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THE WASTE-TO-ENERGY POTENTIAL OF THE REGION OF GRANDE FLORIANÓPOLIS

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Abstract. *The present work studies the thermal treatment of Municipal Solid Waste (MSW) through incineration applied to the region of Grande Florianópolis. This waste-to-energy technology is widely applied in North America and Europe and is recognized as an efficient method to lessen the MSW volume sent to landfill sites. Landfill sites are considered, in Brazil, an environmentally sound disposal, however, a large energy potential ends up being sealed within it. The energy recovery from waste is one of the alternatives for sustainable waste management presented on the National Policy of Solid Waste from Brazil, although it follows the reduction and recycling on the priority list of the aforementioned Policy. As all the MSW collected in the Region of Grande Florianópolis is dumped in a landfill site, this work intends to evaluate the energy potential that could be generated in a suitable power plant. Based on the gravimetric composition reported previously by the local collection and disposal company, the lower heating value of MSW was calculated. In order to take advantage of the energy potential of the waste, a Rankine cycle with reheat was proposed. The results indicate an electricity production potential of 31 MW burning 1000 tonnes of MSW per day, achieving a value of 0.7 MWh/t.*

Keywords: *Waste-to-Energy, Incineration, Florianópolis*

1. INTRODUCTION

It was only a few decades ago that measures for the proper disposal of solid waste were brought up in the halls of major cities of Brazil. When accumulated in areas unprepared for such, the garbage reflects harmful consequences to the environment and to humans. The leachate from the decomposing organic matter permeates the soil and reaches the groundwater, making it non-potable, apart from the disease spreading by animals, which are attracted by the pile of trash. In contrast, landfills impose total isolation of the waste with soil impermeabilization, drain for the leachate and coverage protection so that rainwater does not spread the mulch. However, even if the landfill is considered in Brazil as an environmentally sound disposal, a large energy potential ends up being sealed within these landfills. Nowadays, there are countless ways to recover this wasted energy, and most of these solutions also eliminate another major problem: lack of space.

The National Policy of Solid Waste (PNRS), promulgated law n°12305/2010, obliges every city to proper dispose its MSW, providing guidelines for such. It states that, regarding the most sustainable waste management, the priority is on the reduction of MSW generated followed by reutilization and recycling, energy recovery and finally sanitary landfill disposal. Still, there are no waste-to-energy (WtE) plants in Brazil and 37.9% of the municipalities do not offer any type of selective waste collection (ABRELPE, 2014), despite landfilling appears to be the most convenient economical alternative, given all the available space that Brazil has.

In the current Brazilian scenario, the construction of sanitary landfills are indeed necessary, since, according to ABRELPE (2014), 41.74% (78,987 t/d) of the MSW collected goes to inadequate landfills or clandestine disposal sites without any preparation. given the opportunity set into motion by the PNRS framework, the city halls should rectify inadequate landfills and strive for high rates of recycling and composting. For the not reusable or recyclable fractions, an energy recovery method becomes the best option, considering the multiple benefits. Unlike the landfill alternative, it can lessen the use of fossil fuels, minimize the environmental and health problems of waste disposal and greatly reduce the spatial need to storage it – up to 90% in volume (SOARES,2011).

Figure 1 presents the distribution of the main MSW disposal methods in some well-developed countries, demonstrating a great deployment of incineration with associated energy recovery, and the fact that the MWS disposal do not rely on landfilling anymore (it is used only if necessary).

