ECONOMIC EVALUATION OF THE GENERATION ELECTRICITY OF VINASSE BIOMETHANIZATION

Karina Ribeiro Salomon, karinas@unifei.edu.br
Electo Eduardo Silva Lora, electo@unifei.edu.br
Federal University of Itajubá – UNIFEI / Thermal Systems Study Group – NEST/ IEM - Avenue BPS 1303, CP 50, Itajubá, MG, 37,500-903 CEP - Brazil
Edgar F.Castillo Monroy, efcastil@uis.edu.co
Industrial University of Santander – UIS / Enviromental Research Center – CEIAM - Carrera 27 Calle 9 Ciudad Universitaria. Edif. Antiguo de Petróleos. 2ª Piso. Bucaramanga – Colombia.

Abstract. *The Solid and liquid residues are an alternative source of energy and they also present a significant contribution towards environmental issues. Vinasse is the main sub-product of the sugarcane agro-industry, given that it is a highly polluting effluent whose production reaches sizeable amounts, which makes its transport and elimination difficult. Vinasse results from the distillation and the fermentation of the sugarcane during the alcohol producing process. This study presents an economic analysis regarding the generation of electric energy out of the biogas produced by the vinasse biodigestion process. Among the several technologies and thermodynamic cycles available for the conversion of biogas into electricity, the use of an advanced technology was considered: the gas microturbine. A comparison with internal combustion engines (they are the most commonly used technology for this type of fuel because of their reduced implementation cost and easy maintenance) was also carried out. The most important results will be presented through comparative graphs.*

Keywords*: vinasse, biomethanization, economic analysis.*

1. INTRODUCTION

PROINFA (a program that encourages power production out of alternative sources of energy), which was instituted by Law 10438, April 26th, 2002, and reviewed by Law 10762, November 11th, 2003, aims at diversifying the Brazilian energy matrix and searching for regional solutions using renewable sources of energy through the economic use of the available renewable resources and the applicable technology. (ELETROBRÁS, 2006).

In relation to the country's electric energy supply, PROINFA is an instrument that can complement hydraulic power, responsible for 90% of the power generation in the country, with seasonable energy. The use of new renewable sources will avoid the emission of 2.5 million tons of carbon dioxide/year, increasing the possibilities of businesses of Certifications Emission Reductions (CER's), according to the Kyoto Protocol.

Vinasse, the main sub-product of the sugarcane agro-industry, is a highly polluting effluent whose production reaches sizeable amounts, which makes its transport and elimination difficult. Vinasse results from the distillation and the fermentation of the sugarcane during the alcohol producing process. Vinasse is an interesting source of alternative energy.

Among the several technologies and thermodynamic cycles available to convert biogas into electricity is the use of advanced technologies such as gas microturbines. This study presents the economic analysis of a project that uses the biogas from the anaerobic biodigestion of the vinasse in two different scenarios, including the possibility of selling the Certificates Emission Reduction (carbon credits).

2. VINASSE BIOMETHANIZATION

Among the alternative ways to convert the biomass into secondary energy, one can highlight the anaerobic biodigestion of residues (agro-industrial, residential residues, etc.). This conversion allows the residue to be used as biogas (methane). In fact, the production of methane is only one of the advantages of the anaerobic biodigestion, whose main purpose is the treatment of effluents. The advantages are: high COD reduction, the production of biofertilizers, small production of sludge, low operation and investment costs and the possibility of having decentralized treatment systems. As far as concentrated residues are concerned, vinasse for example, the free production of biogas is high in relation to the remaining residue that is dissolved. In this case, practically speaking, a production of 0.30 to 0.45 l CH_4/g consumed COD is obtained, and the rate of CH4 in the biogas ranges between 55% and 65% CH_4 (the remaining fractions is mainly constituted by CO_2) (Pompemayer, 2000). The technology considered to carry out this study regarding the industrial scale of biodisgestion was the UASB (Upflow Anaerobic Sludge Blanket), which treats effluents with high organic levels, e.g., 30 kg COD/m^3 reactor/day.

The parameters of the biodigestion plant are presented in Tab.1.

