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POSSIBILITIES FOR ENERGY EXPLOITATION OF LANDFILL GAS FROM OLD MUNICIPAL SOLID WASTE LANDFILLS IN SLOVENIA

MOŽNOSTI ENERGETSKEGA IZKORIŠČANJA DEPONIJSKEGA PLINA IZ STARIH ODLAGALIŠČ KOMUNALNIH ODPADKOV V SLOVENIJI

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Keywords: greenhouse gas emissions, landfill gas (LFG), landfill gas power plant, municipal solid waste landfill (MSW), non-dangerous waste

Abstract

In Slovenia, landfill gas is presently exploited at only fifth municipal solid waste (MSW) landfills. Practice has shown that the installation of facilities for the exploitation of landfill gas for producing electrical energy is cost-efficient only at those landfills that collect over 60,000 tons or m^3 of waste annually. A quick calculation for Slovenia shows that the use of landfill gas in gas-operated generators could be done at 17, not merely 10 MSW landfills (and it is presently done at only 4). In this way, Slovenia could quickly achieve the prescribed 21% of electrical energy from renewable energy sources by the year 2020 (which presently ranges between 18% and 19%). Although there is a possibility of cost-efficient exploitation of landfill gas even at smaller MSW landfills, which receive from 20,000 to 60,000 tons of municipal solid waste per year, in the case of smaller gas-operated generators (143 kWe) that require more demanding maintenance and the need to construct an additional system for active landfill degassing, such investments may be at the limit of profitability. This paper presents potentially generated

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quantities of landfill gas and assesses the possibilities for energy exploitation of landfill gas from the already closed old non-hazardous waste deposits at Leskovec and Bukovzlak, using the LandGEM software package.

Povzetek

V Sloveniji se deponijski plin danes izkorišča na štirih lokacijah odlagališč nenevarnih odpadkov. V Sloveniji bi lahko izkoriščanje deponijskega plina v plinskih agregatih v Sloveniji potekalo kar na 17, namesto na samo 10 odlagališčih komunalnih odpadkov (danes poteka samo na 5 odlagališčih). To bi lahko Slovenija hitreje dosegla zahtevan cilj glede doseganja 21 % deleža pridobljene električne energije iz obnovljivih virov do leta 2020 (danes med 18 in 19 %). V praksi je uveljavljeno pravilo, da je postavitev objektov za energijsko izrabo deponijskega plina ekonomsko upravičena le na odlagališčih, ki sprejmejo več kot 60.000 t oz. m^3 odpadkov letno. Kljub temu, da obstaja možnost ekonomske upravičenosti izrabe deponijskega plina tudi v primeru manjših odlagališč z 20.000 do 60.000 t/leto odloženih količin komunalnih odpadkov, je lahko investicija v primeru zahtevnejšega vzdrževanje manjšega plinskega agregata (143 kWe) in potrebne dodatne izgradnje sistema aktivnega odplinjevanja lahko na meji rentabilnosti. V članku je podana ocena in možnosti energetskega izkoriščanja deponijskega plina iz danes že zaprtega starega odlagališča nenevarnih odpadkov Leskovec in starega odlagališča nenevarnih odpadkov Bukovžlak s programskim paketom LandGEM.

1 INTRODUCTION

Due to the negative effect of landfill gas on the atmosphere and ground water, its use for the purpose of power supply is increasingly important and also cost-efficient. This is evident from many examples of its use in EU member states and throughout the world, [1].

In accordance with Directive 2001/77/EU, by the year 2010, all EU member states were required to cover about 12% of their power supply needs from renewable energy sources, including landfill gas. In Slovenia, this goal was not achieved and, based on the current trends, this value is between 18% and 19%. The EU supports all systems for using renewable energy sources through tax relief, green certificates and specific tariffs for electrical energy production; it also encourages and stimulates investments into such programs [2].

The exploitation of landfill gas at closed and new MSW landfills requires the construction of systems for collecting landfill gas and the prompt shielding of waste with appropriate coverage or by installing a suitable covering layer. Practice has shown that the installation of facilities for the exploitation of landfill gas for power supply purposes is cost-efficient only at landfills that are able to collect over 60,000 m^3 of waste annually.

