TECHNO-ECONOMIC ASSESSMENT COMPARATIVE BETWEEN RANKINE CYCLE AND COMBINED CYCLE FOR GENERATION OF ELECTRIC ENERGY IN AMAZONIAN REGION, USING BIOMASS.

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Abstract*. The district of Paragomina located in Amazonian region has about sixty eight sawmills in operation that produce great amount of wood residues that could be used for generation of electric energy to lumbermen's benefit. In this work it is done a comparative techno-economic viability study for biomass conversion (wood residues) in electric energy between the Rankine cycle and combined cycle to verify the profitability of the investment through of the analysis of economic viability and to demonstrate the possibility to supply the demand in the consumption of electric energy and to contribute to avoid a possible lack or rationing that it is already part of the reality of Brazil.*

It is analyzed two power plants of 15MW each. The economic viability analysis was determined using the method of the internal rate of returrn, the method of the net present value and the method of the discounted payback period as economic evaluation measure. Sensitivity analysis of biomass price shows the economic viability of the project. On the other hand constant rise in the petroleum price and the uncertainties about its long term availability is more one reason for researches investments in projects that involve renewable energy.

Keywords*: Rankine cycle, combined cycle, renewable energy, biomass*.

1. Introduction

The use of wood residues for generation of electric energy using the Rankine cycle or the combined cycle, or the use of both technologies, is an alternative that will be able to solve the problem of shortage of electric energy in the Amazonian region. In particular, this work does a techno-economic study of a Rankine cycle and of a combined cycle of 15MW of power each, with the finality of determining the economical viability of these plants of generation of electric energy for the city of Paragominas located in Amazonian region. The generation of electric energy in rural zones of Amazonia, besides contributing with the energetic national matrix, can contribute with the production of work for the population of the region, contributing so, to avoid the rural exodus in the area object of this study. The recent menace of nearby countries to cut the supply of natural gas to Brazil serves of alert for that be intensified researches and investments for generation of electric energy using biomass in steam cycle, as for example, the Rankine cycle that is a technology totally dominated in the country.

The use of the biomass for energy ends provokes emissions of carbonic gas. The advantage in relation to the fossil fuels resides in the fact of those emissions be at maximum equivalent to the amount of carbonic gas captured by the biomass during its growth. The culture and the combustion of the biomass represent, like this, a neutral balance. Should be considered, also, the perspectives of the Protocol of Quioto, establishing the possibilities of development of Clean Development Mechanisms, in partnership with the developed countries that need to reduce its emissions of carbon. This way, the energetic self-sufficiency of this industrial segment (or even the generation of surpluses for the sale) it can be an important opportunity for investments of foreign capital, through this mechanism, in view of the balance of almost null carbon referring its generation of energy. "Recent work (Velazquez, 2000)".

Careful should be taken for biomass be produced in sustainable way, for that the environment, already so attacked, can be preserved. On the other hand the continuous rise of the petroleum price it is an indicative for that be intensified researches investments in renewable energy. At once that Amazonia it is an area rich in biomass, investments in projects of this nature could contribute with energy matrix of Brazil and to reduce the greenhouse effect. As in the Amazonian region exist many areas of degraded lands, such areas could be used for the cultivation of energy forests without a possible competition with food production, turning projects of this nature every time attractive economically. "Recent work (Melo & Lima filho, 2005)".

2. Methodology

The methodology in order to reach the objectives of the analysis techno-economic of this project followed the next steps:

- Revision of the literature on generation of electric energy using biomass.

- Lifting of the quantity of biomass (wood residues) of the region of Paragominas.
- Calculation of the combined cycle power in agreement with the quantity of biomass available in the region.
- Determination of the total costs of the plants of generation of electric energy.
- Analyses of economical viability of the combined cycle and Rankine cycle.
- For the determination of the quantity of biomass (wood residues) produced in the region of Paragominas there was applied a specific questionnaire to the wood enterprises.
- The analysis of economical viability was done using the method of the net present value, the method of the internal rate of return and the method of the discounted payback period.

