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Landfill gas recovery and its utilization in India: Current status, potential prospects and policy implications

Faisal Zia Siddiqui* and Mohd Emran Khan

Department of Mechanical Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, New Delhi

ABSTRACT

The methane emissions from landfills in India are ranked second next only to coal mining. The estimation of methane emissions from landfills is important in order to evaluate measures for reduction these greenhouse gases. The main objective of this research was to evaluate the energy potential of methane from selected urban landfill sites in India. The evaluation of energy potential was done using the first order decay model. The paper also examined the current status, future prospects and various barriers for landfill gas (LFG) recovery and utilization in India. Although it seems that technological and economic constraints might be a major factor in the implementation, but the main hurdle is a lack of national policy framework and an integrated action plan for LFG recovery and utilization.

Keywords: Green house gas, Landfill gas, Municipal solid waste, Energy recovery.

INTRODUCTION

With rapid economic development and increased urbanization levels and material consumption, the amount of Municipal Solid Waste (MSW) disposed in landfills in India is increasing significantly. India is one of the world's largest emitters of methane from landfills, currently producing around 16 Mt CO_2 eq per year, and predicted to increase to almost 20 Mt CO_2 eq per year by 2020 [1].

Methane makes up around 29% of the total Indian GHG emissions, while the global average is 15%. However, emissions from waste (6%) are also proportionally higher than the global average (3%) [1].

The Municipal Solid Waste (MSW) is disposed using the technology of traditional landfill, without consideration of recovery and utilization of methane. The landfills have not equipped the system of LFG recovery, resulting in methane emission to the atmosphere.

2. Status of LFG recovery studies in India

All of the waste disposal sites in the country are open dumps. These sites emit several gases including methane. Hence open disposal of waste is a prevalent practice in India [11]. In Delhi, the Municipal Corporation of Delhi (MCD) with the help of the World Bank carried out feasibility studies at three landfill sites viz Okhla, Ghazipur and Bhalswa in 2008 [1]. Feasibility studies were conducted at Okhla landfill site in Delhi [3], Deonar and Gorai Landfill sites in Mumbai [4] and [5]. Pirana Landfill site in Ahmedabad [6], Uruli Devachi landfill site in Pune [7] and one site in Auto Nagar, Hyderabad. The results of these feasibility studies are encouraging except for Hyderabad site [8]. The LFG utilization potential for selected landfills in India is summarized in Table 1.

Table 1: LFG Utilization Potential for Selected Landfills in India

S. No.	Name and location of Landfill	Amount of waste disposed	LFG Energy Potential (MW)
1.	Okhla landfill, Delhi	6,732,000	2.7
2.	Gazipur landfill, Delhi	14,256,000	2.0
3.	Balswa landfill, Delhi	8,910,000	3.7
4.	Deonar Landfill, Mumbai	12,716,660	1.6
5.	Pirana Landfill, Ahmedabad	4,590,000	1.3
6.	Gorai Landfill, Mumbai	4,237,889	4.0
7.	Auto Nagar Landfill, Hyderabad	193,500	Nil
8.	Urli Devachi, Pune	2,806,900	0.7

In India, not a single landfill site has been developed for LFG recovery and utilization. The Research and Development (R&D) status for LFG Projects in India is given in Table-2 [10].

Table 2. R&D status for LFG Projects in India

S. No.	Technology/Aspect	LFG
1.	Relevance to India	Yes
2.	Type of R&D Required	Mainly adaptive
3.	Experience in India	Nil
4.	Expertise in India	Very limited
5.	Priority/Urgency of Program	High
6.	Need for Pilot Plant	Yes
7.	Identified gaps	Mainly Engineering
8.	Scale of Funding	Medium (< 500 Million Rupees)
9.	Opportunity for Commercialization	Medium

The interest in landfill gas recovery has not increased significantly, due to lack of national policy framework and an integrated action plan for LFG recovery and utilization.

