THE USE OF LANDFILL BIOGAS AS A RENEWABLE FUEL FOR TRUCK FLEET

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ABSTRACT

Solid waste management contributes significantly to greenhouse gas (GHG) emissions due to uncontrolled biogas in landfills and the use of fossil fuels in collection and compaction trucks. This study evaluates the feasibility of using biogas generated in landfills as a renewable fuel for these trucks, considering its high calorific value and its potential to reduce both fuel costs and environmental impacts. A qualitative analysis of the benefits and a quantitative evaluation of the potential for biogas production in the Jardim Gramacho landfill, in Rio de Janeiro, were carried out. The results indicate that only 5% of the biogas generated daily could supply the entire fleet of collection trucks, demonstrating the feasibility of this approach.

Keywords: Biofuel. Biogas. Urban solid waste. Resource recovery.

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INTRODUCTION

According to the United Nations (1), the world population will increase from 7 billion to 9 billion by 2050, and in the same period the population residing in cities will jump from the current 3.5 billion to almost 6.3 billion. The Brazilian population has increased by 12% in the last ten years and the production of waste, in the same period, by 90%. In large centers, the increase in waste generation is much higher than the population growth; Thousands of tons of garbage are dumped daily in dumps or sanitary landfills, requiring larger and proportional investments (2).

Municipal solid waste (MSW) typically includes food and kitchen waste from homes and restaurants, waste from food processing plants, and biodegradable waste from gardens and parks (3). Among the possibilities of final disposal of MSW, the use of sanitary landfills is one of the most economical alternatives, being the most used form of treatment in Brazil due to the lower operating costs, the ease of execution and the great capacity of waste absorption, when compared to other forms of final disposal (or treatment). such as incineration, composting and recycling (4).

In Brazil, MSW disposed of in landfills contain an estimated 51.4% of organic matter (5) that is degraded by the action of microorganisms, transforming it into a gas known as biogas. In most Brazilian landfills, the biogas generated has a concentration of 30% of CO_2 (Carbon Dioxide) and 50-55% of CH_4 (Methane), a gas with high calorific value and can be used as a renewable source of energy. Biogas can be purified to biomethane and used for different applications, including electricity generation and as vehicle fuel (CNG) (6).

There is a great interest in the use of biomethane in the transport sector, due to the potential benefits related to the diversification of the supply of transport fuels and the reduction of greenhouse gas (GHG) emissions and other pollutants in the atmosphere (7).

OBJECTIVE AND METHODOLOGY

The objective of this article is to evaluate the feasibility of adopting biogas generated in landfills as a renewable fuel for the fleet of compactor trucks that collect urban waste, listing the main advantages of this substitution in terms of the reduction in pollutant gas emissions resulting both from the collection and decomposition of urban solid waste in landfills.

To obtain the results that enabled the analyses and propositions, an exploratory analytical method was used based on the review of the bibliography, obtaining data and information, available in the city hall and in sources referenced on the Internet, where the variables of the analyzed system were defined and qualified, followed by the application of the quantitative method where the results were obtained that enabled the indication of the actions and the potential for future research.

URBAN CLEANING: CLASSIFICATION, COSTS AND TRANSPORT OF MW

MSU COLLECTION AND TRANSPORTATION

Waste collection services can be classified as regular, special or private. Regular services are those performed at certain regular intervals, and should not exceed one week, in order to avoid proliferation of vectors (8). The special modality serves waste not included in the regular collection, such as debris from small generators, dead animals and garden pruning. Private collection is usually conditioned to the type of waste or the amount generated, and it is the responsibility of the generator to provide for its forwarding. Large generators such as supermarkets, construction companies and contractors, as well as hospitals, outpatient clinics, health centers and pharmacies exemplify private collection services.

Collection requires the use of vehicles and a set of employees, respecting existing restrictions and must be done while reducing costs. Fuel consumption is the portion with the greatest weight in the operational cost of collection, varying mainly as a function of the vehicle's travel speed (collection speed, urban and highway traffic) and its load (full, empty and loading) (7).