3. Technical aspects

Rankine cycle is a heat engine with vapor power cycle where the working fluid is commonly the water. The efficiency of a Rankine cycle is usually limited by the working fluid. The cycle consists basically of a boiler where heat is supplied in a isobaric process, a steam turbine where there is a steam isentropic expansion, a condenser where there is a isobaric heat rejection and a feed pump of isentropic compression. The combined-cycle unit combines the Rankine cycle (steam turbine) and Brayton cycle (gas turbine) by using heat recovery boilers to capture the energy in the gas turbine exhaust gases for steam production to supply a steam turbine for generation of work.

4. Conversion technologies of energy

The technologies for the primary conversion of biomass for electricity production are direct combustion, gasification, and pyrolysis. Direct combustion involves the oxidation of biomass with excess air, giving hot flue gases which are used to produce steam in the heat exchange sections of boilers. The steam is used to produce electricity in a Rankine cycle; usually, only electricity is produced in a condensing steam cycle, while electricity and steam are cogenerated in an extracting steam cycle. In air-based gasification cycles, biomass is partially oxidized by substoichiometric amounts of oxygen, normally with steam present, to provide energy for thermal conversion of the remaining biomass to gases and organic vapors. For power production the cleaned gasification product gases will be fed directly to a boiler or to the combustion section of an industrial or aeroderivative turbine. In indirect gasification cycles an external heat source, instead of oxygen, is used to provide the energy for high-temperature steam gasification of the organic fraction of biomass to vapors and gases. In pyrolysis processes, indirect heating is also used to convert biomass to a mixture of gases and organic vapors. Pyrolysis is defined as the thermal destruction of organic materials in the absence of oxygen. "Recent work Craig et al. (1996)".

5. Economic Measures

The economic measures can be used to compare alternative investments of project." Recent work (Short, 1995)".

5.1. Net Present Value (NPV)

The net present value of project is one way of examining costs (cash out flows) and revenue (cash inflow) together. "Recent work (Palm and Qayum, 1985)".The Eq. (1) bellow can express the net present value.

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{1}$$

n = analysis year
NPV = net present value
F_n = net cash flow in year n
N = analysis period
d = annual discount rate

5.2. Internal Rate of Return (IRR)

The internal rate of return (IRR) for an investment that has a series of future cash flows (F_0,F_1,...F_n) is the rate that sets the NPV of the cash flow equal to zero. The IRR can be expressed by Eq. (2) bellow:

$$0 = NPV = \sum_{n=0}^{N} \left[F_n \div (1+d)^n \right] \tag{2}$$

NPV = net present value of the capital investment
F_n = cash flows received at time n
d = rate that equates the present value of positive and negative cash flows when used as a discount rate

5.3. Discounted Payback Period (DPB)

The discounted payback period is the number of the year necessary to recover the project cost of an investment while accounting for the time value of money. DPB is recommended when risk is an (i.e., significant uncertainties are present) because DPB allows for a quick assessment of the duration during which an investor's capital is at risk. "Recent work (Short, 1995)". DPB is determined by Eq.(3).

$$UCFR = [d(1 + d)^n]]/[(1 + d)^n – 1)] \quad (3)$$

UCFR = uniform capital recovery factor
d = discount rate
n = analysis year

6. Economic analysis

6.1. Rankine cycle cost estimation

The Rankine cost plant estimation was determined through the equations shown in tab. (1). Purchased equipment costs PE (€) have been evaluated on the basis of correlations resulting from interpolation of experimental and literature data having the following general expression PE = aS^b, where a and b are specific coefficients, while S is a characteristic equipment parameter. In particular, equipment costs have been parameterized in function of the plant net electric power output W_{NE} (MW), the power generated by steam cycle WST (MW), the gas turbine power WGT (KW), the biomass flow rate $M_{G/CC}$ (kg h^{-1}) feeding the gasifier, the steam flow rate produced by heat recovery steam generator MHRSG (kg h^{-1}). The adopted correlations for purchased equipment costs evaluation are based in Tab. 1. The reliability of such equations has been verified by resorting to a comparison between calculated costs and actual cost data obtained from vendors. "Recent work Caputo et al. (2004)". The monetary values of the table are in Euro that were converted for dollar using the rate of exchange of the month of April 2005, 1€ = 1,34 US$. Substituting W_{NE} = 15MW in tab. 1, the total plant cost is estimeted.