Table 1: Parameters of the Biodigestion Plant

Data	Value	Units
Alcohol daily production	500	m^3/day
Vinasse daily production	5,000	m^3/day
Biogas daily production	73,125	Nm^3/day
Biogas composition		
CH_4	60	%
CO_2	40	%
H_2S	>1	%
PCI	21,320	kJ/Nm^3
Biogas density	0.784	kg/Nm^3
LCV	27,193.9	kJ/kg
COD – Biogas conversion factor	0.45	m^3 of biogas/kg CODr
Electric power consumption	230	kWh

2.1. Biogas costs

This economic assessment was carried out based on the analysis regarding the biogas production costs. This cost involves the costs of the biodigestion plant, the annual investment and the O&M, the expense reduction with nitrogenized fertilization due to the fertirrigation of the biodigestion effluent and the amount of biogas produced. Then the following Eq. (1) is obtained:

$$\textbf{Biogas cost} = \frac{\textbf{Biodisgestion plant annual cost – Nitrogenized fertilization annual cost}}{\textbf{Amount of generated Biogas}} \quad (1)$$

Guanoni (2003) presented a study on the cost of applying vinasse and other mineral fertilizers per hectare. In order to carry out that study, the author considered an amount of 183 kg of nitrate per hectare at a cost/value of US$ 57.25 and an ideal vinasse application distance of 40km. Considering a rise in the amount of N (ammoniacal and total) in the effluent of the vinasse biodigestion, the application value of the nitrogenized fertilizer was inserted in the previous equation

3. ECONOMIC EVALUATION MODEL

The economic analysis of electric energy generation projects use a series of indicators (economic parameters) to assess whether they are financially attractive or not. The economic and financial studies aim at assess the economic efficiency and the way the projects may be funded, estimating the costs and the benefits that will come from their execution within the considered planning scenario (Benacouche and Cruz, 1995). According to the same authors there are two main groups containing economic evaluation methods. The methods, deterministic and non-deterministic ones, are also methods that evaluate actual data. They allow the establishment, with absolute certainty, of a single value for each course of action. Methods that use this focus are: invested capital return period methods, cost/revenue rate method, present value method, equivalent annual cost method, internal return rate method and the cost/benefit index method.

The economic evaluation used by this study aims at identifying the economic feasibility of implementing different projects that use biogas that comes from vinasse biodigestion in sugar/alcohol mills. A mill that produces 500 m^3/day of alcohol and 5,000 m^3/day of vinasse, an average capacity among the mills installed in the country, was adopted as the reference mill. For that, two scenarios using different electricity generating technologies out of biogas were analyzed.

The economic-financial evaluation model was set up based on a cash flow that considers the initial investment and the net annual profit within a perspective of project funding of ten years. Based on this cash flow the Internal Return Rate and the Investment Present Net Value are then calculated. The unitary investment cost, the variable and non-variable operational costs, the market price of electric energy and the perspectives of appreciation, the part of the investment that was funded, the interest rate of the funding, the grace periods and the amortization are basic parameters that determine the behavior of the cash flow and of the final results of the project at its initial phase and during its useful life.

Due to several uncertainties regarding the project variables, the sensitivity analysis carried out in the evaluation calculated the internal return rate of the project within a variation range of 50% of the four main variables according to the studied scenarios:

1. Investment Cost;

2. Biogas Cost;
3. Carbon Credit Prices;
4. Electric Energy Sales Price

This study compares the electricity sales price with the value homologated by PROINFA (a program that encourages power production out of alternative sources of energy), launched by the Federal Government in 2003. However, it is greatly important to remember that the government's value refers to the biogas that comes from landfills, where the landfill itself works as a biodigestor. This way, there are no investment cost with the biodigestion plant, only with the collection of the biogas and the power generation.

3.1 Analyzed Scenarios

Based on the use of biogas that comes from the biodisgestion of vinasse with several energy conversion technologies, two scenarios were analyzed:

I) Biodisgetor Set + Internal Combustion Engine (ICE): The use of biogas in combustion engines is widely known from several ongoing experimental studies and projects such as landfills, anaerobic lagoons, etc.

II) Biodigestor Set + Gas Microturbine (MT): The use of biogas in microturbines is growing in the past few years throughout the world. In Brazil, CENBIO was one of the first research centers that developed this type of study (Coelho, 2004). In the United States and Europe, the generation of electricity and heat out of the biogas of microturbines is already a reality.

The general data of the generating plants for the economic assessment were the following in Tab. 2:

Table 2: General data of the generating plants.