2 MUNICIPAL WASTE MANAGEMENT IN SLOVENIA

The first strategic orientations for waste management in Slovenia, which are an integral part of the National Environmental Protection Program, were prepared in 1996. The current situation and problems in the field of waste management in Slovenia also include the general method of removing waste from its place of origin and its subsequent deposition at more-or-less controlled landfills. The operative waste disposal program, with the goal of reducing the

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quantities of deposited biodegradable waste, which was initially prepared for the period from 2004 to the end of 2008 and was supplemented in March of 2008, is an important strategic document and will remain in force until the end of 2013. In Slovenia, about 912,981 tons of waste were deposited at municipal waste landfills in 2009; i.e. 449 kg of municipal waste were created per capita per year (1.23 kg per capita per day); this is about 13% below the EU-27 average. Municipal solid waste comprises about 35% to 40% of organic waste, and according to some data the quantity of all biodegradable waste is up to 60%. Based on European requirements, the amount of municipal waste deposited at Slovene MSW landfills should have been reduced by 20% by the year 2010 compared to the year 2000, but this goal was not attained.

Table 1: *Quantities of municipal solid waste produced in Slovenia and the EU (kg per capita), source:EUROSTAT (http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do;jsessionid=9ea7d07e30d77f896c3db973483d8c3b9940ce3d128a.e34MbxeSahmMa40LbNiMbxaMbNaMe0 (retrieved 24.04.2013))*

Year/Amount	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
EU-27 (kg/capita)	526	514	513	515	521	522	519	509	507	503
Slovenia (kg/capita)	407	418	485	494	516	525	542	524	490	411
Slovenia (kg/capita)*	411	402	417	422	430	437	453	449	422	352
Slovenia (1000 t/year)	812	834	969	989	1,036	1,060	1,095	1,069	1,004	844

* source: SURS (http://www.stat.si/eng/novica_prikazi.aspx?id=4244)

In 2009, there were 61 waste landfills in Slovenia, including 14 industrial waste landfills, 47 MSW landfills and one hazardous waste landfill. The regional concept of waste management dictates that from 15 July 2009 onward, within the framework of the prescribed 15 waste regional centres, only those Slovene landfills are allowed to operate that have acquired a specific permit in accordance with the EU Directive on Integrated Pollution Prevention and Control (IPPC). With the environmental protection permit issued by the Slovenian Environmental Agency (ARSO/SEA), there are presently six MSW landfills in Slovenia (Figure 1), but a total of 21 MSW landfills are currently still in operation without this permit and will have to cease operations soon or their managers risk a fine of €10,000. The Environmental Inspectorate may also repeat this sanction until landfill managers obtain the said environmental protection permit.

Figure 1: *MSW landfills in Slovenia with monthly deposited quantities of municipal solid waste (MSW) in tons, source: Delo, April 2012.*

At the 27 current MSW landfills that are still in operation, less than 20,000 tons of municipal solid waste are deposited annually; at 10 there are between 20,000 and 60,000 tons of deposited municipal solid waste, and at a further 10 (including all four landfills already possessing the environmental protection permit) there are over 60,000 tons of deposited municipal solid waste (Figure 1) from which the exploitation of landfill gas using gas-operated generators would be possible.

For biodegradable waste, the Decree on the Landfill of MSW (Official Gazette, No. 32/06) lays down the permitted quantity of biodegradable components in MSW that may be landfilled within Slovenia (Table 2).

Table 2: *The quantity of biodegradable components in municipal waste that may be disposed annually at all MSW landfills in Slovenia, source: Official Gazette, No 32/06)*

Period	Reduced annual quantities of disposed biodegradable MSW, expressed through reduction of the % of biodegradable waste in MSW generated in 1995	Annual quantity of disposed biodegradable substances in MSW, expressed as a % of the mass of MSW generated in 1995	Annual quantity of biodegradable components in disposed MSW
	(%)	(%)	(in 1.000 t)
Base year 1995		63	445

2001	5	60	423
2002	5	57	401
2003	5	54	378
2004	5	50	356
2005	5	47	334
2006	5	44	312
2007	10	38	267
2008	10	32	223
2012	5	28	200
2016	5	25	178

