Viability-Gap Assessment for Municipal Solid Waste-Based Waste-to-Energy Options for India

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Abstract Most of the urban local bodies in the country are grappling with the problems of proper management of municipal solid waste. With limited finances at their disposal, they are unable to provide proper treatment and disposal to the waste collected in cities. As the solid waste streams in most cities contain around 50% of organic waste, waste-to-energy projects provide viable option for treating this waste. This paper examines the viability of two waste-to-energy options (biomethanation and RDF-based projects) which have been implemented with some degree of success in the country. The projects with capacities—3, 5 and 10 MW—were considered for biomethanation route, and single project with capacity 6.5 MW was considered for RDF-based option. The viability-gap analysis shows that there exists a funding gap of Rs. 0.24, Rs. 0.82 and Rs. 1.51 per kWh, respectively, for the three biomethanation options and gap of Rs. 2.35 per kWh for RDF-based option. The funding gap to some extent can be met by availing certified emission reductions (3 MW projects would not require any more funding) but would require more support in terms of subsidies for these projects to be financially viable in Indian context.

Keywords Waste-to-energy · Biomethanation · RDF · Certified emission reduction · Financial viability · Levelised unit cost of electricity

1 Introduction

There are close to 7000 cities and notified towns across India representing an urban population of around 300 million, generating almost 115,000 TPD (tonnes per day) of municipal solid waste (MSW) [4]. The solid waste generated in the country has grown in a rapid manner over the last decade. This is mainly due to rapid

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urbanisation, rising consumption patterns, related increase in MSW generation, change in waste characteristics over the year and lack of awareness and public apathy towards the seriousness to deal with the issue. In India, the characteristics of MSW vary place to place and season to season as it is a large country with varied climate. Bulk of this waste is being dumped in the open in an uncontrolled manner, resulting in pollution of water bodies and land and causing uncontrolled emission of methane. It is estimated MSW generated would require about 1240 ha of land every year if it is disposed on land [2]. If all the treatable waste is processed biologically or thermally, it is estimated that land requirement for disposal of waste will reduce by 90%, thus reducing the load on landfills substantially.

The calorific or fuel value in the MSW is due to biodegradable waste such as food waste and horticulture waste and non-biodegradable waste such as leather, wood, plastics, paper, rubber. This variability coupled with higher moisture content in the MSW in India affects combustion of waste in waste-to-energy (W2E) processes. The waste generation varies on the daily basis and hence has to be homogenised before feeding to W2E processes like incineration. Presence in high inert which is abrasive in nature can also cause wear and tear in waste processing units and combustion chamber. Combustion of MSW can also result in formation slag and fused ash deposits in the equipment employed in W2E system, thus reducing the efficiency of combustion and higher cost of operation. Additionally, higher moisture content and halogen in waste can form acidic gases in the flue and cause corrosion in the W2E systems.

Urban local bodies (ULBs) in India—responsible for municipal solid waste management—have been under pressure to safeguard public health and maintain compliance with the legislative framework as provided by the Municipal Solid Waste (Management and Handling) Rules of 2000 and now 2016 notified by Ministry of Environment and Forests, Government of India.

ULBs in recent years have developed and launched various initiatives for transforming service levels and for improving compliance with these rules. Despite these efforts, the situation of MSW management and compliance of ULBs with the MSW Rules remain far from satisfactory. Resource, capacity and financial constraints have resulted in poor collection, transportation and safe disposal of MSW. In addition, clandestine disposal of biomedical waste and electronic waste has not made the task of ULBs easy. While daily collection efficiency is typically 50–60% (except for metro cities like Delhi and Mumbai where it has been reported in the range of 80–90%), only around 13% of waste is treated/processed and literally nothing is disposed as per the provisions of MSW Rules [2].

The problem of treating organic portion of MSW can be addressed by adopting W2E technologies for treatment and processing wastes before disposal. This will not only divert the waste from landfill sites but also recover some energy and other resources like manure while treating the waste. As per the draft National Master Plan (NMP), 2006 by MNRE (Ministry of New and Renewable Energy, Government of India), there is potential to generate around 2200–2300 MW of the power in the urban areas of the country if this waste can be properly segregated. Biomass and municipal solid waste (MSW) have widely been accepted as important, locally available renewable energy sources with low carbon dioxide emissions [6].

2 Objective of the Research

The availability of source-segregated waste and cost of infrastructure both in terms of capital and operation and maintenance costs remain major barriers for gainful implementation of such W2E options in Indian cities. There is therefore a need to look at various non-regulatory barriers, particularly technological and financial aspects and to evaluate mechanisms that could make such projects viable and attractive in the future.