Data	Value	Unit	Reference
Plant's generating capacity	5,000	kW	
Operation hours	4,320	Hours/year	
ICE useful life	80,000	Hours	
Microturbine useful life	80,000	Hours	Ingersoll Rand, 2006
ICE efficiency	30	%	Brasmetano, 2007
ICE - annual costs	473,298,9	US$/year	Brasmetano, 2007
MT efficiency	32	%	Ingersoll Rand, 2006
MT -annual costs	1,669,669	US$/year	Thiangco (2006).
Sales price of the electric energy generated with biogas	79.01	US$/MWh	Proinfa,2004
Calculated biogas cost	0.0062	US$/kg	calculated
CER's Values	10	US$/tCO2eq	Pecorá, 2006
Biodigestion plant annualized investment	328,809.15	US$/year	Brasmetano, 2007
Biodigestion plant annualized O&M costs	78,756.07	US$/year	Brasmetano, 2007
Cleanness equipment of biogas	10,525,23	US$/year	USEPA, 1997

3.2 Adopted Premises for the Economic-Financial Evaluation

The main premises and some variables and conditions adopted for this economic evaluation are the following:

- The Minimal Attractiveness Rate is 15% a year;
- The studied period was 10 years according to the funding period. This means that the investor wants the investment return to be such that, for the adopted attractiveness rate, the cash flow net present value is zero in the tenth year. In order words, in the tenth year, the funding has been amortized and the capital has returned;
- The part of the capital funded by the BNDES (National Bank for Social and Economic Development) is 70%; (BNDES, 2007)
- The total funding period is 10 years;
- The grace period is 1 year, given that the project only operates 6 months/year. The BNDES considers that the plant must be producing for the payment of the funding to start;
- The interest rate is 9.25 a year, where the long-term interest rate is 6.85% a year, plus the BNDES spread (1.4% a year), plus the risk spread of the funding agent (1.0 % a year) (BNDES, 2007);
- The adopted Income Tax Rate is 25% a year (CTC, 2004);
- The Constant Amortization System (BNDES, 2007);
- The useful life of the equipment: 18 years;
- Effective hours of production and generation with biogas: 4,320 hours/year;

- The depreciation is linear, along the equipment useful (10%);
- The residual value is not considered, given that the economic analysis does not evaluate the cash flow until the end of the equipment life cycle;
- The adopted exchange rate is R$2.14/US$ (Bank of Brazil, 2007)
- With comparative purposes, the sales value of the energy generated from landfill biogas is established by PROINFA and it is US$79.01/ MWh (Ministry of Mines and Energy, March/2004);
- The cost of the sales with RCE for the generation of electric energy out of sugarcane bagasse is US$108,000 a year, according to the methodology approved by UNFCCC's MDL executive board (Pecorá, 2006).

3.3 Economic-Financial Evaluation Results

The results are presented as cash flow tables and charts for each one of the evaluated scenarios.

Scenarios I and II present which electric energy sales prices are necessary in order to achieve economic feasibility at a Minimum Attractiveness Rate of 15% within a period of 10 years, mandatory for both technologies.

The study regarding the sensitivity analysis the variation of the investment cost, the biogas cost, the electric energy sales price and the CER's sales price is considered for each scenario

- **Scenario I – Biodigestor + Internal Combustion Engine**

The adopted conditions have already been described. Table 3 presents the cash flow of the investment and Tab. 4 shows the necessary electricity sales value in order achieve a rate of 15% a year and obtain a zero Net Present Value.

Table 3: Scenario I cash flow.

Description	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Revenue		1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213
Gross profit		1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213	1812213
General Expenses		134563	134563	134563	134563	134563	134563	134563	134563	134563	1812213
Depreciation		181724	181724	181724	181724	181724	181724	181724	181724	181724	181724
Funding Expenses		3131,6	3131,6	2783,64	2435,69	2087,73	1739,78	1391,82	1043,87	695,911	134563
Profit before the income tax		1492795	1492795	1493143	1493491	1493839	1494187	1494535	1494883	1495231	1495578
Income tax/Social contribution tax		373199	373199	373286	373373	373460	373547	373634	373721	373808	373895
Net Profit after Income Tax		1119596	1119596	1119857	1120118	1120379	1120640	1120901	1121162	1121423	1121684
(+) Depreciation		181724	181724	181724	181724	181724	181724	181724	181724	181724	181724
(-) Amortization		0	376168	376168	376168	376168	376168	376168	376168	376168	376168
(-) Investiments	-4836449										
(+)Funding release	3385514										
CASH FLOW	-1450935	1301320	925152	925413	925674	925935	926196	926457	926717	926978	927239

Table 4: Electric Energy Sales Value Scenario I.

