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Review of past research and proposed action plan for landfill gas-to-energy applications in India

Faisal Zia Siddiqui[1], Sadaf Zaidi[2], Suneel Pandey[3] and Mohd Emran Khan[1]

Abstract

Open dumps employed for disposal of municipal solid waste (MSW) are generally referred to as landfills and have been traditionally used as the ultimate disposal method in India. The deposition of MSW in open dumps eventually leads to uncontrolled emission of landfill gas (LFG). This article reviews the MSW disposal practices and LFG emissions from landfills in India during the period 1994 to 2011. The worldwide trend of feasibility of LFG to energy recovery projects and recent studies in India indicate a changed perception of landfills as a source of energy. However, facilitating the implementation of LFG to energy involves a number of challenges in terms of technology, developing a standardized framework and availability of financial incentives. The legislative framework for promotion of LFG to energy projects in India has been reviewed and a comprehensive strategy and action plan for gainful LFG recovery is suggested. It is concluded that the market for LFG to energy projects is not mature in India. There are no on-ground case studies to demonstrate the feasibility of LFG to energy applications. Future research therefore should aim at LFG emission modeling studies at regional level and based on the results, pilot studies may be conducted for the potential sites in the country to establish LFG to energy recovery potential from these landfills.

Keywords

Landfill gas, municipal solid waste, methane emissions, energy recovery, landfill emissions, open dumps, carbon credits

Introduction

Millions of tons of municipal solid waste (MSW) are deposited daily in thousands of landfills and other dumping sites worldwide (Williams, 2008). In the US, as well as in Europe, waste disposal represents the second largest source of anthropogenic CH_4 emissions, comprising 22 to 23% of the total anthropogenic CH_4 emission (Bogner et al., 2007; EEA, 2008; Scheutz et al., 2009; US EPA, 2009). Landfilling is the most common waste disposal method practised worldwide. CH_4 is a major emission from landfills caused by degradation of organic matter, but it may be recovered and used for energy purposes thereby potentially off-setting fossil-fuel-based energy generation (Manfredi et al., 2009). Methane emissions from landfills are expected to decrease in industrialized countries and increase in developing countries. Developing countries' landfill gas (LFG) emissions are expected to increase due to expanding populations, combined with a trend away from open dumps to sanitary landfills with increased anaerobic conditions (IEA, 2009a; 2009b).

In south and west Asia, open dumps are the most prevalent waste disposal method. Some metropolitan areas designate open and often low-lying dumpsites as landfills, but these sites lack the most basic components of a sanitary landfill such as provision of daily cover, a leachate collection/treatment system, compaction of waste and proper site design. LFG recovery has been tried on an experimental basis (IEA, 2009b). Currently, the United States, China, Russia, Canada and Southeast Asia are the main contributors of CH_4 emissions from MSW (IEA, 2009a) (Figure 1).

India ranks fifth in aggregate greenhouse gas (GHG) emissions in the world, after the USA, China, the European Union and Russia. The emissions of the USA and China were almost four times that of India in 2007 (MoEF, 2010a).

[1]Department of Mechanical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia (JMI) University, New Delhi, India
[2]Department of Chemical Engineering, Faculty of Engineering and Technology, A.M.U, Aligarh, India
[3]Centre for Environmental Studies, The Energy and Resources Institute (TERI), New Delhi, India

Corresponding author:
Faisal Zia Siddiqui, Department of Mechanical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia (JMI) University, New Delhi 110 025, India.
Email: faisalziasiddiqui@rediffmail.com

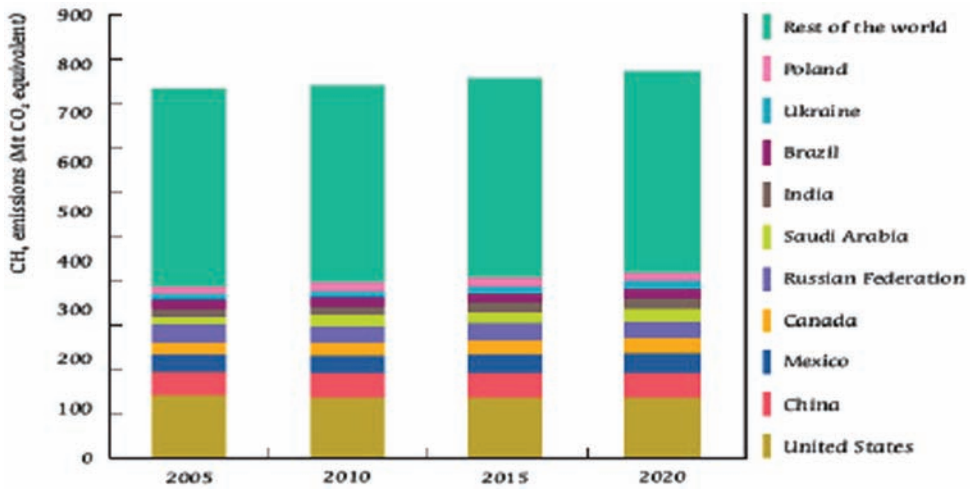

Figure 1. Methane emissions from MSW management (Reproduced from IEA, 2009a. Energy Sector Methane Recovery and Use – The Importance of Policy, pp. 24–25, with permission from © OECD/IEA.).

MSW management and methane emissions in developing countries

An estimated 7.6 million tons of MSW is produced per day in the developing countries (Nagendran et al., 2006), of which around 60–90% is disposed off in open dumps. This practice of waste disposal is environmentally unsafe (Khajuria et al., 2010). The paucity of financial resources earmarked for MSW management in many developing countries would mean that solid waste managers must aim at modest improvements to their current operations and gradually move from open dumps to sustainable waste management in a phased manner (Joseph et al., 2007). The general conditions which distinguish the different types of landfills and dump sites are given in Table 1. These conditions vary from region to region, from nation to nation, and even from site to site (Johannessen et al., 1999).

The construction and operational practices in landfill management play a very important role in LFG production and distribution within the landfill body as well as in LFG emission. The operational features of a landfill and its effect on LFG production and migration have been well explained by Mavropoulos and Kaliampakos (2011). According to Chandramohan et al. (2010), the open dumps pose serious health risks to the population, trespassers and rag-pickers due to microbial pollution of air, soil and MSW. Some recent findings of a health survey conducted (Schrapp and Mutairi, 2010) indicate a higher prevalence of dermatological, neuromuscular, respiratory and gastrointestinal symptoms among people living in the area surrounding the landfill. Furthermore, the survey around such landfills indicates a high amount of airborne dust, bacteria and fungi within the breathing zone of the nearby residences.

The landfill is an unavoidable component in MSW management and its planning, design, construction, operation and maintenance involves technical skills and safety measures in terms of protection of health and environment (CPCB, 2008). The landfilling of biodegradable waste can lead to many environmental problems including fires and explosions, odour nuisance, vegetation effects, pollution of water bodies and soil, local air quality impacts and GHG emissions (Donovan et al., 2011).

MSW management scenario in India

India produces around 70 million tons of MSW annually, of which at present less than 5% is processed scientifically (Planning Commission of India, 2011). Given the scarcity of urban land for scientific waste disposal there is a common practice of open dumping with most of the dumpsites overflowing in urban cities. Due to this practice waste continues to be one of the biggest public health, environmental, and land-use challenges for urban cities in India (Planning Commission, 2011). Almost all cities have adopted open dumping for MSW disposal (TERI, 2010). Rapid urbanization and population growth are largely responsible for the very rapidly increasing rate of MSW in urban areas, its proper management and recycling is a major problem for urban local bodies (Gautam et al., 2009). The outskirts and slums of most cities and towns are characterized by open dumps (Nema and Baker, 2008). Figure 2 provides an overview of the main components of MSW in India (Hanrahan et al., 2006).

There are more than 5100 municipalities in India. The average collection efficiency of MSW ranges from 22 to 60%. The waste characterization data showed that MSW typically contains 51% organics, 17% recyclables, 11% hazardous and 21% inert. Municipalities have been mandated to implement the MSW (Management & Handling) Rules, 2000 in all towns/cities of India to cover 100% collection, segregation, transportation, treatment and disposal of waste (MoEF, 2010b). India's per capita waste generation varies from 0.2 to 0.6 kg in cities with population varying from 0.1 to 5.0 million and it is increasing by 1.3% per annum. Moreover, with the growing urban population, the MSW is expected to increase by 5% (Ahmad and Choi, 2010).