3 Current Scenario

As of now, as per the MNRE regarding energy recovery from MSW, three projects, namely at Hyderabad, Vijayawada and Lucknow with total capacity of 17.6 MW had been set up in India. The projects at Vijayawada and Hyderabad were based on use of refuse-derived fuel (RDF), while the Lucknow one was based on anaerobic digestion.

The plant was shut down only after a year of operation at much lower capacity despite biomethanation being identified as most attractive option for W2E in NMP of MNRE. Only operating project based on MSW to energy is 16 MW project at Okhla in Delhi. Other non-MSW-based projects include a 1-MW biomethanation project using cattle dung as feedstock at Ludhiana; a 0.5-MW project for sewage treatment plant at Surat; and a 150-kW project using vegetable market and slaughterhouse wastes at Vijayawada.

4 Energy Generation Potential

Any one or all W2E technologies, landfill with gas recovery, biomethanation, gasification or incineration, can be considered to be applicable for W2E projects utilising sorted MSW as the feedstock. Among these options, landfill with gas recovery is excluded as a potential technology option in view of the Solid Waste Rules, 2016, which state that landfilling of waste will only be allowed for non-biodegradable, inert waste and waste not suitable for material recovery and recycling or for biological processing. Landfilling will be allowed for disposal of pre-processing reject and residues from waste processing facilities. The Rules also state that landfilling of mixed waste will be allowed only if it is found unsuitable for waste processing.

As per the average waste characteristics for MSW in India, reportedly around 50% of waste is organic. Considering past poor performance of W2E projects in Hyderabad and Vijayawada and for the limited period of operation in Lucknow, it is safe to assume that every 150 tonnes of organic waste would produce around 1 MW of power which would be minimum requirement for the projects using above-mentioned technologies to be technically and financially viable. So cities generating at least 300 TPD of MSW would be candidate for W2E projects in the country on stand-alone basis. As per CPCB assessment, there are at present 31 such cities producing around 36,000 TPD of MSW. The annual power generation potential of these cities processing MSW would be around 36,000 MW.

5 Financial Viability

W2E projects provide for a beneficial way of disposing off MSW. Technology options like incineration, biomethanation, use of RDF, gasification and pyrolysis have been considered possible solution to recover energy from MSW. However, conventional MSW incineration while considered as an important sustainable solution for waste management and energy recovery, apart from being cost-intensive, provides low overall efficiency due to emission of acidic flue gases in the boiler [3, 5]. On the other hand, projects based on biomethanation and uses of RDF have proven to be commercially viable in Indian market. Hence for the sake of assessing the cost of power generation from such projects, we have considered only two options (biomethanation and RDF-based projects) for financial analysis.

In case of biomethanation, three cases are developed depending on the capacity of plant to process the waste. In case the waste generated in the city is around 450 tonnes per day (TPD) of organic waste, then a small-capacity plant (3 MW) would be sufficient. On the other hand, if the waste generated in the city is around 1500 TPD of organic waste as in large cities like Delhi, then a higher-capacity plant would be needed. Thus, three cases are developed, i.e. 3-MW plant that can process up to 450 TPD, 5-MW plant that can process up to 750 TPD and 10-MW plant that can process 1500 TPD of organic waste.

While in case of RDF, it is necessary to operate it minimum waste input feed level. Based on experience of previous projects in India, such projects would be economical only for the cities generating at least 500–700 TPD of organic waste, such as Hyderabad. Thus in case of RDF, only one capacity plant is taken of 6.5 MW that can process up to 700 TPD of organic waste.

5.1 Inputs and Assumptions

5.1.1 Technical Parameters

The technical inputs and assumptions used for estimating the levelised cost of power generation using biomethanation and RDF-based waste-to-energy plants are summarised in Table 1.

5.1.2 Generation

For computing annual generation for each case, assumptions regarding parasitic consumption during the plant operations and annual operating hours are assumed on the basis of the NMP for development of W2E projects in India as prepared by

Table 1 Technical inputs and assumptions

Particulars	Units	Biomethanation			RDF
Plant capacity	MW	3	5	10	6.5[b]
Organic waste processed	TPD	450[a]	750[a]	1500[a]	700[b]
Life of plant[a]	Years	15	15	15	15
Capital cost	Rs. Crores	40.25[a]	57.30[a]	102.00[a]	60.00[b]
Land cost[b]	Rs. Crores	0.3	0.5	0.6	0.4
Operation and maintenance cost	Rs. Crores	2.72[a]	4.13[a]	8.25[a]	3.00[b]
Yearly escalation in O&M cost[c]	%	4.83	4.83	4.83	4.83
Debt–equity ratio[d]	Ratio	70:30	70:30	70:30	70:30
Interest rate[d]	%	12.00	12.00	12.00	12.00
Repayment period (including 1 years moratorium)[d]	Years	10	10	10	10
Return on equity[e]	%	14.00	14.00	14.00	14.00
Discount rate (weighted average cost of capital, i.e. WACC)	%	12.60	12.60	12.60	12.60
Capital recovery factor	%	15.16	15.16	15.16	15.16

