Conceptual Design for Landfill Gas Capture and Re-Use in Mumbai, India

by

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A Report Submitted to the Faculty of the

Milwaukee School of Engineering

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Environmental Engineering

Milwaukee, Wisconsin

August 2016

Abstract

The purpose of this report is to explain an investigation concerning Municipal Solid Waste (MSW) in Mumbai, India, Mumbai, and the use of modern landfill technology, particularly for the conversion of landfill gas (LFG) to energy. LFG contains 50 percent methane and 50 percent carbon dioxide and less than one percent non-methanic content. In a typical landfill, LFG will be produced after five years, and is generated from the anaerobic digestion of the organic fraction of municipal solid waste. The existing landfill system of the Municipal Corporation of Greater Mumbai (MCGM) has many drawbacks with respect to Municipal Solid Waste Management (MSWM), including a lack of environmental codes, a lack of proper funding, and issues associated with management and operational systems. The MCGM would benefit from a proper infrastructure, improved maintenance, and an upgrade for all activities. The capture of LFG can be flared for control of methane and non-methanic content. LFG has a large potential for combustion and use as a fuel. The basic purpose of this project was to explain how LFG could be captured, and how its innovative beneficial reuse can be realized in the Deonar Landfill in Mumbai, India. Operational and maintenance costs associated with reusing the LFG can be covered through tipping fees, the selling of gas, and the selling of energy. LFG, itself, can be sold in containers. LFG as a renewable energy source is recommended for direct use in Mumbai, India.

Acknowledgments

Thanks to God who is the most beneficent and merciful who gave me the ability to do this project. I would like to express my sincere gratitude to my committee chair, Professor James Drought, and my other committee members, Dr. Frank Mahuta and Dr. Jay Karls, for their support and guidance during the course of this capstone design project. Gary Shimek, Director of the Library and Assistant Professor, provided extensive assistance in writing and format tasks.

I would like to thank my friends, colleagues, and other faculty members in the Department of Civil Engineering at Milwaukee School of Engineering for making my coursework an enjoyable as well as enlightening educational experience.

Finally, I would like to thank my family for their continued support and encouragement.

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Nomenclature

Btu	British thermal unit
CCL	Compacted Clay Liner
CO_2	Carbon dioxide
CPCB	Central Pollution Control Board
ECS	Engineered Containment System
Ft	Foot
GCCS	Gas Collection and Control System
GHG	Green House Gas
HDPE	High Density Polyethylene
Hr	Hours
In	Inch
Kw	kilowatt
Kwh	kilowatt-hour
LCA	Life Cycle Assessment
LCAs	Life Cycle Assessments
LCS	Leachate collection system
LDPE	Low Density Polyethylene

LFG	Landfill Gas
LFGE	Landfill Gas Energy
MCGM	Municipal Corporation of Greater Mumbai
MDPE	Medium Density Polyethylene
MSW	Municipal Solid Waste
MW	Mega watts
MPI	Ministry of Power India
O&M	Operation and Maintenance
PVC	Polyvinyl Chloride
Psi	Pound per Square Inch
SCFM	Standard Cubic Feet per Minute
SPCB	State Pollution Control Boards
SWM	Solid Waste Management
Scf	Standard Cubic Feet
TCE	Trichloroethylene
WTE	Waste to Energy

CHAPTER 1

Recovery of the Landfill Gas

1.1 Introduction

Karapidakis, Tsave, Katsigiannis, and Moschakis [1] observe that "The interest in landfill gas (LFG) recovery for use as an energy resource has increased as a consequence of conventional resource limitations and significant worldwide environmental problems." They go on to note that "The utilization of … recuperated biogas in municipal solid waste (MSW) sites" is "considered" to be "an effective process for treating organic wastes" [1]. Shah [2] states that "The daily per capita solid waste generated in India ranges from about 100 grams in small towns to 500 grams in large towns." A "major portion of the collected waste is dumped in landfill sites" [2]. Many of these sites are "unregulated dumps" or landfills not based on scientific principles (i.e., unscientific landfills) [2]. Shah goes on to note, "However, data collected from 44 Indian cities have revealed that about 70% of the landfills do not have adequate capacity for collection and transportation of municipal solid waste (MSW)" [2].

The United States Environmental Protection Agency (U.S. EPA) states that "LFG is a natural byproduct of the decomposition of organic material" in MSW under "anaerobic conditions" [3]. They go on to clarify that "LFG contains roughly 50 to 55 percent methane and 45 to 50 percent carbon dioxide, with less than one percent non-methane organic compounds and trace amounts of inorganic compounds" [3]. The EPA further observes that when "waste is first deposited in a landfill, it undergoes an aerobic (i.e., with oxygen) decomposition stage" during which "little methane is generated" [3]. "Then, typically within less than one year, anaerobic" (i.e., without oxygen) "conditions are established and methane-producing bacteria" "decompose the waste and" produce "methane" and carbon dioxide [3]. The U.S. EPA states that "Methane is a potent greenhouse gas" (i.e., "heat trapping"), over 20 times more potent than carbon dioxide [3].

Ramani, Sprague, Zietsman, Kumar, Kumar, and Krishnan [4] report that "Landfills in" Mumbai, "India are mostly undesigned, open dumping grounds that accumulate thousands of tons of waste every year." They state that "The concept of a landfill in India is often an open piece of land that is allocated for dumping waste" [4]. "Approximately three-fourths of the" MSW "generated from urban India is collected and disposed of in" unscientifically "managed dumping grounds" [4]. "Almost 70%–90% of landfills in India are open dump sites" [4]. There are three landfills in Mumbai: Deonar, Mulund, and Gorai [4].

Figure 1.1 shows that Mumbai, formerly called Bombay,

> is a sprawling, densely populated city on India's west coast. On the Mumbai Harbour waterfront stands the iconic Gateway of India stone arch, built by the British Raj in 1924. Offshore, nearby Elephanta Island holds ancient cave temples dedicated to Shiva. The city is also famous as the heart of the Hindi-language Bollywood film industry. [5]

Figure 1.1: India-Mumbia Map [6].

1.2 Deonar Landfill

Stege [7] – in a report published under the auspices of the U.S. EPA – provides a description of the Deonar Landfill.

> The Deonar Landfill is located in Mumbai, India, a coastal city in the western region with a population of approximately thirteen million people. The climate in the region is tropical and wet. The region experiences a humid season from March through October and a dry season from November through February. Annual average temperature is 27 degrees C (81 degrees F), and annual average precipitation is 2,130 millimeters (84 inches) [7].
>
> The landfill is an unlined historical dump site which is owned and operated by the City of Mumbai. The site opened in 1927 and is expected to remain in operation for approximately another 30 years; however, by Indian law the landfill will be required to receive only inert wastes after an organic waste processing and composting facility is built and begins operation. The composting facility will be constructed in modules over the next few years during which disposal in the landfill will decline [7].
>
> The existing landfill property covers a total of 131 hectares, of which approximately 120 have been used for waste disposal. The landfill is currently in the process of removing wastes from approximately 69 hectares in the southern and eastern portion of the site and depositing it in a 51 hectare area in the northwest portion of the site. This will create space within the site boundary for developing composting areas, leachate treatment areas, and future waste disposal areas. The 69 hectare area to be excavated contains wastes deposited approximately 20 to 80 years ago. The 51 hectare disposal area, which contains wastes disposed over the past 20 years, has been closed since 2010. Figure 1.2 is an aerial photograph showing the 69 hectare area to be excavated and the 51 hectare area to receive the excavated waste from the site management plan proposed by the City of Mumbai [7].

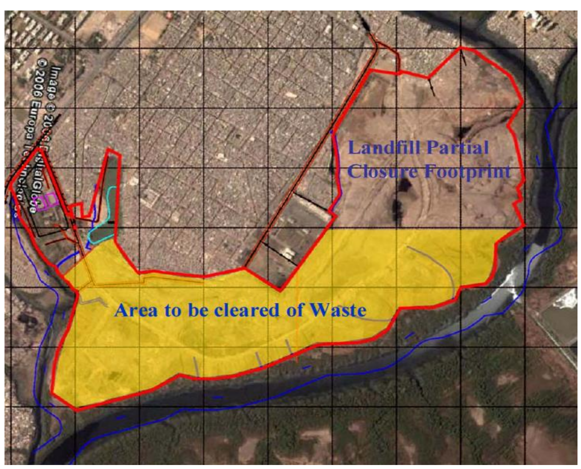

Figure 1.2: Site Management Plan Deonar Landfill [7].

1.3 Objectives

The aim of this report is to develop a procedure that can analyze the associated economic benefits and the costs incurred for the installation of one or two LFG utilization options for the Mumbai, India landfill. The following objectives were investigated.

- Optimization of the gas collection system design.
- The capturing of LFG and its utilization as an energy source.
- The assessment of "the technical and economic feasibility of the development of an LFG control and utilization project at the landfill" [7].
- The prevention of harmful waste generation.
- The promotion of waste byproduct re-use.

1.4 Scope

In its protocol for landfill gas capture and combustion, Alberta Environment provides a useful statement of scope for this Master of Science in Environmental Engineering (MSEV) project report.

> LFG is passively emitted due to the anaerobic decomposition of the organic components within the landfill. As the carbon dioxide component of the LFG is biogenic, this protocol is focused on the methane component. Landfill gas collection and combustion reduces the quantity of methane emissions released to the atmosphere from the landfill. The combustion of the methane component of the landfill gas results in emissions of biogenic carbon dioxide, thus achieving a reduction in man-made Greenhouse Gas (GHG) emissions. In addition, the generation of heat, power and electricity will offset other sources, which can include the combustion of fossil fuels. [8]

1.5 Purpose

A United Kingdom Department for Environment, Food, and Rural Affairs report provides a useful purpose statement for this MSEV project report: "Where there is residual waste (i.e., remaining waste that cannot be economically or practically reused or recycled"), the "aim is to get the most value from it via energy recovery, where doing so is the best overall environmental option. This can contribute to renewable energy targets and help with a more secure fuel supply" [9].

1.6 Waste Management Challenges

In India, solid waste management services are provided by Municipal Corporations and Municipalities in compliance with their regulations. Many of the laws are quite old and they need to be revised, which is required by law. Their enforcement is also very poor. In most of the municipalities, there is no separate department for waste management. "Solid waste management (SWM) is the responsibility of a health officer who is assisted by the engineering department in the transportation work. The activity is mostly labor intensive, and two to three workers are provided per 1000 residents served. The municipal agencies spend 5%-25% of their budget on SWM" [10]. "In spite of this huge expenditure, services are not provided to the desired level" [11]. "Present practices regarding solid waste in India are as follows:

- Generally, solid waste is disposed of in low-lying areas, the outskirts of cities, alongside roads or any vacant place wherever waste collectors find that they will not be seen or objected to by anybody" [11].

- Lack of “coordination among various departments of civic bodies also” leads “to poor management of solid waste management” [11].
- Waste is considered as having no value.
- There are no environmental codes.

CHAPTER 2

Literature Review

India is a developing country; there is no advanced-level landfill. Most landfills are open dumps. Developing countries use open dumps due to their low cost [7]. In Mumbai, India, no engineered method of landfill to dispose of solid waste and hazardous waste materials exists. Solid waste management is a big issue in populated cities and developing countries [4].

In India, the government is giving attention to SWM due to its environmental problems and the growing rate of improper solid waste disposal. Solid waste contains organic and inorganic materials. Vijay Kumar and Dr. R.K. Pandit observe that “it is in the obligatory function of urban local bodies, but in actual practice the solid waste management is given the last priority and the duties are either not performed or poorly performed; consequently the city has to face numerable problems related to environment and sanitation” [12].

The MSW department collects the waste door to door. The department has made systematic routine work and collection must be on regular basis. There is no scientific method employed to adopt for the sorting of the waste. There is no proper education for the people on how to handle the waste. People are not putting the garbage in a garbage bins. There is no street sweeping on a daily basis in most of the cities of India. Ranjith Kharvel Annepu observes that “The composition of urban MSW in India is 51% organics, 17.5% recyclables (paper, plastic, metal, and glass) and 31 % inert. The moisture content of urban MSW is 47% and the average calorific value is 7.3 MJ/kg (1745 kcal/kg). The composition of MSW in the North, East, South and Western regions of the country vary between 50%-57% of organics, 16%-19% of recyclables, 28%-31% inert and 45%-51% of moisture. The calorific value of the waste varies between 6.8-9.8 MJ/kg (1,620-2,340 kcal/kg" [13].

The Municipal Corporation of Greater Mumbai (MCGM) is a local government department of Mumbai which provides the services for handling the increasing quantity of solid waste. The MCGM department collects garbage bins and waste from other places and transports it to the transfer station, using different types of vehicles. Niyaz Ahmad Khan, and Ab. Qayoom Mir observe that "Most of these vehicles make a number of trips every day to the disposal site through specified routes. The transfer of waste from community bins to disposal site is done by using a variety of vehicles such as conventional trucks of non-tipping and tipping type, tractors with detachable trailers and hydraulic lifting system which directly lift the waste or relatively large sized containers to disposal sites" [14].

LFG is the product of the anaerobic decomposition of organic materials in a landfill. Methane comprises approximately half of this gas and can be converted into a renewable energy product [15]. The Republic Services Department states that "LFG is available for renewable energy source that offsets the need for nonrenewable resources such as coal and oil. LFG is the only renewable energy source that, when used, directly prevents atmospheric pollution. LFG can be converted and used in many ways: to generate electricity, heat, or steam; and as an alternative vehicle fuel to power fleets like buses, taxis, and mail trucks; or in niche applications like micro turbines, fuel cells and greenhouses" [16].

There are many ways to extract the gas from the landfill. In India, an internal combustion engine is typically used for this purpose.

Climate Tech Wiki Company states that “LFG is extracted from landfills using a series of wells and a blower/flare (or vacuum) system. This system directs the collected gas to a central point where it can be processed and treated depending upon the ultimate use of the gas. From this point, the gas can be simply flared (thereby converting methane into CO2) or used to generate electricity and/or heat, and replace fossil fuels in industrial and manufacturing operations. The gas could also be upgraded (purified) to natural gas standards” [17].