3. Legal and Policy Framework for LFG Recovery in India

The MSW (Management and Handling) Rules, 2000 stipulates that LFG control system should be installed including a gas collection system at the landfill sites in order to minimize odor, prevent off-site migration of harmful gases and to protect flora on the rehabilitated landfill site. The rule also specifies that the concentration of methane gas emissions at landfill site shall not exceed 25% of the Lower Explosive Limit (LEL) which is equivalent to 650 mg/m^3. Further the LFG from the site shall be utilized for either direct thermal applications or power generation as per the practicability; otherwise LFG shall have to be flared and not allowed to be discharged directly into the atmosphere. Flaring reduces the volatile organic compounds (VOC's) and mitigates odor problems. If LFG utilization or flaring is not possible then passive venting shall have to be done [9].

4. Energy potential from landfills in India

The MSW generated in the major cities of India is normally disposed off in unsecured landfills where it gradually decomposes to produce methane and carbon dioxide both considered as potent GHGs. If LFG is not actively collected, it escapes into the atmosphere. Due to a high proportion of biodegradables, and the warm, wet climate, the rate of MSW decomposition in India is faster than in landfills in developed countries. The rates of methane flow can therefore be expected to peak shortly after a landfill is closed, and afterwards rapidly decrease. Due to the high rate of MSW decomposition, only large landfill sites will be able produce methane at a high level over a long period of time [1].

LFG generated from landfills can be captured by gas collection and control systems that typically burn the gas in flares. Alternatively, the collected LFG can be used as fuel in energy recovery facilities, such as internal combustion engines, gas turbines, micro turbines, steam boilers, or other facilities that use the gas for electricity generation thereby reducing GHG emissions. However before installation of such systems it is important to predict the methane generation from the landfill site.

5. Methodology and Approach

The information needed to estimate the LFG generation and recovery from a landfill includes 1) The design capacity of the landfill; 2) The amount of waste in place in the landfill, or the annual waste acceptance rate for the landfill; 3) rate of decay of organic matter (k); 4) The potential methane generation capacity (L_0); 5) The collection efficiency of the gas collection system; and 6) The years the landfill has been and will be in operation.

The Ecuador Landfill Gas Model (Ecuador LFG Model) is an estimation tool for quantifying landfill gas generation and recovery from landfill sites. The model is based on a first order decay equation. The model requires data for landfill opening and closing years, waste disposal rates, average annual precipitation, and collection efficiency. The LFG Model evaluates the feasibility and potential benefits of collecting and using the generated landfill gas for energy recovery or other uses. The model employs a first-order exponential decay function that assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation. The mathematical equation is given below [11]:

$$Q = \sum_{0}^{n} 1/\%_{vol} * k * M * L_0 * e^{-k\,(t-t_{lag})}$$

Where:

Q total quantity of landfill gas generated (Normal cubic meters)
n total number of years modeled
t time in years since the waste was deposited
t_{lag} estimated lag time between deposition of waste and generation of methane
$\%_{vol}$ estimated volumetric percentage of methane in landfill gas
L_0 estimated volume of methane generated per tonne of solid waste
k estimated rate of decay of organic waste
M mass of waste in place at year t (tones)

The two variables of L_0 and k are dependent on the composition of waste in the site; however these are still based on estimates and empirical experience of gas generation rate on similar sites. The variable 'k', the rate at which the organic fraction of waste decays within the waste mass, can vary between 0.1 and 0.01. This wide variation (a factor of 10) results from the availability of organic carbon in the waste and is dependent on moisture content within the waste. The L_0 depends on the waste characteristics particularly the amount of organic carbon within the waste. Therefore organic carbon plays a key role in the amount of biogas generated and is a function of the condition of the waste; on the other hand the amount of organic carbon is a function of the type of waste.

Determining the exact values for both k and L_0 requires a detailed knowledge of the waste inputs at the site and the biological conditions of the landfill site. Table 3 shows the default values of L_0 and k for the Ecuador model.