The costs of urban cleaning are divided between collection, sweeping, treatment and final disposal of USW. In many Brazilian cities, solid waste collection consumes a very significant percentage of the municipal budget (4). In a 1996 study, Bhat estimates that the costs related exclusively to the stages of collection and transportation of solid waste are responsible for 75 to 80% of the budget made available for waste management (9).

LANDFILLS: DEFINITIONS AND CHARACTERISTICS

The Sanitary Landfill has the function of providing the proper destination of waste not used for recycling, resulting from the improvement of old grounding techniques (10) being executed from the compaction of interspersed layers of waste and soils. However, growing urbanization limits the areas available for the final disposal of waste in such a way that large cities are often forced to export waste to areas of neighboring municipalities (6), further increasing transportation costs and associated gas emissions.

A sanitary landfill must operate in such a way as to provide protection to the environment, avoiding the contamination of groundwater by leachate, and the accumulation of biogas resulting from the anaerobic decomposition of garbage inside the landfill, which can come out of the landfill uncontrollably in a way that can cause explosions (6).

In order to mitigate these problems, gas drain systems are implemented, consisting of a network of branched and connected pipes, a main line that leads the biogas to the burning or energy reuse systems. The biogas is burned at high temperatures (around 1000ºC) so that the total destruction of the methane molecules occurs (7).

A solid waste landfill can be considered as a large biological reactor, rather than functioning only as a disposal site, where the main inputs are waste and water and the main outputs are gases and leachate (11).

GAS EMISSIONS

AIR POLLUTION ASSOCIATED WITH MW TRANSPORT

The sectors that emit the most GHG in the State of Rio de Janeiro are transportation and waste, with road transport accounting for 80% of this total (4,391 GgCO2), subdivided between light vehicles (68%) and heavy vehicles (32%) (7).

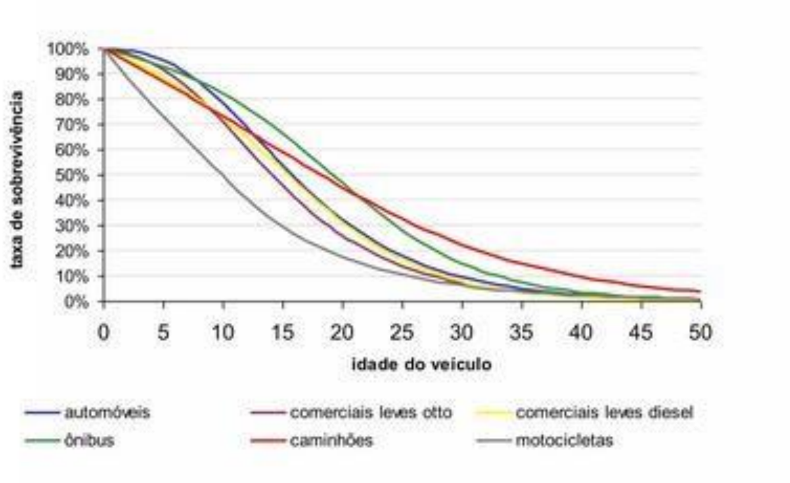
A study carried out with 15.7 thousand vehicles throughout Brazil found that the transport of waste is the one that emits the most carbon dioxide per kilometer driven. According to the survey carried out by the company Ecofrotas, garbage collection trucks emit about 1.24 kg of CO2 per kilometer driven. In second place are those used in the chemical sector, which emit an average of 1.11 kg of the gas per km, and in third place the heavy agricultural machinery with 1.02 kg of CO2 per km (12).

The high CO2 emission of garbage trucks is more related to the characteristic of the operation and use of diesel than to the maintenance management of the vehicles. According to Meyer (13), traffic characteristics influence emissions mainly with regard to the vehicle's mode of operation, as emissions are usually higher in slow and congested traffic and lower at intermediate speeds. Thus, the intermittent displacement of collection trucks, imposed by the need to collect waste at various points, ends up generating high consumption (12).