Hydrogeological conditions are very important in the design of the landfill. It is important to observe how far the water table is from the ground surface. The landfill designs and drawings show the source and method of obtaining and stockpiling daily, the intermediate and final soil cover, and the construction of cells. The final sequencing plan for each phase of a landfill needs to show closure of that portion of the landfill and the final grade after application of the final soil cover [18].

Debra R. Reinhart and Philip T. McCreanor observe that “All landfill designs typically utilize a drainage envelope around the collection pipe consisting of a high permeability drainage material, usually large rock, wrapped with a geotextile. Variations in design can exist. For example, one design evaluated as part of this literature review initially indicated socking the collection pipe, but this was changed prior to approval of the design. The drainage system, located above the liner, is perhaps the most critical element of the collection system, and generally consists of highly permeable natural materials such as sand or gravel or a geosynthetic net. The drain is often protected by a natural soil or a geosynthetic filter in order to minimize clogging" [19].

MSW landfill leachate poses a potential pollution threat to local ground and surface waters and thus has a bad effect on the health of residents living in the surrounding area. The groundwater must be saved from the leachate, which has to be collected and transported from the landfill body to a local wastewater treatment plant.

The leachate collection system (LCS) is the barrier between solid waste and groundwater level. The United States Environmental Protection Agency (U.S. EPA) states that "The LCS must be designed to convey the predicted leachate flow, using the peak monthly impingement rate onto the collection system over the life of the landfill cell, so that the leachate head on the primary liner does not exceed the thickness of the drainage media" [20].

Debra R. Reinhart states that "LFG includes odor control, environmental and safety protection, and energy recovery. Collection of gas reduces the emission of methane from landfills into the atmosphere. Furthermore, when LFG is converted to energy, some emissions from the use of fossil fuels, such as oil, coal, and natural gas, are avoided. The efficiency of gas collection must be measured as a function of soil type and the extent of gas collection system coverage" [21].

LCA is a technique for assessing the environmental aspects and potential impacts of a system from raw materials acquisition through production, use, and disposal [22]. Kip Funk, Jana Milford, and Travis Simpkins state that "Energy and environmental life cycle assessments (LCAs) attempt to estimate the impacts of products and services across all their life stages, from raw materials to disposal. In the case of waste-to-energy (WTE) facilities, life stages considered may include waste collection and transportation to the WTE plant location, as well as municipal solid waste (MSW) combustion and recycling and disposal of combustion residuals" [23].

CHAPTER 3

Laws and Regulations Concerning Solid Waste

3.1 Introduction

In India, the management of solid waste is a major issue. In this regard, solid waste management has all administrative, financial, legal, planning, and engineering functions which provide the solutions of the problem of the solid waste. The legislative framework of any department is the backbone of that department. The Strategic Action Plan for Integrated Solid Waste Management Plan, Pune State, states that "It is covered through various national, as well as some state level, regulations. Some guidelines are also prescribed by Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCB)" [24].

India is trying to make a shift towards the technologies and other methods adopted for waste management that are popular in developed countries. But before making such shifts, it is necessary to understand the potential and risk involved in the process. Dr. Manju Raina states that "The management strategy that stipulates the hierarchy of reduction in waste generation, and re-use and recycling options ahead of ultimate disposal, have been the core objective, as specified in the National Environmental Policy in 2006 and also in the National Hazardous Waste Management Strategy of the Government of India's Ministry of Environment and Forests, published in the year 2012" [25].

The Central Pollution Control Board Ministry of Environment & Forests, New Delhi, India, states that "A landfill is an unavoidable component in MSW management and its planning and design, construction, and operation and maintenance involve technical skills and safety measures in terms of health and environmental protection. The MSW (Management and Handling Department) Rules 2000 specify relevant points with regard to site selection for proposed landfill sites, facilities required at landfill sites, specifications for landfilling, pollution prevention, water quality monitoring, ambient air quality monitoring, plantation at landfill sites, closure of landfill sites and post closure, and other regulations. These specific provisions are to be implemented as per rules and need to be followed during the planning and design stage" [26].

3.2 The Legal and Regulatory Framework for the Environmental System

Dr. Manju Raina observes that "The policy and legislative framework forms the backbone of any institutional and implementation system. At the national level in India, there are numerous provisions in the Indian legislative structure that have a bearing on the Mumbai's management of environmental resources. Some of the relevant environmental legislation in India is listed below:

- Water (Prevention and Control of Pollution) Act, 1974
- Air (Prevention and Control of Pollution) Act, 1981
- Environment (Protection) Act, 1986
- Biomedical Waste (Management and Handling) Rules, 1998
- Municipal Solid Wastes (Management and Handling) Rules, 2000

• Hazardous Wastes (Management and Handling) Amendment Rules, 2000

• Batteries (Management Handling Rules), 2001

• Hazardous Waste (Management, Handling and Tran boundary Movement) Rules, 2008

• Plastics (Manufacture, Usage and Waste Management) Rules, 2009

• National Green Tribunal Act, 2010

• E-waste (Management and Handling) Rules, 2011" [27].

3.3 Rules 2000 For Solid Waste Management

A book, *Improving Municipal Solid Waste Management in India*, states that "Indian municipal authorities are responsible for implementing provisions of the 2000 rules. They must provide the infrastructure and services with regard to collection, storage, segregation, transport, treatment, and disposal of MSW. Municipal authorities are requested to obtain authorization (that is, permission or technical clearance) from the state pollution control board or committee to set up waste processing and disposal facilities. The key objectives of these rules are as follows:

• To provide scientific management of municipal solid waste.

• To ensure proper collection, segregation, transportation, processing and disposal of solid waste.

• To upgrade existing facilities to arrest contamination of soil and ground water" [28].

3.4 Limitations and Challenges of Solid Waste Management

In India, SWM has become a major challenge due to its lack of management. The population is increasing every year. The Mumbia City Hall has no advanced-level equipment to collect the solid waste and transfer it to a scientifically managed landfill.

There is no proper way to collect, transport, store, process, and dispose of solid waste as there is in advanced countries. In some parts of the city, the waste goes to the open dump area, which is not cleaned or treated.

There is no advanced-level landfill to dispose of the solid waste and from it, to collect energy.

CHAPTER 4

Collection of Waste

4.1 Introduction

The solid waste in India is collected by the SWM from door to door, which also collects from the open area dustbins. Sharholy Mufeed , Ahmad Kafeel , Mahmood Gauhar , and Trivedi R.C state that "The collection of MSW is the responsibility of the management of municipalities. The predominant system of collection in most cities is through communal bins placed at various points along the roads, and sometimes this leads to the creation of unauthorized open collection points. Efforts to organize house-to-house collection are just starting in many megacities in India, such as Delhi, Mumbai, Bangalore, Madras and Hyderabad. It has been observed that many municipalities have employed private contractors for secondary transportation from the communal bins or collection points to the disposal sites" [29].

4.2 Collection of Waste in Mumbai

Nagabooshnam states that "The solid waste generated in Mumbai can be classified into five categories: general waste, garden waste, soil, clinical waste and construction waste. General waste, garden waste and soil are considered as domestic waste generated by the individuals in day to day processes. The generation of general waste and garden waste in commercial sectors and industries is, however, quite high when compared with the households. The general waste can be primarily classified into two sub categories, organic and inorganic. The organic waste consists of food waste, garden waste, papers and cardboards, wood and other organic materials. The inorganic waste consists of bottles, cans, plastic, glass, electronic waste, metals, and other kinds of waste" [30].

Mahadevia Darshini, Pharate Bela, and Mistry Amit state that the "Municipal Corporation of Greater Mumbai (MCGM), from time to time, carries out campaigns through newspapers, instructing the citizens/ institutions to collect their own garbage and store the same in bins to be kept at the gates from where the municipal vehicles would pick them up mechanically at a specified time. The citizens and the institutions are also instructed that the municipal authorities would not enter individual premises for the purpose of garbage collection and lifting" [31]. R. Taylor and A. Allen state that "Household waste represents waste generated in the home and collected by municipal waste collection services. Municipal solid waste (MSW) includes this plus shop and office waste, food waste from restaurants, etc., also collected by municipal waste collection systems, plus waste derived from street cleaning, and green (organic) waste generated in parks and gardens" [32].

4.3 Organic Waste

Organic waste consists of household food waste, agricultural waste, and human waste. When this waste goes into the landfill, it is broken down by micro-organisms to form a liquid 'leachate.' Leachate is the contaminant solution that is stored in the landfill and can enter into the water table. The organic waste which goes into a landfill generates a large quantity of methane gas, which is harmful gas. Landfill methane gas is also a big source of energy, because it can be captured and used for energy.

Recycle Ann Arbor states that “The production of landfill gas is directly related to the amount of organic matter present in waste. Some forms of organic matter, such as cellulose, break down quickly, whereas matter such as lignin breaks down more slowly. The rate at which landfill gas is produced depends on the proportions of each type of organic matter present in the waste” [33]. The bacteria that break down the waste require small amounts of specific minerals, such as calcium, potassium, magnesium and other micronutrients. Bacteria are able to thrive and produce landfill gas if the minerals and micronutrients are present. If the minerals and micronutrients are not present or if substances that inhibit bacterial growth exist, landfill gas production will occur at a reduced rate.

Different factors can be influential here, including:

- Source Reduction.
- Onside Storage.
- Collection and Transfer.
- Processing Techniques.
- Disposal.

Figure 4.1 shows the flow diagram of the waste. It shows how solid waste is handled from waste generation to disposal site.

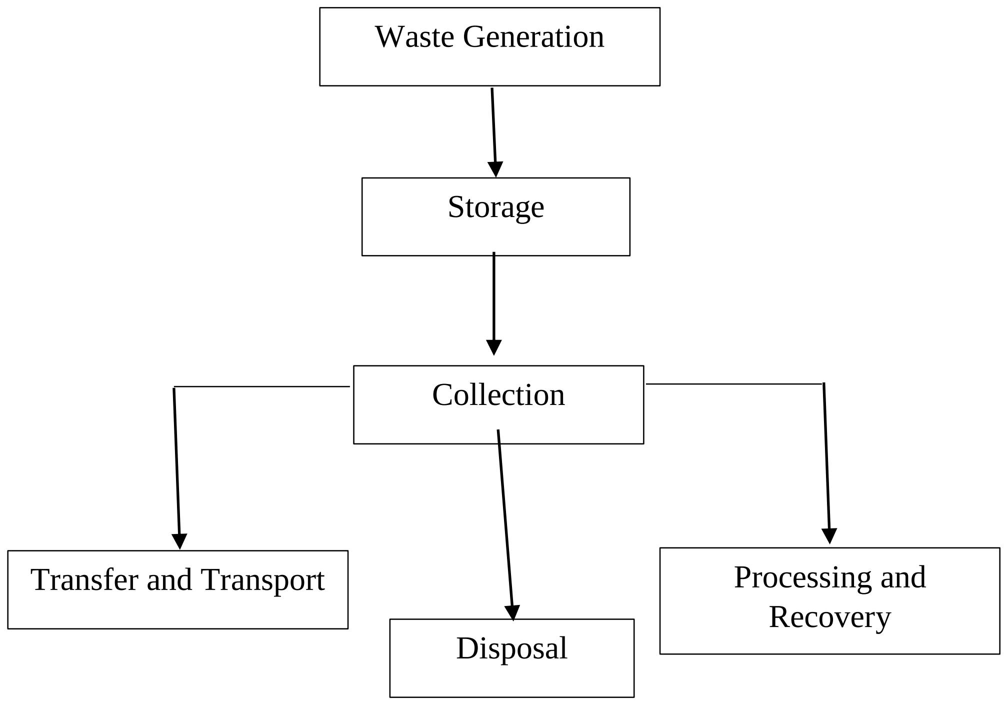

Figure 4.1: Collection Schematic Representation.

4.4 Waste Composition

Alex Stege states that "Waste composition is an important consideration in evaluating an LFG recovery project, in particular the organic content, moisture content, and 'degradability' of the various waste fractions. For example, landfills with a high amount of food wastes, which are highly degradable, will tend to produce LFG sooner but over a shorter length of time" [7].

In his investigation, Strege observed that "Data on the composition of wastes disposed at the Deonar Landfill in Mumbai was not available for this capstone project. Waste composition data from the Gorai Landfill in Mumbai, reported by Trichloroethylene (TCE) Consulting Engineers in a Methane to Markets workshop presentation in Mumbai on March 6, 2007, was instead used for this study. Waste materials observed during the pump test well drilling operations were recorded but did not provide a representative sampling for estimating the percentages of each waste type. General observations of waste composition during the pump test appear consistent with the waste composition data provided in Table 4.1, which shows that food waste and construction and demolition waste (including earth fill) make up over 65 percent of wastes disposed" [7]. Table 4.2 shows the waste disposal rate at Deonar Landfill.

Table 4.1: Waste Composition Data [7].

Component	Fraction of Waste Stream (%)
Food Waste	35.7
Garden Waste	6.3
Wood Waste	0.0
Paper and Cardboard	11.8
Plastics	5.0
Rubber, Leather	2.5
Textiles	7.5
Other Organics	0.0
Metals	0.8
Glass and ceramics	0.4
Construction and demolition waste (including sand and earth fill)	30.0
TOTAL	**100.0**

Table 4.2: Waste Disposal Rate Deonar Landfill [7].

Year	Waste Disposed (Metric Tons/year)	Year	Waste Disposed (Metric Tons/year)
1970	27,700	1991	204,900
1971	30,470	1992	225,400
1972	33,520	1993	247,900
1973	36,870	1994	272,700
1974	40,560	1995	300,000
1975	44,620	1996	330,000
1976	49,080	1997	363,000
1977	53,990	1998	399,300
1978	59,390	1999	439,200
1979	65,330	2000	483,100
1980	71,860	2001	531,400
1981	79,050	2002	584,500
1982	86,960	2003	643,000
1983	95,660	2004	707,300
1984	105,200	2005	765,000
1985	115,700	2006	1,095,000
1986	127,300	2007	1,205,000
1987	140,000	2008	1,326,000
1988	154,000	2009	730,000
1989	169,400	2010	91,000
1990	186,300	2011	0

CHAPTER 5

Transportation of Waste

5.1 Introduction

In Mumbai, waste is transported and stored at regular intervals at storage depots by the transportation department. This procedure ensures that there is no overflow of garbage bins/ containers and no waste is littered on the streets. If the garbage bins or containers overflow, the hygienic condition of the city will not be maintained.

