1.0	248	1.0	1.30
2015	1.1	281	1.1	1.43
2020	1.3	318	1.3	1.69

In addition, processing the MSW in a WTE facility would reduce the number of fires that are lit by ragpickers to salvage recyclable materials, and hence prevent greenhouse gas emissions from open burning as well. Current emissions from open burning at dumps tend to be much higher than those from waste-to-energy plants (See Section 3.5), contrary to the stance adopted by environmental groups.

5.4.8 WTE is an Integral Part of Mumbai Life

The previous sections show the numerous benefits Mumbai can derive from waste-to-energy technology. Waste-to-energy is not only a solution to reduce the volume of waste that is generated and provide a supplemental energy source, but also yields a number of social benefits that cannot easily be quantified. For citizens who live or work near dumps, it provides a cleaner, less polluted, and less congested neighborhood. In addition to all these reasons, a waste-to-energy facility in Mumbai could serve as an example of how a municipality can adopt a successful solid waste management strategy for the benefit of all its citizens. A WTE facility in Mumbai can provide leadership and encourage other cities in India to adopt similar waste management solutions. As other cities have done, Mumbai can create a WTE facility that is a highlight of the city. For example, Figures 56a and 56b shows a WTE facility in Vienna, Austria that has become a landmark of the city.

Figures 56a and 56b: Two views of the Spittelau WTE facility in Vienna, Austria. The façade was designed by the famous architect F. Hundertwasser {13}

6. CONCLUSIONS AND RECOMMENDATIONS

As presented in this report, India, and in particular Mumbai city, face 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.

Although the Indian economy has been rapidly developing over the last decade or so, it still lacks sanitary landfills. Similar to other developing countries, the majority of MSW disposal takes place in open dumping grounds. These dumping grounds do not have mechanisms for landfill gas capture or leachate collection, thus contributing to both increased greenhouse gas emissions as well as environmental pollution. The average waste generated in urban areas is 0.46 kg/person/day, which is very low compared to developed countries. However, it is estimated that the amount of MSW generated will increase by 1-1.33% annually. India is also similar to other developing countries in terms of its general waste characteristics: it has a high fraction of organic matter and inert materials and moisture content between 30-60%.

Mumbai, the financial and commercial capital of India, is known as the City of Gold, because of the employment opportunities it provides. Although it attracts thousands of people everyday, it has been unable to maintain and upgrade its infrastructure, including roads, water supply, electricity supply, housing, and solid waste management. Mumbai generates 5,800 tons of MSW, 2,200 tons of C&D waste, and 25 tons of biomedical waste daily. The collected waste is taken to three dumping grounds, either directly or via transfer stations. Mumbai plans to shut one of the dumps and open a new one in 2008, following which all three dumps will be located on the east side of the city.

Following the creation of the Municipal Solid Wastes (Management and Handling) Rules, 2000 by the central government, the Municipal Corporation of Greater Mumbai has adopted a number of approaches to improve its waste management services. It has introduced source segregation in neighborhoods across the city and plans to establish composting, biomethanation, and RDF facilities to treat the MSW. At present, the MCGM is not planning to establish a waste-to-energy facility in the city.

The goal of this report is to highlight the suitability and benefits of introducing waste-to-energy technology in India, and uses Mumbai as a case study. As India's GDP increases, the amount of waste generated will increase correspondingly. Mumbai has already run out of space for landfills and faces strong NIMBY-ism in neighborhoods where landfills could have been constructed.

The Government of India recognizes incineration as a renewable technology and provides various funding mechanisms for development of WTE facilities. The Ministry of New and Renewable Energy estimates that the potential power generation from MSW and industrial waste is 3,850 MW as of 2007.

Although there is strong environmental opposition to waste-to-energy, it offers a more environmentally friendly option of waste disposal compared to landfilling. It reduces the amount of greenhouse gas emissions by diverting MSW from landfills and providing a renewable source of power. Emissions of pollutants from waste-to-energy, such as dioxins, are often much lower than national limits. Finally, waste-to-energy prevents surface and groundwater and air pollution from landfills. From an economic standpoint, an integrated waste management approach that includes waste-to-energy is also favorable for a city like Mumbai. The revenues generated from tipping fees, selling electricity, and greenhouse gas emission reduction credits make waste-to-energy a profitable venture.