LIFE CYCLE OF A HEAVY TRUCK

In Brazil, the truck fleet is mostly made up of heavy vehicles powered by highly polluting fossil fuels. As can be seen in figure 1, the average age of trucks in Brazil is approximately 20 years. Regarding garbage collection, there are still several municipalities with fleets of trucks, some with 15 years of use or more, which consume more fuels and generate a greater volume of pollution than the current models.

Figure 1 - Vehicle scrapping curve in Brazil.



Source: MMA (2009).

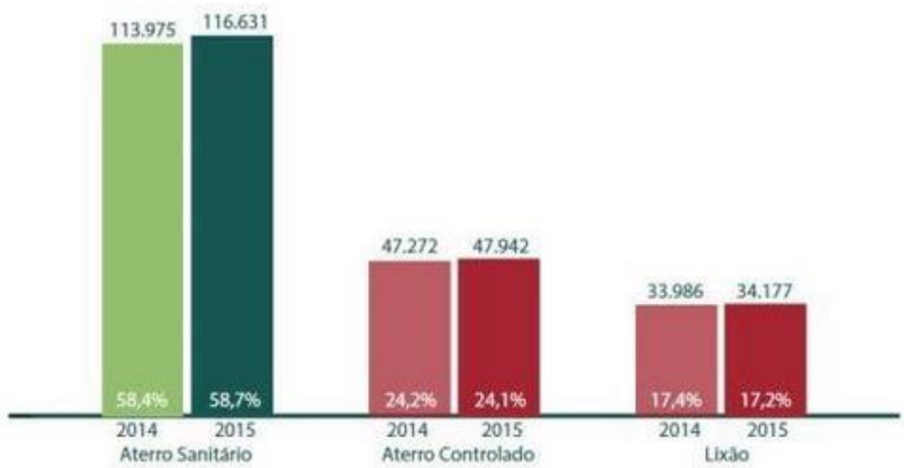
ISSUANCE DUE TO DISPOSITION

In addition to the pollution emitted by MSW transports, estimates of global methane emissions from landfills reach 70 Tg/year, while the total estimated emissions from anthropogenic sources are equivalent to 360 Tg/year (21), indicating that landfills may produce about 20% of the total methane. It is worth mentioning that when considering a period of 100 years, 1 gram of Methane contributes 21 times more to the formation of the greenhouse effect than 1 gram of Carbon Dioxide (14).

DISPOSAL OF MSW WITHOUT ADEQUATE PREPARATION

According to data from Abrelpe (15), and presented in figure 2, it can be seen that open-air dumps, controlled landfills and sanitary landfills are still significant forms of waste disposal in the ground in Brazil.

Figure 2 - Final disposal of USW in Brazil by type of destination (t/day).



Cast Iron: Abrelpe (2015).

Most landfills use the open drain system, where there is a flame to burn the naturally drained biogas.

This system has a low efficiency and it is estimated that only 20% of the drained biogas is actually burned (7).

RENEWABLE ENERGY: LANDFILL BIOGAS AND ITS USE

According to Borba (16), the potential for methane generation depends solely on the type of waste and varies between 5 and 310m³. CH4/three (cubic metre of methane per tonne of waste), varying as a function of moisture, nutrient availability, pH and temperature (7).

The biogas originating in landfills has its composition listed in table 1, below:

Table 1: Composition of Landfill Biogas.

Composition	Percentage
Methane	45 - 60
Carbon Dioxide	40 - 60
Nitrogen	2-5
Sulphur	0,1 – 1,0
Ammonia	0 – 0,1
Hydrogen	0 – 0,2
Carbon Monoxide	0 – 0,2
Other	0,01 – 0,6

Source: Borba (2006).

Biogas can be used as natural gas, however for vehicular use there is a need to remove some of its components, such as hydrogen sulfide gas (H2S), carbon dioxide (CO2), as well as moisture and any particulates. According to the ANP (17), through Resolution No. 8, of January 30, 2015, establishes the minimum percentage of methane in natural gas for vehicular use should be 90% and maximum CO2 of 3%.