Table 3. Lo and k values

Precipitation (mm/yr)	**K Medium Food waste (≤ 50%)**	**K High Food Waste (≥65%)**	**L_o (M_3/MT) Medium Food Waste (≤ 50%)**	**L_o (M_3/MT) High Food Waste (≥ 65%)**
0	0.040	0.043	60	62
250	0.050	0.053	80	83
500	0.065	0.69	84	87
1000/saturated	0.080	0.085	84	87
2000/saturated	0.080	0.085	84	87

The table defines the values of k and L_o for different waste compositions and for different rainfall areas. L_o and k values have been selected depending on site conditions. Landfills with high organic content generally contain high levels of liquid even in areas where rainfall is low. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years).

Methane generation is estimated using two parameters i.e L_0, the methane generation potential of the waste, and k, the methane generation rate constant. The methane generation rate constant, k, determines the rate of generation of methane from waste in the landfill. The k value describes the rate at which waste placed in a landfill in a given year decays and produces methane gas. The higher the value of k, the faster total methane generation at a landfill increases (as long as the landfill is still receiving waste) and then declines (after the landfill closes) over time. The value of k is a function of the following factors: (1) waste moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, and (4) temperature.

The value for the potential methane generation capacity of waste (L_0) depends only on the type of waste present in the landfill. Higher the cellulose contents of the waste, the higher the value of L_0. In practice, the theoretical L_0 value may not be reached in dry climates where lack of moisture in the landfill reduces the action of methane-generating bacteria. The L_0 value describes the total amount of methane gas produced by a tonne of waste.

Collection efficiency will vary depending on the construction of the landfill and the level of water (leachate) within the landfill. The design of gas collection wells also affects the collection efficiency. The default vales of LFG collection efficiency used in the model is given in Table 4.

Table 4: Default values of collection efficiency for Landfills

Capping Layer Collection Technique	Saturated Clay/ Geo-membrane	Non- Saturated Clay
Drilled Gas Wells Horizontal Collectors	80%	70%
Converted (existing) Passive vents	60%	40%

Because some site may satisfy the conditions of both the 'Saturated' and 'Non-Saturated' columns depending on the season (Wet or Dry) a collection efficiency should be calculated based on the proportion of time the capping layer is expected to satisfy each condition.

On many landfills there are areas from which gas cannot be easily extracted. These may include active waste disposal cells, completed but uncapped areas, areas which are planned to accept further waste, areas of intensive vehicular movement, areas with high gradients or areas of particularly shallow or older waste. These areas will contain a mass of waste that is not available for collection. Therefore a percent factor for the available mass from which landfill gas can be extracted is included in the model. The Ecuador gas model therefore includes a column where available percentage of mass can be inserted for each year of operation of the landfill. This value is then multiplied by the collection efficiency to provide an available gas yield for each year.

The type and number of landfill sites selected for evaluating the LFG energy potential was based on the population figures of different cities. These cities were having a population greater than 2 millions. According to CPCB, 2008, the waste generation in these cities ranged between 0.22-0.62 kg/capita/day. The compostable fraction varied between 40-60%, Recyclables 11-22%, C/N ratio 21-39, higher calorific value (on dry weight basis) 800-2632 Kcal/Kg and moisture content 21-63%. For the sake of gathering the needed data related to landfill opening and closure year, and waste design capacity, we use the data of Municipal authorities provided to US EPA's international methane to markets partnership program and some of the data was gathered from CPCB.

The values assigned for model input variables for LFG projections are given in Table 5.

