

Electricity Generation by Use of Urban Solid Waste

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Abstract.

This article presents a case study of the feasibility of power generation using biofuels from a landfill, with a high concentration of solid waste from the city of Criciúma, SC, Brazil. The main objective of this paper is to show the potential energy existing in landfills, even in medium-sized cities, and that the energetic use of biogas is an accessible alternative to be implemented. For this, it was analyzed two forms of energy generation from municipal solid waste. At the first case it was considered the use of biogas generated in landfills and at the second the waste incineration and for both cases it is presented a study of economic feasibility.

Key words

Biogas, Incineration, Environment, Solid Waste, Electricity Generation.

1. Introduction

Electricity is a basic input for the development of human beings, since it contributes to improving the quality of life and the social and economic growth of the people. However, the rampant use of natural resources cause harmful effects on the global climate, increasing the search for alternative sources of clean energy generation and less impact on the environment.

In this sense, the use of municipal solid waste (MSW) emerges as a promising and advantageous alternative from the standpoint of environmental and financial. The proper reuse of the "trash" improved sanitation in urban centers, decreases emissions of greenhouse gases due to its decomposition and helps reduce the consumption of fossil fuels.

Solid wastes are considered the remains of human activities. Basically consist of food scraps, papers, plastics, glass and metals, and may be deposited into the environment in several ways, such as in garbage dumps or

landfills. There are also other ways to treat and allocate these waste, such as composting, incineration and pyrolysis, however, these techniques are still little used in Brazil [1].

Currently, there is a rapid growth of the quantity of municipal waste mainly due to population growth and industrial development and a major problem is the emission of greenhouse gases, a fact that led the UN member states to sign an agreement to control of greenhouse gas protocol (Quito) [2].

In nations such as China, Japan, Germany and the United States since the eighties power plants are deployed to harness the energy potential of waste. These countries process 130 million ton of waste, generating electricity and thermal energy in 650 facilities. In Brazil there are few initiatives. The metropolitan region of São Paulo has two landfills transformed into power plants, which produce 43MW of power by burning biogas [3].

The MSW matter is a structural problem that requires great investments. In Brazil, there has always been the lack of public policies to regulate the management of MSW. However, with the growing environmental concern and the intensification of the problems caused by these residues, was recently deployed the National Policy on Solid Waste, which will provide greater oversight and a significant change with regard to waste management.

2. MSW Deposits

As already mentioned, there are several ways to dispose of municipal solid waste in nature. Everyone has a right intention, but not the ideal that would be to use the RSU in power generation, polluting the environment as little as possible.

A. Dump

The dump is an inappropriate way to dispose municipal solid waste. This process is characterized by mere disposal of garbage on the ground. In these low-hazardous wastes are deposited along with the industrial and hospital high-polluting power. The application of this method promotes the proliferation of infectious diseases, soil pollution and the emission of greenhouse gases. Moreover, cause the contamination of water resources through seepage of leachate, black liquid produced by decomposition of organic matter contained in the MSW [4].

B. Controlled Landfill

Basically, this method consists in compacting waste in the soil, arranging them in cells that are periodically covered with earth or other inert material so as to provide space for new waste [5]. This reduces the environmental impacts caused by deposits in the open, but it has no base waterproofing, systems of dispersion of generated gases or leachate treatment.

C. Sanitary Landfill

Sanitary landfill isolates any harmful action caused by MSW deposited in the environment. This method has systems to collecting and treating of leachate and draining of the gases due to decomposition of MSW. It consists of an open large trench in the ground, waterproofed due to compaction of clay and placing a mantle of high density polyethylene, where waste is deposited. However, these places emit greenhouse gases, blamed for global warming. Landfills distributed around the world produce between 20 and 60 million tonnes of methane per year, resulting from the decomposition of organic waste [6].

3. Electricity Generation

With the technological evolution that is intensifying human activities in recent decades, there is a growth in electricity consumption. The generation that was once based on the availability and economic feasibility, today is based on efficiency and in the environmental impacts [7]. In Brazil, after the electricity rationing occurred in 2001, a tendency of diversification of energy sources has begun to stimulate the energy generation from alternative sources [8]. Although there are still large potential of hydropower to be explored, factors such as the difficulty in obtaining environmental permits, concerns about the energy market and climate changes, suggest the development of alternative systems for power generation.

To supply small demands, alternative sources are viable, however, the large scale use requires high initial investments and the installation of these generation methods depends on the definition of regulatory policies that ensure incentive and government support [9]. Because of this, the Brazilian government had created the PROINFA (Incentive Program for Alternative Sources of Electric Energy) in order to increase the participation of electricity produced by these sources in the national power electric system.