In terms of future work, two important topics stand out: more research and more outreach. More research is needed to quantify various aspects of the solid waste management sector. A number of key statistics, such as the value of recyclables, the amount of environmental pollution from waste sources, and the quantity of industrial waste generated, need to be computed to get a better understanding of this sector. In terms of research related to waste-to-energy, detailed analysis of costs and available funding is needed. In addition, investigating the suitability and quantifying the costs and benefits of combined heat and power for Mumbai would be useful. Independent researchers or consultants should carry out such research in order to prevent any biases that may otherwise occur.

Outreach to both environmental groups as well as the public at large is important in order to demonstrate the benefits of waste-to-energy technology to the community, city, and local government. This can be achieved by educating the public through campaigns, workshops, town hall meetings, university lectures, and so on. Creating an open dialogue with environmental groups is an essential first step to sharing information and collaborating to create better environmental conditions.

Furthermore, it would be useful to develop a methodology for incineration to be included in the approved CDM methodologies. This would make incineration a more viable option for local promoters and encourage funding from foreign companies in developed countries.

Appendix 1
Estimating the waste generation and related carbon dioxide emissions for India in 2030
[3, 7, 8, 9]

Year	Urban Population	Urban Population ('000s)	Waste Generation Rate (kg/capita/day)	Total Waste Generated (kg/day)	Total Waste Generated (MT/day)	Total Waste going to landfills/dumps (MT/day)	CO_2 emissions (MT)
1995	249,100,000	249,100	0.460	114,586,000	114,586	85,939.50	111,721.35
1996	258,338,483	258,338	0.465	120,024,059	120,024	90,018.04	117,023.46
1997	267,576,966	267,577	0.469	125,559,421	125,559	94,169.57	122,420.44
1998	276,815,449	276,815	0.474	131,193,488	131,193	98,395.12	127,913.65
1999	286,053,932	286,054	0.479	136,927,680	136,928	102,695.76	133,504.49
2000	295,292,415	295,292	0.483	142,763,436	142,763	107,072.58	139,194.35
2001	304,530,899	304,531	0.488	148,702,215	148,702	111,526.66	144,984.66
2002	313,769,382	313,769	0.493	154,745,493	154,745	116,059.12	150,876.86
2003	323,007,865	323,008	0.498	160,894,767	160,895	120,671.08	156,872.40
2004	332,246,348	332,246	0.503	167,151,551	167,152	125,363.66	162,972.76
2005	341,484,831	341,485	0.508	173,517,382	173,517	130,138.04	169,179.45
2006	350,723,314	350,723	0.513	179,993,814	179,994	134,995.36	175,493.97
2007	359,961,797	359,962	0.518	186,582,423	186,582	139,936.82	181,917.86
2008	369,200,280	369,200	0.524	193,284,805	193,285	144,963.60	188,452.68
2009	378,438,763	378,439	0.529	200,102,576	200,103	150,076.93	195,100.01
2010	387,677,246	387,677	0.534	207,037,374	207,037	155,278.03	201,861.44
2011	396,915,729	396,916	0.539	214,090,858	214,091	160,568.14	208,738.59
2012	406,154,212	406,154	0.545	221,264,707	221,265	165,948.53	215,733.09
2013	415,392,696	415,393	0.550	228,560,625	228,561	171,420.47	222,846.61
2014	424,631,179	424,631	0.556	235,980,335	235,980	176,985.25	230,080.83
2015	433,869,662	433,870	0.561	243,525,582	243,526	182,644.19	237,437.44
2016	443,108,145	443,108	0.567	251,198,137	251,198	188,398.60	244,918.18
2017	452,346,628	452,347	0.573	258,999,790	259,000	194,249.84	252,524.80
2018	461,585,111	461,585	0.578	266,932,356	266,932	200,199.27	260,259.05
2019	470,823,594	470,824	0.584	274,997,674	274,998	206,248.26	268,122.73
2020	480,062,077	480,062	0.590	283,197,605	283,198	212,398.20	276,117.66
2021	489,300,560	489,301	0.596	291,534,035	291,534	218,650.53	284,245.68
2022	498,539,043	498,539	0.602	300,008,873	300,009	225,006.65	292,508.65
2023	507,777,526	507,778	0.608	308,624,055	308,624	231,468.04	300,908.45
2024	517,016,009	517,016	0.614	317,381,540	317,382	238,036.15	309,447.00
2025	526,254,493	526,254	0.620	326,283,312	326,283	244,712.48	318,126.23
2026	535,492,976	535,493	0.626	335,331,381	335,331	251,498.54	326,948.10
2027	544,731,459	544,731	0.632	344,527,783	344,528	258,395.84	335,914.59
2028	553,969,942	553,970	0.639	353,874,580	353,875	265,405.94	345,027.72
2029	563,208,425	563,208	0.645	363,373,861	363,374	272,530.40	354,289.51
2030	572,446,908	572,447	0.652	373,027,739	373,028	279,770.80	363,702.05