Table 1. The adopted purchased equipment correlation.

Plant sections	PE correlation(€) C/ST
Boiler	$1.340.000 W_{NE}^{0.694}$
Steam turbine	$633.000\ W_{NE}^{0.398}$
Condenser	$398.000\ W_{NE}^{0.333}$
Heat exchanger (cooling water)	$51.500\ W_{NE}^{0.5129}$
Alternator	$138.300\ W_{NE}^{0.6107}$
Fans	$35.300\ W_{NE}^{0.3139}$
Condensate extraction pumps	$9.000\ W_{NE}^{0.4425}$
Feed pumps	$35.000\ W_{NE}^{0.6107}$
Pumps	$28.000\ W_{NE}^{0.5575}$
NOx and SOx removal equipments	$126.000\ W_{NE}^{0.5575}$

C/ST(Combustion/steam). PE (Purchased Equipment). W_{NE} (Net Power -MW).

6.2. Combined cycle cost estimation

The combined cycle cost estimation was determined based in the work developed for the U.S Environmental Protection Agency-EPA (Turnure et all, 1995) what it invested in a study to value the penetration at the market of several technologies of plants of generation of electric energy and his effects for the emission of carbon at the atmosphere. In this study it is done a estimate analysis of costs and efficiency of power plants of generation of energy using biomass, coal and natural gas. Given the disparity of opinion in the published literature, a panel consisting of representatives from NREL, the Electric Power Research Institute (EPRI), the Princeton Center for Energy and Environmental Studies, EPA, the United State Department of Agriculture (USDA), and the Colorado School of Mines was convened to arrive at a consensus position. The result of this consensus shows that for combined cycles using biomass with industrial turbines of low and high technology, the specific cost of the plant varies between 1.230 US$/KW and 1.488 US$/KW and the efficiency between 39,4 % and 36,3 % (Craig et all, 1996). The estimate cost of the plant is given by the equation (4), bellow. "Recent work"(Correa Neto, 2000).

6.3. Installation cost (IC)

Installation cost (USS/KW) = 3.315,1x IP $^{-0,2227}$ (4)

Where Installed power (IP) is give in MW.

IC =3.315,1x 15 $^{-0,2227}$ = 1.813,77 US$ / KW

6.4. Efficiency of the plant

Efficiency (%) = 0,3538 x IP^{0,041} (5)

Efficiency (%) = 0,3538*15^{0,041} = 0,40 or 40%

6.5. Total investment in the plant (I)

I = 1000 x IP x IC (6)

I = 1000 x 15 x 1813,77 = US$ 27.206.480,82

6.6. Biomass consumption

Is determined trough the Eq. (7), bellow:

$$M = \frac{W_{NE} \times 3600 \times OH}{\eta \times LHV} \quad (7)$$

M = biomass consumption (Ton / day)
W_{NE} = net power (MW)

OH = hours

η = efficiency
LHV = low heating value (KJ Kg^{-1})

6.7. Cost of energy

Is determined by Eq. (8), bellow. “Recente work (Reis, 2003)”.

$$COE = C_{\cos t} + C_{o\&m} + B_{\cos t} \quad (8)$$

COE = cost of energy (US$/MWh)
C_{Cost} = cost of capital (US$/MWh)
$C_{0\&M}$ = operation and maintenance costs (US$/MWh)
B_{cost} = biomass cost (US$/MWh)

6.8. Cost of capital

The cost of capital is an important factor in the economic analysis of firm, utilities, and other business entities. The cost of capital has that to be recovered by the investor to warrant his investment. Higher returns attract increased investment, whereas lower returns discourage investment and lead to inadequate supplies and sources of investment capital. “Recent work (Short, 1995)”. The cost of capital is calculated by Eq. (9) bellow.