A. Biomass

Biomass is one of the alternative sources for producing electricity with great growth potential in the coming years. It is conceptualized as part of biodegradable products and waste from agriculture, forests and urban and industrial activities.

There are various processes for converting these compounds into energy. The direct combustion in boilers, the gasification using thermo chemical reactions and even the anaerobic digestion are methods employed to process this energy.

B. Biogas

The process of utilization of biogas generated in landfills is the simplest to explore the energy potential of MSW for energy generation. This is an alternative that can be applied to manage and solve the problems related to greenhouse gas emissions.

The transformation of the energy potential of biogas into electricity is made from a process central station, where are the equipment of biogas capture and power generation [10]. The generation of electricity from biogas is performed using devices that convert the chemical energy, present in this gaseous fuel, into electricity. This conversion can be performed in several ways; however the technology most widely used are the gas turbines and the internal combustion engines. The Table I shows a comparison between these techniques.

Table I. – Technology for Conversion of Biogas

Equipment	Power	Yield
Internal combustion engine	30 KW – 20 MW	30% - 40%
Gas turbines (mid size)	500 KW – 150MW	20% - 30%
Micro turbines (small size)	30KW – 350KW	24 % - 28%

Internal combustion engines are most often used. The application of this system presents a good cost-effective due to its low investment cost and the ease of operation and maintenance.

Gas turbine is the second most applied technology. The use of these turbines in landfills requires large flows of gas, and is indicated mainly for projects with generation capacity of 3-4 MW [6].

Micro turbines have the same working principle of gas turbines and provide electricity generation on a small scale. The advantages of its use are the low atmospheric emissions, low levels of noise and vibration, fuel flexibility and simplicity of installation. However they require a high investment for a low efficiency [11].

C. Incineration

Power generation from waste incineration is the use of the calorific value of the materials that compose the garbage. Incineration promotes the burning of waste destroying their organic components and ensuring sanitary treatment [12]. The efficiency of this technique depends directly on the calorific power of the incinerated material and the capacity of conversion of heat into electricity.

4. Landfill Characteristics

The landfill used in this case study belongs to SANTEC (Centro de Gerenciamento de Resíduos Sólidos). This private company active in the environmental area provides services for municipal governments and industrial companies of the southern Santa Catarina state, related to techniques of management, treatment and disposal of MSW.

SANTEC has the ability to store and handle up to 2,500 tons of MSW per day and has approximately 700,000 tons of waste from companies, commerce, residences and establishments of health services. By day, they are received 500 tons of MSW, which generate approximately 450m³/hr of methane, which is drained, burnt and converted into carbon dioxide and water [13].

5. Power Generation Using Biogas

A. Determination of the Biogas Volume

Primarily it's necessary to project the volume of available landfill biogas. In SANTEC, an analysis conducted recently by the Federal University of Santa Catarina indicated an estimated production of 20,000 m³/day of biogas, a value consistent with the study by ECOINVESTCARBON [14], who estimated the gas generation curve shown in Figure 1.

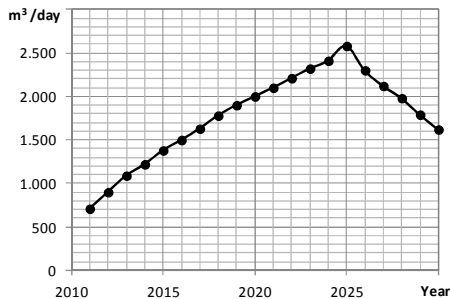


Fig. 1. Biogas Generation Curve [14]

This study was based on the current conditions of the landfill and on the already estimated biogas generation curve. Note that the quantity of gas available to generate energy varies over time and exponentially decreases after the deposition of waste on the site to be interrupted. The maximum quantity of biogas captured must be equal to 80% of the calculated value. This is because due to the constant operation of the landfill, not all drains are connected to the suction system, thereby enabling that a fraction of biogas escapes through landfill surface [10].

Thus, by using the biogas generation curve and capture coefficient, it is possible to estimate the quantity of biogas generated and captured in the landfill SANTEC for a period of 20 years, as shown in Figure 2.

B. Determination of Generation Capability

To verify the electricity generation capability, it was used a calculation model developed by ICLEI (International Council for Local Environmental Initiatives), which

determines the maximum power available per year using the following equation: [15]

$$P(x) = \frac{Q(x) \cdot PCI \cdot \eta}{860000} \quad [\text{MW/year}] \quad (1)$$

Where:

Q [m³/year]: quantity of methane captured by the Project;
 PCI [Kcal/m³]: inferior calorific value of methane;
 η [%]: efficiency of the conversion device.