3 EXPLOITATION OF LANDFILL GAS IN SLOVENIA

Landfill gas exploitation becomes possible when the percentage of methane exceeds 35 vol.%. The exploitation of the energy value of landfill gas is possible through its incineration for various heating processes (e.g. steam or hot water production) and this is the most favourable approach from the thermodynamic standpoint. If there are no appropriate thermal energy consumers in the vicinity of the landfill site (1 to 2 km), it makes sense to exploit landfill gas to produce electrical energy with gas-operated generators. However, for energy exploitation of landfill gas to be possible, the percentage of methane should be at least 40 vol.%. The calorific value of landfill gas containing 50% of methane is about 18.8 MJ/Nm^3 = 5.2 kWh/ Nm^3 and the calorific value of natural gas is 38.4 MJ/Nm^3. At landfill gas powers of over 1,000 kW, the use of gas-operated generators (turbogenerators) having a thermodynamic coefficient of 28% efficiency is sensible, while that of gas engines is only around 25%. The actual coefficient of efficiency of a gas engine depends primarily on its load and it decreases with a reduction in the gas-operated generator load.

In Slovenia, landfill gas is exploited at five non-hazardous waste landfills (Table 3), specifically at small gas-operated power plants of Barje, Pobrežje, Dogoše, Bukovžlak and Tenetiše.

Table 3: *Power of generators for the exploitation of landfill gas at Slovene landfills.*

Landfill	Aggregate power installed	Rated electric power*	The annual production of electricity
Barje	(1996) 2 × 625 kWe (2007) 2 × 1,063 kWe 1 × 867 kWe 4,243 kWe	2,702 kWe	6,595 MWh (1996) 1.8 MW heat power
Pobrežje	(2001) 630 kWe	625 kWe	4,665 MWh (2004) 4,500 MWh (2005)

			5,000 MWh (2008) 2,000 MWh (2010)
Dogoše	(2012) 330 kWe	330 kWe	2,500 MWh (2012)
Bukovžlak	(2002) 625 kWe (2007) 1,063 kWe 1,688 kWe	1,669 kWe	8,400 MWh
Tenetiše	(2010) 469 kWe	469 kWe	Np
Total	7,360 kWe	5,795 kWe	

* Source: Energy Agency of the Republic of Slovenia (www.agen-rs.si) [5].

In Slovenia, the most widely used gas-operated generators are those manufactured by Jenbacher, having nominal powers of 625 kWe, 836 kWe and 1,048 kWe, but Jenbacher generally manufactures gas-operated generators having the following nominal powers: 143 kWe, 330 kWe (Figure 2), 511 kWe, 625 kWe, 836 kWe, 1,048 kWe, 1,413 kWe and 1,698 kWe.

Figure 2: *Small gas-operated power plants at the MSW landfill Dogoše [4].*

The maximum number of operating hours of a gas engine is about 90,000 hours, i.e. operating about 10 years at an 88% working efficiency.

Based on data about annually collected quantities of landfill gas estimated using a different mathematical models, it is possible to select the necessary power and number of gas-operated engines to attain their maximum load (i.e. maximum landfill gas flow).

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4 MODELS FOR CALCULATING LANDFILL GAS QUANTITIES

Gas emissions (primarily those of CH_4 and CO_2) from landfill gas to air can be estimated using numerous mathematical models and software packages. In the EU, the following are the most widely used:

- German EPER method,
- Landfill Emission Model (LandGEM).

The German EPER method is based on the TIER-1 IPPC proposal. Depending on the degradability of waste, the annual quantities of methane and carbon dioxide emissions from landfills (controlled, uncontrolled, and with or without controlled degassing) can be calculated from the mass of deposited waste per year using the following equation

$$S_{P,Y} = Q_Y \cdot DOC \cdot DOCF \cdot F \cdot k \cdot A \cdot e^{-k \cdot \Delta t} \tag{4.1}$$

where $S_{P,Y}$ is the annual methane emissions in the year P [kg]; Q_Y is the total amount of waste deposited in the year Y (kg); *DOC* is the percentage of degradable organic carbon in the waste (%); *DOCF* is the percentage of organic carbon in the waste that is converted to landfill gas (%); *F* is the percentage of methane in landfill gas (%); *k* is the annual rate of waste degradation ( ); *A* normalization constant calculated on the basis of time in which all biodegradable waste components are degraded (for degradation in 50 years at k = 0.05, A = 1.3); the percentage of uncollected or biologically oxidized methane CH_4 also depends on the landfill type (covered, uncovered), efficiency of degassing, etc., ( ); and Δt is the time from deposition of waste in year Y until degradation in year P (year).