The present policy and infrastructure are inadequate in dealing with the enormous quantity of MSW generation

(Talyan et al., 2008). As the population keeps increasing, the MSW quantity also increases, which in turn, exhausts the landfill sites (Narayana, 2009). The leachate collection and treatment, or LFG recovery from landfills is not practiced in most of the cities in India (CPCB, 2006a). The landfill sites lack any LFG collection and monitoring systems (Sharholy et al., 2008). A mindspace landfill located in Mumbai in Western India was being used after closure for construction of a commercial and residential complex. Due to the chemical reactions below the ground, obnoxious gases were observed to be emitted throughout the year but they intensified during the summer and affected the local residents, equipment and property. Therefore, there was a need for a scientific method for disposal of MSW and closure of exhausted disposal sites (Sahu, 2007).

Table 1. Condition of landfills based on waste management practices (Modified from Johannessen LM and Boyer G (1999) Observations of Solid Waste Landfills in Developing Countries: Africa, Asia, and Latin America with permission from the International Bank for Reconstruction and Development, The World Bank.).

Type	Engineering measures	Leachate management	LFG management	Operation measures
Open dumps	None	Unrestricted contaminant release	Limited	Few, scavenging
Controlled dump	None	Unrestricted contaminant release	Limited	Placement/compaction of waste
Engineered landfill	Infrastructure and liner in place	Containment and some level of leachate management	Passive ventilation or flaring	Placement/compaction of waste; uses daily soil cover
Sanitary landfill	Proper siting, infrastructure; liner and leachate treatment	Containment and leachate treatment	Flaring	Placement/compaction of waste; uses daily of soil cover, final top cover
Controlled contaminant release landfill	Proper siting, infrastructure, with low-permeability liner in place. Potentially low-permeability final top cover	Controlled release of leachate in the environment, based on assessment and proper siting	Flaring or passive ventilation through top cover	Registration and placement/compaction of waste, uses daily soil cover. final top cover
Landfill bioreactor	Proper siting, infrastructure, liner and leachate recirculation/generation system	Controlled recirculation of leachates for enhanced degradation and stabilization of wastes and leachates	LFG recovery	Placement/compaction/daily cover/closure/mining and material recovery

Landfill methane emissions and its quantification in India

By virtue of its large population, India is among the world's largest emitters of methane from solid waste disposal, currently producing around 16 million tons carbon dioxide equivalent (CO_2e) per year, and predicted to increase to almost 20 million tons CO_2e per year by 2020 (IEA, 2008). A study using the Integrated Assessment Model for Developing Countries (Garg et al., 2004) projects a much larger increase to 48 million tons CO_2e by 2020 and 76 million tons CO_2e by 2030 (Figure 3).

The same study shows that landfills are the second-fastest growing source for methane emissions in India after coal mining (IEA, 2008). The total net GHG emissions from India in 2007 were 1727.71 million tons of CO_2e of which methane emissions were 20.56 million tons. GHG emissions from the waste sector constituted 3% of the net CO_2e emissions (2.52 million tons of methane). The waste sector emissions were 57.73 million tons of CO_2e. It is estimated that MSW generation and disposal resulted in the emissions of 12.69 million tons of CO_2e in 2007. The total GHG released from the waste sector in 2007 was 57.73 million tons of CO_2e, of which, 2.52 million tons was emitted as methane (Table 2); that is, 22% of the emissions were from MSW disposal (MoEF, 2010a).

Table 3 summarizes various methane emissions quantification studies that have been carried out on selected landfills in India.

Energy potential of LFG

The conversion of landfill gas to energy in general is an important component of an integrated approach to MSW management and can help to move the handling of waste further up the waste management hierarchy, creating renewable energy and reducing GHG emissions (Frankiewicz et al., 2011). Table 4 shows the theoretical and experimental estimates of LFG generation potential from MSW disposed in open dumps.

A high proportion of decomposable organic material and a high moisture content of MSW favour LFG generation

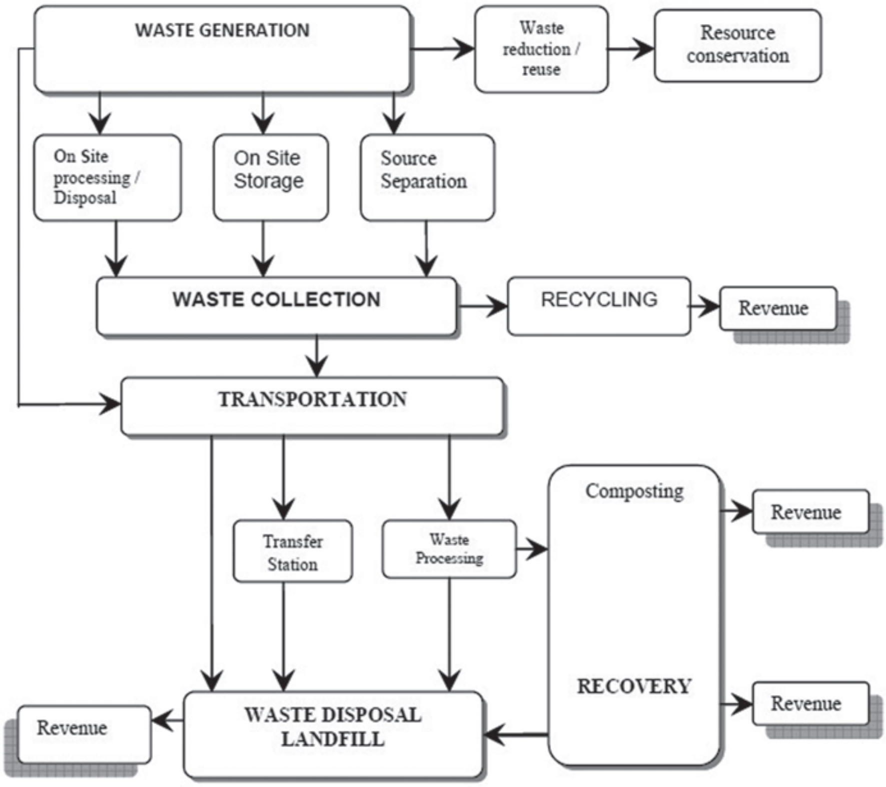

Figure 2. Overview of main components of MSW management in India (Reproduced from Hanrahan D, Srivastava S and Ramakrishna AS (2006) Improving Management of Municipal Solid Waste in India – Overview and Challenges, pp 38–62 with permission from the International Bank for Reconstruction and Development, The World Bank).

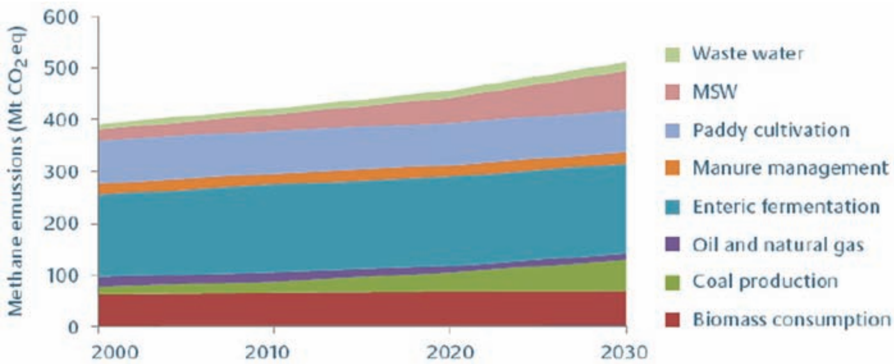

Figure 3. Methane emissions projections in India (Reproduced from Garg A, Shukla PR, Kapshe M, et al. (2004) Indian methane and nitrous oxide emissions and mitigation flexibility. Atmospheric Environment 38(13): 1965–1977 with permission from Elsevier).

Table 2. GHG emissions from waste sector (million tons) (Reproduced from MoEF, 2010a).

