TECHNICAL AND ECONOMIC ASSESSMENT OF POWER GENERATION FROM MUNICIPAL SOLID WASTE INCINERATION ON STEAM CYCLE

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Abstract.
Nowadays, there is a concern in development of environmentally friendly methods for a municipal solid waste (MSW) management and demand for renewable energy sources. The source of waste is increasing, and the capacity and availability Landfill treatment and disposal are coming to be insufficient. In São Paulo City, the 10 million inhabitants produce 10,000 t of residential solid waste daily, being that 76% this quantity goes to landfill sites. In order to adopt a new treatment technology for MSW that will promote a solution minimizing this problem, within the order of priorities regarding waste management, the MSW incineration with energy recovery shown as the leading choice on the point of view of efficiency in converting energy.
MSW incineration with energy recovery received wide acceptance from various countries including European Union members and the rest of the world in the past 15 years. Incineration has the ability decrease 90 % the volume of waste to be used in landfills, increasing the useful life of existing as well as a reduction in the emission of greenhouse gases. MSW incineration systems have a low global warming potential (GWP). now has become a less important source of dioxins and furans due to the current available technology. MSW incineration with energy recovery could contribute considerably in the energy matrix, thus promote the conservation of non-renewable resources.
This paper proposes the assessment the technical and economic feasibility of a steam cycle with conventional steam generator for MSW incineration with energy recovery for power generation in São Paulo City. Will be developed a thermoeconomic analysis aiming at the total power generation product of MSW incineration, and the assessment investment cost regarding the total sale of power generated. The study shows that Sao Paulo City has potential for power generation from the MSW incineration, although it has a high cost investment this technology shown as a suitable alternative for RSM disposal.

Keywords*: Incineration, Municipal solid waste, Power generation, Steam cycle*

1. INTRODUCTION

The municipal solid waste (MSW) has become one of the most serious problems that modern society faces, and improper disposal of these wastes causes environmental degradation. The RSM is an important source of methane emissions, roughly one ton of MSW deposited in landfills producing 62 cubic meters of methane through anaerobic decomposition of biodegradable part of waste, the methane has more than twice the global warming potential than one tonne of CO2, which would have been produced by incineration (Themelis, 2003).

Considering the environmental issues arising from the management of RSM, and the increasing demand for alternative energy sources, it is necessary to discuss the advantages and aspects of technical feasibility, economic and environmental aspects of energy use of the RSM. Within the order of priorities on waste management are: prevention, reuse, recycling, energy recovery, landfilling. But due to the nature of the RSM possibilities of reuse is limited by economic and health issues, so only a part of RSM can be reused and recycled. Thus, incineration is presented as a method for high efficiency in removing the RSM and methane emissions that would occur if the RSM were dumped in landfills, is a good option to reduce emissions of greenhouse gases (GHGs). Incineration is a heat treatment process that aims to destroy any harmful component of the waste, reducing about 75% by weight and 90% of improving their final disposal in landfills, the energy released by the combustion process can be used in form of electricity, heat and combination of them (Autret et al. 2007; Kreith, 2007, Qiu and Hayden 2009).

Worldwide, the basic technology for the incineration of MSW has been improved in Europe in the 1960s and 1970s, where most of the industrialized countries with a high population density have kept the incineration of MSW as an alternative method of managing the landfill controlled. Currently, Austria is a leader in the field of power generation from MSW, which uses the waste site in a manner efficiently. Due to the calorific value of the RSM and the potential polluter emissions, encouraged the development of incineration systems capable of achieving higher yields in combustion and in tackling emissions. On the other hand, incineration has been criticized by environmental risks, because their emissions have toxic chemicals such as dioxin, furans and heavy metals. But as the rules and laws that limit the emissions are growing stronger, to achieve compliance to stimulate the continuous development of new technologies in treatment of combustion and emissions.

In Brazil, the first municipal incinerator was installed in 1896 in Manaus to process 60 tons per day of household garbage, and was deactivated in 1958 only by maintenance problems. Similar equipment was installed in Bethlehem in 1978 and disables the same reasons. In Sao Paulo are installed two incinerators with a capacity of 300 ton per day in 1993 but were stalled due to limited technology, not having the capacity to meet the requirements of current environmental laws. In 1994 it launched a mega project to build two new incinerators with a capacity of 2500 tons per day, associated with steam thermal plants of 40 MW; the project was not implemented due to political and environmental issues (Henriques 2004).