C_{Cost} = 1000 x W_{NE} x S_{Cost} x UFCR (9)

W_{NE} = net power (MW)
S_{Cost} = specific cost of the plant (US$/KW)
UCFR = uniform capital recovery factor

6.9. Operation and maintenance costs

There is no absolute standard as to which costs are included in O&M costs. For mature technologies, estimation of future O&M costs is generally based on historical performance. For mature conventional fossil fuel system, it is often assumed that annual O&M costs will equal about 1% to 2% of the system’s capital initial costs. However, for for conservation and renewable energy systems that are typically in the early stages of technical and market development , O&M costs are more difficult to estimate. “Recent work (Short, 1995)”. In this work is adopted 1,5% of the system’s capital initial costs based on “Caputo et al.(2004)”. The O&M costs is calculated by Eq.(10).

$C_{O\&M} = 1000 \times F_{O\&M} \times W_{NE} \times S_{Cost}$ (10)

$F_{O\&M}$ = operation and maintenance fator

6.10. Biomass cost

It was determined by Eq. (11), that follows:

$$B_{cost} = \frac{B_{price} \times 860}{LHV \times \eta} \quad (11)$$

B_{cost} = biomass cost (US$/MWh)

B_{price} = biomass price (US$/Ton)

LH =low heating value (KJ Kg^{-1})

η = efficiency (%)

6.11. Administration costs

According to literature data, the operator number has varied in the range 12-36 for project of this nature. "Recent work Caputo et al. (2004)". In this project is considered 12 employees, representing the cost shown in the cash flow in the end of this paper. The value is considered with 60% of tax.

7. Premises considered for calculations

For determination of the parameters above and of the cash flow in this work, is considered the following premises:

- Rankine Cycle and combined Power Plant:15MW
- Standardizing value for April 2005 for generation of energy through biomass: US$ 59,41. "Recent work (Tradener)" .
- Discount Rate: 12% annual.
- Income Tax: 33%.
- Taxes on the gross revenue: 0,0403.
- Biomass price: 25 US$/Ton (1,7US$/GJ). Recent work (ebmm-UFPa).
- Biomass low heating value(LHV) with an average moisture content of 30%: 14.630KJ/Kg.
- Exchange Rate for April , 2005: 1€ = 1,34US$.
- Hours of annual plant operation: 8048 hours.
- Efficiency of the cycle: 25%.
- Duration of the plant: 25 years. "Recent work (Short,1995)".
- Operation and maintenance factor : 0,015. "Recent work Caputo et al.(2004)".
- Depreciation: 25 year. "Recen work (Short,1995)".
- Specific mass of the drought wood: 725Kg/m^3. "Recent work (Nogueira & Silva Lora,2003)".
- Available Biomassa: 470 Ton / daily.

8. Results and discussion

The table 2, summarizes the values calculated to Rankine and combined cycle. It is very clear that Rankine cycle shows more economical attractiveness agreement with the economic measures. Can be observed that the internal return rate has a superior value then the discount rate to Rankine cycle while that to combined cycle the internal rate of return is smaller than the discount rate adopted in this work. The net present value is positive to Rankine cycle and negative to combined cycle showing, this way, that the combined cycle is not economically viable. The time to return of the investment it is nine years to Rankine cycle and eighteen years to combined cycle what turns the investment in the combined cycle yet lass attractive economically. Regarding to the costs of investment, the tab.2, display that cost of energy, cost of capital , operation and maintenance costs and consequently specific cost of the plant for Rankine cycle has a value inferior than the results to combined cycle what justifies, in this work, investment in this plant.