Appendix 2
MSW collection points by ward in Mumbai
[6]

Ward	Compactor Container	Dumper Placer	Open Dump*	Round Bin*	Shed*	Stationary Container**
A	17	27	2	0	1	2
B	4	10	1	0	7	0
C	13	0	2	0	0	2
D	29	36	3	2	7	2
E	13	45	0	1	3	0
F / S	58	43	29	8	0	0
F / N	60	26	6	1	40	0
G / S	48	46	9	2	0	1
G / N	74	45	35	47	3	2
H / E	140	15	8	9	39	0
H / W	36	13	0	0	13	0
K / E	163	15	0	116	0	0
K / W	66	7	18	15	6	0
P / S	137	0	45	53	0	0
P / N	193	8	10	43	0	0
R / S	38	5	0	50	0	0
R / C	65	40	4	29	0	0
R / N	34	8	8	58	0	0
L	110	43	78	50	53	0
M / E	89	20	0	14	71	0
M / W	92	25	2	12	2	0
N	84	22	30	13	24	0
S	209	27	0	49	14	0
T	128	10	2	37	25	0
Total	1900	536	292	609	308	9

* As mentioned in Section 4.5, 6,000 community bins will replace open dumps, round bins, and sheds by September 2007.

** The number of stationary containers is expected to increase to 15 by September 2007. [117]

Appendix 3
Financial incentives and eligibility criteria for WTE facilities through the National Programme on Energy Recovery from Urban and Industrial Wastes of the MNRE (Excerpts)
and
Eligibility of Waste-to-Energy Projects (Excerpts)
[4]

Financial Incentives:

A. Commercial Projects

Financial assistance in the form of an interest subsidy for reducing the rate of interest to 7.5%, capitalized with an annual discount rate of 12%, shall be paid to Financial Institutions (FIs) as follows:

Financial assistance to institutions		
Type of Projects	Maximum eligible Interest Subsidy to reduce the interest rate to 7.5% (Rs. million/MW)	
	Urban and Municipal Waste	Industrial Waste
Waste to Power	20	15
Waste to fuel	5	5
Fuel to power	10	10

B. Demonstration Projects

Financial assistance of up to 50% of the capital cost of a project, limited to Rs. 30 million per MW, can be provided for innovative demonstration projects for generation of power from MSW and selected industrial wastes.

Incentives for Municipal Corporations and State Nodal Agencies:

A. Urban Local Bodies

Financial incentives of Rs.1.5 million per MWe is payable to municipal corporations for providing garbage free of cost at the project site and land on a long-term basis (>30 years) on nominal lease rent. However, this incentive will be reduced to 50% in case of generation of power from fuel or fuel from waste.

B. State Nodal Agencies

Financial incentives of Rs.500,000 per Mwe is payable to state nodal agencies for the promotion, coordination, and monitoring of projects. However, this incentive will be reduced to 50% in case of generation of power from fuel or fuel from waste.

C. Financial Institutions

A service charge of 2% of the actual subsidy channelized through the FI to the promoter or other FIs, subject to a maximum of Rs.200,000 per project.

D. Preparation of Detailed Project Report

50% of the cost of preparation of a detailed project report or techno-economic feasibility report to municipalities only, subject to a maximum of Rs.200,000 per report.