Description		**Year 1 at 10**
Sold Quantity	EE (MWh)	21,600
Price	Product (US$/MWh)	79.01
Annual Income	Product (US$/year)	1,704,212.79
CER's Income	CER's (US$/year)	108,000
Total Income		1,812,212.79

Considering the electric energy sales value homologated by PROINFA, this scenario presents economic feasibility. The results of the economic-financial analysis were favorable to the project, reaching an Internal Return Rate of 74.75%, a Net Present Value of US$ 3,531,631.35 and a investment return period of 3.5 years.

Figure 1 presents the sensitivity analysis for Scenario I.

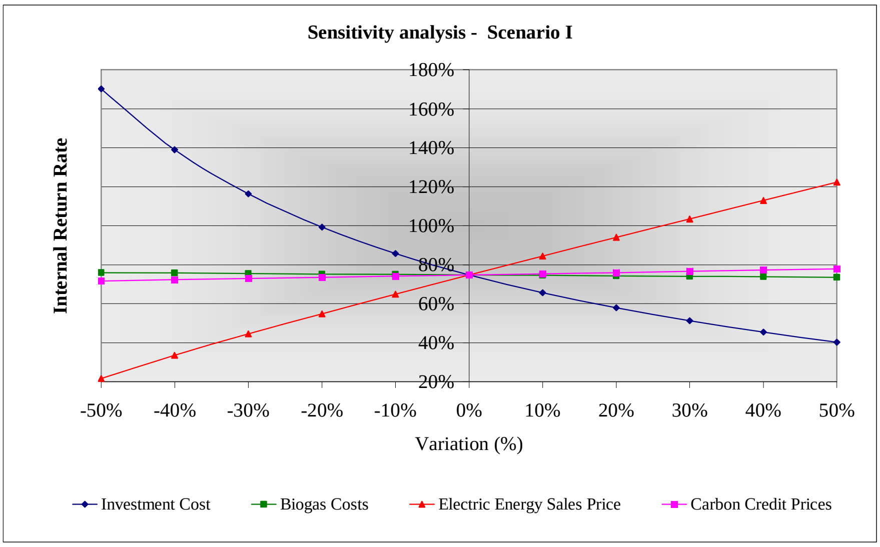

Figure 1: Sensitivity Analysis – Scenario I.

Analyzing the figure above it is clear that the reduction in the investment costs improves the feasibility of the project, making it possible for the electric energy sales value to be reduced.

It is possible to verify that the sales price of the generated electric energy is the price that presents the greatest influence on the economic analysis. However, in general, it can vary up to ±50% and the project will still present feasibility.

- **Scenario II – Biodigestor + Gas Microturbine**

This scenario analyzes the burn of the biogas, produced in the same conditions as the previous scenario, in gas microturbines. The cash flow is presented in Tab. 5 and Tab. 6 presents the electric energy sales value for Scenario II.

Table 5: Cash flow for Scenario II.

Description	0	1	2	3	4	5	6	7	8	9	10
Revenue		2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393
Gross profit		2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393	2040393
General Expenses		1085336	1085336	1085336	1085336	1085336	1085336	1085336	1085336	1085336	1085336
Depreciation		302778	302778	302778	302778	302778	302778	302778	302778	302778	302778
Funding Expenses		4121	4121	3663	3205	2747	2290	1832	1374	916	458
Profit before the income tax		648158	648158	648616	649074	649532	649990	650448	650905	651363	651821
Income tax/Social contribution tax		162039	162039	162154	162268	162383	162497	162612	162726	162841	162955
Net Profit after Income Tax		486118	486118	486462	486805	487149	487492	487836	488179	488522	488866
(+) Depreciation		302778	302778	302778	302778	302778	302778	302778	302778	302778	302778
(-) Amortization		0	495033	495033	495033	495033	495033	495033	495033	495033	495033
(-) Investiments	-6E+06										
(+)Funding release	4E+06										
CASH FLOW	-2E+06	788896	293863	294207	294550	294894	295237	295581	295924	296267	296611

Table 6: Electric Energy Sales Value for Scenario II.

Description		**Year 1 at 10**
Sold Quantity	EE (MWh)	21,600
Price	Product (US$/MWh)	89.46
Sales Income	Product (US$/year)	1,932,392.52
CER's Income	CER's (US$/year)	108,000
Total Income		2,040,392.52

For this scenario, the electric energy sales value that reached the economic feasibility was 89.46 US$/MWh. This figure is 13.38% above the value of the previous scenario. Wit this electricity sales value the Internal Return Rate became the same as the Minimum Attractiveness Rate of 15%, but the investment return period was approximately 11 years. It is important to evaluate not only the financial issues concerning the microturbines, for they also have a huge advantage environmentally speaking, presenting lower atmospheric polluting emissions.