Currently, the Brazilian energy matrix depends mainly of petroleum and hydropower, a renewable energy share in energy production should increase in coming years. Considering that the RSM is composed mainly of biomass is in a renewable energy source, the use of RSM in the generation of electricity in Brazil and especially in large cities like Sao Paulo prolong the useful life of existing sources of primary energy by reducing the their demand.

2. CHARACTERIZATION OF MUNICIPAL SOLID WASTE

RSM is a highly heterogeneous mixture of many components, including combustible materials, moisture and ash. The combustible material is composed mainly of carbon, hydrogen, oxygen, nitrogen, sulfur and other elements in smaller quantities such as chlorine, fluorine and heavy metals.

In industrialized countries, the RSM are produced at a rate of about 400 kg per person per year, about 1.10 kg per day, so the cumulative quantities and produced daily, it constitutes an important source of bio-renewable fuel power generation (Autret et al. 2007; Qiu and Hayden, 2009; Psomopoulos et al. 2009).

In Brazil, the study by Mendes et al. (2004) indicate that only in São Paulo city inhabited by about 10 million people daily on average produces 10,000 ton. of residential waste, or 3.65 million ton per year, with a daily production rate of 1.00 kg of trash per capita, and the 76% of that amount goes to final landfill sites. However the municipal urban development of the city government of Sao Paulo reported for 2006 a population of 10,998,813 inhabitants and 5,490,836 tons. Garbage collected the rate of daily output of garbage from about 1.37 kilograms per capita, this indicates a considerable increase in the amount of MSW produced. Table 1 shows the typical composition of MSW in the city of Sao Paulo which will be considered in the study.

Table 1. Physical composition of MSW of São Paulo City and general average moisture and ash content, and ultimate analysis

Component	Content in São Paulo (wt. %)	Moisture (wt. %)	Ash (wt. %)	Ultimate analysis (wt. % dry basis)				
				C	H	N	S	O
Kitchen garbage	49.5	70	5.0	48.00	6.40	2.60	0.40	37.60
Paper	12.0	10.2	6.0	43.50	6.00	0.30	0.20	44.00
Cardboard	6.8	5.2	5.0	44.00	5.90	0.30	0.20	44.60
Plastics	22.9	0.2	10.0	60.00	7.20	0.00	0.00	22.80
Textiles	2.4	10.0	2.5	55.00	6.60	4.60	0.15	31.20
Rubber	0.3	10.0	10.0	78.00	10.00	2.00	0.00	0.00
Leather	0.3	10.0	10.0	60.00	8.00	10.00	0.40	11.60
Wood	1.3	1.5	1.5	49.59	6.00	0.20	0.10	42.70
Glass[1]	1.5	2.0	98.9	0.50	0.10	0.10	0.00	0.40
Ferrous metals[1]	1.9	2.0	90.5	4.50	0.60	0.10	0.00	4.30
Aluminum[1]	0.9	2.0	90.5	4.50	0.60	0.10	0.00	4.30
Other	0.2	3.2	68.0	26.30	3.00	0.50	0.20	2.00

([1]) Organic content is from coatings, labels, and other attached materials
Source: Tchobanoglous *et al.* 1993

Table 1 is the result of an elemental analysis in dry basis which mainly determines the mass fraction of chemical constituents such as carbon (C), hydrogen (H), nitrogen (N), sulfur (S) and oxygen (O) . Usually other references also consider the presence of chlorine (Cl) in composition, but this will depend on the city, region or country, as well as factors such as diet, level of development and the economy. Finally, the ash content, which is largely a mixture of Fe, Zn, K, Na, Al, Ca, Mg and Si, is also included as a simple fraction. Using statistics from the municipality of São Paulo between the years 1998 and 2003, Figure 1 summarizes roughly the amount of combustible material that can be valued energy of the total MSW collected. One can observe that the share of combustible material contained in the RSM presents slight variations over the years.

For the year 1998, an 95.5% of the RSM is composed of combustible material being made of biomass products such as household waste, paper, cardboard, cloth, rubber, leather and wood, which are a renewable energy source, lastly we also have oil-derived compounds such as plastics which are a source of energy is not renewable. The remaining 4.5% is composed of recyclable material such as ferrous metals, aluminum and others, thus considering a ton. RSM collected, could only be valued energetically 0.95 ton.