The greatest shortcoming of the EPER method lies in the fact that it yields precise results only when the quantity of waste deposited at a landfill remains unchanged from year to year. The selection of appropriate parameters is also problematic. This especially refers to constant A, which primarily depends on the efficiency of degassing, the gas-permeable and sealing layers, vegetation, waste compression, etc. Its value can range from 0.1 to 1.

The Landfill Gas Emission Model (LandGEM) is a software package developed by the Control Technology Center (CTC) of the U.S. Environmental Protection Agency (EPA), [3]. Its calculations are based on data about the annual quantities of deposited waste and various parameter settings (CH_4 and CO_2 content in landfill gas, degradation constant, amount of CH_4 generated from the degradation of 1 ton of waste, landfill type, planned year of landfill closure, etc.). The mathematical model of the LandGEM software package uses the following equation for the first phase of degradation of organic substances in the waste.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0,1}^{1} k \cdot L_0 \cdot \left(\frac{M_i}{10} \right) \cdot e^{-k \cdot t_{ij}} \tag{4.2}$$

where Q_{CH4} is the methane generation in time t [m^3/year]; *i* is the one year − time of increase (year); *n* is the year of calculation ( ); *j* is the 0.1 year − time of increase (year); *k* is the methane generation rate constant ($year^{-1}$); L_0 is the potential methane generation capacity (m^3/t); M_i is the mass of waste received in year i (t); and t_{ij} is the year of j-th part of mass of waste M_i received in i-th year (decimal years, e.g.: 3.2 year) (t)

LandGEM uses the following basic parameters:

- Specific data for the particular landfill,
- The CAA's set of assumed values as determined by the Clean Air Act (CAA),
- The AP−42 set of assumed values for average quantities of generated gas at US landfills issued by the U.S. Environmental Protection Agency in its publication 'Compilation of Air Pollutant Emission Factors Ap-42'.

LandGEM enables the use of various annual quantities of waste deposited during landfill operation, the estimation of the emissions of generated landfill gases, such as methane and carbon dioxide as well as various non-methane organic compounds, the calculation of the total quantity of landfill gas emissions, and the prediction of emitted quantities of waste substances several years in advance. The possibility of using different annual quantities of deposited waste throughout the period of landfill operation and setting different parameters of waste degradation enables the calculation of numerous data on generated landfill gases and thus promotes its widespread use.

5 EXAMPLES OF POSSIBLE EXPLOITATION OF LANDFILL GASS

The calculation of potential landfill gas quantities was done using the LandGEM software package. It was performed for two old, already closed MSW landfills at Leskovec and Bukovzlak. Figure 3 shows the trend of waste deposition for the Leskovec MSW from 1992 to 2007. During the period of its operation, about 23,381 tons of waste on average were deposited at the landfill each year. Since 2007, no waste has been deposited and the landfill is now closed.