S. no.	Category	Methane	CO_2e (million tons)	Percentage contribution
1	Municipal solid waste	0.604	12.69	22.0
2	Domestic waste water	0.861	22.98	39.8
3	Industrial waste water	1.050	22.05	38.2
4	Total emissions	2.52	57.73	100

considerably (Khajuria et al., 2009). LFG capture at India's landfills will need to occur almost exclusively in closed and capped areas if not fully closed landfills. Only concentrations of methane over 25% are worth exploiting for energy production (Kumar, 2000).

Estimation of power generation potential from landfills in India

1. Quantity of MSW generated per day in India (MoEF, 2010b) = 0.573 MMT day^{-1}

Table 3. Methane emissions from selected landfills in India

Landfill	Method	Methane emissions (Gg/year)									References
		2008/09	2005	2004	2002/03	2001	2000	1998	1995	1991	
Ghazipur	Field samples	0.24	–	–	–	–	–	–	–	–	Rawat and Ramanathan (2011)
Bhalswa	Field samples	0.16	–	–	–	–	–	–	–	–	Rawat and Ramanathan (2011)
Okhla	Field samples	0.14	–	–	–	–	–	–	–	–	Rawat and Ramanathan (2011)
Bhandewadi	Field samples	–	–	1.83–11.20	–	–	–	–	–	–	Akolkar et al. (2008/CPCB(2006b)/
Bhandewadi	Default method	–	–	7.65	–	–	–	–	–	–	Akolkar et al. (2008)/CPCB(2006b)/
Bhandewadi	Triangular method	–	–	6.16	–	–	–	–	–	–	Akolkar et al. (2008)/CPCB(2006b)/
Amravati	Field samples	–	–	0.06–2.63	–	–	–	–	–	–	Akolkar et al. (2008)/CPCB(2006b)/
Amravati	Default method	–	–	2.28	–	–	–	–	–	–	Akolkar et al. (2008)/CPCB(2006b)/
Amravati	Triangular method	–	–	1.81	–	–	–	–	–	–	Akolkar et al. (2008)/CPCB(2006b)/
Six landfills in India	Field samples	–	–	–	0.21	–	–	–	–	–	Rawat et al. (2008)
Delhi	Modelling	–	138	–	–	–	115	–	100	83	Talyan et al. (2007)
Kodungaiyur		–	–	–	–	–	0.12	–	–	–	Jha et al. (2007)
Kodungaiyur	Mass balance	–	–	–	–	–	8.10	–	–	–	Jha et al. (2007)
Kodungaiyur	FOD	–	–	–	–	–	2.49	–	–	–	Jha et al. (2007)
Perungudi		–	–	–	–	–	0.12	–	–	–	Jha et al. (2007)
Perungudi	Mass balance	–	–	–	–	–	9.80	–	–	–	Jha et al. (2007)
Perungudi	FOD	–	–	–	–	–	3.0	–	–	–	Jha et al. (2007)
Ghazipur	IPCC/modified triangular method	–	–	–	–	15.3	–	–	–	–	Mor et al. (2006)
Okhla	Field samples	–	–	–	–	1.78	–	–	–	–	Kumar et al. (2004b)
Okhla	Default method	–	–	–	–	14.20	–	–	–	–	Kumar et al. (2004b)
Okhla	Modified triangular method	–	–	–	–	7.67	–	–	–	–	Kumar et al. (2004b)
–	–	–	–	–	–	–	–	–	132	113	Gurjar et al. (2004)
–	–	–	–	–	–	–	–	–	–	86	Sharma et al. (2002)
–	–	–	–	–	–	–	–	–	106	–	Garg et al. (2002)
–	–	–	–	–	–	–	–	0.33	–	–	Bhide (1998)

Table 4. Theoretical and experimental results of LFG generation from MSW.

S. no.	Method of estimation	Amount of LFG per ton of waste (m^3 LFG ton^{-1})	References
1	Experimental	450 (without shredding)	Kumar et al. (2004a)
2	Experimental	720 (after shredding)	Kumar et al. (2004a)
3	Theoretical	150–250	CPCB (2003)
4	Theoretical	130–230	MoUD (2000)
5	Experimental	225	Sharma et al. (1998)
6	Experimental	249	Sharma et al. (1998)
7	Experimental	266	Sharma et al. (1998)
8	Experimental	150	Sharma et al. (1998)
9	Experimental	300	Shekdar (1997)
10	Theoretical	460	Wake (1997)
11	Experimental	95	NEERI (1996)

2. Therefore quantity of MSW generated per year in India = 209 MMT $year^{-1}$
3. Collection efficiency of MSW (MoEF, 2010b) = 60%
4. Therefore quantity of MSW collected per year = 125.5 MMT $year^{-1}$
5. The percentage of MSW disposed in landfill (CPCB, 2003) = 90%
6. Therefore quantity of MSW disposed in landfill in 2008 = 113 MMT $year^{-1}$
7. The percentage of organics/biodegradables in MSW (MoEF, 2010b) = 50%
8. Therefore quantity of organics disposed in landfill in 2008 = 56.5 MMT $year^{-1}$
9. One hundred tons of MSW with 50% organics can generate (MoUD, 2000) 1–1.5 MW power
10. Therefore 56.5 MMT of organics can generate 565 000 MW power $year^{-1}$ = 0.56 million MW power $year^{-1}$
11. Population of India in 2008 = 1.15 billions
12. Therefore per capita power consumption = 0.56/1.15 = 0.487 KW

In general, 100 tons of raw MSW with 50–60% organic matter can generate about 1–1.5 MW power, depending upon the waste characteristics.

In bio-chemical conversion, only the biodegradable fraction of the MSW contributes to the energy output:

Total MSW quantity: 100 (tons)
Total organic/volatile solids (VS) = 50% (assumption)
Organic bio-degradable fraction: approximately 66% of VS = 0.33 × W
Typical conversion efficiency = 60%
Typical LFG yield (m^3) = 0.80 m^3 kg^{-1} of VS decomposed
= 0.80 × 0.60 × 0.33 × W × 1000
= 158.4 × W
Calorific value of LFG = 5000 kcal m^{-3} (typical)
Energy recovery potential (kWh) = B × 5000/860 = 921 × W
Power generation potential (kW) = 921 × W/24 = 38.4 × W
Typical conversion efficiency = 30%
Net power generation potential (kW) = 11.5 × W
= 11.5 × 100
= 1150 KW
= 1.15 MW

Status of feasibility studies on LFG recovery potential in India

Studies carried out in 59 selected cities by CPCB in India have revealed that not a single landfill site has LFG to energy facility (Kumar et al., 2009). Pre-feasibility studies have been completed for evaluating LFG to energy potential at landfills in Pune, Ahmedabad, Mumbai, Hyderabad, and Delhi. Taken together, these sites have a combined emissions reduction potential of 300 000 MT CO_2e (US EPA, 2009). A survey of 48 cities conducted by FICCI and responses from 22 cities showed that the maximum potential for LFG to energy projects based on quantum of MSW deposited in the dumpsite are Delhi, Kanpur, Jaipur, Pune, Surat, Ludhiana and Ahmedabad. Greater Mumbai is the only city which has initiated a LFG flaring project, five out of 22 of the surveyed cities have conducted feasibility studies on methane emissions (Delhi, Ahmedabad, Surat, Greater Mumbai and Jamshedpur) and the balance are interested in undertaking LFG to energy projects. Furthermore, the majority of cities have indicated a lack of technical know-how within the municipal corporation for LFG to energy projects as the prime reason for not conducting feasibility studies. Around half of the municipal corporations have indicated that lack of accurate estimates of methane emissions and lack of technical know-how account for not undertaking LFG to energy projects. Most of the municipal corporations have sought assistance for carrying out studies for estimating waste quantification and methane emissions (FICCI, 2009). Tables 5 and 6 show the landfills identified for LFG recovery studies in India and the projected LFG to energy recovery potential from these sites.

An important factor determining the viability of LFG to energy projects is the way in which MSW is collected, sorted and processed (Zhu et al., 2008). Due to a high proportion of food scraps, 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 the landfill is closed. Due to the high rate of MSW decomposition,

Table 5. Details of selected landfill sites identified for LFG recovery studies in India.