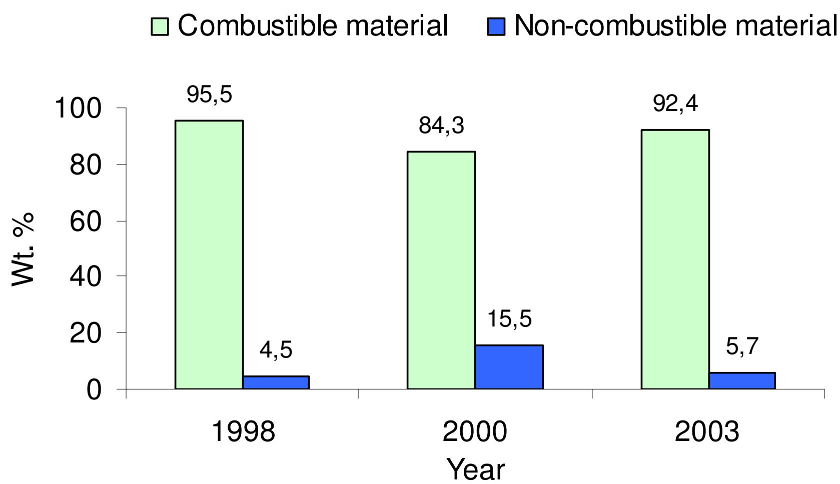


Figure 1. RSM at São Paulo

Besides the chemical composition of the RSM is also important to determine the calorific value of the RSM, extremely important parameter for evaluating the potential energy in analysis and design of incineration with energy recovery. For this there are two ways to determine the calorific value, is the first experimentally through bomb calorimetry and the second through empirical correlations based on elemental analysis of RSM. The literature provides several empirical correlations for determining the lower heating value (LHV) and higher (PCS), they have some considerations such as its application may determine the calorific value of coal, MSW and residue-derived fuel (RDF) with a good approximation (Sopian et. al. 2003; Zhiqiang, et al. 2006 and Chyan, 2007).

$$LHV = 81\left(C - \frac{3}{8}\times O\right) + 57\times\frac{3}{8}O + 345\left(H - \frac{O}{16}\right) + 25S - 6(W + 9H) \tag{1}$$

LHV: Lower Heating Value
W : Moisture

Based on the above premises, and from Table 1 is estimated the lower calorific value of MSW considering only the combustible material is to tell the entire biomass of the RSM using the correlation of STEUER (Equation 1) developed specifically for the RSM is that for the state of Sao Paulo PCI was equivalent to 2535.09 kcal / kg or 10606.80 kJ / kg.

3. POWER GENERATION USING THE STEAM CYCLE (RANKINE)

The mass burn technology is more consolidated in the incineration of MSW with energy recovery. Incineration is a thermal process that involves the controlled combustion of MSW, where it develops a chemical reaction between oxygen and combustible material RSM which passes through four stages are: drying, ignition, combustion and subsequent destruction, causing the combustion gases which contains most of the energy from the combustible material of RSM in the form of heat. Incineration uses thermal decomposition through the oxidation process at a high temperature (800 - 1000 ° C), and consequently destroyed the entire organic fraction of waste in this way reduces its volume (Margulis, B. et. al 2008).

To allow the combustion to take out if you need a sufficient amount of oxygen to fully oxidize the combustible material of RSM. The process operates with excess air to ensure complete combustion by controlling the temperature not exceeding the 1100 ° C, avoiding the formation of nitrogen oxides (NOx) and molten ash.

Current processes of combustion are carried out in gas phase in fractions of seconds with the simultaneous release of energy. This leads to a series of thermal reactions and the very livelihood of combustion, this means that the need for the addition of other fuels. The emission control system includes a system of non-catalytic reduction (SNCR) fed urea to control NOx formation, a gas scrubber system with dry calcium oxide (Dry Scrubber) and an activated carbon filter to removal of acid gases, dioxins and heavy metals (Consonni, et al. 2005; Knox, 2005; Autret, et al. 2007; Kreith, 2007).

Basically there are four types of incineration processes RSM on a commercial scale: grid system, multiple chambers, fluidized bed, rotary. The typical configuration of facilities for energy recovery from MSW combustion are based on the use of cycles of steam turbine (Rankine cycle) powered by a recovery boiler.

Figure 2 shows in simplified form the steam cycle by using the exhaust gases from the incineration process, where the energy from the incineration of MSW is recovered through the recovery boiler to generate steam. Of the total available energy in the waste, approximately between 80-95% can be recovered. The steam produced can be fully utilized for power generation plants with a single condensing turbine (CT). On the other hand can be used completely or in part in the generation of combined heat and power systems known as (CHP), using a simple condensing turbine (SPOCT) and a backpressure turbine type (BPT) (Caputo, et al., 2004, Knox 2005).