The Deganutti Study (18) establishes a comparative equivalence relationship of 1m³ of biogas with the usual fuels:

- 0.61 litres of petrol
- 0.55 liters of diesel oil
- 0.45 kg of liquefied gas
- 0.79 litres of fuel alcohol
- 1,428 kWh of electricity

COMPARISON OF EMISSIONS BETWEEN HEAVY-DUTY VEHICLES POWERED BY DIESEL, DIESEL-GAS AND CNG

One of the best possibilities for using biogas is with the conversion of older collection trucks to transit through diesel-gas technology, based on the use of the original diesel cycle engine and the combined burning of natural gas with diesel oil. This process is implemented by installing an original engine retrofit kit without structural modifications, maintaining a more efficient operating cycle (19).

Emissions of vehicular origin are the result of the burning of fuel with carbon dioxide (CO2), carbon monoxide (CO), hydrocarbons (HC), sulfur dioxide (SO2), nitrogen oxides (NOx) and particulate matter as primary pollutants. The evaluation of the levels of pollutant emissions from diesel, compressed natural gas (CNG) and CNG-diesel engines found a significant difference in the quantities emitted.

Table 2 shows that diesel had the highest levels of overall emissions in the comparison between the three types of engines tested (7).

Table 2: GHG emissions by heavy-duty vehicles and by fuel.

	MP g/km	NOX g/km	HC g/km	CO g/km
Diesel	1,15	14,60	1,35	10,35
GNC- Diesel	0,19	9,47	6,10	2,65
GNC	0,01	10,13	8,35	1,55

Source: Comlurb Rio de Janeiro, RJ, 2014.

According to Araújo (7), the main advantages of using CNG/CNG are:

- The world average indicates that CNG consumption is 66% cheaper than gasoline and 33% more economical than diesel.
- CNG/CNG engines produce 25% less carbon dioxide than those powered by gasoline and 35% less than those using diesel.
- CNG/CNG does not contain sulfur (there are diesel engines in which 18.4g/particles, lead or traces of heavy metals are released).
- Natural gas is non-toxic or corrosive and does not contaminate groundwater.
- The burning of the mixture between CNG/CNG and air is perfect at any ambient temperature, generating a residue-free combustion, favoring the maintenance of the cleanliness of the spark plugs and engine cylinders, which results in better and more effective lubrication.
- The vehicle can become bi-fuel. Converting to CNG does not eliminate the possibility of using the original fuel.

THE BIOGAS SUPPLY CAPACITY IN RELATION TO THE NUMBER OF TRUCKS SERVED

Once the qualitative benefits of the use of landfill biogas have been presented, a quantitative evaluation of the potential for biogas generation in the Jardim Gramacho landfill is presented below in view of the demand for fuel from the fleet of collection trucks and transporters of the Municipal Company of Urban Cleaning of Rio de Janeiro.

LANDFILL JARDIM GRAMACHO, RIO DE JANEIRO, RJ

The Jardim Gramacho landfill operated for 34 years, from 1978 until June 3, 2012, during which time it was the largest landfill in Latin America and the main one in the metropolitan area of Rio de Janeiro, accumulating 80 million tons of garbage. (20). Thus, it has a production of 480,000 m³ of biogas per day with a content of 50% methane and a calorific value of approximately 5,000 kcal/Nm³ (7).

To carry out the cleaning in the municipality of Rio de Janeiro, the company has a fleet of 296 compactor collection trucks.

The amount of waste collected in December 2014 was 184,500 tons and the average mileage traveled by each vehicle was 4,160 km, presenting an average variation of 15% of the total traveled.

The average consumption of the vehicles was 1.9 km/liter (7).

Table 3 summarizes the input data of the collection of MSW by diesel-powered vehicles.

Table 3: Input parameter of the collection.

Número de caminhões	296
Consumo médio	1,9 km/L
Distância média por turno de 8h	80 km
Capacidade de combustível	126 m³
Produção diária de biogás no aterro	480.000 m³
Poder Calorífico do metano puro	9274 kcal/Nm³
Poder Calorífico do biogás de aterro	5000 kcal/Nm³

Source: Comlurb Rio de Janeiro, RJ, 2014.