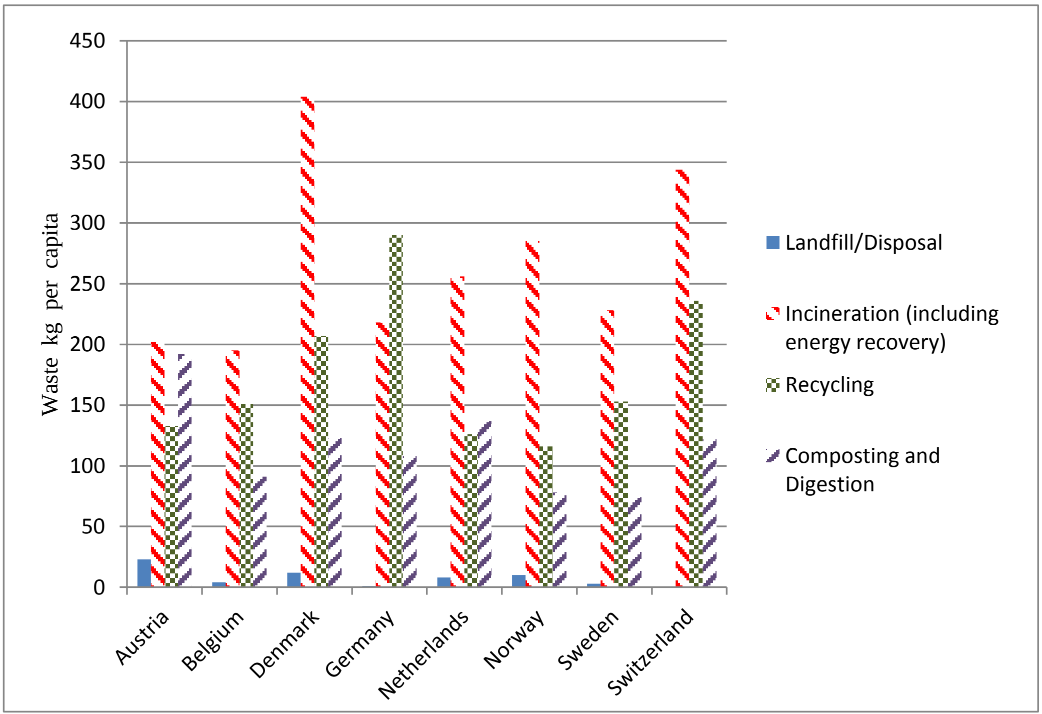

Figure 1. Waste treatment by method, in weight per capita, at 2013 in Europe. Source: Eurostat, 2015

Nevertheless, energy recovery systems, as waste-to-energy plants, demand a meticulous study in order to assure technical and economic feasibility. An accepted method of initially assess the possibility of energy recovery through incineration is to evaluate the energy potential (relation MWh/t) of the local waste. Table 1 shows some relations MWh/t of MSW of different waste-to-energy plants throughout the world.

Table 1. Technical data from Waste-to-Energy plants worldwide. Source: FEAM, 2012.

Plant	Country	MSW processed [t/d]	Power [MW]	Relation MWh/t
Covante (Semass)*	USA	3,000	70	0.56
AEB	Netherlands	2,800	67	0.57
Veolia (Miame-Dade)*	USA	2,688	64	0.57
Covanta (Hempstead)	USA	2,500	69	0.66
Bréscia	Italy	2,230	70	0.82
Valorsul	Portugal	2,016	38	0.45
HVC	Netherland	1,800	60	0.80
Lipor II	Portugal	1,100	21	0.46

*Plants that process Refuse-Derived Fuel

The present paper works with the hypothesis of a waste-to-energy plant that serves all the cities from the region of Grande Florianópolis, rather than the current system of landfill. As there is no solid data of energy recovery through incineration due to the lack of WtE plants in Brazil, the main objective of this paper is to evaluate the energy potential of the region of Grande Florianópolis based on reference values.

1.1 Waste Management in Florianópolis

The Tijuquinhas landfill, located in Biguaçu/SC, receives waste from 25 cities, from which 21 are from the Region of Grande Florianópolis. This landfill is owned and operated by PROACTIVA, which is also responsible for the collection and transportation of the MSW in the most of these cities. A PROACTIVA report from 2011 shows the present year quantity amount of MSW Tijuquinhas received and their projections for 2012 and 2013 based on a 7% year growth (PROACTIVA, 2011), as shown in Table 2.

Table 2. Data from the MSW weighting on Tijuquinhas landfill and future projections. Source: PROACTIVA, 2011.

Year	Total MSW Collected (t)	Daily Average of MSW Received (t/d)
2010	326,150	893.56
2011[(1)]	348,981	956.11
2012[(1)]	373,409	1020.24
2013[(1)]	399,548	1094.65

[(1)] Years with values projected

The capital of the region analyzed, Florianópolis, is the major contributor of all the waste received by the landfill (COMCAP, 2014). Unlike most of the other cities, Florianopolis has its own public company for waste management, called COMCAP (Companhia de Melhoramentos da Capital). COMCAP releases yearly activities reports, from which we can obtain the daily MSW collected, as shown in Table 3.