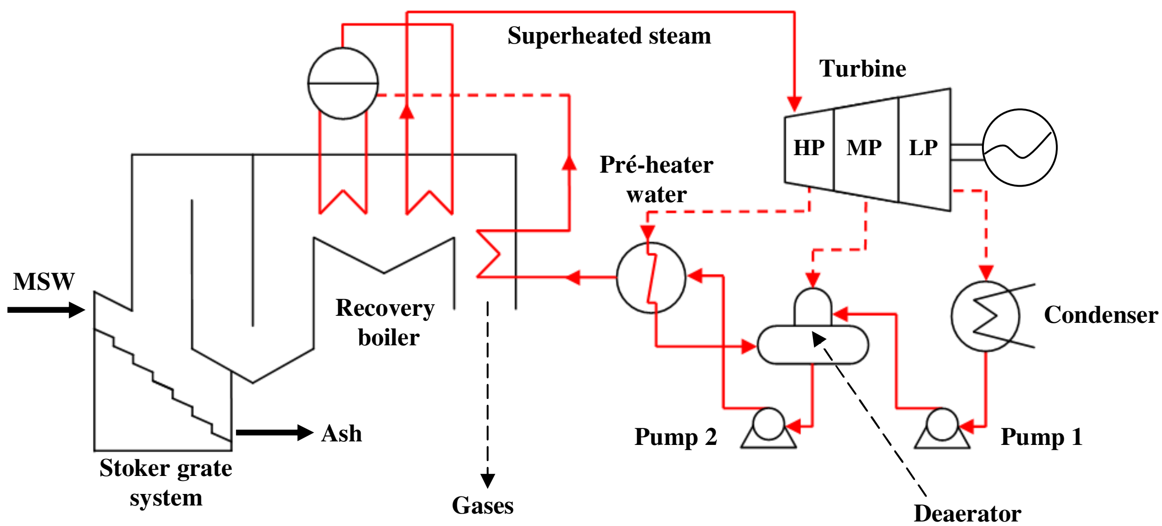


Figure 2. MSW incinerator configuration.

The aggressive nature of exhaust gas limits the temperature of steam generation, all with the purpose of preventing corrosion of metal structures in the hot heat exchangers in the recovery boiler, therefore the RSM for incineration plants have low parameters steam. Therefore it is obtained a poor efficiency in power generation due to the steam produced is in the range 40-60 bars and a temperature range between 380 and 450 ° C with an efficiency of power generation between 25-30 %. The table 2 shows the parameters of the steam cycle regard in the study.

Table 2. Specification steam cycle parameters

Steam superheat temperature	425 °C
Evaporation pressure	40 bar
Extraction temperature (1)	163.77
Extraction pressure (1)	4.3 bar
Extraction pressure (2)*	1.3 bar
Condenser pressure	0.13 bar
Deareator pressure	1.3 bar
Pump pressure (1)	1.3 bar
Pump pressure (2)	40 bar
Pre-heater pressure	4.3 bar
Pre-heater temperature	146 °C
Isentropic efficiency of steam turbine	90 %
Isentropic efficiency of pump	85 %

4. DISCUSSION AND RESULTS

According to the report of technical guidance from the World Bank, (1999) for an incineration system of RSM with electric power generation is economically feasible, the capacity of individual incineration lines should be at least 240 tons per day in two processing lines thus improve the flexibility and availability of incineration, in addition, a willingness to annual operating time of 7500 hours. The principle of burns in mass scale mobile is applied in the economic analysis of the investment cost, being the technology most commonly used in the incineration of MSW, the lifetime considered for these plants is in the range of 20 to 30 years. Table 3 presents the results of thermodynamic analysis assuming a treatment capacity of 500 ton. as the work of Oliveira et al. (2003).

Table 3. Results of thermodynamic analysis MSW incineration

MSW	500 ton/day
Load factor	75 %
Heat capacity	61.4 MW
Power potential	17.5 MW
Auxiliary consumption	1.90 MW
Net energy produced	15.6 MW
Thermal energy dissipated	35.0 MW
Power generation efficiency	25.4 %

MSW incineration plant must be economically sustainable for the municipality, so the feasibility analysis is a task complicated by the different factors involved such as the cost of the investment, operation cost and maintenance among others. The investment cost of incineration depends primarily on the amount of MSW processing and its calorific value, and units of low processing capacity prove to be more expensive than that of high capacity drives. Basically the implementation of the incineration of MSW associated with a steam cycle in the city of São Paulo is subject to the minimum requirement that the total costs are offset by profits from the sale of electricity generated in the process.