CNG PRODUCTION ESTIMATES

The daily energy availability of the landfill can be expressed by:

$$480000\ m^3 \cdot 5000\frac{kcal}{m^3} \cdot 4.1868\frac{kJ}{kcal}$$
$$= 10048320000\ kJ$$
$$= \frac{10048320000}{3600}\ kW = 2791200\ kWh$$

Where:

1kcal = 4.1868 kJ

The energy contained in 1 m³ of fuel biogas for vehicular use composed of 100% methane can be expressed as:

$$9274\ \frac{kcal}{m^3} = 9274 \cdot 4.1868\ \frac{kJ}{m^3} = \frac{9274 \cdot 4.1868}{3600}\frac{\frac{kW}{h}}{m^3} =$$
$$= 10{,}786\ kWh/m^3$$

Where:

9274 kcal/m³ = Heat power of methane

Thus, each m³ of biogas has 10.786 kWh of energy. Assuming the efficiency of the engine of the order 0.34 for conversion of combustion energy into mechanical energy, we have the following effective energy per m³:

$$0{,}34.\ 10{,}786\frac{kWh}{m^3} = 3{,}667\ \text{kWh/m}^3$$

Assuming a fleet composed of 296 vehicles and that each truck has a supply capacity of 126 m³ of gas, with 1 m³ of gas equivalent to 3.667 kWh, it is possible to evaluate the total expenditure necessary to supply the entire fleet:

$$3{,}667\frac{\text{kWh}}{\text{m}^3} \cdot 126\frac{\text{m}^3}{\textbf{vehicles}} \cdot 296\ \textbf{vehicles}$$
$$= 136763\ kWh$$

Each 8-hour shift, each truck travels about 80 km, making a total of 240 km daily. Assuming that each truck has a supply capacity of 126 m³ of gas and that the average consumption of the vehicles is 1.9 km/m³, there is a range of 239.4 km.

$$126\frac{m^3}{\text{vehicles}} \cdot 1{,}9\frac{km}{m^3} = 239{,}4\frac{km}{\text{vehicles}}$$

It is observed that the values of the autonomy and total daily traveled are practically identical, indicating that each vehicle in the fleet needs to be fueled on average once a day, making the total consumption per day 136763 kWh

Soon:

$$\frac{\text{Fleet demand of 136763 kWh}}{\text{Landfill capacity of 2791200 kWh}} = 0.05$$

The results showed that only 5% of the total gas produced daily by the Gramacho landfill would be sufficient to supply the fleet of compactor collector vehicles, with 95% still remaining to be sold.

CONCLUSIONS

The cost of public transport is underestimated, as the environmental liability resulting from pollution is disregarded. Thus, the transition from diesel or gasoline to natural gas represents a benefit, as the adaptation of engines to biogas is feasible from a mechanical point of view, generating beneficial impacts on waste operating costs by reducing fuel expenses.

If there are surpluses in the production of natural gas, it can be sold or transformed into electricity, indicating feasibility studies for the conversion of potential GHG emissions from landfills into electricity, which may generate quotas in the international carbon market.

The preliminary calculations presented indicate that biogas recovery from the Jardim Gramacho Landfill, in Rio de Janeiro, proved to have potential for the total supply of the fleet of collection trucks, and the hypothesis is possibly verifiable in other Brazilian municipalities, thus avoiding the use of fossil fuel, reducing GHG emissions.

A significant advance in research on the production of vehicular biomethane via biodigestion of municipal solid waste was presented by Romanholi (25).

The result of this research demonstrated the potential for environmental, social and governance (ESG) gains (24), made possible through the development of business models (22), which prove the viability for new investors from different sectors, for the use and commercialization of surplus energy, which can be a topic for future research.

It is concluded that it is feasible to adopt biogas generated in landfills as a renewable fuel for the fleet of compactor trucks that collect urban waste, reducing the resulting GHG emissions both due to the collection and decomposition of urban solid waste in landfills and also the generation of new business models, in compliance with the UN Sustainable Development Goals (SDGs). mainly with SDG 7 – Affordable and Clean Energy (23).

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