Table 5: LFG Model input variables

S.No.	Input Variables	Delhi (Okhla)	Hyderabad	Mumbai (Deonar)	Ahmedabad (Pirana)	Pune (Uruli Devachi)	Mumbai (Gorai)
I.	Annual Precipitation (mm/Yr)	706	796	2130	820	704.2	2130
II.	Ultimate methane generation potential (Lo) in m3/tone	84	84	84	84	84	84
III.	Methane generation rate constant (k) in per year	0.065	0.065	0.08	0.065	0.065	0.08
IV.	LFG Collection System Efficiency (%)	60	60	60	60	60	60
V.	Waste Mass Utilization (%)	80	80	80	80	80	80

The projected LFG generation and recovery for Okhla landfill site is given in Figure-1. As is evident from the graph, the peaking value of LFG was in the year 2008. If the gas recovery starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 2,000 Nm3/hr of LFG can be recovered.

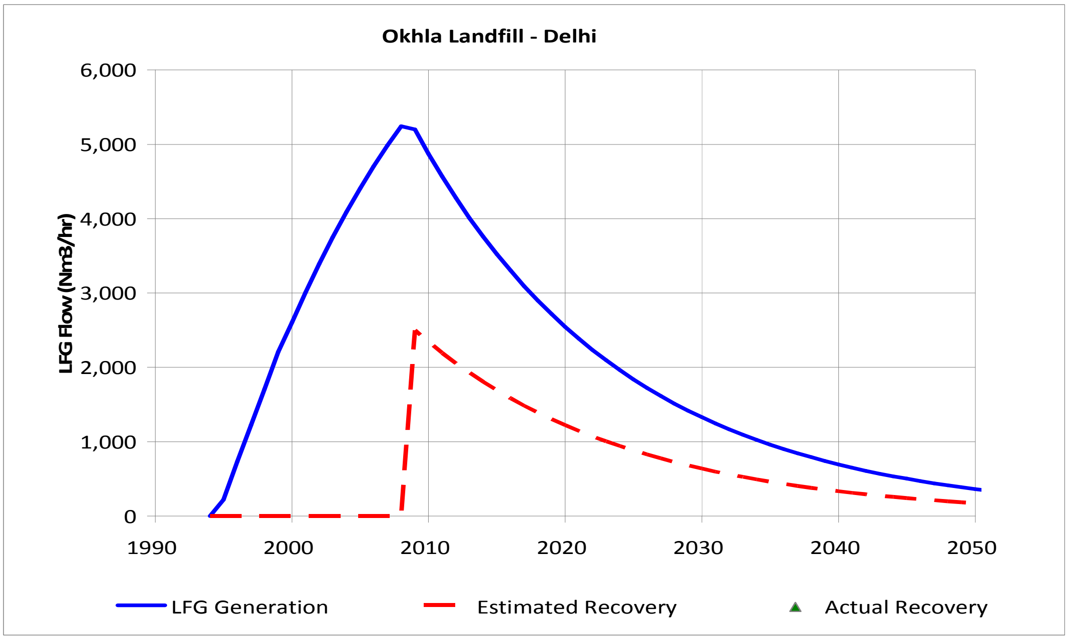

Figure 1. Projected LFG Generation and Recovery for Okhla Landfill Site

The projected LFG generation and recovery for Hyderabad landfill site is given in Figure 2. As is evident from the graph, the peaking value of LFG was in the year 2005. If the gas recovery is starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 40 m3/hr of LFG can be recovered.