The MCGM is responsible for the management of waste in the city. The MCGM is responsible for collecting the waste from households and other waste, and also for cleaning up the garbage cans. The MCGM has its own fleet for garbage collection and also hires contractors to collect and transport MSW to transfer stations and dumps. The average distance from the collection points to the dumping grounds ranges from 20-28 km [34]. The collection and transportation of this huge amount of waste is a matter of concern for any corporation. The MCGM operates a huge fleet of 983 municipal and private vehicles for collection of waste, totaling 1,396 trips each day [35]. Solid waste materials transfer from collection points to disposal sites by using different types of vehicles which depends on the distances to be covered by them. The details of the municipal equipment can be seen in Table 5.1

Table 5.1: Transportation Vehicles Deployed [34].

Type	Municipal	Outside	Total
Compactor (Big)	117	313	430
Compactor (Small)	-	258	258
Small Tipper (1 Tonner)	-	106	106
Dumper Placers (Skip Vehicles)	89	-	89
Tippers (8 Tons)	90	-	90
Stationary Compactors	10	-	10
Total			983

There are two basic steps involved in transportation:

- Transportation of the waste from the smaller collection vehicle to the larger equipment.
- The transport of the waste, usually taken over long distance which will be processed at disposal site. The transfer usually takes place at a transfer station.

The waste which is collected from the garbage bins and containers is transported to the transfer station where it is sorted. The recycled waste goes to the recycling site and other waste goes to the Deonar Landfill site.

5.2 Methods of Transportation

In the country of India, there are two basic methods used for the transportation of solid waste:

- The so-called “unscientific” method, which refers to a manual procedure that is not based on scientific principles.
- The so-called “scientific” method, which refers to modern procedures for transporting waste.

The larger vehicles are used to carry out the waste from the collection points to the disposal sites. The small vehicles are used to discharge waste at transfer stations, where the wastes are loaded into larger vehicles for transportation to the disposal sites.

5.2.1 Unscientific Method (Manual)

There is manual sweeping of all the roads on a day-to-day basis. The city area is divided so that sweepers clean their assigned areas. Collected wastes are deposited in nearby community dustbin containers, and then, the MCGM takes it. A sweeper is shown in Figure 5.1.

Figure 5.1: Manual Method of Sweeping [36].

5.2.2 Scientific Method (Transported)

All types of waste are collected by the employees of the MCGM on a daily basis. This department has 430 compactor vehicles. The waste is carried by a compactor vehicle and then is disposed of by towing the compactor to the landfill site. The waste should be transported on a regular basis to ensure that the containers and trolleys and dustbin sites are cleared. A trailer carries an empty stationary compactor from the site and then replaces the filled stationary compactor with an empty one at a particular site where it is placed. The filled stationary compactor is then taken to the landfill site. The empty stationary compactor returns to the location.

The MCGM has formed eight groups. Each group is supplied with four types of vehicles by the contractors – a regular compactor, a small compactor, and a small tipper vehicle of 6 tons, 2.5 tons, and one ton capacity, respectively. In addition, a watch and ward vehicle is supplied for each ward and an emergency maintenance vehicle [37]. Figure 5.2 shows the compactor vehicle.

The dumper collects waste from different community bins and then disposes of it at the landfill site. The MCGM uses a dumper to collect waste from different community bins over a period of 24 hours. The dumpers directly carry the waste to the landfill site for disposal. A dumper is shown in Figure 5.3.

Other equipment is also used to transport the waste. The design of an efficient vehicle will transfer the waste with less time, but the wrong vehicle will take more time to transfer the waste. The collection vehicle should be small and simple with trained people.

Figure 5.2: Compactor Vehicle [34].

Figure 5.3: Dumper Vehicle [38].

The flow chart in Figure 5.4 is designed to show the collection and transportation of MSW in Mumbia.

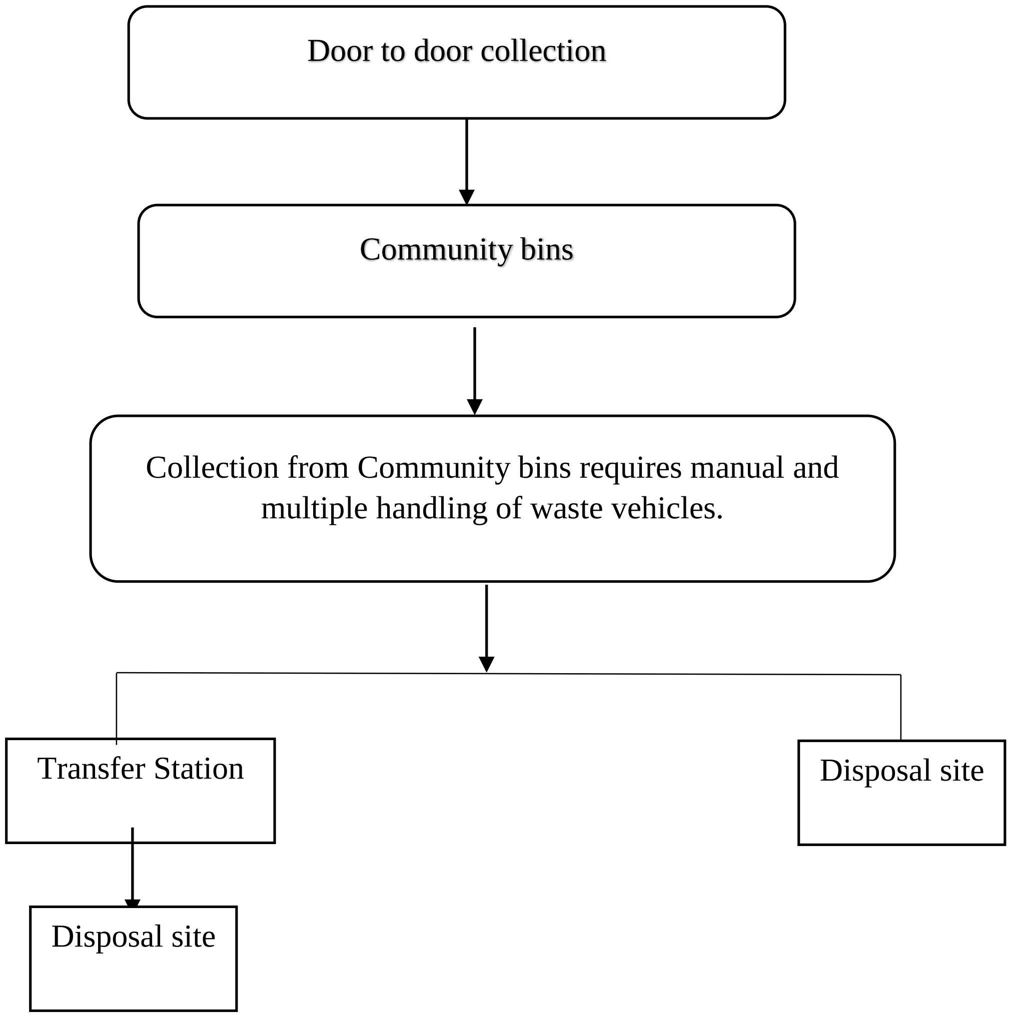

Figure 5.4: Flow Diagram of Collection and Transportation.

CHAPTER 6

Benefits of Landfill Gas

6.1 Introduction

Frankiewicz A. Thomas, Leatherwood A Chad, and Dieleman L. Brent observe that "Landfill gas energy (LFGE) is a critical component of an integrated approach to managing solid waste. With multiple environmental, social, and economic benefits, LFGE plays a critical role in the overall handling and management of municipal solid waste (MSW). In general, energy recovery within the solid waste sector plays a role in displacing fossil fuel use and reducing greenhouse gas (GHG) emissions. LFGE reduces GHG emissions and local air pollution, displaces fossil fuel use, and benefits the communities served by the landfill through economic development and job creation" [39].

6.2 Heat or Electricity Benefits

LFG is the biggest source of methane gas. When LFG is captured, it can be used to generate heat and electricity, and it also can be burned as a heat for industrial processes. The United States Environmental Protection Agency (U.S.EPA) states that "Biogas can be flared to control odor if energy recovery is not feasible. Both the flaring and use of biogas reduce GHG emissions. Biogas is a renewable source of energy with much lower environmental impacts than conventional fossil fuel" [40].

Due to the climate condition in India, it is warm, and the rate of MSW decomposition is faster than in advanced countries. The production of the methane gas can be expected to occur more quickly than in cooler climates. Only those large landfill sites will produce methane gas which has high rate of MSW. Power can be recovered from LFG, which can reduce the amount of electric energy to be produced using fossil fuels, that is, non-renewable sources of energy.

6.3 Economic Benefits

LFG can be captured from the landfill by the use of a series of wells. LFG can provide huge benefits for the long term against energy price volatility. LFG can reduce pollution, increase production of renewable energy, and also create job opportunities for the public. In India, a large portion of energy is obtained from coal and water. A big opportunity exists to capture methane gas and to use it to generate energy. Right now, the cost per unit of electricity is 25 cents. After leveraging the LFG to generate energy, the cost of electricity could be reduced; the unit cost could be as low as 11 cents [41].

The use of LFG can produce a significant amount of energy, and its use is associated with the following advantages:

- LFG can serve as a local source of energy.
- LFG has a good potential for business.
- LFG reduces the air pollution and odor that can be associated with some landfills.
- The cost of landfill gas energy (LFGA) is less expensive.
- The local government will get the revenue by selling the LFGE.

- Developing the landfill can create more jobs.
- LFGE can reduce the emission of greenhouse gas.
- LFGE can reduce the hazards associated with organic pollutants.
- LFGE can be generated by different technologies, including internal combustion engines, gas turbines, and microturbines.
- Designing the landfill in India reduces waste.

CHAPTER 7

Technologies

7.1. Landfill Gas Technologies

The basic purposes for the utilization of LFG include direct use and electricity generation energy. This chapter explains the utilization of different technologies. The electricity generated from LFG can be sold to the grid, and also, LFG can be sold to a third party. LFG generates electricity through the use of different technologies, such as:

• Internal combustion engines

• Gas turbines

• Microturbines

The vast majority of projects use internal combustion engines, with microturbine technology being used at smaller landfills [42].

7.2. Electricity Generation Technologies

The Global Methane Initiative states that “LFG can be used as a fuel in internal combustion engines or combustion turbines driving either an electrical or gas-powered generator. The generated electricity can be used to power on-site needs such as the blowers for the active gas collection system or leachate treatment system or, more typically, it can be sold to the local electricity grid. Electricity generation from LFG accounts for the majority of LFGE projects globally” [43].

7.3. Internal Combustion Engine

Inogate states that "The most common LFG utilization technology for small to relatively large LFGE projects is the internal combustion engine. Internal combustion engines are available in various sizes with electrical outputs ranging from less than 0.2 MW to more than 3.0 MW per unit. About 500 to 540 m^3/hr. of LFG at 50 percent methane is necessary to generate 1 MW of electricity. Internal combustion engines that use LFG as a fuel are commercially available and may be obtained as modular units or within a complete parallel generator package" [44]. Caterpillar low-energy gas engines and generator sets, as seen in Figure 7.1, can turn landfill gas into a valuable and sustainable power solution [45].

Figure 7.1: Internal Combustion Engine [45].

7.4. Direct Use

The United States Environmental Protection Agency (U.S. EPA) states that “Directly using LFG to offset the use of another fuel (natural gas, coal, and fuel oil) is occurring in about one third of the currently operational projects. This direct use of LFG is in a boiler, dryer or other thermal applications. It can be used directly to evaporate or leachate. Current industries using LFG include auto manufacturing, chemical production, food processing, waste water treatment, and hospitals” [42].

7.5. Gas Turbines

Wikipedia states that “A larger LFGE technology example is a gas turbine. LFG-fired gas turbines are similar to natural gas turbines except that, because of the lower pipeline quality value, twice the number of fuel regulating valves and injectors are used. The majority of gas turbines currently operating at landfills are simple cycle, single-shaft machines. Gas turbines are generally larger than internal combustion engines and are available in various sizes from 1 MW to more than 10 MW” [46]. The Global Methane Initiative states that “Although smaller gas turbine units or microturbines (less than 1 MW) have been used at landfills, they are not normally the primary generating unit. Gas turbines are available as modular and packaged systems” [43]. Figure 7.2 shows a gas turbine engine.

Figure 7.2: Gas Turbine Engine [46].

7.6. Selection of Suitable Technologies

The basic purpose for LFGE is to generate electricity or the direct use of LFG as a fuel. The best selection of technology for energy recovery will depend on a number of factors. The Deonar Landfill should include appropriate LFGE technologies and practices. For example:

- Proper design of the infrastructure
- Minimum distance to the grid
- Proper maintenance of the collection system, to improve the efficiency of the landfill
- Internal combustion engines should be used for the conversion of LFG to electricity
- Sale of the gas and electricity will improve the economy
- Local suppliers will provide the service equipment

- Well-trained employees
- The agreement for the selling of gas and energy should be secure

7.7. Direct Thermal Use Considerations

The Global Methane Initiative states that “The major benefits of direct thermal applications are that they maximize utilization of the gas, require limited treatment, and allow for blending with other fuels. Direct thermal applications have been demonstrated for a wide range of project sizes as long as there is a match between the quantity of LFG available and the demands of a prospective end user, or adequate LFG to supplement the primary fuel consumption of the end user. Direct thermal applications may be most useful when electricity regulations or markets restrict the sale of electricity generated from LFG” [43].