Financial Assistance for Resource Assessment Studies:

Financial assistance may also be provided towards the full cost of carrying out studies for assessment of resources for setting up waste-to-energy projects, if considered necessary.

Financial Assistance for Promotional Activities:

Financial assistance can also be provided for the organization of training courses, business meetings, national workshops and seminars, to create awareness and publicity. Requests received from urban local bodies, industries associations, central or state government departments or agencies, corporate bodies, state or national level financial and other institutions for technical or financial assistance for such activities may be considered under this program.

Support from State Governments:

Some state governments, namely Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Rajasthan, Maharashtra, Haryana, and Karnataka, have announced policy guideline measures pertaining to the allotment of land, supply of garbage, and facilities for evacuation, sale and purchase of power to encourage setting up of waste-to-energy projects.

Implementation Arrangements:

The scheme is implemented through state nodal agencies, state government departments, and urban local bodies who have to forward the project proposals to MNES (now known as MNRE) in accordance with a prescribed procedure for applying for central financial assistance. This scheme is applicable to both private as well as public sector entrepreneurs and investors having technical and managerial capabilities for implementing projects on the basis of Build, Own, Operate, and Transfer (BOOT), Build, Operate, and Transfer (BOT), Build, Own, and Operate (BOO), and Build, Operate, Lease, and Transfer (BOLT).

Eligibility of Waste-to-Energy Projects

1. Criteria based on Wastes

i. Projects based on any waste of renewable nature from Urban and Industrial sectors are eligible under this programme. While rice husk, straw, stalks, bagasse and fines of biomass origin are not covered under this programme, mixing of urban or industrial wastes with other wastes of renewable nature from Urban and Industrial sectors, including rice husk and bagasse, as back-up fuel or feedstock up to a maximum of 30% is permissible under this programme. Projects based on waste heat (flue gases), wastes, residues or derivatives from non-renewable sources viz. coal rejects, dolochar, oil refinery waste, etc. shall not be eligible.

ii. Projects for production of biogas from distillery effluents (spent-wash) are not eligible under this programme. However, projects for generation of power from biogas produced from Urban and Industrial Wastes (including distillery effluents), through biogas engines / turbines, dual fuel engines using diesel oil up to a maximum of 5% as pilot fuel, and steam turbines with a minimum steam pressure of 42 bar shall be eligible.

In case of any violation of the conditions stipulated above by the project promoters, within first five years of the project operation, the total subsidy would have to be refunded to MNES. Decision of Secretary, MNES shall be final in case of ambiguity or violation in respect of provisions of this scheme**.**

2. Criteria based on Technologies

Projects based on conversion technologies namely, biomethanation, pelletization (only for urban waste), gasification, pyrolysis, incineration, combustion, sanitary landfilling, etc. or combination thereof shall be eligible under this programme. Power generation through steam turbine route shall be permitted for a minimum steam pressure of 42 bars**.**

3. Criteria based on Capacity of Projects

i) Minimum capacities of waste-to-energy projects.

Form of Energy	**Minimum Capacity**
Waste to Energy (in the form of fuel pellets):	15 TPD
Waste to Energy (in the form of biogas):	300 cu.m./day
Waste to Energy (in the form of steam):	2.5 tonnes/hr. at min. pressure of 20 bars.
Waste to Energy (in the form of Electricity):	25 KW**.**

ii) Maximum capacity of waste-to-energy projects

Type of projects **Maximum Capaci**ty

MSW based demonstration projects: 5 MW
Industrial waste based demonstration projects: 2 MW

Commercial Projects There is no upper limit of capacity of waste to energy project, however, the interest subsidy shall be restricted to a capacity of 5 MWe only**.**

Note: Amount of subsidies would be determined on the basis of net output i.e. gross installed capacity minus the auxiliary power consumption

Appendix 4
Emissions from waste-to-energy facilities around the world
[2, 1, 5]

Amsterdam, The Netherlands
As Figure 57 shows, emissions from WTE facilities in Amsterdam are significantly lower than national standards.