Table 3. Data from the MSW collected in Florianopolis in 2012. Source: COMCAP, 2013

Year	Total MSW Collected (10^3 t)	Daily Average of MSW Collected (t/d)
2010	154.9	424.38
2011	164.2	449.86
2012	174.7	477.32
2013	192.2	526.58

The amount of MSW incinerated on the proposed WtE plant, will be the daily average of MSW received by the Tijuquinhas landfill on 2013. Concerning the MSW composition, the Florianópolis MSW gravimetric composition will be adopted, since the capital is the biggest contributor of the MSW landfilled at Tijuquinhas, with almost 50% of the total amount.

2. METHODOLOGY

2.1 Gravimetric Composition

The gravimetric composition has direct influence over the LHV, moisture content and bulk density. As previously stated, on the present paper the MSW composition of the city of Florianópolis will be applied for the total amount of MSW taken to the Tiijuquinhas landfill. According to the Table 4, the organic fraction is the most significant, representing 46% of the total weight.

Table 4. Gravimetric composition of the MSW of Florianopolis. Source: COMCAP, 2002.

Component	Weight Fraction [%]	Weight Average [t/d]
Organic	0,46	503,54
Hard Plastic	0,05	54,73
Soft Plastic	0,10	109,47
Paper	0,11	120,41
Cardboard	0,03	32,84
Glass	0,04	43,79
Textiles/leather	0,04	43,79
Sanitary Material	0,09	98,52
Metals	0,03	32,84
Wood	0,01	10,95
Others	0,04	43,79
Total	**1,00**	**1.094,65**

It is worth mentioning that within the component weight averages are considerable amounts of ashes and moisture contents. Also, the item “Sanitary Material” stands for disposable diapers, toilet papers, tampons/pads and paper towels.

2.2 Moisture Content and Ashes

The moisture content is the quantity of water present in the MSW, being the organic fraction of the MSW, the component that has the highest rates of moisture. High moisture content results in less useful energy released, as the water absorbs heat in the vaporization process and is further rejected along with the flue gas, diminishing its potential contribution for the steam generation of the Rankine cycle. Therefore, as higher the moisture content, the lower the LHV will be.

Just as the moisture content, the ashes also contribute in reducing the MSW LHV. It is due to the fact that the ash does not react in the combustion (inert),and represents a residue of the process. When incinerated, the MSW generates two different types of ashes: fly ashes and bottom ashes.

According to FEAM , 2012, the fly ashes are small solid particles that are dragged by the flue gas and are normally retained in the filter system, whereas the bottom ashes are the residual substances that rest on the grates after the combustion. The fly ashes are classified, according to NBR 1004 (ABNT, 2004), as hazardous waste (class I), since they can carry a considerable amount of highly toxic substances and, therefore, should be neutralizes with hydrated lime and sodium bicarbonate before landfilling. Its transportation and disposal have significant costs and must be taken in account on the economic planning of the plant. On the other hand, the bottom ashes have multiple uses as they can be utilized in civil construction, road paving and landfill covering.

For the present work, it will be considered typical values of moisture content and ashes presented by FEAM (2012) and ENGEBIO (2010), shown at the Table 5.

Table 5. Moisture content and ashes present in MSW. Source: FEAM, 2012 and ENGEBIO 2010.

Component	Moisture content [%]	Ashes [%]	Combustible fraction [%]
Organic	66	3	31
Paper and Cardboard	21	5	74
Textile and Leather	36	10	54
Wood	25	5	70
Plastics	17	3	80

2.3 Lower Heating Value

The Heating Value (HV) is the capacity of the material to release determined amount of energy by mass unit when in combustion or oxidation. This feature varies according to the composition of MSW, moisture content, ashes content and can be subdivided in Higher Heating Value (HHV) and Lower Heating Value (LHV). The first considers all the energy released in the combustion, including the energy spent in the water vaporization, as useful energy. The latter is determined by subtracting the heat of vaporization of the water vapor from the higher heating value, hence this value assumes that the latent heat of vaporization is not recovered or utilized as useful energy for thermal cycle.

To determine the potential of the MSW on this paper, it will be considered the mass-burning of the MSW As Received (AR), in other words, without any pretreatment. In order to establish the LHV AR of the MSW in Grande Florianópolis, reference values of LHV Moisture Free (MF) brought by FEAM (2012) and ENGEBIO (2010) was used, as exposed on Table 6.

Table 6. LHV (MF) of MSW components. Source: FEAM, 2012 and ENGEBIO, 2010.