Figure 2 presents the sensitivity analysis for this scenario.

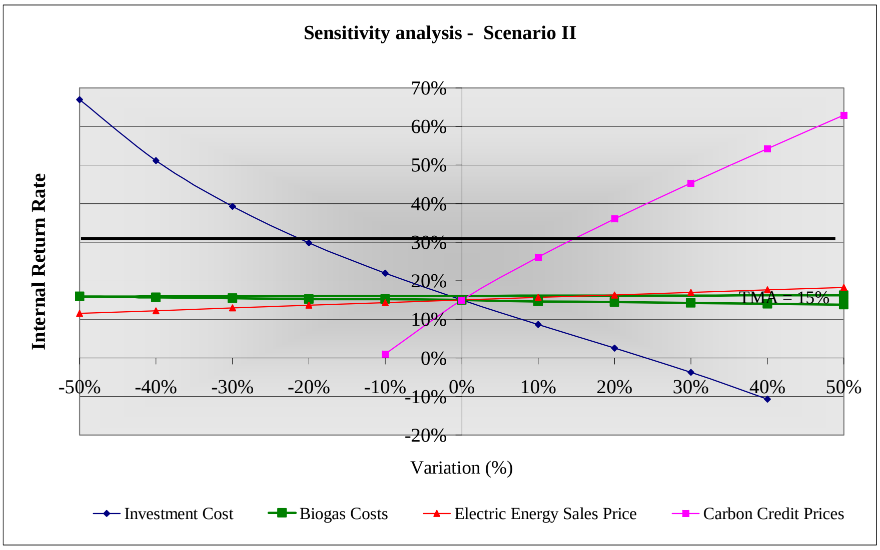

Figure 2: Sensitivity Analysis – Scenario II.

The sensitivity analysis shows us that the electricity sales price cannot present TIR values for variations lower than -10%. In this case, there must be a reduction in the investment costs for the feasibility to be possible under PROINFA’s conditions. For this scenario to achieve economic feasibility with the sales price homologated by PROINFA, a reduction of 22% in the project investment value would be necessary.

3.4 Comparison between scenarios I and II

Figure 3 presents a comparison between the electricity sales values of scenarios I and II, and the normative value homologated by PROINFA.

It is possible to observe that the use of advanced generating technologies is still considerably more onerous, economically speaking.

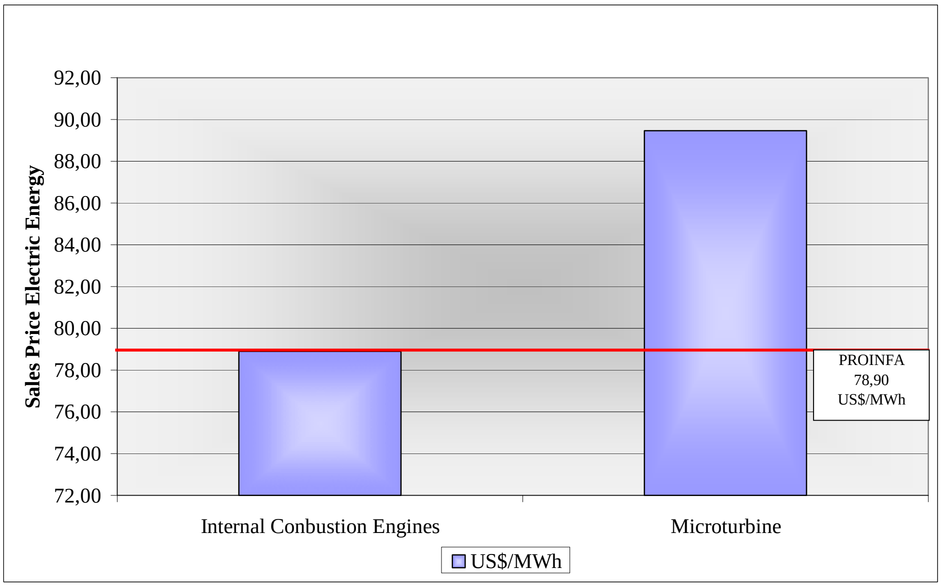

Figure 3: Comparison between the electric energy sales values of scenarios I and II.