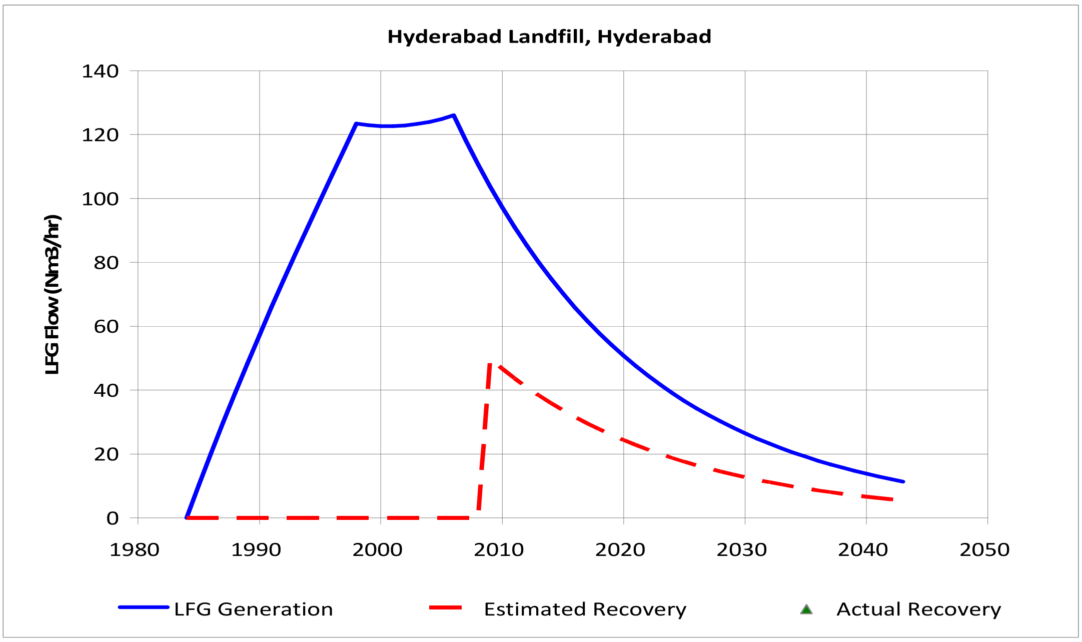

Figure 2. Projected LFG Generation and Recovery for Hyderabad Landfill Site

The projected LFG generation and recovery for Pirana landfill site is given in Figure 3. As is evident from the graph, the peaking value of LFG was in the year 2008. If the gas recovery is starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 1,500 m3/hr of LFG can be recovered.

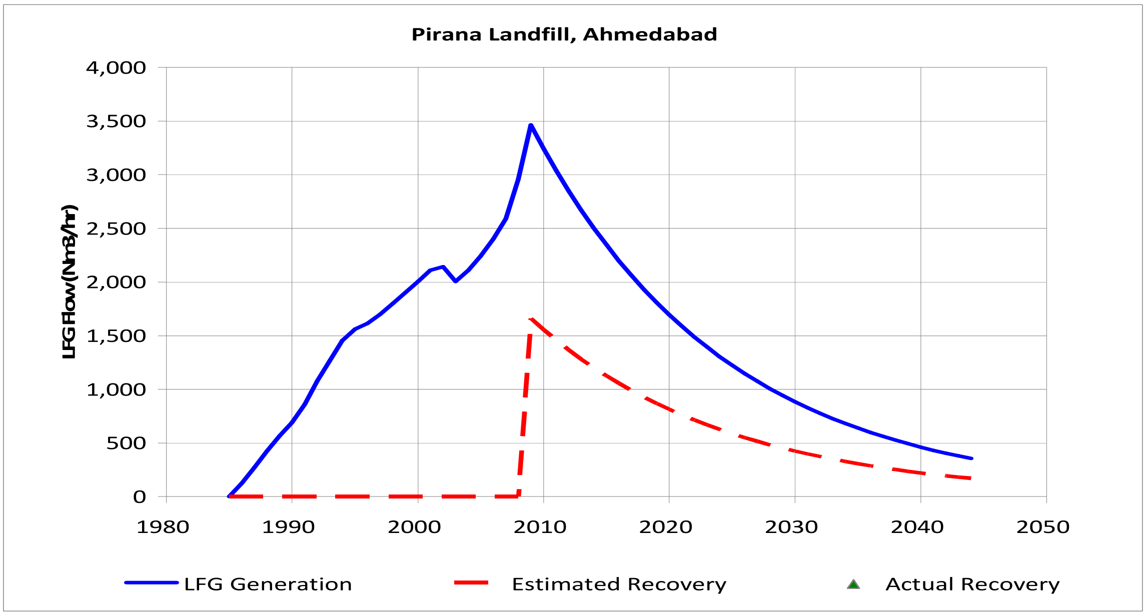

Figure 3. Projected LFG Generation and Recovery for Pirana Landfill Site

The projected LFG generation and recovery for Deonar landfill site is given in Figure 4. As is evident from the graph, the peaking value of LFG will be in the year 2010. If the gas recovery is starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 5,000 m3/hr of LFG can be recovered.