CHAPTER 8

Application of Landfill Gas

8.1 Introduction

Dudek, Klimek, Kolodziejak, Niemezewska, and Bartosz observe that “A landfill site containing municipal waste works like a bio-reactor in which landfill gas (a gas mixture, composed primarily of methane, carbon dioxide, and nitrogen) is produced in a biochemical process from the decomposition of organic matter. The composition of LFG produced by organic matter deposit in a municipal landfill varies significantly, both during the operation phase (acceptance of waste by the landfill) and after landfill closure. The intensity of gas production varies too, depending on the time elapsed since the deposition of waste in the landfill. The composition of LFG and its flow are key factors determining the correct and beneficial use of the energy potential of a landfill” [47].

Guney Irfan, Onat Nevzat, and Kocyigit Gokhan note that “The technologies used for conversion of renewable energy sources to heat, electricity, and fuels are plentiful. Their development has contributed to the gradual lowering of technology prices on the one hand, and to improvement in their efficiency on the other hand. Gradually, renewable energy and its different energy conversion technologies have become economically viable, capable of competing with fossil-fuelled technologies in the energy market” [48].

LFG is produced continuously after the decomposition of solid waste by the landfill. A scientifically managed landfill generates a significant amount of LFG.

8.2 Utilization of Landfill Gas

LFG is utilized naturally as an occurring byproduct of the anaerobic stabilization within the waste mass of a municipal solid waste landfill. The Indian government has been charged with finding viable options for the beneficial use of this resource. In general, there are three primary end-use categories.

- On-site generation of electricity for sale to an electric utility
- Direct thermal utilization of the LFG by piping the gas to a nearby thermal energy-user
- Processing of LFG on-site to produce natural gas quality for pipeline sale or other alternative fuel use

These three end-use categories have individual benefits and drawbacks, and all have a variety of particular technologies and usage.

8.3 Electricity Generation

The most common use of LFG is to convert it into energy. Different technologies are used to convert LFG into electricity, like internal combustion engines, gas turbines, and micro-turbines.

The benefit from using methane as biogas to generate electricity can be calculated based on CO_2 equivalent emission. For instance, a 1 MW gas generator needs around 700 m^3 of 50% methane per hour [49].

The main components of a typical landfill-gas-to-energy system are shown in Figure 8. Figure 8 shows how LFG is collected and converted to energy. When LFG is captured from a landfill, a number of vertical extraction wells are drilled into the landfill. In this way, gas is recovered from the landfill through the blower. After the collection of gas, it will be processed into the compressor. The temperature of the compressor gas will be low, when gas next enters into the chiller. The gas from the chiller will enter into the generator, where the gas will be converted into the energy.

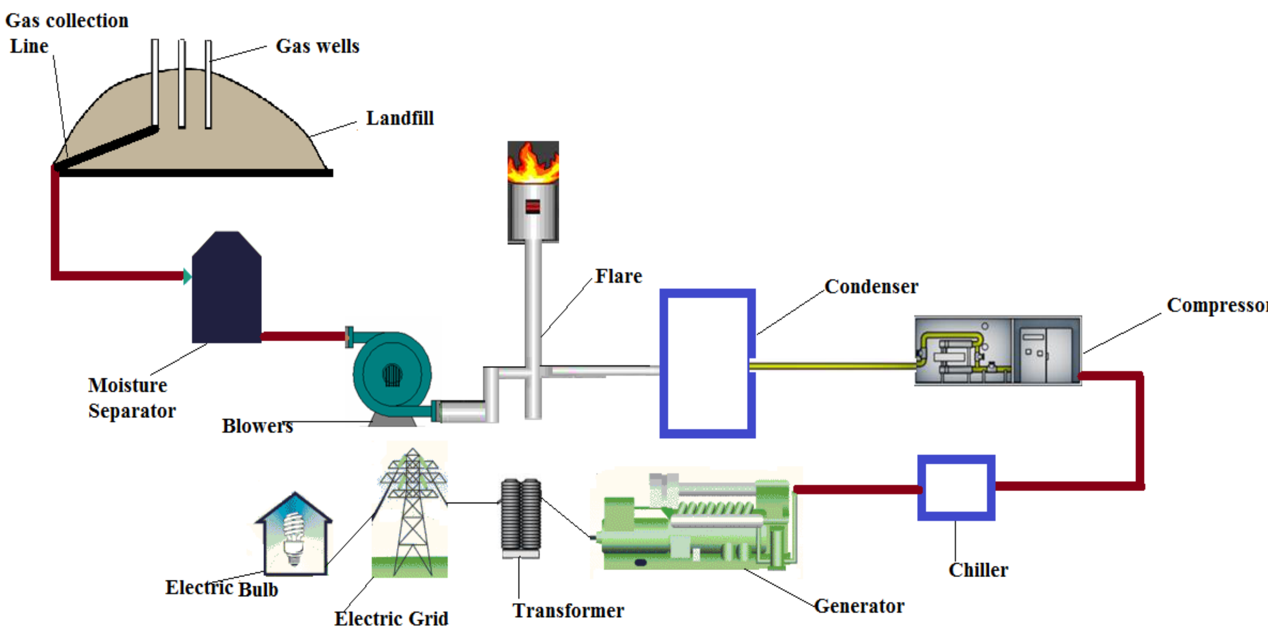

Figure 8.1: Collection of LFG to Energy.

CHAPTER 9

Design and Construction of Landfill

9.1 Introduction

A landfill is important to manage the MSW of the city. In Mumbai, India, no modern MSW landfill exists. An engineered landfill consists of a combination of regulatory, design, operational, maintenance, and monitoring features. In advanced countries, the landfills can protect human health and environmental concerns. The modern design of landfills also protects groundwater and surface water.

Safe and reliable disposal of municipal solid wastes and residues is an important component of integrated waste management [50]. In Mumbai, India, the Deonar Landfill is an open dump. An engineered landfill is a disposal site where, through planning before construction or through modifications at an existing site, a more managed and scientific approach is conducted. This is the goal for the Deonar Landfill.

The city of Mumbai generates approximately 6000 tons of MSW per day. The Deonar Landfill receives 1000 tons per day [7]. The Municipal Corporation of Greater Mumbai (MCGM) decided to adopt the guidelines provided by the MSW 2000 ruling. The closed site has no facilities to store the gas and to utilize it as energy. By capturing gas and utilizing it as energy, the Deonar Landfill can be re-designed to be a modern landfill and its service life can be extended.

Chen Yunmin, Tang Xiaown, and Zhan Liangtong state that "The landfill cover and gas collection system needs to control both the ingress of moisture (which generates leachate) and the egress of landfill gasses. In order to minimize the leakage of landfill gas to the atmosphere, the cover needs to include a liner system to provide resistance to gas escape, and a gas collection system that reduces the driving force for gas escape by collecting the gas (thereby reducing gas pressures in the landfill). The liner system in the cover often is similar to that in the bottom liner. In addition to the liner and gas collection system, there may also be a moisture distribution system to provide moisture to the waste to encourage biodegradation and gas generation" [51].

9.2 Site Design

The current Deonar Landfill was already closed in 2010. The site will be extended on the east side of the land. The United States Environmental Protection Agency (U.S. EPA) states that "The primary objective of the landfill east-side site design is to provide effective control measures to prevent or to reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, as well as the resulting risks to human health arising from landfilling of waste" [52].

Ranson David states that "A landfill site is a complex grouping of natural processes and integrated engineered systems, each of which is related to some degree to the others. The design of engineered control systems must take into consideration influencing factors created by and applied to other elements of the landfill system. The design of LFG controls must be integrated into the overall philosophy for design and operation of the site" [53].

The design phase consists of the following components:

- Liner System
- Gas Wells
- Collector Pipe
- Drainage Layer
- Top Soil
- Capping System
- Leachate Collection System
- Ground Water Monitoring Well
- Flare

Figure 9.1 shows these components.

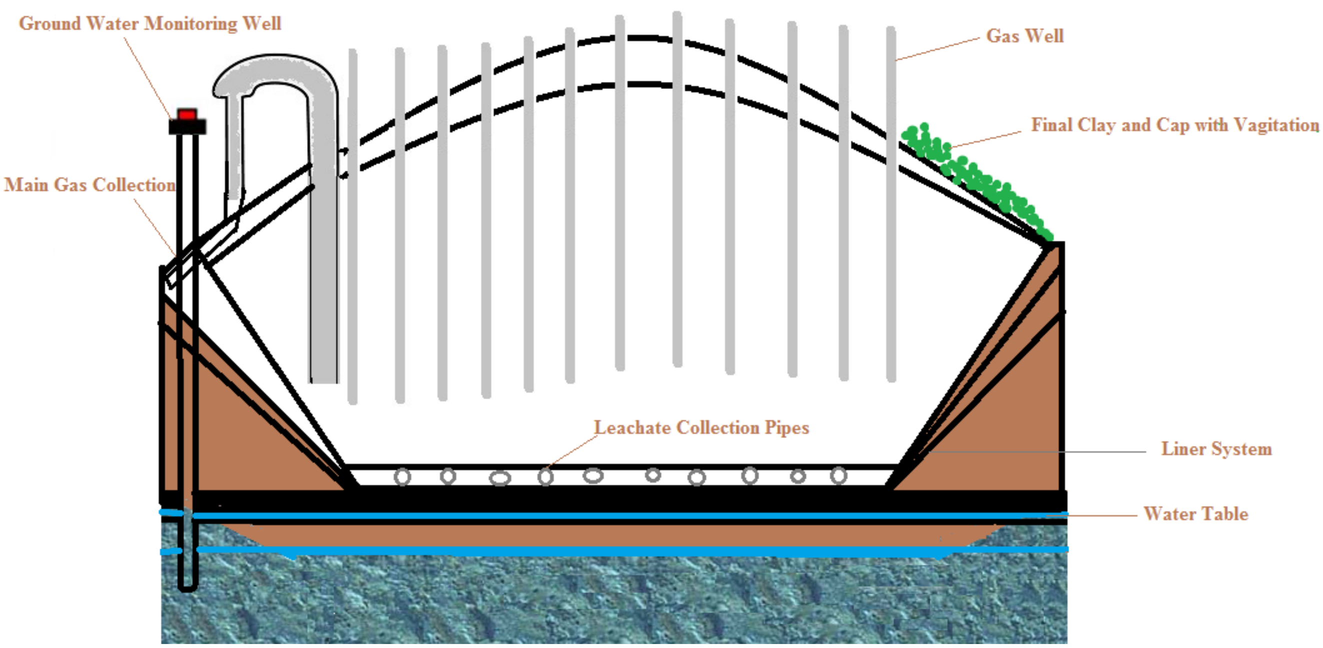

Figure 9.1: Landfill Design.

Engineered landfills are designed in a series of “cells”. Figure 9.1 shows that to build a new cell, the base of the quarry must be levelled with soil to create a platform. By extending the Deonar Landfill and by designing a landfill based on scientific principles in order to capture landfill gas, gas produced by the site can be utilized in different ways. Figure 9.2 shows the footprint of the proposed landfill. It is extended to the east corner of the closed landfill. The specifications of the proposed landfill re-design consist of the data summarized in Table 9.1.

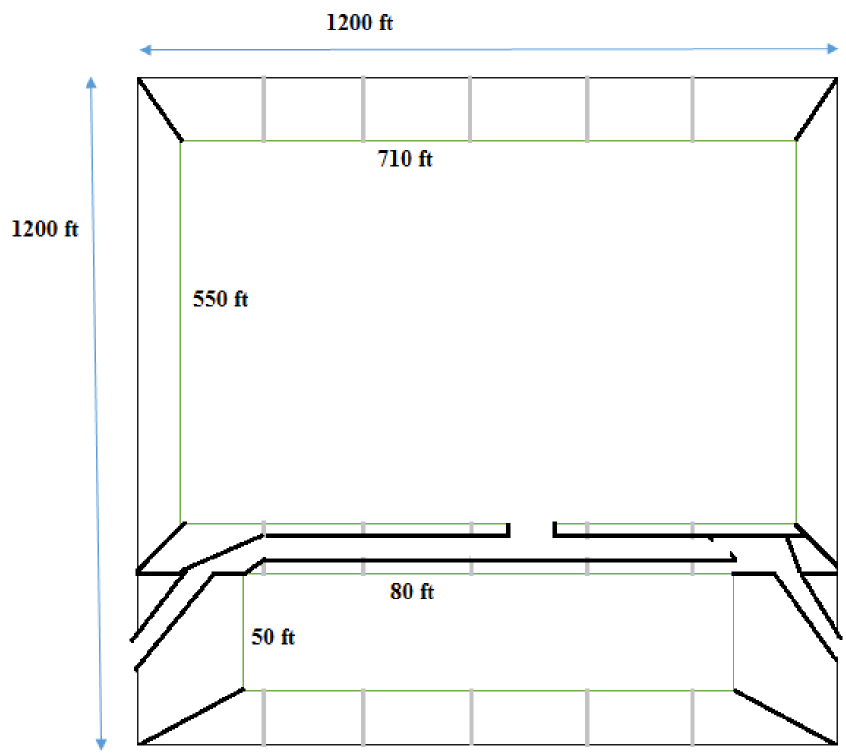

Figure 9.2: Footprint of the Proposed Landfill.

Table 9.1: Deonar Landfill Basic Data [7].

Location	Mumbai
Waste Generation	1000 tons per day
Design Life	50 years
Topography	Flat ground
Subsoil	Sandy silt up to 20m below ground surface, underlain by bedrock
Water Table	10 m below ground surface
Base Year	2014 year
Area of Land	1440,000 ft^2 or 33 acres
Length of Land	1200 ft
Width of Land	1200 ft
Landfill Length	710 ft
Landfill Width	550 ft
Depth of Landfill	25 ft
Area of Landfill	390,500 ft^2

9.3 Liner System

The Department of Environment and Heritage Protection states that “The principal functions of a landfill liner system are to limit contaminant migration to groundwater and to control landfill gas migration. This is achieved by the landfill liner slowing the vertical and lateral seepage of leachate to allow collection and removal by the leachate collection system, and to contain landfill gas within the landfill for appropriate collection. The liner may also attenuate contaminants in leachate seeping through the liner. A further function of the liner is to control infiltration of groundwater" [54].