S. no.	Name and location of landfill in India	Year of start	Waste disposal area (m²)	Average depth of waste (m)	Quantity of MSW disposed (million tons)	Designed capacity (million tons)	Reference
1	Uruli Devachi, Pune	1999	220 000	11.6	2.9 till 2009	3.2	USEPA/SCS Engineers (2008b)
2	Autonagar Landfill, Hyderabad	1984	161 875	15	1.2 till 2005	1.2	USEPA/SCS Engineers (2007)
3	Gorai Landfill, Mumbai	1972	196 000	16.6	2.5 till 2007	2.8	IUEP/URS Coprs (2007c)
4	Bhalswa Landfill, Delhi	1992	222 900	18	6.9 till 2008	8.0	USEPA/SCS Engineers (2010c)
5	Bhalswa Landfill, Delhi	1992	222 900	18	6.9 till 2008	8.0	USEPA/SCS Engineers (2010c)
6	Pirana Landfill, Ahmedabad	1985	650 000	22	4.6 till 2008	4.6	USEPA/SCS Engineers (2008a)
7	Deonar Landfill, Mumbai	1927	1200 000	16	12.6 till 2008	12.7	USEPA/SCS Engineers (2007b)
8	Dhapa, Kolkata	1981	214 000	24	7.0 till 2009	14.8	USEPA/SCS Engineers (2009)
9	Shadra Landfill, Agra	1979	50 491	–	4.7 till 2009	0.5	USEPA/IRADe (2010a)
10	Barikalan Dubagga Landfill, Lucknow	1994	27 786	15.4	2.9 till 2007	0.4	USEPA/SCS Engineers (2010b)
11	Moti Jheel Landfill, Lucknow	1972	32 800	9	2.9 till 1998	0.3	USEPA/IRADe (2009b)
12	Okhla Landfill, New Delhi	1994	540 000	25	6.8 till 2009	7.7	USEPA/SCS Engineers (2007a)
13	Ghazipur Landfill, Delhi	1984	283 280	25.5	11.0 till 2008	1.9	GAIL/SENES (2012)
14	Karuvadikuppam Landfill, Puducherry	2003	28 328	–	0.6	–	USEPA/IRADe (2009a)

only large landfill sites will be able produce methane at a high level over a longer period of time (IEA, 2008). The MSW decomposition is increased or delayed depending on the amount of oxygen, temperature and moisture content. In open dumps, the decomposition of waste is faster because oxygen, heat and moisture are abundant. Open dumps are generally uncovered and exposed to more oxygen and rain. Further they are prone to spontaneous combustion. Table 6 shows the LFG to energy recovery potential from selected landfill sites in India.

Freshly buried waste produces more gas than older waste. Landfills usually produce appreciable amounts of gas within 1 to 3 years. Almost all gas is produced within 20 years after the waste is dumped; however, small quantities of gas may continue to be emitted from a landfill for 50 or more years (Chalvatzaki and Lazaridis, 2010). The investigation of Donovan et al. (2011) indicates that biologically pretreated waste materials will continue to generate gas at very low levels for at least 150 years after deposition.

The maximum achievable LFG collection efficiencies for engineered and sanitary landfills are in the range of 60–95% whereas for open and managed dump sites it is about 30–60% (SCS, 2007). However, most sites in India will have difficulty in achieving even 60% collection efficiency due to conditions that tend to limit LFG collection (Stege, 2007).

Gorai Landfill closure and gas capture project, Mumbai, India

The project is India's first 'landfill closure and gas capture' project implemented by the Municipal Corporation of Greater Mumbai. Future methane emissions generated by decomposition of bio-degradable waste in the landfill site at Gorai in Mumbai will be avoided through the installation of an impermeable cover and a landfill gas collection manifold with flaring system. GHG emissions will be reduced by capturing and utilizing methane from Gorai landfill. The captured methane will be combusted to generate electricity, estimated at 3–4 MW of power, which will feed to the national power grid and be used as an alternative source of energy. The part of LFG that will not be used for power generation will be flared (ADB, 2011a).

The flow diagram for the system is given in Figure 4.

The Asia Pacific Carbon Fund (APCD), a trust fund established and managed by the Asian Development Bank (ADB), extended support to the Gorai landfill project by providing carbon co-financing at the project implementation stage. The fund's upfront financing represented 56% of the project's US$ 9.31 million capital cost. In exchange, the fund secured a portion of the expected future CERs to be generated up to 2012 and verified emission reductions to be generated from 2013 to 2014. The estimated CO_2 savings up to 2012 is projected to be 604,229 $t_{CO2}e$ (ADB, 2011b). The project is estimated to reduce GHGs by an estimated 1.2 million tons of CO_2 over a 10-year crediting period (NIUA, 2012). It is also estimated that approximately 124 028 metric tonnes of CO_2 equivalent per annum would be reduced from this project (UNFCCC, 2009).

Table 6. Projected LFG to energy recovery potential from selected landfill sites in India

S.No.	Name and location of landfill in India	LFG Recovery (m^3 hr^{-1})	Method of Estimation	Projected LFG To Energy Potential	Reference
1.	Uruli Devachi, Pune	400	LFG Modeling and Pump Test Study	335 KW	US EPA/ SCS Engineers (2008b)
2.	Autonagar Landfill, Hyderabad	42	LFG Modeling	–	US EPA/ SCS Engineers (2007c)
3.	Gorai Landfill, Mumbai	684	LFG Modeling	4.8 MW	IUEP/URS Corp (2007)
4.	Bhalswa Landfill, Delhi	2,400	LFG Modeling and Pump Test Study	3.7 to 2.6 MW for 10 years	US EPA/ SCS Engineers (2010c)
5.	Pirana Landfill, Ahmedabad	1,300	LFG Modeling and Pump Test Study	1.0 MW Power for 7 years and 0.75 MW power for 11 years	US EPA/ SCS Engineers (2008a)
6.	Deonar Landfill, Mumbai	2,200	LFG Modeling and Pump Test Study	2.0 MW Power for 7 years and 1.0 MW power for 5 years	US EPA/ SCS Engineers (2007b)
7.	Dhapa, Kolkata	3,200	LFG Modeling	1.0 MW Power for 9 years and 0.5 MW power for 17 years	US EPA/ SCS Engineers (2010b)
8.	Shadra Landfill, Agra	89 to 105	LFG Modeling	173 KW per hour	IRADe/ USEPA (2010a)
9.	Barikalan Dubagga Landfill, Lucknow	33 to 39	LFG Modeling	64 KW per hour	US EPA/ SCS Engineers (2009b)
10.	Moti Jheel Landfill, Lucknow	11 to 12	LFG Modeling	64 KW per hour	US EPA/IRADe (2009b)
11.	Okhla Landfill, New Delhi	1,660	LFG Modeling	800 to 1,000 KW for 10 years	US EPA/ SCS Engineers (2007a)
12.	Ghazipur Landfill, Delhi	1,200	LFG Modeling and Pump Test Study	8.8 MW	GAIL/SENES (2012)
13.	Karuvadikuppam Landfill, Puducherry	22.8	LFG Modeling	–	US EPA/IRADe (2009a)

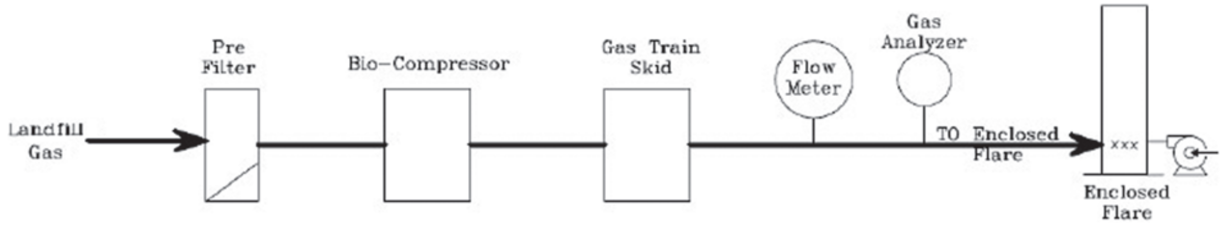

Figure 4. Flow diagram of enclosed flaring system for Gorai Landfill (Reproduced from CRA, 2011).