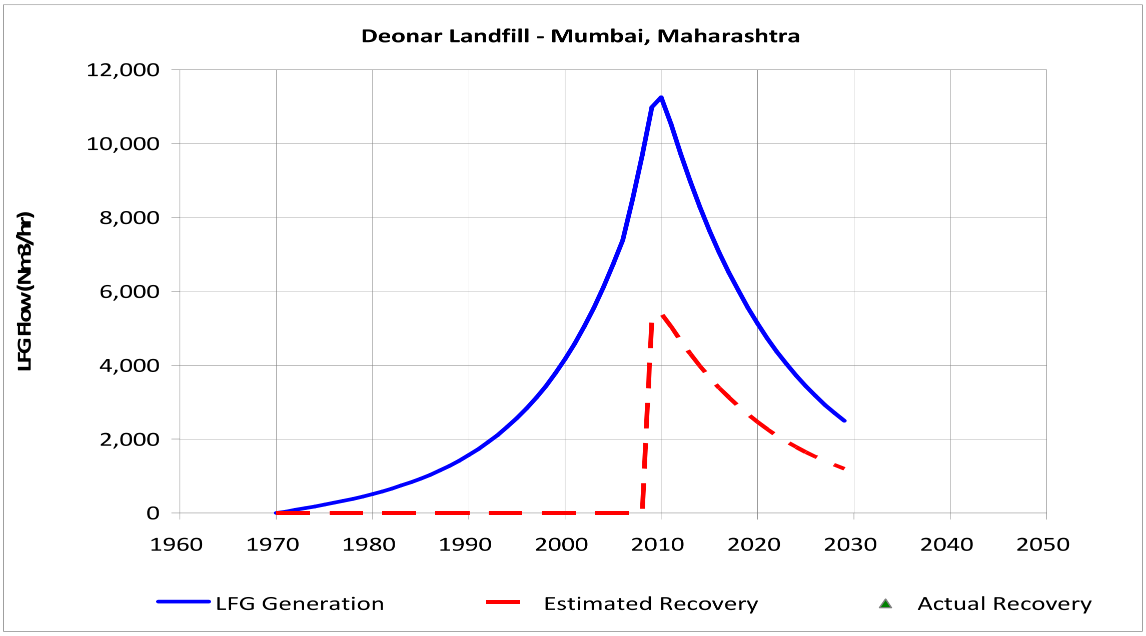

Figure 4. Projected LFG Generation and Recovery for Deonar Landfill Site

The projected LFG generation and recovery for Uruli Devachi landfill site is given in Figure 5. As is evident from the graph, the peaking value of LFG was in the year 2008. If the gas recovery is starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 1,100 m3/hr of LFG can be recovered.