Ranson David states that "Many older sites do not have liners or leachate collection systems. More modern engineered landfills are typically equipped with soil and synthetic membrane liners and leachate collection systems. The effects that liner systems have on LFG management are primarily related to the moisture content of the waste and the liner's effect on subsurface migration of LFG" [53]. In the Deona Landfill, liner systems would be used for the seepage of leachate and landfill gas which protect the groundwater. Figure 9.3 shows the composite liner which consists of a compacted clay liner (CCL) and the geomembrane. CCL is more effective to control seepage.

Low permeability liners with leachate collection systems are recommended to optimize control of LFG migration, along with their primary purpose of controlling potential groundwater impacts [53].

There are two types of liner systems:

- Single Liner System
- Composite Liner System

9.3.1 Single Liner Systems

Single liners consist of a clay liner, a geosynthetic clay liner, or a geomembrane (specialized plastic sheeting) [55].

9.3.2 Composite Liner Systems

Kerry L. Hughes, Ann D. Christy, and Joe E. Heimlich state that “A composite liner consists of a geomembrane in combination with a clay liner. Composite liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. Composite liners are required in MSW landfills” [55]. The basic data associated with the total liner system proposed for the Deonar Landfill site are shown in Table 9.2

Figure 9.3: Composite Liner [56].

Table 9.2: Liner Basic Data [57].

Area of Landfill	390,500 ft^2
Depth of Landfill	25 ft
Type of Linear	Geomembrane
Material	60 mil HDPE
Slope	3:1 Max.

9.4 Gas Wells

The U.S. Army Corporation of Engineers states that “A gas collection and control system (GCCS) is the major part of the landfill which extract the gas from the decomposition of the waste. Well systems consist of a series of vertical LFG extraction wells (perforated or slotted collection pipes) that penetrate to near the bottom of the refuse or to near the depth of saturated waste” [58].

Waste 360 states that “GCCSs are mostly use in sanitary landfills. GCCSs give the long term solution. They are designed to help control odors, minimize non-methanogenic organic compound releases to the atmosphere, and increase safety by controlling migration” [59]. A GCCS is properly designed to operate for many years without major problems. There are four types of gas wells:

- Vertical Gas Well
- Horizontal Gas Well
- Hybrid Type Well
- Gabion Well

A vertical gas well consists of a borehole containing a pipe which has perforations through the wall over the lower part of the pipe length. The pipe is surrounded by coarse aggregate fill [52].

A horizontal gas well consists of perforated pipes laid horizontally in trenches set in the waste or within the gas layer in the final capping system. The pipe is surrounded by coarse aggregate fill [52].

Hybrid types consist of an array of shallow depth perforated vertical wells connected to a single offtake point by lengths of buried horizontal pipe, which may also be perforated [52].

A Gabion well consists of aggregate-filled excavations set in the waste from which gas is drawn off through a perforated pipe located within the aggregate [52].

For the Deonar Landfill, it is proposed that vertical gas wells be installed. These gas wells would be drilled to 75% of the waste depth. Gas wells would be drilled into the landfill, and the pressure will increase at each well, to maximize gas collection. Figure 9.4 shows the design of a landfill gas well. At Deonar, a pipe network would be built to interconnect wells and blower equipment. The basic data associated with the installation of the gas wells are summarized in Table 9.3.

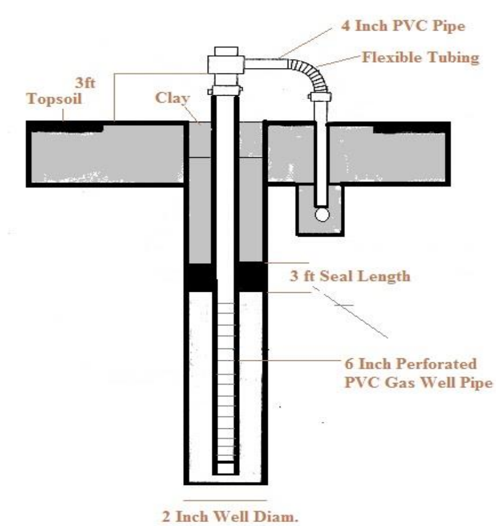

Figure 9.4: Landfill Gas Well [46].

Table 9.3: Gas Wells Data [52, 57].

Gas Well	**Measurements**
Well diameter	2 in.
Diameter hole in the landfill to a minimum	75 % of the landfill depth
Seal length	3 ft
Perforated PVC gas well pipe	4 in.
Layer of top soil	2 ft
Borehole diameter	5 in.
Well drilling rig to dig	24 in.
Boring depth	20 ft
Well pipe material	PVC
PVC cape	4 inch diameter
PVC pipe	4 inch diameter
Height of PVC cape from ground surface	3 ft
No. of wells	15

9.4.1 Pressure Probes

Shallow pressure probes are used in order to check for infiltration of air into the landfill, and deep pressure probes are used to determine the radius of influence [60].

Figure 9.5 shows the radius of influence from an extraction well from which the migration direction of landfill gas will be influenced by a vacuum application, and Table 9.4 summarizes basic data concerning the pressure probes.

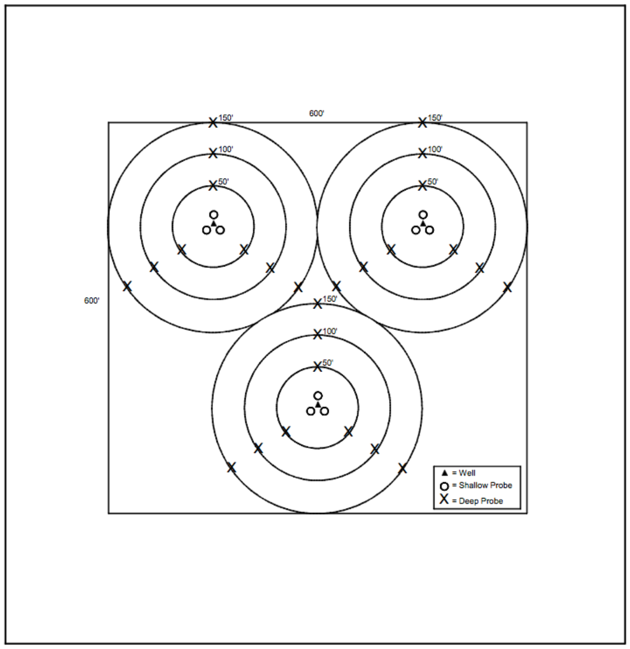

Figure 9.5: Radius of Influence from Well [60].

Table 9.4: Pressure Probes Data [60].

Direction apart	120 degree
Monitoring wells	4
At the distance	10, 50, 100, and 150 ft
Instrument	Auger
Dig a hole	8 in.
Diameter holes spaced	6 in.
Place the pressure Probe	Center of the hole
Backfill with gravel to a level	1 ft
Add a layer of backfill material	4 ft
Add a layer of bentonite at least	1 ft

9.5 Collector Pipe

The design of the gas collection pipe network would feature the transportation of the gas from the point of generation to the point of thermal destruction. The material that would be used for the pipeline needs to chemically resist landfill gas. The materials which are deemed most suitable are polyethylene (MDPE and HDPE) and polypropylene. The pipework should be sized to allow for maximum possible gas flow rate from the site. Polyethylene (MDPE and HDPE) and polypropylene are the most suitable materials which would be used at the Deonar Landfill. The pipework should feature a standard size, as summarized in Table 9.5.

Rajaram Vasudevan, Siddiqui faisal Zia, and Khan Mohd Emran state that “It may be necessary to lay pipes over flat terrain in a saw-tooth configuration to achieve the required minimum fall. Dewatering points should be provided at all drop legs in such a system. The pipeline should have sufficient valves to allow isolation of sections. Pressure testing of the collection pipe network should be carried out to ensure integrity of the pipe material and of joints” [61]. Figure 9.6 shows a collector pipe. The Deonar Landfill gas collection system should use the same pipe that would normally be used [62]. Table 9.5 presents specifications concerning the collector pipes.

Figure 9.6: Collector Pipe [62].

Table 9.5: Data for Collector Pipes [57, 62].

Collector Pipes	**Measurements**
Material of the pipe	HDPE
Trench	3-by-3-foot
Minimum header slope in direction of LFG flow	0.5 %
Minimum slope of header against LFG flow	2 %

9.6 Drainage Layer

Waste Management of USA states that “A layer of sand or gravel or a thick plastic mesh called a geonet drains excess precipitation from the protective cover soil to enhance stability and help prevent infiltration of water through the landfill cap system. A geotextile fabric, similar in appearance to felt, may be located on top of the drainage layer to provide separation of solid particles from liquid. This prevents clogging of the drainage layer" [63].

Most landfills use the drainage layer because it limits the infiltration of water inside the landfill. It reduces the water pressure on the liner and increases the friction, to mitigate the risk of sliding. Figure 9.7 shows that the maximum running distance for water in the geotextile is half the distance between the pipes. Table 9.6 shows the basic data for the drainage layer.

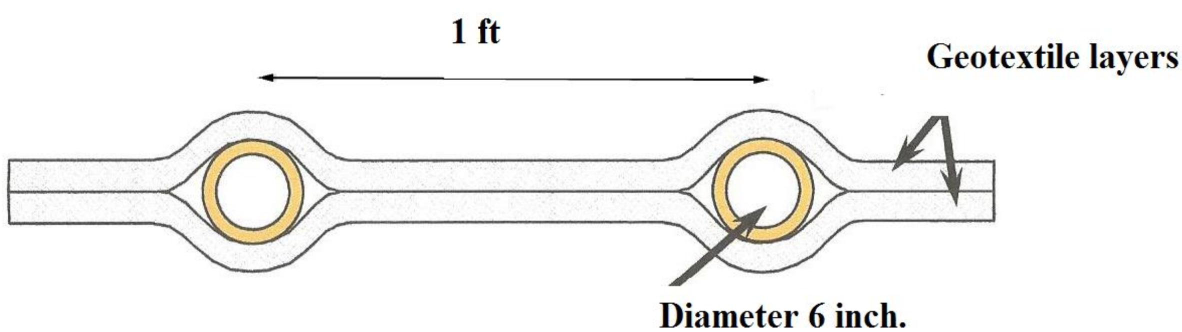

Figure 9.7: Drainage Layer.

Table 9.6: Data for Drainage Layer [57].

Drainage Layer	**Measurements**
Minimum thickness	1 ft
The hydraulic conductivity	$1x10^{-4}$ m/s
The slopes for the drainage layer	no less than 4%
Diameter	6 in.

9.7 Topsoil

Topsoil helps to support and maintain a growth of vegetation by retaining moisture and providing nutrients [63]. The soil layers need to accommodate extreme water conditions, such as summer thunderstorms, or periods of dry time.

Conestoga-Rovers & Associates states that “A six-inch layer of topsoil should be placed over the general fill layer to support a vegetative growth over the entire landfill cover system. Topsoil should consist of six inches of tilled, compacted soil. Topsoil should be reasonably free of roots, rocks or lumps larger than 1/2-inch, weeds, and other vegetation” [64].

9.8 Capping System

Capping involves placing a cover over contaminated material such as landfill waste or contaminated soil. Such covers are called “caps.” Caps do not destroy or remove contaminants [65].

The U.S. Environmental Protection Agency (EPA states that “A top layer of soil planted with grass or other vegetation can help prevent soil erosion and make the area look more natural and attractive. A layer of sand and gravel, often containing rows of slotted pipes, is built to collect and drain any water that makes it through the top layers of a cap. A sheet of strong plastic-like material is used to prevent downward drainage of water and upward escape of gases. A layer of compacted clay also can help prevent the downward drainage of water” [65].

Lane County Oregon states that “A landfill cap has a multiple layers of soil and geotextiles and also looks like the liner system. A landfill should be capped when garbage will no longer be placed. The caps are designed and constructed to capture methane gas and to reduce storm water infiltration into the landfill” [66].

Figure 9.8 shows the typical final cap design of a landfill. The final cap has several layers, as shown in Figure 9.8, and Table 9.7 provides details concerning the layers.

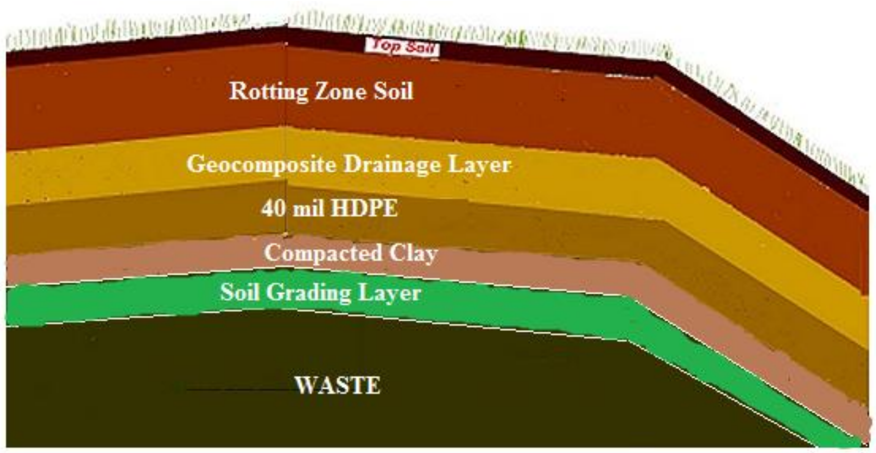

Figure 9.8: Capping System.

Table 9.7: Data for Capping System [57].

Capping System	**Measurements**
Thick low permeability soil layer	1.5 ft
Geomembrane layer	40 LDPE
Granular drainage layer	1 ft
Top soil layer	6 in.
Side slope	1:4
Sand bedding	4 in.
Compacted clay layer	2 ft
Soil grading layer	6 in.