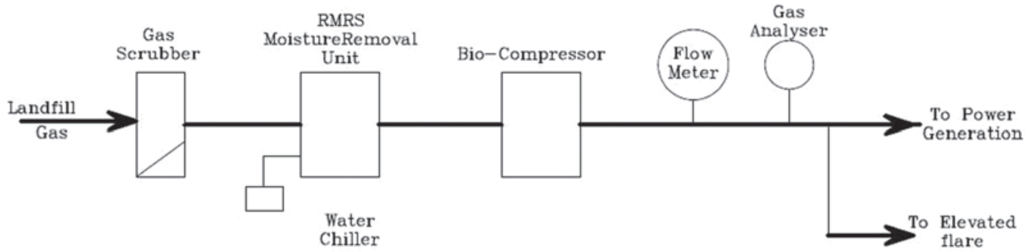

Figure 5. Flow diagram of LFG scrubbing, conditioning and flaring system of Okhla Landfill, Delhi.

Pilot demonstration of clean technology for landfill gas (LFG) recovery at Okhla Waste Disposal Site, Delhi

The Ministry of Environment and Forest (MoEF) has sponsored a pump test for LFG recovery from Okhla landfill site in Delhi. The LFG processing module comprises a gas scrubbing system, LFG compression system and LFG dryer system. The raw LFG from the landfill is required to be processed to make it useful as a source of energy (Vasudevan et al., 2012). This is obtained by scrubbing the LFG to the required level, compressing it and then removing the moisture by refrigerated type moisture removal system (Figure 5).

LFG and carbon credits

Projects in developing countries that are voluntary and reduce emissions and can contribute to the sustainable development of the country qualify under the clean development mechanism (CDM) and can earn certified emission reductions (CERs). Given that methane is a gas 21 that is times more potent as a GHG than carbon dioxide, 1 ton of avoided methane emissions is worth 21 tons of CO_2e or 21 CERs. Considering the latest information published by IPCC which gives global warming potential (GWP) of methane as 25 over a 100-year time scale, 1 ton of avoided methane emissions will be worth 25 tons of CO_2e or 25 CERs for future projects. If a GWP of 21 is replaced by 25 and the baseline emissions are recalculated, there will be increased baseline emissions. SITA/Hyder Consulting (2008) carried out LFG modelling studies to demonstrate the sensitivity of GWP 21 and GWP 25 on landfill methane capture. The results showed that landfill methane capture was 82% for GWP 25 and 79% for GWP 21. The number of CERs is therefore increased if GWP is increased.

To be eligible for CERs, a project must meet all the requirement of CDM such as requirements mentioned in the CDM project standard, etc. as prescribed by UNFCCC. The project must meet the requirements of additionality and demonstrate that it would not otherwise proceed; that is, there are no laws enforcing the capture of methane from landfills. It must also establish a baseline for future emissions if the project were not to exist. The baseline is determined as a methodology. Each methodology such as AM 0025 gives a step-wise approach for determining baseline. Baseline normally in Indian landfills is disposal of waste in landfill without gas capture and anaerobic decomposition of waste and release of methane into the atmosphere. However baseline emissions are determined as per first order decay model (the difference is between baseline and baseline emissions). Baseline emissions are determined as per formula and baseline is the scenario that would exist if the project was not implemented). Once a project is implemented and registered as a CDM project and then during the verification stage the actual amount of methane avoided can be calculated using actual data.

LFG and carbon finance

For India, carbon finance can help in establishing landfill projects that recover LFG which otherwise would not have been possible. For existing dumps, the closing and collecting and flaring of the produced LFG (or using it for fuel) are essential elements of a dump closure programme to achieve the desired emission reductions. Table 7 provides a rough estimate of the potential of carbon finance revenues for LFG recovery and flaring technologies (Hanrahan et al., 2006).

In the past, CERs for LFG projects have been largely overestimated by a factor of about 2. Furthermore, CDM methodologies do not under calculate CERs. In fact CDM methodologies are

Table 7. Potential carbon finance revenues for LFG to energy technologies (Modified from Hanrahan D, Srivastava S and Ramakrishna AS (2006) Improving Management of Municipal Solid Waste in India – Overview and Challenges, pp. 38–62 with permission from the International Bank for Reconstruction and Development, The World Bank).

MSW disposal option	CO_2 emissions ($t_{CO2}e$ t_{MSW}^{-1})	Potential emission reductions ($t_{CO2}e$ t_{MSW}^{-1})	Carbon finance for treatment of MSW (Rs t_{MSW}^{-1})
Assuming landfill without LFG recovery as baseline			
Landfill with LFG recovery and flare	0.20–0.25	0.95–1.20	175–200
Landfill with LFG recovery and energy generation	0.21 (may be less if energy component is considered)	More than 0.95	More than 175 Rs ton^{-1}

based on a principal of conservativeness. The LFG generation patterns tend to fluctuate due to climatic conditions and biogenic waste content. LFG pumping trials should be carried out before the project design document (PDD) to establish how much LFG can be extracted from the landfill (Couth et al., 2011).

Economic feasibility of LFG to energy project

The environmental benefits from LFG collection efficiencies as well as potential economic benefits from energy production, the carbon market, and tax credits, could magnify the value of LFG to energy projects (Amini and Reinhart, 2011). The relative costs of installing a LFG management system to collect and transport LFG to a facility can vary substantively based on site-specific conditions and the applicable design basis. The costs to install a LFG management system can vary dramatically as a function of:

- Quantity of waste in the landfill;
- Landfill dimensions;
- LFG generation potential;
- Cost of petroleum and associated products;
- Local costs for materials such as aggregate, pipe, and bentonite;
- Availability and costs for suitable construction contractors;
- Proximity to material manufacturing facilities;
- Nature of the design.

The specific characteristics of a landfill site will have many direct implications for the design options and related costs of the LFG management system. As such, it is highly recommended that these costs be reviewed carefully on a project-specific basis.

The economic feasibility of LFG to energy technologies also depend on the prevailing local and regional energy prices. The economic feature of LFG to energy technologies can be performed by cost and profit analysis. The cost is divided into capital cost, annual operation and maintenance cost and carbon tax and energy tax. The profit is the sales revenue of energy generation.

In addition to these, a cost–benefit analysis appropriate for small LFG to energy projects can be developed and performed by incorporating the value of the energy generated, the value of the avoided methane emissions, and the value of the avoided groundwater treatment costs when applicable.

Considering a landfill i, the profit (P_i) of initializing the LFG to energy project (Equation (1)) is the difference between the total revenue which includes the revenue from sales of methane (RH_i), the revenue from carbon trading (RC_i), the benefit from groundwater remediation (BG_i) and the expenditure that includes the cost of LFG collection system (CC_i), the cost of operations and maintenance of LFG system (CO_i), and the cost of transporting the collected LFG (CT_i).

$$P_i = RH_i + RC_i + BG_i - CC_i - CO_i - CT_i \quad (1)$$

In spite of the fact that energy recovery from landfill is one of the promising renewable energy technologies, LFG energy recovery projects are not always successful. Most of the projects fail because of non-technical barriers. (Luo and Thomas, 2008).

The evaluation of economic feasibility, selection of most viable alternative and determination of available financing mechanism for the project are key steps for LFG to energy projects. The economics of LFG to energy projects can be considered into six scenarios (TTI, 2009):

1. Conversion of LFG to LNG for use as vehicle fuel.
2. Conversion of LFG to CNG for use as vehicle fuel.
3. Conversion of LFG to pipeline grade natural gas.
4. Conversion of LFG to electricity.
5. Capping the landfill and flaring LFG.
6. Do nothing.

Numerous costs and benefits are associated with each option and some of them are common to more than one scenario. Table 8 summarizes the types of benefits and costs associated with each of the scenarios.

US EPA estimates that a 1 MW LFG to energy project would be equivalent to any one of the following four alternatives:

- Removing emissions equivalent to 8339 vehicles.
- Planting 11 882 acres of forest.
- Offsetting the use of 213 railcars of coal.
- Averting electricity usage of 77 917 light bulbs.

Table 9 summarizes the capital and operation and maintenance cost for setting up a LFG to energy project in the Indian context.

Barriers in LFG project development

While LFG recovery technologies are mature world-wide and there are many options for its utilization, however there are

Table 8. Types of benefits and costs associated with LFG scenarios (Reproduced from TTI, 2009).