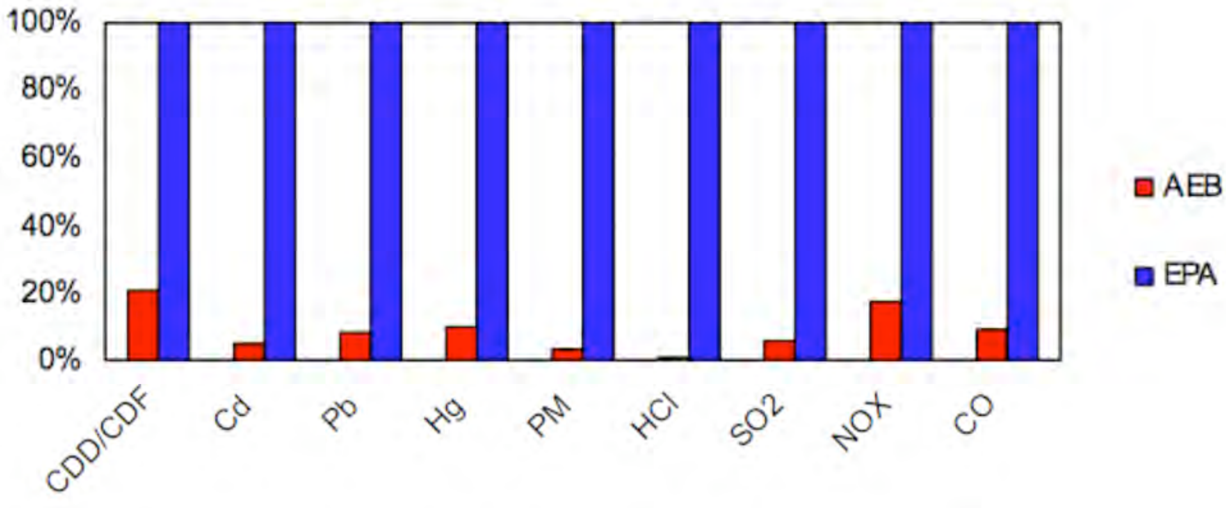

Figure 57: Graph comparing emissions from WTE facilities in Amsterdam to national standards {2}

Austria
As Figure 58 shows, emissions from WTE facilites in Austria have decreased significantly since the 1930s as well as since the 1970s.

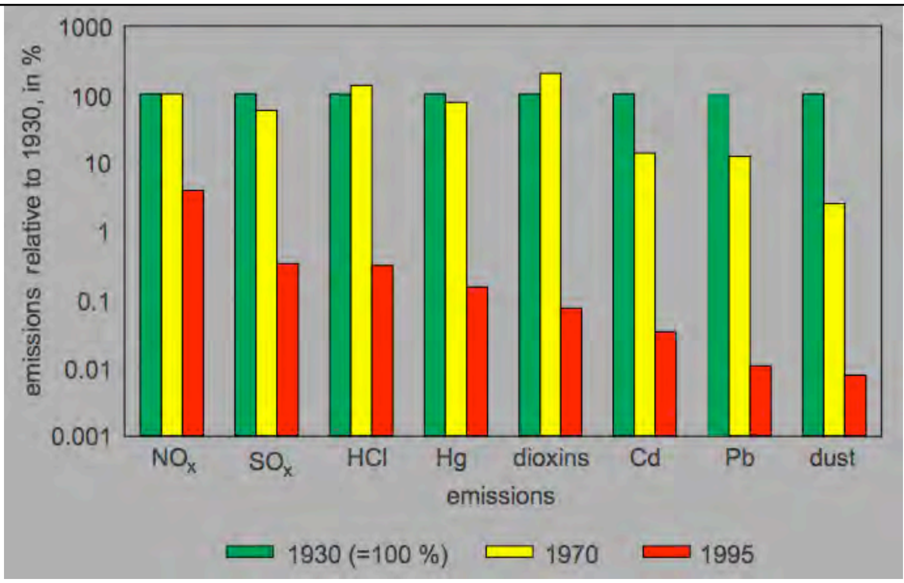

Figure 58: Emissions from WTE facilities in Austria {1}

Sweden

The amount of waste sent to WTE facilities in Sweden has more than doubled between 1985 and 2004, yet emissions have decreased by 99%. In addition, the energy derived from WTE has quadrupled in the same time period.

Dioxin emissions in Sweden have decreased from 90 grams/year in 1985 to 0.7 grams/year in 2004. Today, dioxins emissions from waste-to-energy incinerators are among the lowest compared to other sources, as shown in Table 46.