Sources [a]Based on National Master Plan for Development of Waste-to-Energy in India, Ministry of Non-Conventional Energy Source now Ministry of New and Renewable Energy (MNRE), Government of India; details available at: www.mnre.gov.in, accessed on 25th July 2008
[b]As per discussion with stakeholders
[c]Based on average wholesale price index (WPI) for last three years, i.e. 2005–06, 2006–07 and 2007–08; details available at: https://reservebank.org.in/cdbmsi/servlet/login/, accessed on 25th July 2008
[d]Based on financing norms as given by IREDA
[e]Based on CERC norms for return on equity for power generating plants

Table 2 Estimation of annual generation

Particulars	Units	Biomethanation			RDF
Plant capacity (*A*)	MW	3.00	5.00	10.00	6.50
Parasitic consumption (*B*)	MW	0.45[a]	0.75[a]	1.50[a]	1.00[b]
Net electricity for sale ($C = A - B$)	MW	2.55	4.25	8.50	5.50
Annual hours of generation (*D*)	Hours	7920[a]	7920[a]	7920[a]	6132[a]
Annual generation [$E = (C * D)/10^3$]	MU	20.20	33.66	67.32	33.73

Sources [a]Based on National Master Plan for Development of Waste-to-Energy in India, Ministry of Non-Conventional Energy Source now Ministry of New and Renewable Energy (MNRE), Government of India; details available at: www.mnre.gov.in, accessed on 25th July 2008
[b]As per discussion with stakeholders

MNRE. The assumptions as well as computation of annual generation are being presented in Table 2.

5.2 Levelised Cost of Power Generation

In order to estimate the levelised cost of power generation, the annutised capital cost (i.e. the capital cost levelised over the life of the project, i.e. 15 years for each technology), annual O&M cost and annual fuel cost are estimated.

5.2.1 Levelised Capital Cost

Levelised capital cost is estimated by multiplying the capital cost of each type of plant with the discount factor and capital recovery factor (CRF).

Determination of the Discount Rate

The discount rate has been arrived at based on the weighted average cost of capital (WACC). For arriving at the WACC, the debt–equity ratio and the rate of interest for the debt have been assumed to be 70:30 and 12%, respectively, based on the financing norms specified by Indian Renewable Energy Development Agency (IREDA). The rate of return on equity is taken as 14% which is based on norms for rate of return on equity for generation companies as given by Central Electricity Regulatory Commission (CERC).

Capital Recovery Factor (CRF)

Power generation involves substantial upfront capital commitments. Thus, for computing fixed cost of a project over its whole life, there is a need to provide for a discount factor, which would convert this one-time investment into costs, distributed equally over the life of the system, i.e. 15 years in this case. For this purpose, CRF is computed. CRF is ratio of a constant annuity to the present value

Table 3 Levelised capital cost

MSW technology	Plant capacity (in MWs)	Levelised capital cost (in Rs. Cr)
Biomethanation	3	6.15
	5	8.75
	10	15.55
RDF	6.5	9.15

Source TERI estimates

Table 4 Annual O&M cost

MSW technology	Plant capacity (in MWs)	Annual O&M cost (in Rs. Cr)
Biomethanation	3	1.60
	5	2.43
	10	4.86
RDF	6.5	1.77

Source TERI estimates

of receiving that annuity for a given period of time. CRF in case of MSW projects, for each type of technology, at 12.6% discount rate and life of 15 years comes out to be 15.2%. Table 3 summarises the levelised capital cost for each type of MSW technology.

5.2.2 Annual Operating and Maintenance (O&M) Cost

The O&M cost for each case is taken as per the estimates presented by the NMP. These have further been raised at the rate 4.83% per year. Escalation factor has been determined based on the average of the wholesale price index (WPI) for last three years. Table 4 summarises the annual O&M cost for each type of MSW technology.