Description	Scenario					
	LFG to LNG	LFG to CNG	LFG to pipeline	LFG to electricity	Enclosed flare	Nothing
Benefits						
Petrol, diesel or natural gas savings	X	X	X			
Electricity conversion				X		
Carbon credits	X	X	X	X	X	
Tax credits	X	X	X	X		
Fleet turnover emissions reductions	X	X				
Costs						
Landfill capping costs	X	X	X	X	X	X
CNG/LNG facility and operation cost	X	X				
Pipeline natural gas facility and operation cost			X			
Electricity plant and operation cost				X		
Flaring system and operation costs					X	
Costs of emissions						X

several barriers in using LFG as an energy source. These barriers include technological intricacies, financial and economic limitations, regulatory issues, lack of awareness, and interconnection challenges. These barriers are often interdependent.

The technological barriers identified are generally site specific in nature such as:

- Inability to collect sufficient amount of LFG from a landfill site.
- Insufficient amount of methane in LFG.
- Lack of consistency in the MSW disposed at a landfill.
- Lack of sufficient moisture content in MSW disposed at a landfill.
- Lack of experimental research on the component of MSW and its impact on LFG generation mechanism.
- Lack of accuracy in estimation and forecasting of LFG generation and recovery potential.

The options of LFG utilization mainly include power generation, industrial and residential fuel and vehicle fuel (IEA, 2008).

The non-technical barrier includes the distance between landfill sites and the power grid and the grid connection condition.

If there are industries near the landfill site, the purified LFG can be used as an industrial gas for boilers/kilns. The limitations for its utilization are:

- *Purification of LFG*: The composition of LFG is complex and unstable, and LFG contains noxious and harmful gases, so it requires purification before sending it to the user.
- *LFG transmission and distribution*: The investment for LFG transmission pipes and pressure increasing system is high.

Methane is the main content of purified LFG, which can be used as a fuel as an alternative to natural gas. The conversion of LFG to CNG/PNG can however be expensive.

The key economic limitations include:

- *High cost of project preparation*: the cost of developing LFG power generation project is high, which limit the implementation of LFG recovery and utilization.
- *Lack of financial incentives*: Lack of successful experience in LFG recovery and utilization makes it difficult to attract enterprises to join in the LFG recovery and utilization projects;
- *Lack of facilities*: LFG recovery and utilization is not included in the construction plan of old and existing landfill sites. This makes it difficult to develop LFG recovery and utilization in existing landfill sites.
- *Mechanism barriers*: The landfill operators are unlikely to invest in LFG recovery and utilization project unless it will be sufficiently profitable to justify the capital and operation and maintenance (O&M) costs.

Other barriers related to gainful utilization of LFG include the following situations.

Lack of awareness among regulators and policy makers: There is a lack of awareness of LFG as a renewable energy source. Policy makers may not understand the full extent of the harmful effects of LFG, particularly with regard to climate change. They may also not realize how LFG can be used for energy production. The landfill operators also lack information about the cost and performance of various LFG to energy recovery technologies.

Lack of national policy framework: The development of LFG to energy recovery technologies depends on governmental support. There is a lack of favourable policies at the national and state level for LFG recovery and utilization. Thus a vast potential of LFG remains un-tapped. Since not a single success story for LFG as energy source has been brought forward by the regulators and policy makers therefore not a single

Table 9. Capital and operation and maintenance cost for setting up a LFG to energy projects in India.

S. no.	Component	Capital cost (US$)	Operation and maintenance cost (US$)	Name of landfill	Reference
1	LFG collection and flaring system	2 086 500 to 2 201 500	7% of construction costs or 115 000	Pirana, Ahmedabad	USEPA/SCS Engineers (2008a)
2	Direct use project	390 000 to 440 000	–	Pirana, Ahmedabad	USEPA/SCS Engineers (2008a)
3	1.27 MW reciprocating I.C engine power plant	2 008 600	2% per kWh of electricity output or 204 000 per year	Pirana, Ahmedabad	USEPA/SCS Engineers (2008a)
4	1.08 MW I.C engine power plant	1 782 000	2% per kWh of electricity output or 174 000 per year	Pirana, Ahmedabad	USEPA/SCS Engineers (2008a)
5	LFG collection and flaring system	1 146 000	7% of construction costs or 92 000	Uruli Devachi, Pune	USEPA/SCS Engineers (2008b)
6	Direct use project	180 000	–	Uruli Devachi, Pune	USEPA/SCS Engineers (2008b)
7	0.7 MW reciprocating I.C Engine power plant	1 522 000	2% per kWh of electricity output or 108 000 per year	Uruli Devachi, Pune	USEPA/SCS Engineers (2008b)
8	LFG collection and flaring system	2 961 000	7% of construction costs or 147 000	Deonar, Mumbai	USEPA/SCS Engineers (2007b)
9	1.64 MW reciprocating I.C engine power plant	2 486 000	2% per kWh of electricity output or 264 ,000 per year	Deonar, Mumbai	USEPA/SCS Engineers (2007b)

landfill operator has implemented LFG recovery technology. Furthermore, the existing policy tools do not encourage LFG projects in the form of financial incentives, subsidies and support for technology development and demonstration.

The key barriers identified and proposed remedial measures are given in Table 10.

Legal and policy frameworks for LFG recovery in India

The MSW (Management and Handling) Rules, 2000 stipulates that LFG control system 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 the landfill site shall not exceed 25% of the lower explosive limit (LEL), which is equivalent to 650 mg m^{-3}. Furthermore the LFG from the site shall be utilized for either direct thermal applications or power generation as per the practicability; otherwise LFG will have to be flared and not allowed to be discharged directly into the atmosphere. Flaring reduces the volatile organic compounds (VOCs) and mitigates odour problems. If LFG utilization or flaring is not possible then passive venting will have to be done (MoEF, 2000). Table 11 shows the current R&D needs/status for LFG projects as a source of energy in India.

Proposed action plan for LFG management in India

The proposed action plan focuses on the following elements, aiming at the problems and barriers of LFG recovery and utilization in India (Siddiqui, 2010):

1. Legislation, regulation and standard development;
2. Economic incentives;
3. Education and awareness;
4. Information dissemination and technical training;
5. Institutional strengthening and barriers removal actions;
6. Demonstration and promotion activities;
7. Financial arrangement.

Legislation, regulation and standard development

The national action plan should pay attention to the following issues.

- To develop a national regulation, requiring the utility to purchase the electricity, gas, thermal or other energy products produced by LFG from old and existing landfills.
- To develop laws for the promotion of LFG to energy recovery project.

Table 10. Key barriers and proposed remedial measures (Siddiqui et al., 2011b).

Issue	Major barriers	Actions overcoming the barriers	Related agencies for implementation of actions
LFG recovery	Lack of mechanism of coordination and management	Set up coordination group	MoEF, MNRE, MoUD, CPCB
	Lack of capital for setting up engineered landfill sites	i. Increase government input ii. User charge iii. Bilateral and multilateral fund iv. Commercial finance	i. Municipalities/ULBs ii. WB, ADB, local commercial banks, private investment, etc.
	Lack of successful experiences of LFG recovery and utilization projects	Develop demonstration projects on the basis of international experiences	Gorai, Pirana, Uruli Devachi, Deonar, Okhla
	Lack of O&M experiences for engineered landfills	i. Implement the demonstration projects ii. Prepare training materials iii. Build training centres iv. Conduct the related training	i. International and national experts ii. Municipalities/ULBs iii. Staff of related agencies
	Lack of awareness of harmful impacts of emission of LFG	i. Propaganda by various media ii. Study tours to other countries iii. Print brochures	TV and newspaper Academia and research institutions
	Lack of model for LFG generation potential	Develop the software and models according to Indian conditions on the basis of international experiences	Research institutions like JMI, TERI, NEERI
LFG utilization for power generation	Lack of definite and attractive policy of power price	Determine the power price of LFG for power generation	CEA, power utilities, etc.
	Without standard power purchase agreement (PPA)	Make up standard PPA	CEA, power utilities, etc.
	Difficulty in grid connection	i. Adopt the power grid-connected policy of renewable energys ii. Mandatory market shares iii. Green power prices	i. Existing policies, implemented by CEA, power utilitiess ii. World Bank projects in research or demonstrations iii. Power utilities, and CEAs
	Difficulty in determination of energy potential due to lack of LFG estimation model	Develop suitable models of LFG generation and optimal power capacity	Research institutes, academia, etc.
	Lack of financial support from Government agencies	Financial support from Government agencies	MNRE, MoUD and MoEF
LFG utilization for alternative fuel	Lack of purification technology of LFG	Develop the purification technology	Research institutions, academia, etc
	Lack of financial support from Government agencies	Financial support from Government agencies	MNRE, MoUD and MoEF

Table 11. Current R&D needs/status for LFG projects as a source of energy in India (Reproduced from MNRE, 2009).