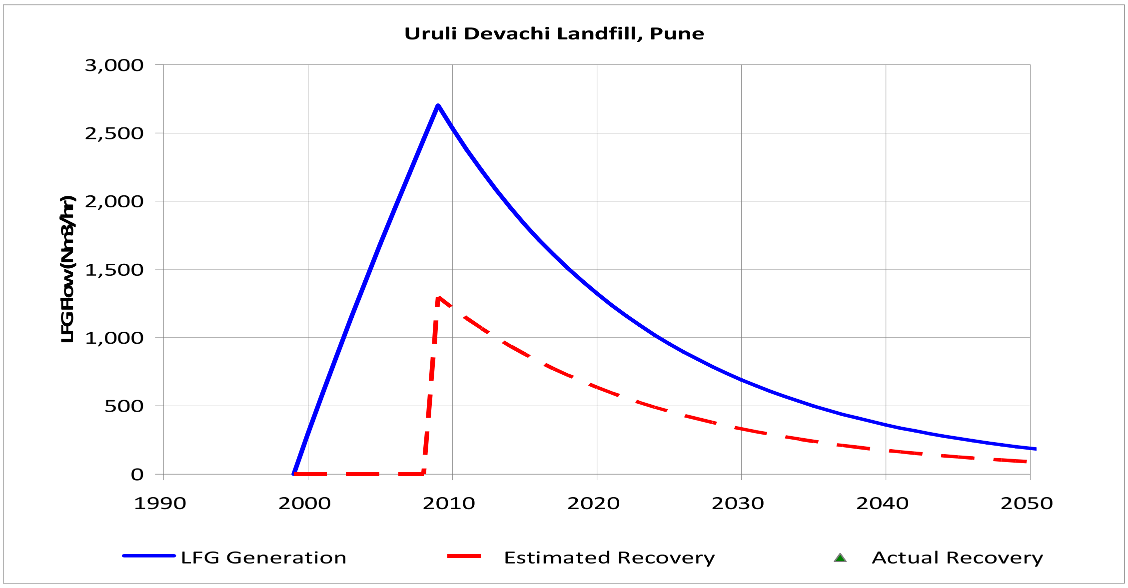

Figure 5. Projected LFG Generation and Recovery for Uruli Devachi Landfill Site

The projected LFG generation and recovery for Gorai landfill site is given in Figure 6. As is evident from the graph, the peaking value of LFG was in the year 2006. If the gas recovery is starts in the year 2011 assuming a collection efficiency of 60% and waste mass utilization of 80% approximately 2,000 m3/hr of LFG can be recovered.