Component	LHV (MF) [kJ/kg]
Organic	18003
Hard Plastic	43124
Soft Plastic	43124
Paper	15910
Cardboard	15910
Glass	0
Textiles/leather	17585
Sanitary Material	15910
Metals	0
Wood	15491
Others	0

By the composition of the “Sanitary Materials”, its LHV MF was considered the same as of the paper. The items referring to “Others”, “Metals” and “Glass” were considered inert and do not contribute to increase the LHV AR of the MSW.

The following equations, Eq. (1) and (2), were used to obtain the LHV AR:

$$LHV\ (AR)_{MSW} = \sum_{j}^{n}\{[LHV(MF)_j \cdot (1 - ashes_j - a_j) - (h_{lv} \cdot a_j)] \cdot Y_j\} \quad (1)$$

$$LHV\ (MF)_{MSW} = \sum_{j}^{n}[LHV(MF)_j \cdot (1 - ashes_j - a_j)] \cdot Y_j \quad (2)$$

The results are summarized in Table 7.

Table 7. LHV (AR) of MSW components calculated.

Component	Weight Fraction - Yj	LHV (AR) [kJ/kg]
Organic	0.46	4091
Hard Plastic	0.05	34116
Soft Plastic	0.10	34116
Paper	0.11	11299
Cardboard	0.03	11299
Glass	0.04	0
Textiles/leather	0.04	8683
Sanitary Material	0.09	11299
Metals	0.03	0
Wood	0.01	10280
Others	0.04	0
Total	**1.00**	**10048**

2.4 Thermal Cycle

In the interest of properly estimate the energy potential of the MSW, the present paper proposes a simple thermal cycle with reheat, consisting in a boiler, a turbine with two stages, deaerator, condenser and two pumps. The proposed thermal cycle is illustrated in the Figure 2 bellow:

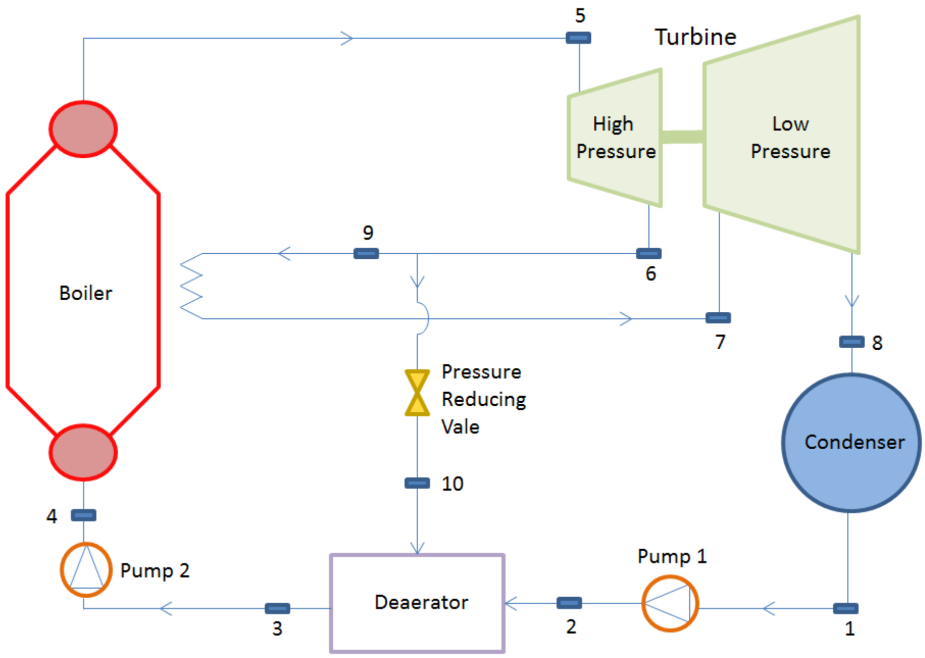

Figure 2. Thermal cycle proposed.

2.5 Assumptions and Data Entry

Assumptions based on typical values were established in order to simulate a real plant. The steam leaving the boiler is set to 4.0 MPa and 673 K as suggested by Ribeiro and Kimberlin (2010) and Madsen (2012). Operating with higher values on pressure and temperature would exponentially increase the corrosive effect from flue gases over the boiler.

The general head loss of the water cycle through the boiler was adopted as 500 kPa. The steam pressure on the extraction of the turbine is 30% of the rated pressure of the boiler and 100 kPa superior to the deaerator pressure. The water is on liquid saturated state at the condenser and deaerator outlets. Also, at the condenser, the temperature of the water drops to 318 K. The rated efficiency of the boiler, turbine, generator and pumps are 85%, 80%, 95% and 90% respectively.