The current investment cost for a MSW incineration plant depends on a wide range of factors, especially the size of the plant which is a function of the processing capacity of garbage a day or year and a corresponding lower calorific value of waste (World Bank , 1999). According to Oliveira et al., 2003 the cost of investment is specific to 1563 U.S. $ / kWh and the cost of operation and maintenance 7.67 U.S. $ / MWh and income tax of 34%. Table 4 presents a hurdle rate (MARR) of each case, with its cost of electricity assumed in the feasibility study project for the incineration only considering the sale of electric energy produced in three different cases.

Table 4. Cases for economic analysis

CASE	MARR	Selling price US$/MWh
Optimistic	8.0 %	150
Intermediate	9.0 %	120
Pessimist	10 %	80

Figure3 and 4, shows the economic indicators used for economic analysis of the incineration of MSW, the Net Present Value (NPV) method known to assess long-term undertaking and the Internal Rate of Return (IRR), which are calculated in each case.

Figure 3. Net Present Value of technologies depending on the variations of the investment value

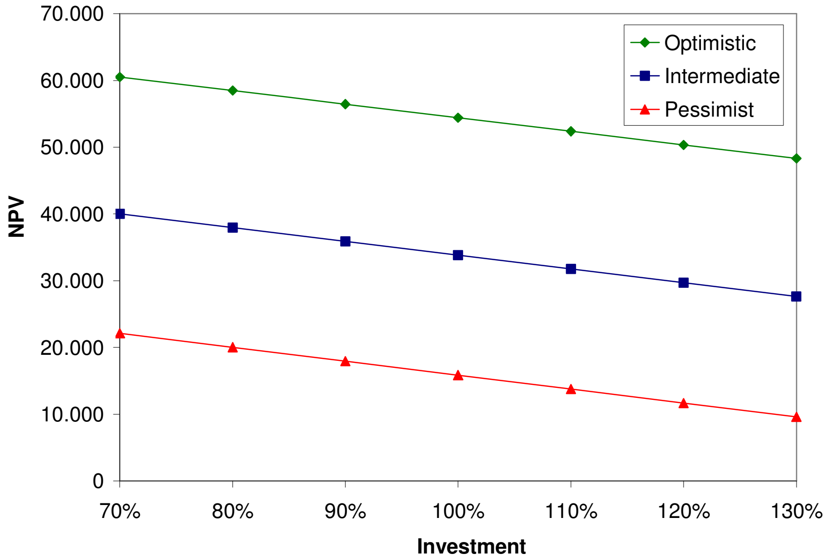
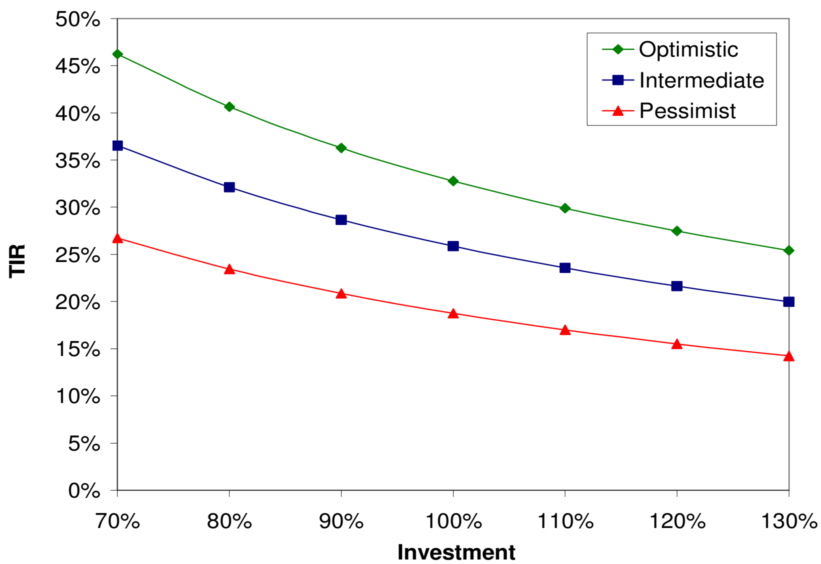


Figure 4. Internal Rate of Return as a function of change in value of investment



5. CONCLUSION

The value of NPV is anticipated to be positive in the end of year 20, a fact, which automatically signals the profitability of the investment. The TIR also presents a good behavior in three cases. This economic analysis is sensitive to current prices of electricity which changes continuously.