Table 45: Decrease in emissions from WTE facilities in Sweden between 1985 and 2004 [5]

Pollutant (tons/year)	1985	2004
Nitrogen oxides	3,400	1,707
Sulfur	3,400	337
Particulates	420	24
Hydrogen chlorides	8,400	101
Pollutant (kg/year)		
Mercury	3,300	37
Cadmium	400	5
Lead	25,000	54
Pollutant (grams/year)		
Dioxins	90	0.7

Table 46: Sources of dioxin emissions in Sweden in 2004 (g/year)[5]

Source	Amount
Waste-to-Energy	0.7
Landfill Fires	3.0 – 30.0
Industries	10.0 – 30.0
Energy Production (excluding WTE)	3.0 – 22.0
Transportation	0.8 – 2.9
Other	50.0

Appendix 5
Comparison of recycling, landfilling, and incineration
[2]

The Netherlands
As Figure 59 shows, the amount of MSW recycled is increasing while the amount of MSW landfilled is decreasing. Since the mid-nineties, WTE capacity has stayed fairly constant in The Netherlands.

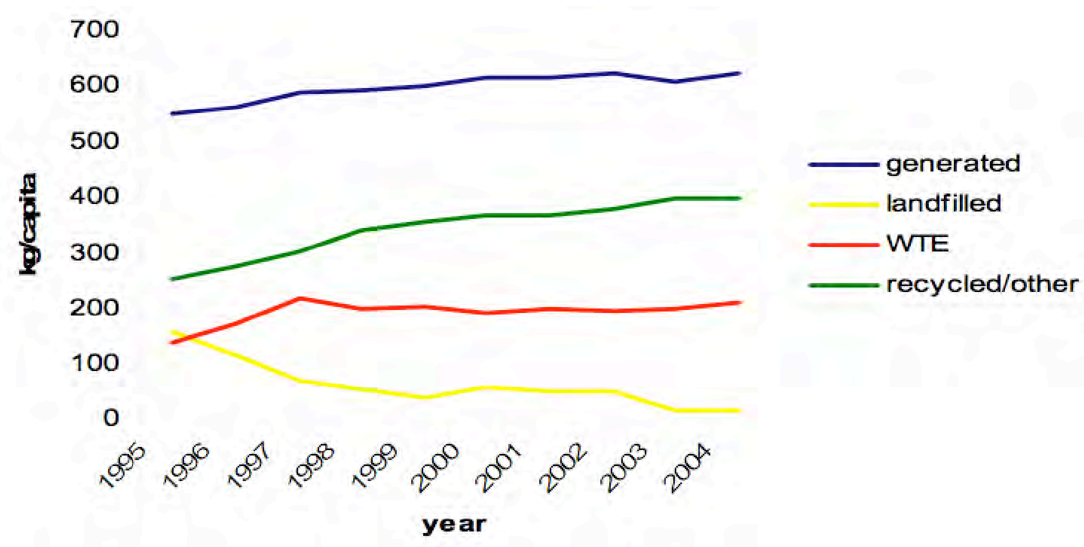

Figure 59: Comparison of recycling-incineration-landfilling in The Netherlands {2}

Appendix 6
Potential revenues from sale of electricity from a WTE facility in Mumbai to the electricity grid

Year	Tariff ($/kWh)*	Electricity generated (kWh/ton)	MSW treated (tons/day)	Daily revenue ($)**	Annual revenue ($)***
1	0.08	533	800	34,112	11,256,960
2	0.08	533	800	35,818	11,819,808
3	0.09	533	800	37,608	12,410,798
4	0.09	533	800	39,489	13,031,338
5	0.10	533	800	41,463	13,682,905
6	0.10	533	800	43,537	14,367,050
7	0.11	533	800	45,713	15,085,403
8	0.11	533	800	47,999	15,839,673
9	0.12	533	800	50,399	16,631,657
10	0.12	533	800	52,919	17,463,240
11	0.12	533	800	51,168	16,885,440
12	0.12	533	800	51,168	16,885,440
13	0.12	533	800	51,168	16,885,440
14	0.13	533	800	53,726	17,729,712
15	0.13	533	800	56,413	18,616,198
16	0.14	533	800	59,233	19,547,007
17	0.15	533	800	62,195	20,524,358
18	0.15	533	800	65,305	21,550,576
19	0.16	533	800	68,570	22,628,105
20	0.17	533	800	71,999	23,759,510
21	0.18	533	800	75,598	24,947,485
22	0.19	533	800	79,378	26,194,860
23	0.20	533	800	83,347	27,504,602
24	0.20	533	800	85,280	28,142,400
25	0.20	533	800	85,280	28,142,400