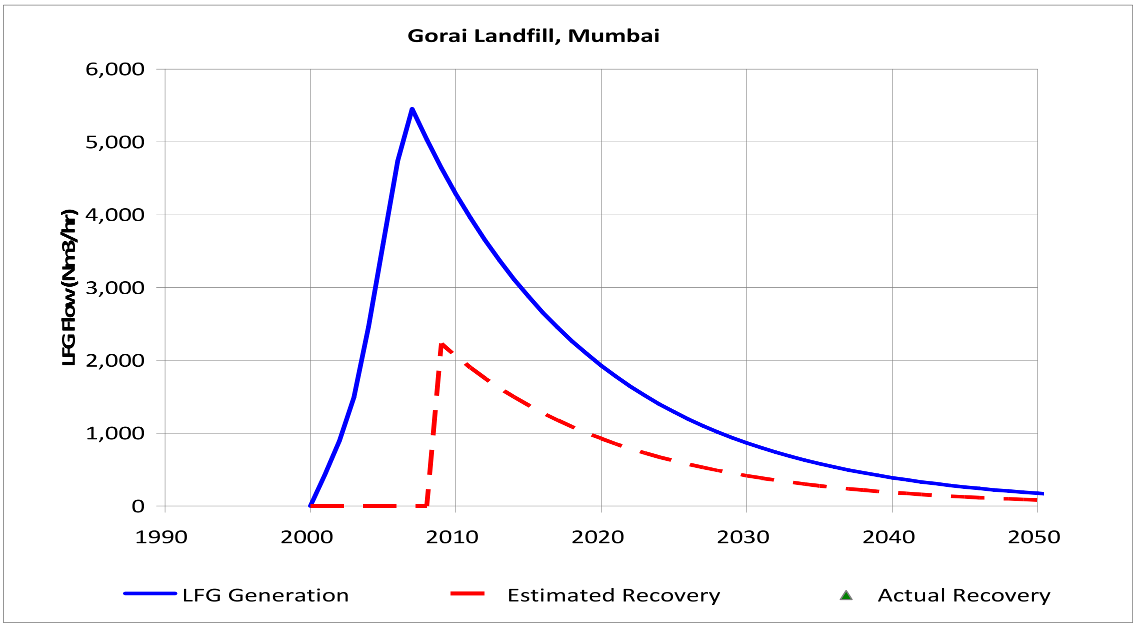

Figure 6. Projected LFG Generation and Recovery for Gorai Landfill Site

RESULTS AND DISCUSSION

The above result shows that the maximum potential for LFG recovery is in Mumbai from Deonar landfill site and the lowest being at the Hyderabad landfill site. The application of LFG Model at different landfill sites in India demonstrates the model's potential to analyze the feasibility of methane recovery potential. The results by the LFG model show that waste disposal rates strongly influence the methane emissions. The Model parameters are highly dependent on prevailing site conditions and LFG capture efficiency and therefore are difficult to quantify. For practical values under Indian conditions, detailed studies are required to arrive at suitable factors and default values. Modeling landfill gas generation and recovery accurately is difficult due to limitations in available information for inputs to the model. However, as new landfills are constructed and operated and better information is collected under Indian conditions, the present modeling approach may be improved. In addition, as more landfills develop landfill gas collection and utilization systems, additional data on landfill gas generation and recovery will become available for model calibration and the development of improved model default values.

Table 6: Key Barriers and Proposed Remedial measures

Issue	**Major barriers**	**Actions overcoming the barriers**
LFG recovery LFG utilization for power generation	Lack of mechanism of coordination and management	Set up coordination group
	Lack of capital for setting up engineered landfill sites	(i) increase government input (ii) user charge (iii) bilateral and multilateral fund (iv) commercial finance
	Lack of successful experiences of LFG recovery and utilization projects	Develop demonstration projects on the basis of international experiences
	Lack of operation and maintenance experiences for engineered landfills	(i) implement the demonstration projects (ii) prepare training materials (iii) build training centers (iv) conduct the related training
	Lack of awareness of harmful impacts of emission of LFG	(i) propaganda by various media (ii) study tours to other countries and other cities (iii) print brochures
	Lack of model for LFG generation potential	Develop the software and models according to country specific conditions on the basis of international experiences
	Lack of definite and attractive policy of power price	Determine the power price of LFG for power generation
	Without standard Power Purchase Agreement (PPA)	Make up standard PPA
	Difficulty in grid connection	(i) adopt the power grid-connected policy of renewable energy (ii) Mandatory Market Share (iii) Green power price
	Difficulty in determination of energy potential due to lack of LFG estimation model	develop suitable models of LFG generation and optimal power capacity
	Lack of financial support from Government agencies	Financial support from Government agencies
LFG utilization as fuel	Lack of purification technology of LFG	Develop the purification technology
	Lack of financial support from Government agencies	Financial support from Government agencies

Several barriers have been identified in using LFG as an energy source in India. These barriers include technological intricacies, financial and economic limitations, regulatory issues, lack of awareness, and interconnection challenges. These barriers are often interdependent. The key barriers identified and proposed remedial measures are summarized in Table 6.

CONCLUSION

The study concludes that there is significant energy utilization potential from existing urban landfills in India. There is an urgent need to examine potential uses for LFG including on-site use for small processes. The construction of regional landfills in place of scattered open dumps is required to properly manage the environmental impacts of LFG. Lastly, the Government of India needs to develop a national action plan for recovery and utilization of LFG. The concerned ministries in India should work closely to develop the incentives required to promote the use of LFG as a renewable energy source from landfills. The land value and development potential from the recovery of LFG and the rehabilitation of old landfills should be studied and the results of the study can be used to provide incentives and training to municipal authorities and Urban Local Bodies (ULBs) for implementing LFG to energy projects. The health impacts of old landfills, and the economic benefits of LFG to energy projects and closure of old landfills should be included in the government policy.

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