9.9 Leachate Collection System

Leachate is the toxic liquid which comes from the waste breakdown that occurs in the landfill. This highly toxic liquid can pollute the groundwater. The HDPE materials are used in the leachate collection pipes. The direction of the leachate flows follow the gravity rule through the pipes to the sump, which is a large collection pit. Landfill leachate typically contains pollutants from whatever materials are buried or decomposing in the landfill facility. The leachate collection drainage layer needs to have a sufficient thickness to manage the maximum hydraulic head between the piping networks without pressurizing the drainage layer, as well as to increase the “life expectancy” of the system from clogging [67]. The Engineered Containment System (ECS) is a well-designed leachate collection system that can be employed so that the leachate that is generated is caught by the liner, and would not seep into the groundwater.

The New York State Department of Environmental Conservation states that “The primary leachate collection and removal system consists of a series of drains and pipes within a layer of sand or gravel designed to collect all of the liquid leachate that has drained through the waste mass. A 60 mm thick geomembrane underlies the leachate collection system. On the bottom of the landfill, the 60 mm geomembrane is underlain by a clay layer or a thin manufactured layer of very strong textiles and an extremely low permeability clay component to make a composite liner. The collected leachate is sent to a wastewater treatment plant” [68].

The leachate collection system would be designed at the Denoar Landfill such that leachate and precipitation would flow to a leachate sump at the south end. The network of the piping and pumps would be used to transport a maximum amount of leachate. The landfill liner would be used as a composite barrier to protect for the leakage. The leachate collection system requires the following: required piping and the spacing of piping, pipe size, pipe strength, and slot size.

Figure 9.9 shows the footprint of the leachate collection system. The specifications of these design elements are given in Table 9.8.

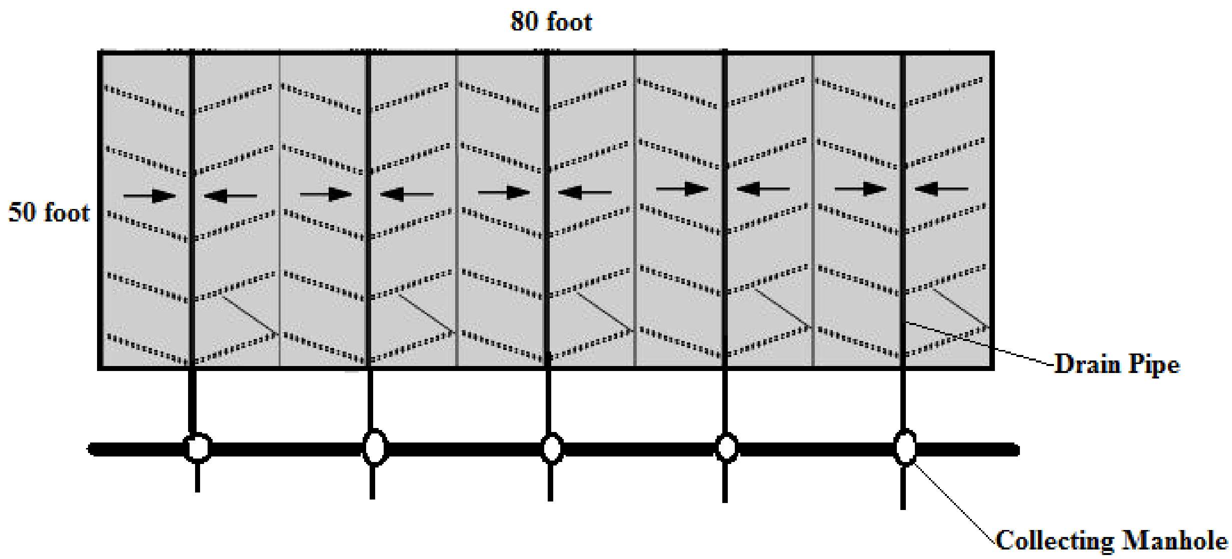

Figure 9.9: Leachate Collection System.

Table 9.8: Data for Leachate Collection System [52, 57].

Leachate Collection System	**Measurements**
Length of Leachate Pond	80 ft
Width of Leachate Pond	50 ft
Area of Leachate Pond	4000 ft^2
Geomembrane	60 mil HDPE
Collection Pipe diameter	8 in.
Pipe Slope	1 %
Drainage Slope	2 %
Leachate Loading Rate	750 gpd/ac
Maximum Leachate Head	11 in.
Pipe Spacing	60 ft

9.10 Flare

Flaring is the open-air burning of natural gas. A flare is included in the design of a gas collection and utilization system in order to properly handle LFG not utilized in the energy facility [69]. Bellovich John, Franklin Jim, and Schwartz Bob state that “Gas flaring in is used in landfill to combust waste methane gas. A flare can only achieve its objective of safe, effective disposal if the exiting gases are ignited and the ignition is sustained” [70].

Landfill gas converts into methane gas by the anaerobic decomposition of waste. Methane is the main component of the landfill which is harmful to the environment. Methane also destroys the components of the landfill, which causes odor and stresses vegetation.

Types of Flares

There are two types of flares:

- Open Flare
- Enclosed Flare

Open Flare

Caine states that “An open flare is essentially a burner with a small windshield to protect the flame. Open flares have been popular because of their simplicity and low cost allied with the absence of emissions standards and controls” [71]. At all times, the open flare shows a visible flame, which becomes more obvious during the night hours.

Enclosed Flare

Stone, Lynch, and Pandullo state that “An enclosed flare's burner head is inside a shell that is internally insulated. This shell reduces noise, luminosity, and heat radiation and provides wind protection. A high nozzle pressure drop is usually adequate to provide the mixing necessary for smokeless operation and air or steam assist is not required. An enclosed flare has less capacity than an open flare and is used to combust continuous, constant flow vent streams, although reliable and efficient operation can be attained over a wide range of design capacities” [72].

Figure 9.10 shows an open flare, which has been designed for the Deonar Landfill. An open flare is less expensive than an enclosed flare. An open flare has a visible flame at the top. This flare is designed to satisfy the minimum requirements of the LFG combustion.

The basic data for the flare are shown in Table 9.9.

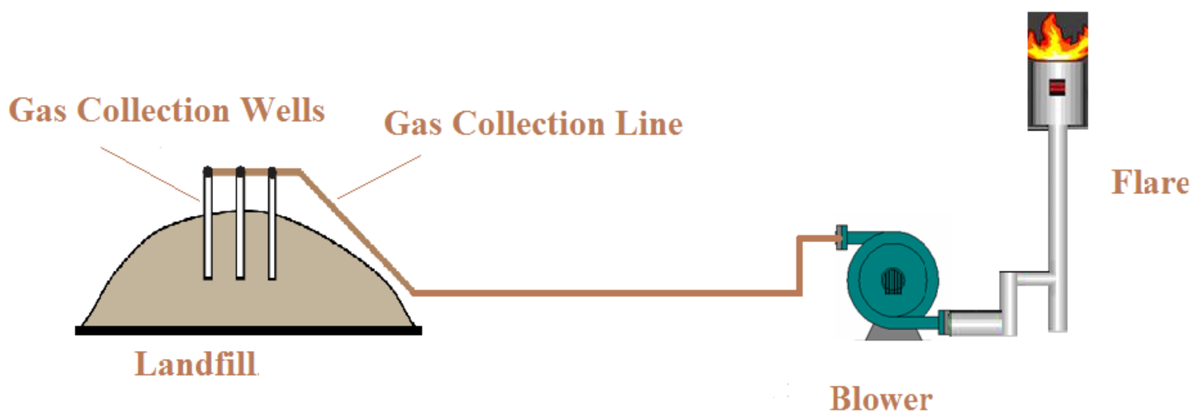

Figure 9.10: Flare System.

Table 9.9: Data for Flare System [73].

Flare System	**Measurements**
Length of Fare Area	15 ft
Width of Flare Area	10 ft
Total Area	150 ft^2
Gas Flows Ranging	14 to 1400 scfm
Gas Heating Values	300 Btu/scf to 1000 Btu/scf
The Height of the Fare at 20 mph	750 Btu/hr-ft2 maximum at property lines
Gas is Burned at the Tip of an Elevated Stack	98%
Flare Tip Diameter	8 in.
Flare Height	20 ft
Blower	0.43 psi.pd@20 msfd
Pipe	8 in. dia.

9.11 Groundwater Monitoring Well

Monitoring wells help to maintain the quality of groundwater and to estimate the flow of water [74]. They are designed and constructed with respect to specific conditions of hydrogeology. Groundwater monitoring is generally accomplished through the construction and sampling of monitoring wells in the vicinity of the landfill [75].

At the Denoar Landfill, monitoring wells will need to be constructed. These pipes would be sunk into the groundwater in order to be able to take a sample and test the presence of leachate chemicals [76].

Monitoring wells should be located both up-gradient and down-gradient of the waste storage facility and at a distance and depth based on the results of the hydrogeological investigation of the site [77].

The monitoring wells bore would be drilled with a truck-mounted drilling rig and the bore diameter should be 4.25 inches. Auger drilling uses a spiral tool that brings excavated soil to the surface while drilling [78]. It is a fast drilling method and can be used to collect soil samples.

Figure 9.11 presents a schematic diagram of a monitoring well and well specifications are summarized in Table 9.10.

The components of the monitoring wells are:

- Well Casing
- Well Screen
- Monitoring Well Filter Pack
- Well Seals, including the Filter Pack Seal and the Annular Seal
- Surface Pad and Additional Protection

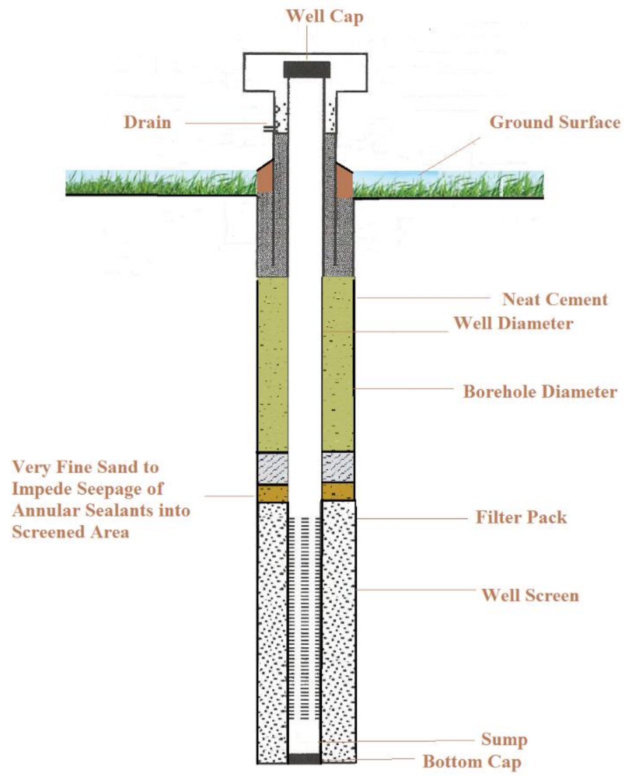

Figure 9.11: Water Monitoring Well.

Table 9.10: Data for Water Monitoring Well [79].

Water Monitoring Well	**Measurements**
Well Diameter	4 in.
Borehole Diameter	10 in.
Filter Pack	2 in. above screen
Very fine sand to impede seepage of annular sealants into screened area	1 in.
Number of Wells	2

Chapter 10

Life Cycle Assessment of Landfill

10.1 Introduction

Life Cycle Assessment (LCA) is an ideal tool for application in MSW management because geographic locations, characteristics of waste, energy sources, availability of some disposal options, and size of markets for products derived from waste management differ widely [80].

Shah Omkumar Priyavadan observes that “Waste disposal is one of the major problems being faced by all nations across the globe. The daily per capita solid waste generated in India ranges from about 100 grams in small towns to 500 grams in large towns. A major portion of the collected waste is dumped in landfill sites. Many of these sites are unregulated dumps or non-scientific landfills. Moreover, data collected from 44 Indian cities have revealed that about 70% of the cities do not have adequate capacity for collection and transportation of MSW” [81].

The Swedish Environmental Protection Agency indicates that “There are several connections between waste and LCA. The waste associated with the product is a part of the life cycle of the product. Every product has a waste stage, when the product is discarded or disposed. There is also waste generated during the manufacture of products -- for example, different types of industrial wastes” [82]. Many other uses of LCA are common in the literature. For example, Keleman [83] used an LCA to investigate the environmental impact of food waste disposal pathways in order to help policy makers and others to assess the role of food waste disposers.

10.2 Economic Analysis of Landfill Costs

The cost analysis for the Deonar Landfill is very important. The final design will depend on the type of the soil, climate, site restriction, and also on regulatory factors, too. The design process will depend on the groundwater level, because it needs to be protected from contamination. The operational and maintenance cost will also need to be considered for this landfill. Other costs will be involved to handle the daily volume of the waste.

Eilrich , Doeksen , and Van Fleet state that "Total landfill costs or life cycle costs are defined as all costs incurred from the time the landfill is conceived, through the 50-year post-closure period. These costs include: preconstruction/planning, engineering, legal, and land acquisition; construction; operating; closure; and post-closure. Life-cycle costs are the basis for tipping fees, which are the fees charged when a quantity of waste is received at a landfill" [84].

Eilrich, Doeksen, and Van Fleet state that "Three factors included in life-cycle costs must be noted. First, a large amount of capital is needed to construct and operate a landfill and, therefore, the cost of capital (interest) must be included. Second, closure and post-closure costs are significant. State regulators administer by law regulations to assure future funds for facility closure and post-closure. The financial instrument filed with a city to guarantee funding for these activities is known as "financial assurance." Finally, inflation over the life of the landfill, including the post-closure period, must be factored into the life-cycle costs. Responsible landfill management will include all the above when establishing charges for solid waste services or tipping fees" [84].

All of these factors should be considered in the extension of the Deonar Landfill and its re-design as a modern landfill based on scientific principles so that landfill gas can be captured and utilized in different ways.