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 programme	High
6	Need for pilot plant	Yes
7	Identified gaps	Mainly engineering
8	Scale of funding	Medium (< 50 crores)
9	Opportunity for commercialization	Medium

- To set up legislation, which encourages LFG to energy utilization project.
- To formulate the technical standards for design and construction of LFG to energy utilization projects.

Economic incentives

Economic incentives are the major driving force for adoption of LFG to energy recovery and utilization projects. The major incentives should include the following activities.

- *Grid connection policy*: Power utilities must buy the electricity produced by LFG or other energy products with reasonable price, the LFG sales price should be less than the natural gas price in the same region.
- *Power price policy*: Green power price or subsidized price can be adopted.
- *Mandatory share*: The green energy certificate market can also be used to meet an obligation to produce a specific amount of renewable electricity in a market.
- *Tariff policy*: The key equipment used for LFG power generation shares the preferential import tariff and the import value added tax.
- *Investment policy*: LFG power generation project to support and offer interest subsidy.

Education and awareness

The following activities for the education and awareness should be conducted.

- To develop a training programme for the personnel engaging in LFG recovery and utilization engineering design and installation of equipment.
- To train the staff of municipalities/urban local bodies (ULBs) for better understanding of design, construction and management of landfill system equipped with LFG recovery and utilization facilities.
- To develop education on 'polluters pays principle' as the basis of implementation of MSW charge system.
- To promote the public awareness on LFG recovery, waste recycling and building a resource-efficient society by all kinds of media.
- The role of non-governmental organization in promoting public awareness activities should be played fully.

Information dissemination and training

Major information dissemination and technical training activities for the popularization of LFG recovery and utilization include the following items.

- To provide landfill data in Global Methane Initiatives (GMI) landfill database. This is a voluntary data repository to promote the development of LFG to energy projects. The database can be used to identify suitable landfills for LFG to energy project evaluation. The database can store information such as: general location and contact information, landfill physical characteristics, gas collection system characteristics, waste characteristics, landfill operations, and additional information and comments. Since 2004, the Methane to Markets (M2M) partnership has served as an important international initiative to focus the global attention on the importance of reducing landfill methane emissions. The GMI was launched in 2010 with a complement of 38 national partners. GMI has been supporting more than 300 projects that when fully implemented will reduce 600 million tons of CO_2Eq year^{-1}. To overcome the barrier of LFG management practices throughout the world, the GMI has been instrumental in formulating ten country-specific LFG action plans. These countries include Argentina, Australia, Brazil, Canada, China, Italy, Japan, Nicaragua, United Kingdom and United States. The action plans contain an overview of the country's solid waste management practices and outlines the country-specific opportunities and challenges to developing LFG to energy recovery projects.
- To develop an India-specific LFG modelling tool. Several country-specific LFG generation models have already been developed under the GMI programme. These models were created to help landfill owners and operators and other interested parties evaluate the feasibility and potential benefits of collecting and using LFG for energy recovery. The models include Central America Landfill Gas Model, China Landfill Gas Model, Ecuador Landfill Gas Model, Mexico Landfill Gas Model, Philippines Landfill Gas Model, Thailand Landfill Gas Model and Ukraine Landfill Gas Model.
- To conduct a regional information dissemination workshop, seminars or training for the national and local government and enterprises.
- To organize technologies, equipment and system exhibition for national and international technical information exchange.
- To encourage the private and public participation for the LFG recovery and utilization, such as promoting residents to buy the LFG and its energy product like electricity, gas and thermal at green price.

- To set up information dissemination agency for LFG recovery and utilization.

Institutional strengthening

The following capacity-building activities should be conducted.

- To set up a coordinating group consisting of senior government officials from selected ministries. Such group can provide guidance on policies and institutional coordination during the action plan implementation.
- To set up a program implementation office under the coordinating group for implementation of the national action plan activities.
- To set up market operation agencies for the LFG recovery and utilization, such as Energy Service Company (ESCO) for power, thermal or gas generation, distribution and marketing.

Encourage and support the project developers of commercial LFG recovery and utilization, and the main activities include:

- The GOI encourages market operation and commercial development of MSW disposal.
- Publicize the information of project investment through seminars and provide fair competition opportunity for the enterprises.
- Set up the large-scale ESCO through market competition.
- The government formulates the standards and regulations to standardize the activities of enterprises.

Demonstration activities

The national action plan needs to develop technical demonstration activities such as increasing the demonstration items in selected metropolitan sites. The demonstration items should include the following:

- Implementation of landfill system design, construction and maintenance and LFG recovery and utilization equipments.
- Management of commercial LFG recovery and utilization project.
- Commercial mode for grid-connected price, power generation and sales.

Financial mechanism

Determining the most appropriate funding mechanism will be dependent on the project type, the project developer and access to each of the various types of funding. The sufficient financial arrangement can ensure the successful implementation of the national action plan. The financial flows can be from:

- Governmental financial budget, which has been put for the municipal MSW management.
- Increasing the disposal fee for MSW.
- Bilateral assistance or Overseas Development Agency financial support.
- Global Environmental Facility, World Bank, Asian Development Bank and other international financial agencies.
- Commercial banks and private investment.

Framework for implementation of proposed action plan

The national action plan has been developed to promote widespread replication and adoption of LFG recovery and utilization technologies in India. The proposed roles and responsibilities by various agencies are given in Table 12.

The Action Plan should be implemented in phases.

Short-term phase

1. Conduct field trials at selected landfills to assess the yield and composition of LFG and use the baseline data to calibrate a theoretical model of LFG yield.
2. Establish institutional arrangements for the construction and operation of the demonstration projects, and the sale of LFG.
3. Disseminate information, maintain databases, train manpower engaged in LFG technology, and conduct research on improving the technology.

Medium-term phase

- Reconstruct 20–30 existing landfill sites, for LFG recovery and utilization.
- Conduct commercial operation for LFG utilization project.
- Promote the MSW management institution reform; summarize the experience of demonstration and pilot projects to make out institutional policy, economic incentive policy framework for government at central, local and municipal level.

Long-term phase

- Build municipal landfill sites meeting the international standard.
- Build facilities of LFG recovery and utilization for power generation, residential fuel and vehicle fuel.
- Establish ESCOs.
- Establish centres for LFG recovery and utilization technology.
- Develop technical standards for construction and operation of LFG recovery facilities.

Indicators for successful LFG projects

- Improvements in energy production or installed capacities.
- Reduction in technology implementation costs.
- Expansion of business and supporting services for LFG to energy projects.

Table 12. Name of agencies with their roles/responsibilities for implementation of LFG action plan.