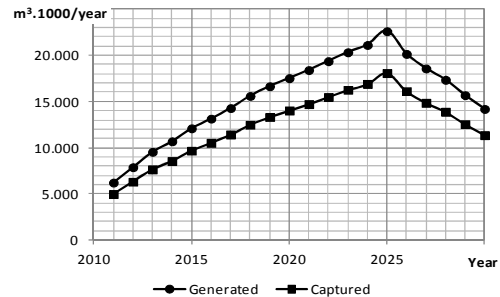


Fig. 2. SANTEC Biogas

According to SANTEC data (2011), the volume of biogas generated in the landfill has 55% of methane and its calorific value is close to 8500 Kcal/m³. For the conversion of the gas, the internal combustion engines were considered, with a yield of 30%.

From this power value, it is possible to estimate the effective generated energy using the following equation:

$$E(x) = \frac{P(x) \cdot \eta}{8760} \quad [\text{MWh}] \quad (2)$$

Where:

P [MW/year]: maximum power generated;
 η [%]: Yield factor of the motor/generator set.

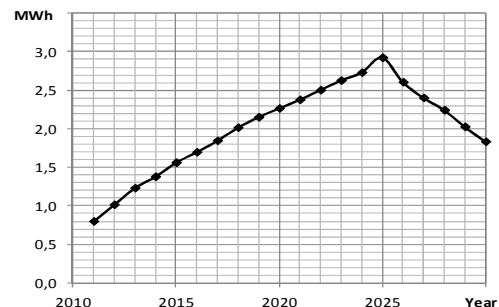


Fig. 3. Energy Production Capacity of the SANTEC Landfill

In this case, the yield factor of 87% is suggested. Figure 3 shows a graph of total energy that can be generated at the site [15].

C. Technical and Economic Feasibility

The energetic use of biogas from solid waste can generate various financial benefits to the landfill. Part of the energy generated can be consumed by its own production facilities and the excess can be sold. This activity also provides obtaining additional revenue from

carbon credits because it reduces methane emissions and contributes to the mitigation of global warming.

For the analysis of investment required it was decided to use a plant to generate electricity with a capacity of 1MW, as this is the lowest power which may be generated from 2012 onwards. With the power of electricity generation it is possible to estimate the investment required for the generation facilities using equation 3.

$$I = 0,080320498 + 0,9616P \text{ [Million US\$]} \quad (3)$$

Where:

P [MW]: power of the generating equipment.

This formula was determined by statistical inference software, which uses World Bank data from feasibility studies and energy production in sanitary landfills and the result represents about 40% to 60% of the total cost installation. The remaining costs are for installation of the capture, treatment and burning of biogas, in order to ensure the continuous reduction of methane emissions [16].

Thus, using (3) and the above information, it was estimated initial investment for the plant around US\$ 2.605 million. The operation and maintenance cost of the generating unit is estimated at US\$18.00 per MWh generated and must be added to the annual spending on the capture and control of biogas annually that represents 5% of the initial investment of the system.

Table II. – Investments on the Generation Plant

ITEM	Cost [US\$]
Generation Plant	1,041,920
Plant of Capture and Burning of Biogas	1,562,881
Initial Investment	2,604,801
Operation and Maintenance of Generation Plant	157,680
Operation and Maintenance of Capture Plant	78,144
Annual Investment	235,824

The monetary values due to the annual produced energy are obtained by the equation:

$$C = P \cdot (1 - F_{cp}) \cdot 8760 \cdot F_s \cdot p_{MWh} \text{ [US\$]} \quad (4)$$

Where:

P [MW]: installed power of generation unit;

F_{cp} [%]: parasitic load factor;

F_s [%]: service factor;

p_{MWh} [US\$]: price received by MWh sold.

It should be provide for a 7% reduction in electricity production to supply the plant's own consumption and parasitic loads, as well as a service factor of 90%, which is associated with the maintenance periods and/or inactivity of the plant [17].

The electricity generated from MSW is free of usage charges of distribution and transmission systems. Based on other plants where energy is sold at US\$ 101/MWh [18], and using equation 4, it is possible to estimate an annual income of US\$741,450.

The incomes from the sale of carbon credits can be estimated using the following formulation [19]:

$$R(x) = p_{ton} (Q(x) \cdot \varphi_q \cdot \rho \cdot GWP + E_{ef} \cdot F_c) \text{ [US\$]} \quad (5)$$

Where:

$$Q(x) = Q_{cap}(x) - (Q_{gen}(x) - Q_{cap}(x))$$

p_{ton} [US\$]: price per equivalent ton of carbon;

Q_{cap} [m³/year]: captured methane quantity;

Q_{ger} [m³/year]: generated methane quantity;

φ_q [kg/m³]: efficiency of methane burning.