10.3 Capital Cost

The capital cost for the Deonar Landfill gas energy project consists of the gas collection system, electricity generation, flaring system, and direct use. It also includes the cost of the rented and purchased equipment and operational and maintenance costs every year. The main cost elements for the Deonar Landfill are listed below:

- Design and engineering and administration
- Site preparation
- Installation of equipment
- Labor
- Utilities
- Financing costs
- Taxes
- Administration

10.4 Electricity Costs

Inogate observes that "Most of the technology use for LFGE is internal combustion engine. Internal combustion engines are available in various sizes with electrical outputs ranging from less than 1.0 MW to more than 3.0 MW per unit. Internal combustion engines that use LFG as a fuel are commercially available and may be obtained as modular units or within a complete parallel generator package. Often, containerized systems are installed in a series to allow for engines to be added or removed in response to fluctuating gas flows over time. Many manufacturers have designed engines specifically to operate on LFG and other biogases, and they should be able to provide examples of these operations" [44].

Table 10.1 shows the data associated with the internal combustion engine and the generator.

Table 10.1: Generator Size [41, 85].

Generator	Internal Combustion Engine
Year	2008
Manufacturer	CAT
Range	2000 kw
Price of Generator	$450,000.00
Price of Blower Unit	$40,000.00
Total	$490,000.00
Chamber Unit Price	$60,000.00

10.5 Electricity Generation

The major role of an LFG system is to convert gas into energy. Energy will be converted into electricity by using the internal combustion engine.

The Deonar Landfill site in Mumbai collects 1000 tons MSW every day. This MSW will generate LFG, which can be converted to power. A 2000 kW generator can be used to generate the electricity. The generated electricity from the landfill gas can be sold for 4 cents/kWh. [41].

10.6 The Design Costs of the Proposed Deonar Landfill Extension

10.6.1 Basic Data

Table 10.2 presents basic statistical data concerning the Deonar Landfill.

Table 10.2: Basic Data of Deonar Landfill [7].

Location	Mumbai
Waste Generation	1000 tons per day (current)
Design Life	Active Period = 50 years
Subsoil	Sand SLIT up to 30 m below ground surface. Underlain by bedrock
Water Table	33 ft below ground surface

10.6.2 Construction of Deonar Landfill

Table 10.3 presents construction-related data and costs concerning the proposed extension at the Deonar Landfill.

Table 10.3: Construction of Deonar Landfill Data [41].

Landfill Days	6 month
Length	710 ft
Width	550 ft
Depth	25 ft
Area of Landfill	390,500 ft^2
Thickness of Clay Layer	2 ft
Volume of Clay Layer	781,000 ft^2
Thickness of Sand or Gravel Layer	1 ft
Volume of Sand or Gravel Layer	390,500 ft^2
Thickness of Fill Layer	1.5 ft
Volume of Fill Layer	585,750 ft^2
Thickness of Topsoil Layer	0.5 ft
Volume of Topsoil Layer	195,250 ft^2
Labor per hour	$5.0/h

10.6.3 Ground Water Monitoring Wells

Table 10.4 presents groundwater monitoring well data and costs for the proposed extension of the Deonar Landfill.

Table 10.4: Ground Water Monitoring Well Data [41, 86, 87].

No. of Wells	3
Unit Cost of well 4″ 5 foot F.J. Casing	$36.00
Sample Collection Cost	$80.36
Drilling Cost	29.53/ft
Total Cost of Wells	$648.00
Vertical Well Depth	30 ft
Total Vertical Well Depth	90 ft
Total Drilling Cost	2,658.00
Labor & equipment Cost	$1,500.00
Total Cost	**$4,806.00**

10.6.4 Installation of Geomembrane

Table 10.5 presents geomembrane data and costs for the proposed Deonar Landfill extension.

Table 10.5: Installation of Geomembrane Data [41, 88].

Area of Landfill	390,500 ft^2
Cost to install 60 mil HDPE	$0.75 per square foot
Installation of 60 mil HDPE	$292,875.00
Labor & Equipment Cost	$3000
Total Cost	**$295,875.00**

10.6.5 Installation of Drainage Layer

Table 10.6 presents data and costs associated with the drainage layer at the proposed Deonar Landfill.

Table 10.6: Installation of Drainage Layer Data [41, 88, 89].

Sand and Gravel Required	390,500 ft^2
Cost of Sand and Gravel per ft^2	$23.00/ ft^2
Total Cost of Sand and Gravel	$8,981,500.00
Length of Drainage Pipe	4,800 ft
Pipe Cost	$25 /ft
Cost	$120,000.00
Labor Cost Five Days & Equipment Cost	$4,890.00
Total Cost	**$9,106,390.00**

10.6.6 Installation of Clay Layer

Table 10.7 presents data and costs associated with the clay layer at the proposed Deonar Landfill extension.

Table 10.7: Installation of Clay Layer Data [41, 90].

Clay Required	781,000 ft^2
Cost of Clay	$20.95.00
Cost	$16,361,950.00
Labor & Equipment Cost	$5,290.00
Total Cost	**$16,367,240.00**

10.6.7 Installation of Gas Collection System

Table 10.8 presents data and costs associated with the gas collection system at the proposed Deonar Landfill.

Table 10.8: Installation of Gas Collection System Data [41, 57].

No. of Wells	15 wells
HDPE Pipe Cost	$1,054.16 / well
Total Cost of Pipes	$15,812.4
Borehole Depth	20 ft
Total Vertical Boring Depth	300 ft
Boring Cost	$15.00/ft
Boring Cost	$4,500.00
Labor & Equipment Cost	$6,480.00
Total Cost	**$26,792.40**

10.6.8 Top Soil

Table 10.9 presents data and costs associated with the topsoil layer at the proposed Deonar Landfill extension.

Table 10.9: Top Soil Data [41, 91].

Topsoil Required	195,250 ft^2
Labor & Equipment Cost per Foot to Construct Conveyances	$26.00/ft
Total Linear Feet of Grass Ditches to Construction	6612 ft
Cost of Linear	$4/ft
Cost	$26,448.00
Total Cost	**$57,648.00**

10.6.9 Leachate Collection

Table 10.10 presents data and costs associated with the leachate collection at the proposed Deonar Landfill extension.

Table 10.10: Leachate Collection Data [41, 88].

No.	Items	Quantity	Cost	Total Cost
1	Area of Leachate Pond	500000ft^2		
2	Site Preparation	1	$50,000.00	$50,000.00
3	HDPE Pipe	6	$1,054.16	$6,324.96
4	Clay Linear	18518 yd^3	$4.00	$7,4072.00
5	Sump Pump	1	$165,000.00	$165,000.00
6	Labor & Equipment Cost		$5000.00	$5000.00
7	**Total Cost**			**$345,396.96**

10.6.10 Stormwater Control

Table 10.11 presents stormwater control data and costs associated with the Deonar Landfill extension.

Table 10.11: Stormwater Control Data [41, 92].

Strom Water Side Slope Conveyance Construction	Measurements
Length of Side Slope	400ft
No. of Conveyance Required	20
Mean Length of Conveyance	40 ft
Total Length of Conveyance	800 ft
Labor and Equipment Cost per Foot	$9.49/ft
Cost	**$7592**
Ditch and Berm Construction	Measurements
Total linear feet of grass ditches to construction	4612 ft

Table 10.11: Strom Water Control Data (Continued) [41, 92].

Labor and Equipment Cost per Foot	$14.83/ft
Cost	$68,396.00
Cost Total Linear Feet of Rip Rap Ditches to Construction	3306ft
Labor and Equipment Cost per Foot	21.21/ft
Cost	$70120.00
Cost to Construct Ditches and Berms	$138516.00
Total Cost of Storm Water Control	**$146,108.00**

10.6.11 Vegetative Cover

Table 10.12 presents data and costs associated with the vegetative cover at the proposed Deonar Landfill extension.

Table 10.12: Vegetative Cover Data [41, 92, 93, 94].

Area of Landfill	390,500ft^2
Labor cost $8/h for 10 days and Equipment Cost	$1640.00
Cost of Seed , $0.11 per Square Foot	$42,955.00
Cost of Mulch, $0.47 per Square Foot	$183,535.00
Total Cost	**$228,130.00**

10.6.12 Tipping Fee

Table 10.13 presents tipping fees for 50 years at the proposed Deonar Landfill extension.

Table 10.13: Tipping Fee Data [7, 41].

Year	Amount	Volume of the Waste	Amount
1 to 25	$10 / tone	500 Tone / Day	$13,00,000.00 per year
26 to 45	$15 / tone	1000 Tone / Day	$39,00,000.00 per year
46 to 50	$20 / tone	1500 Tone / Day	$78,00,000.00 per year

10.6.13 Flare System Cost

Table 10.14 presents the costs associated with the flare system at the proposed Deonar Landfill extension.

Table 10.14: Flare System Cost [41].

System	Amount
Flare System Unit Cost	$2,500,000.00
Labor & Equipment Cost	$6,790.00
Total Cost	$2,506,790.00

10.6.14 Electrical Infrastructure Cost Analysis

Table 10.15 presents the electrical infrastructure costs associated with the proposed Deonar Landfill extension.

Table 10.15: Electrical Infrastructure Cost Analysis.

Component	Amount
Generator	$450,000.00
Blower	$40,000.00
Camber Unit	$$60,000.00
Sump Pump	$165,000.00
Flare System Unit	$2,500,000.00

10.6.15 Landfill Capital Estimate Cost

Table 10.16: Capital Estimate Cost Data.

Component	Amount
Generator Cost	$450,000.00
Chamber Unit Cost	$60,000.00
Blower Cost	$40,000.00
Engineering Cost	$50,000.00
Employee Payment	$50,000.00
Ground Water Monitoring Wells	$4,806.00
Installation of Geomembrane	$295,875.00
Installation of Drainage Layer	$9,106,390.00
Installation of Clay Layer	$16,364,450.00
Installation of Gas Collection System	$26,792.40
Top Soil	$57,648.00
Leachate Collection System	$345,396.96
Strom Water Control	$146,108.00
Vegetative Cover	$228,130.00
Flare System Cost	$ 2,500,000.00
Total Cost	$29,725,596.36

10.7 Operational and Maintenance Service

The operational and maintenance (O&M) service at the proposed Deonar Landfill extension is intended to focus on a comprehensive, cost effective, approach. This approach would include special attention to safety, compliance, scheduling, procedures, optimization, technology, and a cost effective blending of both preventive and predictive maintenance [95]. This O & M would function from Year 2 through Year 50. Table 10.17 summarizes the project costs associated with O & M.

Routine services include the following:

- Landfill gas well field balancing
- Project management technical support
- Stormwater monitoring system
- Final cover and maintenance
- Regulatory compliance
- Emergency response

Table 10.17: Operational and Maintenance Cost Data [41].

Description	Amount
Final Cover and Maintenance	$15,800.00
LFG System	$25,600.00
Project Management Technical Support	$15,000.00
Regulatory Compliance	$9,500.00
Emergency Response	$9,550.00
Storm Water Monitoring	$15,600.00
Total Cost	$91,050.00

10.8 Budget for Landfill Gas

The proposed Deonar Landfill extension in this capstone project would be supported by a mixture of funds from federal and state government entities of India. Therefore, both the State of Mumbai (Maharashtra) and the federal government would contribute to this project. Table 10.18 presents the financial details.

Table 10.18: Budget Estimate [41].

Department	Amount
State of Maharashtra	15,900,600.00
Federal Government Delhi	20,000,000.00
Total Amount	35,900,600.00

10.9 Sale of Gas and Energy

Electricity generated from LFG energy would be sold to The Ministry of Power India (MPI). The Landfill Purchase Agreement would be between the MPI and The Municipal Corporation of Greater Mumbai (MCGM). Gas would be sold for 35 years [41]. The rate would be fixed. Table 10.19 shows the energy cost savings. Table 10.20 shows the selling price of energy and Table 10.21 shows the gas sale price details.

Table 10.19: Energy Cost Saving Data [41].

Potential Source	Electric
Sale of Electricity 4 cent/KWh	Yes
Price Adjust by MPI	Yes
Taxable	Yes
Energy Cost Saving	Yes

Table 10.20: Energy Selling Price [7, 41].

Waste Generation	500 tons per day
1 Metric Tone	550 kwh Energy Generate
Waste Generation	130,000 metric tons per year
130,000 Metric tons Generate Energy	715,00,000 kwh per year
1 kwh	0.001 MWh
715,00,000 kwh per year	71500 MWh
1 kwh Selling Price	4 cent
715,00,000 kwh per Year	$28,60,000.00 per year

Table 10.21: Gas Selling Price [41].

Waste Generation	500 Metric tons per day
1 Metric Tone	150 m^3
Waste Generation	130,000 metric tons per year
130,000 Metric tons Generation per Year	195,00,000 m^3 per year
1 m^3 Selling Price	$3.00
195,00,000 m^3 per Year	$58,500,000.00 per year

10.10 Income for Landfill Gas Recovery

Table 10.22 shows the income for the proposed landfill gas recovery.

Table 10.22: Landfill Gas Income [41].

Component	Amount
Budget Amount	$35,900,600.00
Tipping Fee per Year	$13,00,000.00 per year
Gas Sale per Year	$58,500,000.00 per year
Energy Sale per year	28,60,000.00 per year
Gas and Energy Selling	35 year

10.11 Revenue for 50 Years of Landfill Gas Recovery

Table 10.23 shows the revenue for 50 years for the proposed landfill gas recovery.

Table 10.23: Revenue of Landfill [41].

Component	Amount
Capital Estimate Cost	$30 million
Operation and Maintenance Cost	$45,52,500.00
Budget Amount	$30 million
Net Present Value 50 Year	$128 million

CHAPTER 11

11.1 Conclusion

The current condition of the Deonar Landfill is poor. But the performance can be improved by three basic subsystems: the barrier system below the waste, operation and maintance of the landfill, and landfill cover and gas collection.

The collection of the landfill gas can be used for power generation, which also features environmental implications. The cost benefit analysis therefore will be based on the production of the generation of the electricity and environmental issues that could be solved, like the reduction of the carbon dioxide emissions from the burning of fossil fuels.

In advanced countries, the capturing of methanic gas from landfill has become economically viable. Currently, local government in Mumbai, India is working to address solid waste. LFGE would be a great achievement in terms of energy and environmental solutions for Mumbai, India, and the only limitation are the huge funds required for adopting this project.