5.2.3 Annual Fuel Cost

Fuel cost in case of W2E projects includes the cost of waste as well as the cost of collection and transportation of such waste[1] from source of generation to the plant site. As per national practice, however, the waste is available free of cost in case of biomethanation plants, while in case of RDF projects, the cost of waste includes the cost of processing the waste into fluff which is then used for power generation. Thus, fuel cost in case of biomethanation plants is solely the collection and

[1]The cost for collection and transportation of MSW from source of generation to the plant site also includes salary and wages of the staff involved.

Table 5 Collection and transportation cost of MSW

Particulars	Units	Biomethanation			RDF
Plant capacity	MW	3	5	10	6.5
Quantity of organic waste processed	TPD	450	750	1500	700
MSW collection and transportation charges	Rs./tonne	250	475	675	475
Total collection and transportation cost	Rs. Cr	2.48	7.84	22.28	8.50
Quantity of fluff generated	TPD	–	–	–	200
Cost of fluff	Rs./tonne	–	–	–	130
Annual fuel cost (including fluff cost)	Rs. Cr	2.48	7.84	22.28	9.16

Source Based on discussion with stakeholders including Municipal Corporation of Hyderabad

transportation cost of waste, while in case of RDF plants, cost of fluff is also included. The cost of collection and transportation, in actual, varies from Rs. 250 to 700 per tonne depending on the size of city and quantity of waste generated, collected and transported. Table 5 summarises the fuel cost assumed for each case.

5.2.4 Revenue from Sale of By-Product

The levelised cost on case of plant based on biomethanation technology is further reduced as it earns extra revenue from sale of by-products. Biofertiliser is produced as a by-product of biomethanation process, which in itself is useful manure. Table 6 summarises the levelised unit cost of electricity (LUCE) generated from MSW-based plants for each type of technology.

5.3 Viability-Gap Analysis

This section presents the result of viability-gap analysis for the scheme. Viability gap is computed by comparing the LUCE generation from each type of MSW technology and the benchmark tariff for MSW projects already existing in the country. The LUCE for each type of MSW technology ranges between Rs. 3.84 and 5.11 per kWh in case of biomethanation plants and is Rs. 5.95 per kWh in case of RDF plant. While for purposes of computing the viability gap, benchmark tariff for MSW projects is assumed as Rs. 3.60 per kWh. This is the existing highest tariff approved for MSW projects by Andhra Pradesh Electricity Regulatory Commission (APERC) in FY 2006/07. Table 7 summarises the viability gap for each type of MSW technology.

Table 6 Levelised unit cost of electricity (LUCE) generation from MSW plants

Technology type	Plant capacity	Levelised capital cost[a]	Annual O&M cost	Annual fuel cost[b]	Total levelised cost	Less: sale of by-product[c]	Net levelised cost	LUCE
Units	MW	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. in Cr	Rs. per kWh
Biomethanation	3	6.15	1.60	2.48	10.22	2.48	7.75	3.84
	5	8.75	2.43	7.84	19.02	4.13	14.89	4.42
	10	15.55	4.86	22.28	42.68	8.25	34.43	5.11
RDF	6.5	9.15	1.77	9.16	20.07	Nil	20.07	5.95

Source TERI estimates
Note [a]Total capital cost is considered including land cost
[b]Total fuel cost consists of collection and transportation charges and cost of fluff (in case of RDF only)
[c]Power generation from a biomethanation plant results in generation of biofertiliser which can be sold in market to earn additional revenue and hence reduce cost

Table 7 Viability gap (per unit) for each type of MSW technology

Technology type	Plant capacity	LUCE of MSW	Benchmark tariff	Viability gap[a]
Units	MW	Rs./kWh	Rs./kWh	Rs./kWh
Biomethanation	3	3.84	3.60	0.24
	5	4.42	3.60	0.82
	10	5.11	3.60	1.51
RDF	6.5	5.95	3.60	2.35

Source TERI estimates
[a]Viability gap = LUCE of MSW plants − Benchmark tariff

5.3.1 Mechanisms to Bridge the Viability Gap

A combination of capital and interest subsidy along with funds from CDM benefits through CERs is used for bridging the above gap to make the MSW technology viable. Given the current low rates of CERs, most projects would require additional funding support to make them viable.

Role of Government for Financing the Gap

As these technologies are new and would also help in management of waste, government can finance the remaining gap in case of medium–high-capacity biomethanation (5 and 10 MW) and RDF (6.5 MW) plants through a combination of capital and interest subsidy. Further as the per unit gaps are marginal, this funding may be provided in initial period only and can be removed after the technology becomes fully viable vis-à-vis conventional power systems.