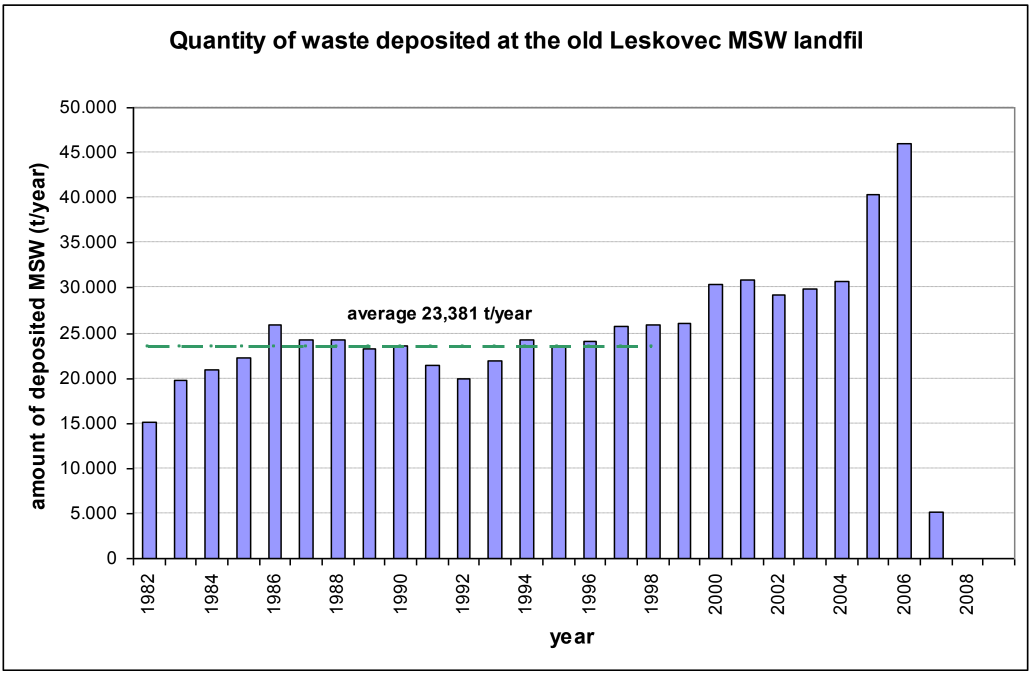

Figure 3: *Quantity of waste deposited at the old MSW landfill Leskovec per years [2].*

Based on the available quantity of methane in landfill gas, Figure 4 speaks in favour of the use of a gas-operated 143 kWe generator from 1996 to 2025. During this period and based on the 10-year anticipated life of a gas-operated generator, three gas-operated generators would probably be used over various time periods, generating a total of 37,380 MWh of electrical energy. An approximate calculation of the costs for the purchase and maintenance of a gas-operated generator and the potential revenue created with the sale of so-called 'green electricity' thus yields a profit of about EUR 2.5 million.

The calculation of the quantity of generated landfill gas at the old Leskovec MSW landfill is additionally confirmed by data obtained by measuring the actual quantities of generated landfill gas at the old Bukovžlak MSW landfill (Figure 5) for a comparable deposited waste quantity (on average 26,036 tons per year from 1972 to 2000).

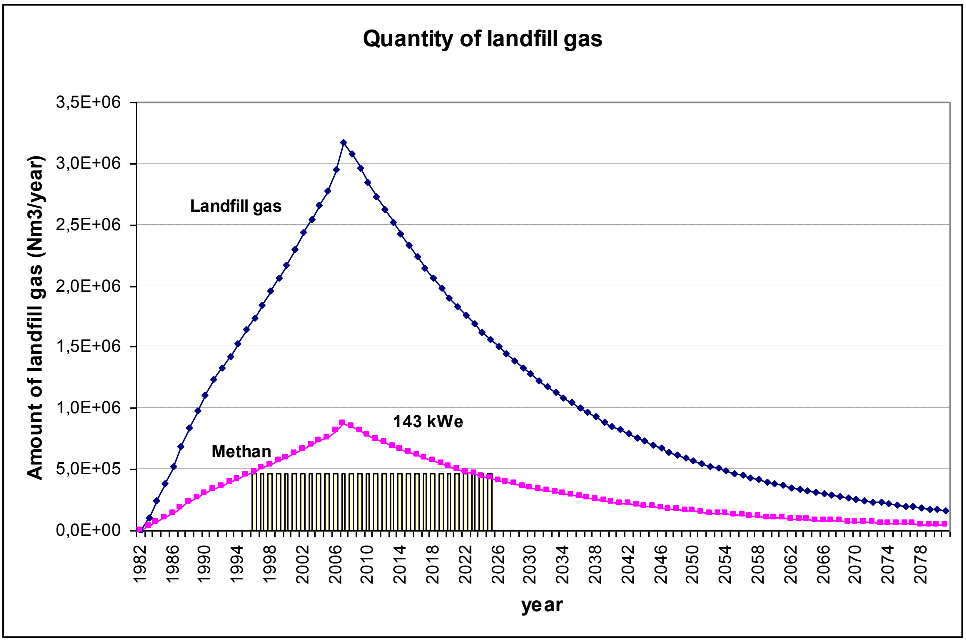

Figure 4: *Calculated quantity of landfill gas and exploitable percentage of methane (taking into account a 50% loss) at the old Leskovec MSW landfill using the LandGEM software package, [2].*