S. no.	Agencies/authorities	Proposed roles/responsibilities
	Ministry of Environment & Forests (MoEF)	• Amendments in existing MSW Rules 2000 to incorporate LFG recovery and utilization • Setting targets and timelines for achieving reduction in LFG generation from MSW • Notification of standards for flaring and LFG recovery • Notification of standards for remediation of old/closed landfill sites • Clearance of LFG projects under CDM programme • Funding for clean LFG utilization technologies • Funding for organization of LFG technologies, workshops, seminars and conferences • Notifications of laboratories for LFG analysis and monitoring work
	State Department of Environment & Forests (SDEFs)	• Monitoring the implementation of MSW Rules, 2000
	Central Pollution Control Board (CPCB)	• Creation of national level data banks with the purpose of disseminating information on landfill sites, landfill methane emissions inventory and energy recovery potential, characteristics of waste generated and management of MSW • Development of a national data base of landfills, LFG system developers, bankers and financial institutions, consultants, engineers, constructors, operators • Developing country-wide, sector-specific methane reduction programmes • Development of standards for flaring and LFG recovery • Development of standards for remediation of old/closed landfill sites • Dissemination of success stories of LFG recovery • LCA studies on MSWM • Strategies for integration with other legislations on e-waste, plastic waste, biomedical waste and hazardous waste
	State Pollution Control Boards (SPCBs)	• Periodic assessment of the amounts of waste being generated • Development of comprehensive database on waste for aiding policy-making and intervention • Creation of state level data banks with the purpose of disseminating information on landfill methane emissions and energy recovery potential
	Ministry of Urban Development (MoUD)	• Λανδφιλλ σιτε δατα χολλεχτιον ανδ χομπιλατιον • Monitoring and implementation of MSW rules 2000 • Identification of suitable areas for sanitary-engineered landfills • Full scale implementation of LFG recovery technologies • Remediation of old/closed landfill sites • Land lease issue • Identification of land for setting up common/zonal/regional sanitary landfills on a priority basis and municipalities to jointly implement and manage such facilities, according to a time bound program.
	State Urban Development Departments (SUDDs)	• Closure of landfill sites which have completed their designed life and installation of LFG recovery facilities. • State governments to prepare detailed project report (DPR) for towns and municipalities in their states and UTs. Local bodies should make budgetary provision to implement the DPR • SUDD should make budgetary provisions including land allotment for waste storage, sorting, recycling, processing and disposal. • Implementation of MSWM Rules in time-bound phases by prioritization/categorization of cities/towns based on population and quantum of waste generation. • Formulation of scheme for providing incentives and disincentives to local bodies to promote LFG recovery as per the MSWM Rules.
	Ministry of New and Renewable Energy (MNRE)	• Establish links with other national and international organizations build up its reputation as the 'one-window' contact and facilitator for LFG projects in India. • Financial assistance for projects that demonstrate methane capture and use from existing landfill sites such as pre-feasibility studies, feasibility studies, or technology demonstrations. • Integration of LFG technologies with other renewable energy technologies • Funding of demonstration projects for methane recovery from landfills and municipal wastewater treatment plants (MWWTPs). • Demonstration projects for methane recovery from MWWTPs.

Table 12. (Continued)

S. no.	Agencies/authorities	Proposed roles/responsibilities
	Indian Renewable energy Development Agency (IREDA)	• National level policy intervention for incorporating LFG energy recovery and utilization into mainstream renewable energy sources of India • Develop a publicity programme to include the production of project documents, videotapes, TV programmes, special interviews, seminars, articles and presentations at national and international conferences and symposiums. In project dissemination effort, information must include: environmental benefits; economic and technical viabilities; innovation in project financing; establishment of independent energy service companies, and project management and institutional capacity
	State Renewable Energy Development Agency (SREDA)	• State level policy intervention for incorporating LFG energy recovery and utilization into mainstream renewable energy sources of India
	Central Electricity Authority (CEA)	• Pricing norms for LFG • Subsidies to project developer for LFG recovery
	State Electricity Authority (SEA)	• State level pricing norms for LFG • State level subsidies to project developer for LFG recovery
	Bureau of Indian Standards (BIS)	• IS codes for LFG recovery • Protocols/standards for LFG analysis
	Department of Science and Technology (DST), Technology Information and Forecasting Assessment Council (TIFAC)	• National level LFG potential estimates • Identification of projects that improve emissions estimates and identify the largest relevant emissions sources to facilitate project development • Funding for feasibilities studies related to methane mitigation in various sectors
	World Bank/Asian Development Bank (ADB) (through private organization)	• Identification of cost-effective opportunities to recover methane emissions for energy production and potential financing mechanisms to encourage investment. • Identification and promotion of areas of bilateral, multilateral, and private sector collaboration on methane recovery and use. • Identification of legal, regulatory, financial, or institutional mechanism necessary to attract investment in international LFG recovery and utilization projects.
	Ministry of Human Resource Development (MHRD), University Grants Commission (UGC) & All India Council for Technical Education (AICTE) (Through Academia)	• Develop training program curriculum and course content for LFG recovery and utilization as well as landfill design and operation. • Identification of projects addressing specific challenges to methane recovery, such as raising awareness, improving local expertise and knowledge, and demonstrating methane recovery and use technologies and management practices. • Environmental liability assessment of existing MSW landfill sites • Compulsory lab and theory course on ISWM incorporating LFG utilization technologies and processes • Creating awareness on LFG recovery and utilization

- Increase of financing availability and mechanisms.
- Development of policies, laws and regulations that support project goals.
- Awareness and understanding of LFG technologies among producers and users.
- Successful project implementation leading to reductions in LFG emissions to the atmosphere.
- Clean emissions from LFG to energy recovery project.
- Reduced groundwater contamination potential.

Global methane initiative

The GMI was launched in 2010. GMI has been supporting more than 300 projects that when fully implemented will reduce 600 million tons of CO_2Eq year^{-1}. To overcome the barrier of LFG management practices throughout the World, the GMI has been instrumental in formulating ten country-specific LFG action plans. These countries include Argentina, Australia, Brazil, Canada, China, Italy, Japan, Nicaragua, United Kingdom and United States. The action plans contain an overview of the country's solid waste management practices and outlines the country-specific opportunities and challenges to developing LFG to energy recovery projects.

As a first step, it is proposed that a strategic LFG recovery action plan be prepared by India. The LFG country profile should contain an overview of India's solid waste and LFG sector and outline of the country-specific opportunities and challenges to developing LFG to energy recovery projects. The strategies could include a country-specific strategic plan – a range of activities, from near-term to longer term, to promote LFG recovery and use in India. Ideally, the strategic plan should identify activities in order of their priority or importance, convey India's overall abilities and goals to promote projects, and outline India's potential to reduce methane emissions during a specified period of time.

Such a country-specific strategic plan can play a very useful role in identifying activities in India that would be most beneficial and effective in promoting the development of methane recovery and use projects. Ideally, these strategies could help to identify and clearly describe the activities that should be undertaken as part of project development in India. The plan can also outline activities that India is involved with other countries. As such, the country-specific strategic plan can provide information to groups that wish to work to develop projects in India and want to know the most effective activities to undertake. Finally, the strategic plan might become incorporated as a component of India's overarching carbon mitigation plan and provide substantive, concrete steps towards the India's overall national emission reductions goal. In these ways, the country-specific strategic plan could help contribute to each India's ongoing environmental, energy, and strategic efforts.

Country-specific strategic plan might be considered 'a living document' to be updated as circumstances change and evolve in the landfill sector of India. It is suggested that each plan be re-examined from time to time to ensure that the action plan remains relevant. Ideally, plan will be based on input from a broad range of stakeholders.

Conclusions

Based on review, it can be concluded that although researches on LFG recovery have been conducted for almost two decades, the field is still somewhat immature when it comes to its implementation in the context of India. It can be concluded that facilitating implementation of LFG to energy from landfills in India involves three main research challenges: technology innovation, developing standardized framework for performance evaluation and provision of financial incentives. Applied research such as pilot demonstration projects and reviews of experiences from previously conducted projects is essential for techno-commercial viability. The policy enabling policy framework should be able to answer questions such as how much of the gas can actually be recovered and processed, how will the current environmental legislations, taxes and subsidies apply to LFG to energy projects. LFG modeling studies are essential for assessing the energy potential for how LFG to energy projects can be organized and managed.

Some of the activities that can be carried out to make the improvements in the solid waste sector inventory data generation of India include:

- Measuring methane emission factors from MSW in metro cities in India.
- Authentication of activity data from municipal sources and its check for consistency in terms of correctness and completeness.
- Adoption of appropriate sampling protocol to capture variability and generation of CH_4 emission.
- Estimation of methane emissions using country specific emission factors.

The Ministry of Urban Development (MoUD), Government of India can adopt the proposed strategy and action plan to work with the state governments to build their capacity in order to implement LFG to energy recovery projects. The MoEF and Ministry of New and Renewable Energy should work closely to develop the incentives required to promote the use of LFG as renewable energy from landfills. The land value and development potential from the recovery of LFG and the rehabilitation of old landfills may be studied by MoUD, and the results of the study be used to provide incentives and training to ULBs for implementing LFG projects. The health impacts of old landfills, and the economic benefits of LFG recovery and closure of old landfills should be included in the government policy.

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