Capital Subsidy

Since the main barrier for power generation from waste-to-energy plants could be the high initial capital cost, it is necessary that this cost should be reduced. Thus giving upfront subsidy in the form of reduction in capital cost can go a long way in promoting W2E to energy plants. In order to make biomethanation plant of high capacity, i.e. 10 MW viable, a capital subsidy of 15% is proposed. While medium-capacity biomethanation plant of 5 MW may not be given any upfront support through capital subsidy as per unit viability gap in this case is very small Table (7). Such plants may be given benefit of subsidised loans which can make the plant viable vis-à-vis conventional plants without putting any upfront burden on government. RDF plant, on the other hand, involves huge initial capital cost; thus, a higher capital subsidy is proposed to be provided to such plants, i.e., of 45%.

Interest Subsidy

Along with capital subsidy, it is proposed to provide subsidised loans to reduce upfront investment by promoter. In the base case, 70% of the remaining capital cost (after subsidy) is considered debt at an interest rate of 12%. To improve the viability, a subsidised interest rate of 7% is proposed (i.e. interest subsidy @ 5%) for both medium-to-high biomethanation and RDF plants. Table 8 summarises the mechanisms used for bridging the viability gap in case of MSW-based plants.

5.4 Fund Requirement (Per Plant)

In case of low-capacity biomethanation plant, i.e. 3 MW, there is no need for government financing as projects become viable after availing benefits through CERs alone, which would imply no additional burden on government. Further, use of funds from CERs and from government in the form of capital and interest subsidy makes the medium-to-high-capacity biomethanation (i.e. 5 and 10 MW) and RDF (6.5 MW) plants viable, by reducing the gap to zero. Table 9 summarises the additional funds required from the government for providing capital and interest subsidies to high-capacity biomethanation and RDF plants.

Further to have a more effective implementation of the MSW-based projects and ensuring that waste is utilised in useful manner, a scheme is to be implemented in phased manner.

It would be of utmost importance to implement the MSW-based W2E options in various cities grappling with day-to-day waste management problems in a fast-track manner. This would also ensure faster compliance of cities with the provisions of MSW Rules. It has been estimated earlier that larger cities generating at least 450 TPD of organic waste can generate around 3600 MW of power annually by processing their organic waste. The present generation capacity is around 11 MW

Table 8 Mechanisms to bridge the viability gap for MSW-based plants

Particulars	Units	Biomethanation			RDF
		3 MW	5 MW	10 MW	6.5 MW
LUCE	Rs./kWh	3.84	4.42	5.11	5.95
Less: benchmark tariff	Rs./kWh	3.60	3.60	3.60	3.60
Viability gap (VG) I	**Rs./kWh**	**0.24**	**0.82**	**1.51**	**2.35**
Less: funds through CERs (per unit)	Rs./kWh	0.50	0.50	0.50	0.50
VG II	**Rs./kWh**	**−0.26**	**0.33**	**1.02**	**1.85**
Less: funds through government					
Capital subsidy	%	–	–	15%	45%
Interest subsidy	%	–	5%	5%	5%
VG III	**Rs./kWh**	**−0.26**	**0.00**	**0.00**	**0.00**

Source TERI estimates

Table 9 Fund required from government towards subsidy (per plant)

Technology type	Plant capacity	Fund required for capital subsidy	Fund required for interest subsidy	Total Fund required for subsidy per plant
Units	MW	USD millions	USD millions	USD millions
Biomethanation	3	–	–	–
	5	–	3.3	3.3
	10	5.1	7.4	11.2
RDF	6.5	6.8	1.9	8.7

Source TERI estimates
Note Assuming exchange rate as 1 USD = 68 INR

based on RDF projects. The wet waste in the cities can be processed by biomethanation process, and the dry organic wastes like paper, plastics, rags, leather can be used for RDF-based power generation.

Further, the fund required from government, to implement the targeted capacities, would depend on whether small-capacity biomethanation plants are commissioned (in this case, there would be no implications on government) or high-capacity biomethanation or RDF plants are being commissioned (in this case, there would arise financial implications for the government).

6 Conclusions

The financial viability-gap assessment shows that among the selected waste-to-energy options (biomethanation and RDF-based projects), the projects with capacities—3, 5 and 10 MW were considered for biomethanation route and single project with capacity 6.5 MW was considered for RDF-based option. The viability-gap analysis shows that there exists a funding gap of Rs. 0.24, Rs. 0.82 and Rs. 1.51 per kWh, respectively, for the three biomethanation options and gap of Rs. 2.35 per kWh for RDF-based option. The funding gap to some extent can be met by availing certified emission reductions but would require more support in terms of subsidies for these projects to be financially viable in Indian context.

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