ρ [kg/m³]: methane density;

GWP: global warming potential;

E_{ef} [MWh/year]: effective energy produced by the generating plant;

F_c [ton/MWh]: factor related to the substitution of electricity generated from fossil fuels.

According to [19] must be considered that methane has a global warming potential 21 times greater than the carbon dioxide, a density of 0.716 kg/m³, a F_c factor equal to 0.1842 and a constant of 0.9 for the burning efficiency.

The remuneration paid for each tonne not emitted of CO₂ equivalent is highly variable, but currently the average price paid for each carbon credit is US\$ 9.72 [20].

Thus, considering the annual quantities of methane captured, as shown in the graph of Figure 2, and with the aid of (5) the annual revenue generated by carbon credits can be estimated (see Figure 4).

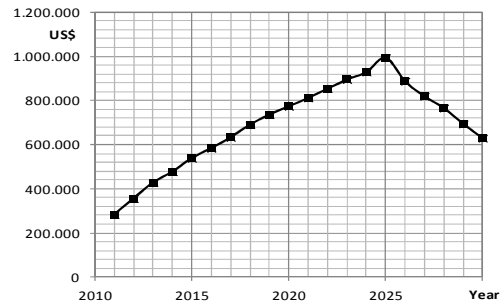


Fig. 4. Revenue Generated by Carbon Credits

6. Energy Generation by Incineration

A. Determination of Generation Capability

The potential for generating electricity by the incineration depends on the calorific value of the fuel. The process of direct incineration of waste is made possible when the collected wastes have a calorific value exceeding 2,000 Kcal/Kg. Based on statistics from field research it was formulated a mathematical expression to determine the factor ICP (inferior calorific power)[21]:

$$ICP = \frac{18,500 \cdot Ya - 2636 \cdot Yb - 628 \cdot Yc - 544 \cdot Yd}{4,185} \text{ [Kcal/Kg]} \quad (6)$$

Where:

Ya [%]: combustible material found in MSW;

Yb [%]: moisture contained in the combustible materials;

Yc [%]: quantity of glass found in MSW;

Yd [%]: quantity of metals found in MSW.

Therefore, analyzing the gravimetric composition of waste deposited in SANTEC landfill and considering that combustible materials have a moisture content of 50%, it was obtained a ICP of 2082 kcal/kg.

B. Analysis of Technical and Economic Feasibility

There are manufacturers that provide modular plants for waste treatment and energy generation from the direct combustion of these. Units with capacity to treat 150 tons of MSW per day and generate 3.3 MW of electricity are available. The technology used in these plants is tuned to recycling and differs from conventional burning methane projects, for take advantage of the calorific value of the waste in direct combustion in boilers.

To estimate the treatment capacity of incineration plant, it was analyzed the information contained in Table III and the quantity of MSW currently received by SANTEC. Thus, it was decided to install a generating plant with capacity for 600 tons/day.

Table III. – Capacity of Treatment and Electricity Generation

Treatment Capacity (ton/day)	Electric Energy			
	Generated (MWh)	Exportable		
		MWh	MWh/month	MWh/year
150 (1 module)	3,3	2,8	2.016	22.848
300 (2 modules)	6,6	5,6	4.032	45.696
600 (4 modules)	13,2	11,2	8.064	91.392

The estimated investment for the implementation of a 150 ton/day module, including the "package" of technology licensing, engineering design, civil works, equipment and materials is approximately US\$24 million. For a unit capable of processing 600 ton/day is necessary to invest about US\$79 million [21].

To estimate the annual costs resulting from the application of this technology, it is necessary to consider the number of employees involved in the process (about 47 for each module of 150 tons/day), the use of auxiliary materials and fuels for the operation of the generation plant and spending on inspection and maintenance of burning process and treatment of formed gases. These values are presented in Table IV [22].

Table IV. – Investments in the Incineration System

Initial Investment (US\$)		
Generation Plant	150 ton/day	600 ton/day
		23.595.506
Annual Investment (US\$)		
Employees and Management	713.483	2.853.933
Operation and Maintenance	466.292	1.865.169
Input Costs	207.865	831.461
TOTAL	1.387.640	5.550.562

Revenues from the incineration of MSW consist of the treatment rate of the same, as well as the commercialization of carbon credits and electricity generated. The use of a 600ton/day unit allows the sale of 91,392 MWh/year and prevents the emission of 120,000 tons equivalent CO₂ to air [21].