* Based on tariff structure used by MERC in 2004 when calculating the price of electricity to be sold from a WTE facility to a licensed distributor in Mumbai [58]

** Daily revenue ($) = Tariff ($/kWh) * Electricity generated (kWh/ton) * MSW treated (tons)

*** Annaul revenue ($) = Daily revenue ($) * 330 days (i.e., WTE facility runs for 90% of the year)

Appendix 7
Potential revenues from tipping fees paid by the MCGM to a WTE facility in Mumbai

Year	MSW treated (tons/day)	Tipping fee ($/ton)	Daily tipping fee ($)	Annual tipping fee ($)
1	800	5	4,000	1,320,000
2	800	5	4,000	1,320,000
3	800	5	4,000	1,320,000
4	800	5	4,000	1,320,000
5	800	5	4,000	1,320,000
6	800	5	4,000	1,320,000
7	800	5	4,000	1,320,000
8	800	5	4,000	1,320,000
9	800	5	4,000	1,320,000
10	800	5	4,000	1,320,000
11	800	8	6,400	2,112,000
12	800	8	6,400	2,112,000
13	800	8	6,400	2,112,000
14	800	8	6,400	2,112,000
15	800	8	6,400	2,112,000
16	800	8	6,400	2,112,000
17	800	8	6,400	2,112,000
18	800	8	6,400	2,112,000
19	800	8	6,400	2,112,000
20	800	8	6,400	2,112,000
21	800	9	7,200	2,376,000
22	800	9	7,200	2,376,000
23	800	9	7,200	2,376,000
24	800	9	7,200	2,376,000
25	800	9	7,200	2,376,000

Appendix 8
Cash Flow Analysis of a WTE Facility in Mumbai

Cash Flow of a Waste-to-Energy Facility in Mumbai

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
CASH INFLOWS													
Revenue from sale of electricity		11,256,960	11,819,808	12,410,798	13,031,338	13,682,905	14,367,050	15,085,403	15,839,673	16,631,657	17,463,240	16,885,440	16,885,440
Revenue from tipping fees		1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	1,320,000	2,112,000	2,112,000
Total Income		12,576,960	13,139,808	13,730,798	14,351,338	15,002,905	15,687,050	16,405,403	17,159,673	17,951,657	18,783,240	18,997,440	18,997,440
CASH OUTFLOWS													
Investment													
Land	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)
Capital investment	(40,000,000)												
Operational costs													
Maintenance		(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(6,000,000)	(7,000,000)	(7,000,000)
Labor		(170,000)	(178,500)	(187,425)	(196,796)	(206,636)	(216,968)	(227,816)	(239,207)	(251,167)	(263,726)	(276,912)	(290,758)
Other		(1,000,000)	(1,000,000)	(1,000,000)	(1,000,000)	(1,000,000)	(1,500,000)	(1,500,000)	(1,500,000)	(1,500,000)	(1,500,000)	(2,000,000)	(2,000,000)
Total Costs		(7,171,200)	(7,179,700)	(7,188,625)	(7,197,996)	(7,207,836)	(7,718,168)	(7,729,016)	(7,740,407)	(7,752,367)	(7,764,926)	(9,278,112)	(9,291,958)
PRE-TAX CASH FLOW	0	5,405,760	5,960,108	6,542,173	7,153,342	7,795,069	7,968,883	8,676,387	9,419,266	10,199,289	11,018,314	9,719,328	9,705,482
Depreciation		(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)
Pre-tax Profits		3,805,760	4,360,108	4,942,173	5,553,342	6,195,069	6,368,883	7,076,387	7,819,266	8,599,289	9,418,314	8,119,328	8,105,482
Tax	35%	1,332,016	1,526,038	1,729,761	1,943,670	2,168,274	2,229,109	2,476,735	2,736,743	3,009,751	3,296,410	2,841,765	2,836,919
AFTER-TAX CASH FLOW		4,073,744	4,434,070	4,812,413	5,209,672	5,626,795	5,739,774	6,199,651	6,682,523	7,189,538	7,721,904	6,877,563	6,868,564
PRESENT VALUE	10%	$59,387,499											
NPV	10%	$19,386,299											
Accumulated Present Value		3,703,404	3,664,521	3,615,637	3,558,276	3,493,797	3,239,953	3,181,401	3,117,446	3,049,066	2,977,128	2,410,544	2,188,536
Discounted Payback Time	13 years		7,367,924	10,983,561	14,541,838	18,035,635	21,275,587	24,456,989	27,574,435	30,623,501	33,600,629	36,011,173	38,199,709