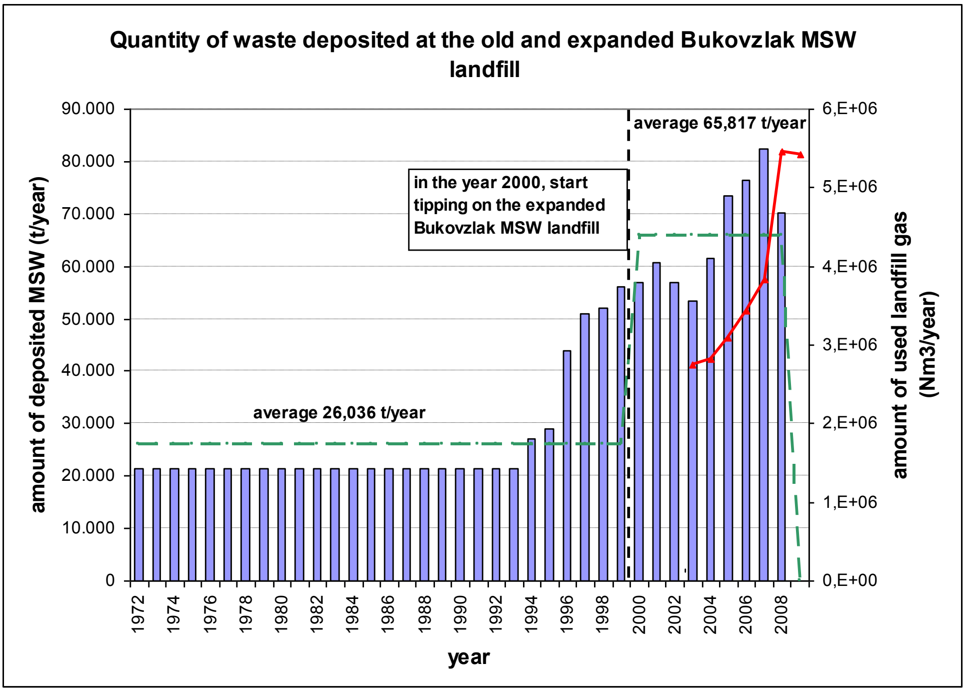

Figure 5: *Quantity of waste deposited at the old and expanded Bukovžlak MSW landfill (columns) and quantity of landfill gas used in gas-operated generators (curve) from 2003 to 2009.*

6 CONCLUSIONS

To achieve an effective turbogenerator power of 143 kWe (taking into account a 25% thermodynamic efficiency in the production of electrical energy) for delivering electrical energy to the power supply network, the landfill gas power at turbogenerator inlet should be about 572 kW (1 kWh = 3,600 kJ). At a thermal value of landfill gas of LHV_{LFG} = 18,000 kJ/Nm^3 or 18.000 kJ/Nm^3/3,600 kJ/kWh = 5 kWh/Nm^3 572 kW/5 kWh/Nm^3 = 114.4 Nm^3/h of landfill gas would be needed at the generator inlet. If the calculation is done on the basis of an established situation at a waste landfill aged 10 years at a minimum, then for assuring effective generator power of 143 kW the annual input of waste at an average TOC content should be at least 20%.

An approximate calculation made with the use of the LandGEM software package can assist in strategic planning and in the search for possibilities for the exploitation of landfill gas energy. A quick calculation for Slovenia shows that the use of landfill gas in gas-operated generators could be done at 17 and not only 10 MSW landfills (and it is presently done at only four). In this way, Slovenia could quickly achieve the prescribed 21% of electrical energy from renewable energy sources by the year 2020 (which presently ranges between 18% and 19%). Although there is a possibility of cost-efficient exploitation of landfill gas even at smaller MSW landfills that receive from 20,000 to 60,000 tons of municipal solid waste per year, in the case of smaller gas-operated generators (143 kWe) that require more demanding maintenance and the need to construct an additional system for active landfill degassing, such investments may be at the limit

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of profitability. This is because in addition to having a gas-operated generator for electrical energy production, it would also be necessary to ensure the pumping and incineration of landfill gas for the case of gas engine failure, other failures or occasional excess landfill gas emissions.

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