Incineration of MSW is an alternative that should be considered, starting from the principle of disposal of solid waste in sanitary landfills appears to be increasingly less viable. The combustion process of solid waste generates benefits that exceed its cost of investment; one should study the possibility of implementation, and feasibility, as concern the alternatives discussed and their attributes, for example, reduction in gas generation greenhouse gas (GHG).

Convert the waste into a value-added product more interesting, such as electricity, steam for industrial processes, among others, reduce the cost and inconvenience arising from the handling, transport and disposal of MSW in landfills. Furthermore, the composition of the RSM is established to change in quality with an increase in calorific value due to improved quality of life.

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7. REFERENCES

Autret, E.; Berthier, F.; Luszezanec, A.; Nicolas, F., 2007, "Incineration of municipal and assimilated wastes in France: Assessment of latest energy and material recovery performances", Journal of Hazardous Materials. v. 139, p 569-574, 2007.

Caputo, A. C.; Palumbo, M.; Cacchia, F., 2004, "Perspectives of RDF use in decentralized areas: comparing power and cogeneration solutions", Applied Thermal Engineering. v. 24, p 2171-2187.

Consonni, S.; Giugliano, M.; Grosso, M., 2004, "Alternative strategies for energy recovery from municipal solid waste: Part A: Mass and energy balances", Waste Management, Milano, n. 25, p.123-135.

Consonni, S.; Giugliano, M.; Grosso, M., 2004, "Alternative strategies for energy recovery from municipal solid waste: Part B: Emission and cost estimates", Waste Management, Milano, n. 25, p.123-135.

Henriques, R. M., 2004, "Aproveitamento energético dos resíduos sólidos urbanos: Uma abordagem técnica"

Holanda, M. R., 2003, "Perspectivas da cogeração com resíduos sólidos municipais sob a ótica da gestão ambiental".

Kathiravele, S.; Yunus, M.; Sopian, K.; Samsuddin, A.; Rahman, R., , 2003. "Modeling the heating value of municipal solid waste", Fuel, v. 82, p 1119-1125.

Kleis, H.; Dalager, S. 2004, "100 Years of waste incineration in Denmark from Refuse Destruction to high-technology energy works".

Knox, A., 2005, "An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW)" University of Western Ontario. http://www.oneia.ca/files/EFW%20-%20Knox.pdf

Kreith, F. 2007, "Handbook of energy Efficiency and Renewable Energy".

Margulis, R., López, G., Hernandez, J., Saucedo, R., Rubio, H. 2008, "Combustión de residuos sólidos municipales en un sistema de lecho fluidizado experimental" http://redalyc.uaemex.mx/pdf/154/15424201.pdf

Mendes, M. R.; Aramaki, T.; Hanaki, K. 2003, "Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA". Resources, Conservation and Recycling, Tokyo, v. 41, n., p.47-63.

Oliveira, L. B., Rosa, L. P. 2003, "Brazilian Waste Potential: energy, environmental, social and economic benefits". Energy policy, v.31, p.1481-1491.

Papagiannakis, K. 2003, "Generating Electricity from a 10 MW MSW combustion plant in the area of Athens, Greece: A feasibility Study", University of Strathclyde in Glasgow, Department of Mechanical Engineering, Glasgow.

Prefeitura do município de São Paulo, 2003, Caracterização gravimétrica de físico-química dos resíduos sólidos domiciliários no município de são Paulo.
http://www.prefeitura.sp.gov.br/servicos/upload/RelatorioGeral2003_1103568035.pdf

Psomopoulos, C. S., Bourka, A., Themelis, N. J. 2009, "Waste-to-energy: A review of the status and benefits in USA", Waste Management v. 29, p 1718-1724, 2009.

Qiu, K.; Hayden, A. 2009. "Performance analysis and modeling of energy from waste combined cycles", Applied Thermal, v.29, p 3049-3055.

Themelis, N. J. "An overview of the global waste-to-energy industry". Waste Management World: 40–47 (July–August 2003). http://www.seas.columbia.edu/earth/papers/global_waste_to_energy.html.

World Bank, 1999, Municipal Solid Waste Incineration A Decision Maker's Guide