Thus, applying the same values used for the negotiation of carbon certificates and energy produced from biogas utilization, it was estimated profitability of this project, as described in Table V. Also it was used an average value of US\$36.5/ton to determine the revenue generated by reception of waste because the current price is between US\$34 and US\$39 per ton [13].

Table V. – Revenues of Incineration System

Annual Revenue	US\$
Waste Treatment	7.997.191
Electric Energy	9.246.944
Carbon Credits	1.166.400
TOTAL	18.410.535

7. Discussion and Analysis of Results

A general analysis of the study shows that both, the use of biogas as the waste incineration are viable alternatives for energy generation.

To evaluate the return on investment it was applied in both projects a minimum attractiveness rate of 12% per year (recommended for these kinds of studies). In this evaluation, in addition to observing parameters such as the Net Present Value (NPV), Internal Rate of Return (IRR) or the Uniform Annual Cost, it was used the method of discounted Payback, in order to determine the time required for recovery of the amount invested by the cash flow of projects.

To analyze the use of biogas formed in the landfill it was considered the possibility of generating 1MW over a period of 12 years which is the useful life of the system. In this study has not been accounted current energy consumption of the landfill, due to unavailability of data. The results of economic analysis can be seen in Figure 5. It was found a Internal Rate of Return of 37.49%, a value well above the Minimum Rate Attractiveness used.

It is also noted that the landfill has a potential to generate about 3MW in 2025, which allows the expansion of the generating plant after this year. This expansion can enable even more this project, that even with a generation of 1 MW, shows a return on investment between the third and fourth year of operation.

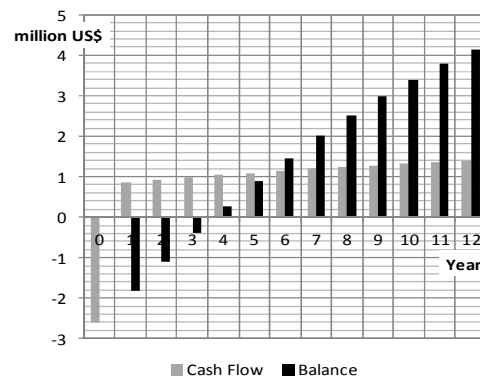


Fig. 5. Payback of Power Generation from Biogas

For the economic evaluation of the incineration process, it was considered a useful life to the project of 20 years, as suggested by the company that owns the technology.

The return on investment is between the eleventh and twelfth year of activities. This technique requires a higher initial investment and has high annual expenditure on operation and maintenance of the system, however, the return is also greater. The results of economic analysis can be seen in Figure 6. The Internal Rate of Return for this example is 15.42%, a value also above the Minimum Rate Attractiveness used.

To facilitate the implementation of an incineration plant it is important to ensure the supply of MSW and the payment for their treatment, because these items are significant and can interfere with the calculation of project feasibility.

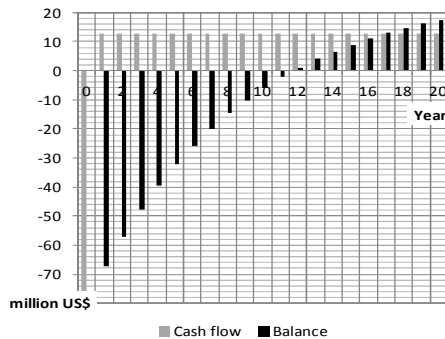


Fig. 6. Payback of Power Generation from Incineration

8. Final Considerations

The intensification of human activities provides increased power consumption and considerable increase in production of waste. This situation has favored the use of solid waste as an alternative source for electricity generation, so that the energy of MSW has been the focus of several studies, receiving significant attention in recent times, especially by the highly industrialized countries. Despite this, the contribution of MSW is still unrepresentative in the world energy matrix.

According to the obtained results it can be concluded that, despite its high cost, the waste incineration process presents an increased potential for power generation in relation to the biogas collection system. The application of these plants can be made possible in large urban centers by the unavailability of sites for construction of new landfills.

It is important to note that this work should be characterized as a preliminary study. The data used here are based on current conditions and in previous studies and were not considered changes in prices, such as electricity, waste reception rate or trading in carbon credits nor it was considered the costs for certification of the project in government agencies. The residual value of the equipment used by each project and the possibility of financing the capital, also influence the viability calculations.

The main objective of this paper is to show the potential energy existing in landfills, even medium-sized cities, and the energetic use of biogas is an accessible alternative to be implemented.

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