4. CONCLUSION

From an economic point of view, it is possible to conclude that the most interesting option to use vinasse as an energy source to generate electric energy is the use of internal combustion engines, once they present lower investment costs. It is important to highlight that the use of microturbines, in spite of having a higher cost and presenting an economic unfavorable analysis, presents environmental advantages regarding the emission of pollutants. Whereas the microturbines release values lower than 9 ppm of NOx, guaranteed by the manufacturer, the engines release about 3000 ppm of NOx.

Generally speaking, the values related to the Certificates Emission Reduction improve the financial analysis.

Although there are economic, technological, and political obstacles, the use of biogas may become interesting for the country within the next years. Most of the advanced generating technologies are imported. It is believed that a greater equipment demand may reduce the investment costs in the future.

5. ACKNOWLEDGEMENTS

The development of this study relied on CNPq’s support through a PhD grant.

6. REFERENCES

BANCO DO BRASIL < http://www.bb.com.br/appbb/portal/index.jsp> Acesso em: mar. 2007.

BANCO NACIONAL DE DESENVOLVIMENTO ECONÔMICO E SOCIAL, BNDES, <http://www.bndes.gov.br/linhas/finem.asp>, Acesso em mar. 2007.

Benakouche,R; Cruz,R. S (1994). “Avaliação Monetária do Meio Ambiente”. Editora Makoron Books do Brasil ltda.

BRASMETANO Indústria e Comércio Ltda, Comunicação Pessoal, 2007.

Casarotto, N. F., “Análise de Investimentos: matemática financeira, engenharia econômica, tomada de decisão, estratégia empresarial”, 8ª Edição, Ed. Atlas, São Paulo, 1998, 458 p.

Coelho, S.T., V, S.M.S.G., Martins, O.S.,Costa, D.F.,Basaglia, F., Bacic, A.C. K., “Instalação e Testes de uma Unidade de Demonstração de Geração de Energia Elétrica a partir de Biogás de Tratamento de Esgoto”, Unicamp, Campinas, 2004, anais em CD-ROM do AgrenerGD.

COPERSUCAR, Centro de Tecnologia Copersucar, Informações Pessoais, 2004.

ELETROBRÁS - Centrais Elétricas Brasileiras S.A. Ministério de Minas e Energia -MME. Disponível no site: <http://www.eletrobras.com.br/EM_Programas_Proinfa/default.asp>. Acesso em: 10 nov. 2006.

Guagnoni, W.C ; Nakao, S. H. ; Ribeiro, M. S . “Investment decisions and environment in the sugar-alcohol sector”. In: Third International Conference of Iberoamerican Academy of Management Proceedings, 2003, São Paulo-Brasil, 2003.

INGERSOLL RAND MICROTURBINE - Disponível: <http://www.ingersollrand.com >Acesso em: 20 out. 2006.

Jeffrey L. Pierce, P.E, “Capstone 30 kw and 60 kw microturbine installations at landfills”, Intermountain CHP - Application Center Workshop, CHP and Bioenergy for Landfills and Wastewater Treatment Plants, Salt Lake City, Utah, 2005.

Pecora, V., “Implantação de uma Unidade Demostrativa de Geração de Energia Elétrica a partir de biogás de estação de tratamento de esgoto residencial da USP – Estudo de Caso”, 2006, 152 p. (Dissertação de Mestrado). Programa Interunidades de Pós Graduação em Energia (PIPGE) da Universidade de São Paulo, São Paulo.

Pompermayer R. S., Paula JR D.R., “Estimativa do potencial brasileiro de produção de biogás através da biodigestão da vinhaça e comparação com outros energéticos”, Anais 3. Encontro de. Energia no Meio Rural Setembro de 2000.

Tiangco, Valentino, Zhang, Z.,Sethi, P., “Results of California’s Biomass R&D Initiatives”, Commission Joint Forum on Biomass, Biofuels, and Bioproducts, Energy Generation Research Office, Energy Research & Development, Division California Energy, California, 2006. Disponível em <http://biomass.ucdavis.edu/pages/forum/3rd/VTiangco.pdf> Acesso em: 05 nov.2006.

USEPA – United States Environmental Protection Agency. “Energy Project Landfill Gas Utilization Software (E-PLUS) User´s Manual”. EPA-30-B-97-006. 1997b.

7. RESPONSIBILITY NOTICE