If LFG is utilized as a power source and as fuel, the end-user can obtain significant economic benefits. If modern landfill methods are implemented in Mumbai, problems of MSW management can be addressed, and also, health issues can likely be reduced.

As a result of this study, it is recommended that all future landfills in India should be constructed in compliance with solid scientific principles, procedures, and techniques, i.e., landfills should feature both bottom and top liners, leachate collection systems, and gas collection systems so that groundwater contamination is minimal, and consequently, methane recovery would also increase. Also, it is recommended that all present disposal sites in India should have proper maintenance and operation throughout the year. To avoid negative problems, a proper management system is required to facilitate maintenance, including an improved gas control system.

11.2 Recommendations

The following recommendations are endorsed for a proposed extension of the Deonar Landfill.

- The Deonar Landfill extension will provide an economically viable LFG-to-electricity solution.
- The Deonar Landfill extension will result in the most greenhouse gas reduction benefits, especially from LFG -to-electricity technology.
- The Deonar Landfill extension will require detailed LFG collection and flaring system design and cost estimates.
- At the Deonar Landfill extension, the quantity of energy from the collected LFG that will actually be available for use will be a function of the recovery efficiency of the energy conversion technology used.
- The proposed Deonar Landfill extension is an example of a waste-to-energy plant, which is highly efficient and utilizes municipal solid waste as fuel rather than coal, oil or natural gas.
- In the proposed Deonar Landfill extension, a LFGTE system would provide significant improvement with respect to waste management systems and power supply systems.

- With respect to the proposed Deonar Landfill extension, a detailed evaluation of potential revenues from emission reductions and from electricity sales should be conducted, so that the revenue sharing expectations of the City of Mumbai can be clarified.

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Appendix A: Gas Sale Projections for the Proposed Deonar Landfill Extension in Mumbai, India

Appendix A shows the projected sales data for gas energy associated with the proposed extension of the Deonar Landfill. The life cycle of the landfill here is assumed to be 50 years. Gas sales are projected for Years 6 through 35.

Components	0	1	2	3
aqusition Cost (Generator, and Blower)	-$490,000.00			
Land cost	$0.00			
Chamber unit	-$60,000.00			
Installation of Geomembrane	-$295,875.00			
Installation of Clayer Layer	-$16,367,240.00			
Installation of Drainage Layer	-$9,106,390.00			
Ground Water Monitoring Wells	-$4,806.00			
Installation of Gas Collection System	-$26,792.40			
Top soil	-$57,648.00			
Leachate Collection System	-$345,396.96			
Storm Water Control	-$146,108.00			
Vegetative Cover	-$228,130.00			
Engenerring Design	$50,000.00			
Flare System Cost	-$2,500,000.00			
Operational and Maintenance Cost		-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)		-$50,000.00	-$50,000.00	-$50,000.00
Tipping fee		$1,300,000.00	$1,300,000.00	$1,300,000.00
Sale of Gas				
Sale of energy				
Depreciation		-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes		$1,149,150.00	$1,149,150.00	$1,149,150.00
Tax provision		-$287,287.50	-$287,287.50	-$287,287.50
Net Income		$861,862.50	$861,862.50	$861,862.50
Add Back Depreciation		$9,800.00	$9,800.00	$9,800.00
Cash Flow	-$29,578,386.36	$871,662.50	$871,662.50	$871,662.50
Discount factors	$1.00	$1.02	$1.04	$1.06
Present Value	-$29,578,386.36	$854,571.08	$837,814.78	$821,387.04
Net Present Value 50 year	$1,288,889,296.55			
Net Present Value 25 year	$813,119,534.18			

Components	4	5	6	7	8
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$50,000.00	-$50,000.00	-$50,000.00	-$50,000.00	-$50,000.00
Tipping fee	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00
Sale of Gas			$58,500,000.00	$58,500,001.00	$58,500,002.00
Sale of energy			$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	$0.08	$0.08	$0.08	$0.08	$0.08
Profit before taxes	$1,158,950.08	$1,158,950.08	$75,498,950.08	$75,498,951.08	$75,498,952.08
Tax provision	-$289,737.52	-$289,737.52	-$18,874,737.52	-$18,874,737.77	-$18,874,738.02
Net Income	$869,212.56	$869,212.56	$56,624,212.56	$56,624,213.31	$56,624,214.06
Add Back Depreciation	-$0.08	-$0.08	-$0.08	-$0.08	-$0.08
Cash Flow	$869,212.48	$869,212.48	$56,624,212.48	$56,624,213.23	$56,624,213.98
Discount factors	$1.08	$1.10	$1.13	$1.15	$1.17
Present Value	$805,281.41	$789,491.58	$50,282,855.77	$49,296,918.07	$48,330,312.48

Components	9	10	11	12	13
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$50,000.00	-$50,000.00	-$55,000.00	-$55,000.00	-$55,000.00
Tipping fee	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00
Sale of Gas	58,500,003.00	58,500,004.00	$58,500,005.00	$58,500,006.00	$58,500,007.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$75,489,153.00	$75,489,154.00	$75,484,155.00	$75,484,156.00	$75,484,157.00
Tax provision	-$18,872,288.25	-$18,872,288.50	-$18,871,038.75	-$18,871,039.00	-$18,871,039.25
Net Income	$56,616,864.75	$56,616,865.50	$56,613,116.25	$56,613,117.00	$56,613,117.75
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$56,626,664.75	$56,626,665.50	$56,622,916.25	$56,622,917.00	$56,622,917.75
Discount factors	$1.20	$1.22	$1.24	$1.27	$1.29
Present Value	$47,382,659.92	$46,453,588.77	$45,539,718.71	$44,646,783.64	$43,771,357.09

Components	14	15	16	17	18
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$55,000.00	-$55,000.00	-$55,000.00	-$55,000.00	-$55,000.00
Tipping fee	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00
Sale of Gas	58,500,008.00	58,500,009.00	$58,500,010.00	$58,500,011.00	$58,500,012.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$75,484,158.00	$75,484,159.00	$75,484,160.00	$75,484,161.00	$75,484,162.00
Tax provision	-$18,871,039.50	-$18,871,039.75	-$18,871,040.00	-$18,871,040.25	-$18,871,040.50
Net Income	$56,613,118.50	$56,613,119.25	$56,613,120.00	$56,613,120.75	$56,613,121.50
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$56,622,918.50	$56,622,919.25	$56,622,920.00	$56,622,920.75	$56,622,921.50
Discount factors	$1.32	$1.35	$1.37	$1.40	$1.43
Present Value	$42,913,095.75	$42,071,663.06	$41,246,729.03	$40,437,970.18	$39,645,069.33

Components	19	20	21	22	23
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$55,000.00	-$55,000.00	-$60,000.00	-$60,000.00	-$60,000.00
Tipping fee	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00	$1,300,000.00
Sale of Gas	58,500,013.00	58,500,014.00	$58,500,015.00	$58,500,016.00	$58,500,017.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$75,484,163.00	$75,484,164.00	$75,479,165.00	$75,479,166.00	$75,479,167.00
Tax provision	-$18,871,040.75	-$18,871,041.00	-$18,869,791.25	-$18,869,791.50	-$18,869,791.75
Net Income	$56,613,122.25	$56,613,123.00	$56,609,373.75	$56,609,374.50	$56,609,375.25
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$56,622,922.25	$56,622,923.00	$56,619,173.75	$56,619,174.50	$56,619,175.25
Discount factors	$1.46	$1.49	$1.52	$1.55	$1.58
Present Value	$38,867,715.54	$38,105,603.98	$37,355,961.61	$36,623,492.26	$35,905,385.04

Components	24	25	26	27	28
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$60,000.00	-$60,000.00	-$60,000.00	-$60,000.00	-$60,000.00
Tipping fee	$1,300,000.00	$1,300,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00
Sale of Gas	58,500,018.00	58,500,019.00	$58,500,020.00	$58,500,021.00	$58,500,022.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$75,479,168.00	$75,479,169.00	$78,079,170.00	$78,079,171.00	$78,079,172.00
Tax provision	-$18,869,792.00	-$18,869,792.25	-$19,519,792.50	-$19,519,792.75	-$19,519,793.00
Net Income	$56,609,376.00	$56,609,376.75	$58,559,377.50	$58,559,378.25	$58,559,379.00
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$56,619,176.00	$56,619,176.75	$58,569,177.50	$58,569,178.25	$58,569,179.00
Discount factors	$1.61	$1.64	$1.67	$1.71	$1.74
Present Value	$35,201,358.35	$34,511,136.09	$34,999,727.20	$34,313,458.48	$33,640,646.00

Components	29	30	31	32	33
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$60,000.00	-$60,000.00	-$65,000.00	-$65,000.00	-$65,000.00
Tipping fee	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00
Sale of Gas	58,500,023.00	58,500,024.00	$58,500,025.00	$58,500,026.00	$58,500,027.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$78,079,173.00	$78,079,174.00	$78,074,175.00	$78,074,176.00	$78,074,177.00
Tax provision	-$19,519,793.25	-$19,519,793.50	-$19,518,543.75	-$19,518,544.00	-$19,518,544.25
Net Income	$58,559,379.75	$58,559,380.50	$58,555,631.25	$58,555,632.00	$58,555,632.75
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$58,569,179.75	$58,569,180.50	$58,565,431.25	$58,565,432.00	$58,565,432.75
Discount factors	$1.78	$1.81	$1.85	$1.88	$1.92
Present Value	$32,981,025.91	$32,334,339.55	$31,698,303.62	$31,076,768.65	$30,467,420.64

Components	34	35	36	37	38
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$65,000.00	-$65,000.00	-$65,000.00	-$65,000.00	-$65,000.00
Tipping fee	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00
Sale of Gas	58,500,028.00	58,500,029.00	$58,500,030.00	$58,500,031.00	$58,500,032.00
Sale of energy	15840000	15840000	$15,840,000.00	$15,840,000.00	$15,840,000.00
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$78,074,178.00	$78,074,179.00	$78,074,180.00	$78,074,181.00	$78,074,182.00
Tax provision	-$19,518,544.50	-$19,518,544.75	-$19,518,545.00	-$19,518,545.25	-$19,518,545.50
Net Income	$58,555,633.50	$58,555,634.25	$58,555,635.00	$58,555,635.75	$58,555,636.50
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$58,565,433.50	$58,565,434.25	$58,565,435.00	$58,565,435.75	$58,565,436.50
Discount factors	$1.96	$2.00	$2.04	$2.08	$2.12
Present Value	$29,870,020.62	$29,284,334.31	$28,710,132.05	$28,147,188.64	$27,595,283.34

Components	39	40	41	42	43
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$65,000.00	-$65,000.00	-$70,000.00	-$70,000.00	-$70,000.00
Tipping fee	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00	$3,900,000.00
Sale of Gas	58,500,033.00	58,500,034.00			
Sale of energy	15840000	15840000			
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$78,074,183.00	$78,074,184.00	$3,729,150.00	$3,729,150.00	$3,729,150.00
Tax provision	-$19,518,545.75	-$19,518,546.00	-$932,287.50	-$932,287.50	-$932,287.50
Net Income	$58,555,637.25	$58,555,638.00	$2,796,862.50	$2,796,862.50	$2,796,862.50
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$58,565,437.25	$58,565,438.00	$2,806,662.50	$2,806,662.50	$2,806,662.50
Discount factors	$2.16	$2.21	$2.25	$2.30	$2.34
Present Value	$27,054,199.70	$26,523,725.53	$1,246,186.81	$1,221,751.77	$1,197,795.86

Components	44	45	46	47	48
Operational and Maintenance Cost	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$70,000.00	-$70,000.00	-$70,000.00	-$70,000.00	-$70,000.00
Tipping fee	$3,900,000.00	$3,900,000.00	$7,800,000.00	$7,800,000.00	$7,800,000.00
Sale of Gas					
Sale of energy					
Depreciation	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00	-$9,800.00
Profit before taxes	$3,729,150.00	$3,729,150.00	$7,629,150.00	$7,629,150.00	$7,629,150.00
Tax provision	-$932,287.50	-$932,287.50	-$1,907,287.50	-$1,907,287.50	-$1,907,287.50
Net Income	$2,796,862.50	$2,796,862.50	$5,721,862.50	$5,721,862.50	$5,721,862.50
Add Back Depreciation	$9,800.00	$9,800.00	$9,800.00	$9,800.00	$9,800.00
Cash Flow	$2,806,662.50	$2,806,662.50	$5,731,662.50	$5,731,662.50	$5,731,662.50
Discount factors	$2.39	$2.44	$2.49	$2.54	$2.59
Present Value	$1,174,309.66	$1,151,283.98	$2,305,009.44	$2,259,813.18	$2,215,503.12

Components	49	50
Operational and Maintenance Cost	-$91,050.00	-$91,050.00
Woker Time (Employees)	-$70,000.00	-$70,000.00
Tipping fee	$7,800,000.00	$7,800,000.00
Sale of Gas		
Sale of energy		
Depreciation	-$9,800.00	-$9,800.00
Profit before taxes	$7,629,150.00	$7,629,150.00
Tax provision	-$1,907,287.50	-$1,907,287.50
Net Income	$5,721,862.50	$5,721,862.50
Add Back Depreciation	$9,800.00	$9,800.00
Cash Flow	$5,731,662.50	$5,731,662.50
Discount factors	$2.64	$2.69
Present Value	$2,172,061.88	$2,129,472.43

Engineering

Capstone Report Approval Form

Master of Science in Environmental Engineering – MSEV

Milwaukee School of Engineering

This capstone report, titled "Conceptual Design for Landfill Gas Capture and Re-Use in Mumbai, India," submitted by the student Qudrat Ullah Ayaz, has been approved by the following committee:

Faculty Advisor: ___________________________ Date: ______________________

Professor James Drought, M.S., P.H.

Faculty Member: ___________________________ Date: _______________________

Dr. Jay Karls, Ph.D.

Faculty Member: ___________________________ Date: _______________________

Dr. Frank Mahuta, Ph.D., J.D.