Cash Flow of a Waste-to-Energy Facility in Mumbai *(contd.)*

	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
CASH INFLOWS													
Revenue from sale of electricity	16,885,440	17,729,712	18,616,198	19,547,007	20,524,358	21,550,576	22,628,105	23,759,510	24,947,485	26,194,860	27,504,602	28,142,400	28,142,400
Revenue from tipping fees	2,112,000	2,112,000	2,112,000	2,112,000	2,112,000	2,112,000	2,112,000	2,112,000	2,376,000	2,376,000	2,376,000	2,376,000	2,376,000
Total Income	18,997,440	19,841,712	20,728,198	21,659,007	22,636,358	23,662,576	24,740,105	25,871,510	27,323,485	28,570,860	29,880,602	30,518,400	30,518,400
CASH OUTFLOWS													
Investment													
Land	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)	(1,200)
Capital investment													
Operational costs													
Maintenance	(7,000,000)	(7,000,000)	(7,000,000)	(7,000,000)	(7,000,000)	(7,000,000)	(7,000,000)	(7,000,000)	(8,000,000)	(8,000,000)	(8,000,000)	(8,000,000)	(8,000,000)
Labor	(305,296)	(320,560)	(336,588)	(353,418)	(371,089)	(389,643)	(409,125)	(429,582)	(451,061)	(473,614)	(497,294)	(522,159)	(548,267)
Other	(2,000,000)	(2,000,000)	(2,000,000)	(2,500,000)	(2,500,000)	(2,500,000)	(2,500,000)	(2,500,000)	(3,000,000)	(3,000,000)	(3,000,000)	(3,000,000)	(3,000,000)
Total Costs	(9,306,496)	(9,321,760)	(9,337,788)	(9,854,618)	(9,872,289)	(9,890,843)	(9,910,325)	(9,930,782)	(11,452,261)	(11,474,814)	(11,498,494)	(11,523,359)	(11,549,467)
PRE-TAX CASH FLOW	9,690,944	10,519,952	11,390,409	11,804,390	12,764,069	13,771,733	14,829,779	15,940,728	15,871,225	17,096,046	18,382,108	18,995,041	18,968,933
Depreciation	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)	(1,600,000)
Pre-tax Profits	8,090,944	8,919,952	9,790,409	10,204,390	11,164,069	12,171,733	13,229,779	14,340,728	14,271,225	15,496,046	16,782,108	17,395,041	17,368,933
Tax	2,831,831	3,121,983	3,426,643	3,571,536	3,907,424	4,260,106	4,630,423	5,019,255	4,994,929	5,423,616	5,873,738	6,088,264	6,079,127
AFTER-TAX CASH FLOW	6,859,114	7,397,969	7,963,766	8,232,853	8,856,645	9,511,626	10,199,357	10,921,473	10,876,296	11,672,430	12,508,370	12,906,777	12,889,806
Accumulated Present Value	1,986,841	1,948,116	1,906,462	1,791,709	1,752,240	1,710,750	1,667,676	1,623,407	1,469,720	1,433,911	1,396,912	1,310,368	1,189,678
Discounted Payback Time	40,186,550	42,134,667	44,041,129	45,832,838	47,585,078	49,295,827	50,963,503	52,586,911	54,056,631	55,490,542	56,887,454	58,197,822	59,387,499

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