The variations of the kinetic and potential energies were disregarded, just as the heat loss over the pipes. The entry data is summarized at the Table 8:

Table 8. Entry data of the fluid properties and plant operation

Fluid Property	Value	Fluid Property	Value
P_4 [kPa]	4500	x_3	0
P_5 [kPa]	4000	$\eta_{generator}$	95%
P_6 [kPa]	1200	$\eta_{turbine}$	80%
P_{10} [kPa]	1100	η_{pump}	90%
T_5 [K]	673	η_{boiler}	85%
T_7 [K]	673	$\dot{m}_{MSW}$ [kg/s]	12,67
T_1 [K]	318	$LHV(AR)_{MSW}$ [kJ/kg]	10048
x_1	0	$E_{thermal}$ [kW]	127308

3. RESULTS AND DISCUSSION

The thermal energy delivered to the processes, $E_{thermal}$, is defined by Eq. (3):

$$E_{thermal} = \dot{m}_{MSW} \cdot LHV(AR)_{MSW} \tag{3}$$

The state of the fluid in each stage was solved with the aid of Engineering Equation Solver, based on the data present in Table 8. The results are showed in Table 9.

Table 9. Calculated fluid properties along the thermal cycle and resulting variables

Fluid Property	Value	Fluid Property	Value
P_1 [kPa]	9.52	T_9 [K]	536.9
P_2 [kPa]	1100	T_{10} [K]	535.4
P_3 [kPa]	1100	x_6	1
P_7 [kPa]	1200	x_8	0.973
P_8 [kPa]	9.52	$\dot{m}$ [kg/s]	40.68
P_9 [kPa]	1200	$\dot{m}_7$ [kg/s]	31.99
T_1 [K]	318	$\dot{m}_{10}$ [kg/s]	8.68
T_2 [K]	318	$Q_{condenser}$ [kW]	74525
T_3 [K]	457.2	$W_{turbine\ HP}$ [kW]	10078
T_4 [K]	457,6	$W_{turbine\ LP}$ [kW]	23781
T_6 [K]	536.9	$W_{pump\ 1}$ [kW]	35.23
T_8 [K]	318	$W_{pump\ 2}$ [kW]	156.7

Therefore, the work produced W, thermal energy available $E_{thermal}$, global efficiency of the cycle η_{cycle}, and the energy potential Pot_{MSW} can be determined by the Eq. (4) to (6).

$$W = (W_{turbine\ HP} + W_{turbine\ LP}) \cdot \eta_{generator} - W_{pump\ 1} - W_{pump\ 2} \tag{4}$$

$$\eta_{cycle} = W / E_{thermal} \tag{5}$$

$$Pot_{MSW} = W / \dot{m}_{MSW} \tag{6}$$

Figure 3 presents the operation conditions of the proposed thermal cycle on the T-s diagram.

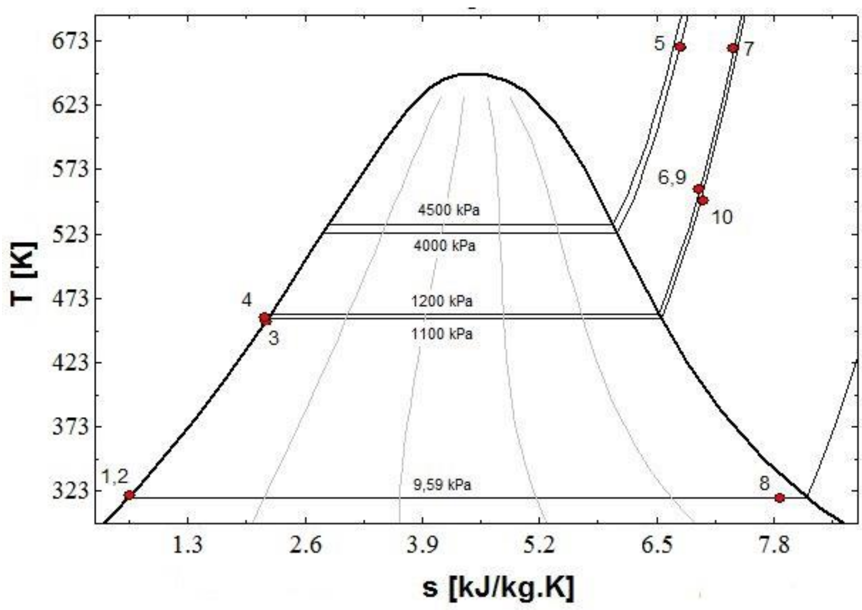

Figure 3. T-s diagram of the proposed thermal cycle

The waste-to-energy plant output is compiled at Table 10:

Table 10. Calculated output results

Fluid Property	**Value**
W [kW]	31974
η_{cycle}	0.2512
Pot_{MSW} [MWh/t]	0.701

The relation MWh/t (also called efficiency) calculated, Pot_{MSW}, is coherent and consistent with the values found on the literature. The quality of the waste in question, regarding its energy suitability, is on par with the United States and European countries. Grande Florianópolis is a well-developed region, thus the population has unrestrictedly access to industrialized goods, which increases paper and plastic fraction, whereas diminishing the organic portion, which results in a higher LHV. The similarity between the values of stablished waste-to-energy plants, shown at Table 1, and theoretical relation of MWh/t presented in this paper indicates that the energy recovery through incineration in Grande Florianópolis is technically possible.

Aside state capitals, all important urban centers of Brazil gather over the coastal line. Additionally, taking into consideration the similar consumption standard, is safe to assume that the majority of coastal cities in Brazil tend to be as well-developed as Grande Florianópolis, which suggests that these said areas meet the requirements to receive waste-to-energy plants.

Still, we must take into account the MSW heterogeneity prevents the generalization of the LHV. For instance, the plastic has a great variety of types and, even so, only one LHV value was utilized in the calculations. Also, it is worth mentioning the simple cycle applied, where the heat and head loss may be underrated and need to be best evaluated.

To improve the results, local MSW samples should be tested with heat release rates measurement techniques, such as calorimeters. A specific study over the ashes and moisture content should also take place to certify the assumptions adopted.

4. CONCLUSIONS

The energy recovery through incineration were evaluated in order to avoid inappropriate disposal of MSW in the region of Grande Florianópolis. The following conclusions can be drawn from this study.

Waste-to-energy plants are adopted in most developed countries in Europe to replace landfills.

Based on a simple thermal cycle with reheat, the results using MSW composition of the city of Florianópolis show cycle efficiency equal to 25,1% and a potential to generate 0,701 MWh/t. These values are consistent with the values found on the literature.

Considering similar consumption standard of urban centers, it suggests that Brasil has a great potential to receive waste-to-energy plants, concluding that MSW incineration is a good alternative to The National Policy of Solid Waste (PNRS).

5. REFERENCES

ABNT, 2004. *NBR 10004 – Resíduos Sólidos - Classificação*. Rio de Janeiro, Brazil.

ABRELPE, 2014. *Panorama dos Resíduos Sólidos no Brasil – 2013*. São Paulo, Brazil.

COMCAP, 2002. *Caracterização Física dos Resíduos Sólidos Urbanos de Florianópolis.* Florianópolis, Brazil.

COMCAP, 2014. *Relatório da Administração do Exercício de 2013*. Florianópolis, Brazil.

ENGEBIO ENGENHARIA S/A LTDA., 2010. *Relatório 1- Estado da Arte do Tratamento Térmico de Resíduos Sólidos Urbanos com Geração de Energia Elétrica.* Belo Horizonte, Brazil.

EUROSTAT, 2013. "Municipal waste generation and treatment, by type of treatment method". 25 May 2015 <http://ec.europa.eu/>

FEAM, 2012. *Aproveitamento Energético de Resíduos Sólidos Urbanos: Guia de Orientações para Governos Municipais de Minas Gerais.* Belo Horizonte, Brazil.

Madsen, O. H., 2012. *Next Generation of Waste Fired Power Plants*. Denmark.

PROACTIVA, 2011. "Formulário de Documento de Concepção do Projeto. Projeto de Captura e Queima do Gás de Aterro Sanitário de Tijuquinhas da Proactiva". 25 Oct. 2013 < http://cdm.unfccc.int/Projects/DB/DNV-CUK1200058130.23/view>

Ribeiro, S. G., Kimberlin , T., 2010. "High Efficiency Waste to Energy Power Plants Combining Municipal Solid Waste and Natural Gas or Ethanol". *In: Proceedings of the 18th annual North American waste-to-energy conference. NAWTEC18*. Florida, USA.

Soares, E. L. S. F., 2011. *Estudo da Caracterização Gravimétrica e Poder Calorífico dos Resíduos Sólidos Urbanos*. Rio de Janeiro, Brazil.

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