Table 2. Results for Rankine and Combined cycle

	RANKINE CYCLE	COMBINED CYCLE
Power Plant	15MW	15MW
efficience	25%	40%
Biomass consumption	355Ton/day	225Ton/day
Net Presen Value	US$ 1.377.686,05	US$ -4.262.241,40
Internal Rate of return	13,12%	9,61%
Pay back	9 years	18 years
Specific cost of the plant	1.213,86 US$/KW	1.813,77US$/KW
Cost of energy	48,01 US$/MWh	54,25 US$/MWh
Cost of capital	20,97 US$/MWh	31,34 US$/MWh
Operation and maintenance costs	2,47 US$/MWh	7,37 US$/MWh
Biomass cost	24,57 US$/MWh	15,54 US$/MWh
Annual gross revenue	US$ 6.576.022,65	US$ 6.575.939,65
Annual net revenue	US$ 6.311.008,94	US$ 6.310.929,28

8.1. Sensitivity analysis for Rankine cycle: Impact of biomass cost

In this analysis was verified the value of the internal rate of return and the value of the net present value varying the biomass price of 0% up to 12%, the result is shown in the figure below. It is observed that values above 10% in the biomass price turns the project unviable economically because the internal return rate from this value becomes negative as show the figure. Can be observed that while increase the biomass price the net present value becomes each time more negative and the project becomes without economically attractiveness. See fig.1 and fig. 2.

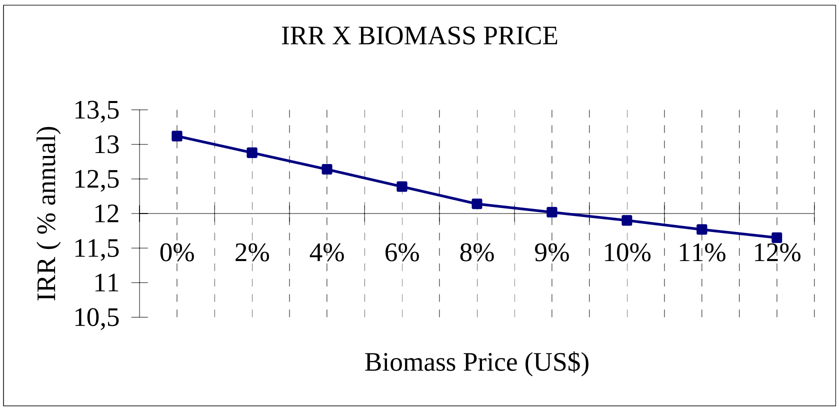

Figura 1. Internal Rate of return in function of variation of the biomass price.

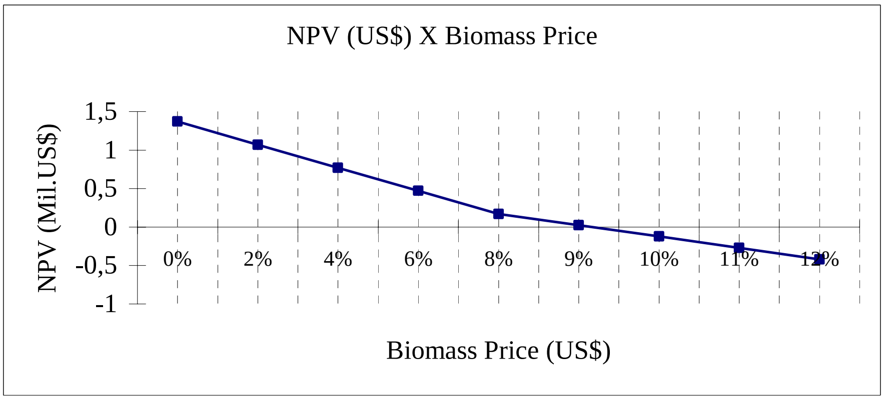

Figure 2. Net present Value in function of the variation of the biomass price.

8.2. Sensitivity analysis reducing the cost of investment up to 30%

A plant of generation of energy using national equipment can have a reduction of up to 30% in its total investment. “Recent work (Tolmasquim, 2003)”. Based on this information was made a sensitivity analysis reducing the cost of generation to the combined cycle up to 30%. The figure 3, shows result of analyses. To the Proportion that reducing the plant price, the project becomes more economically attractiveness. It is clear that from 15 per cent of reduction in the cost of investment the internal rate of return becomes positive and the project becomes viable economically agreement with the fig. 3.

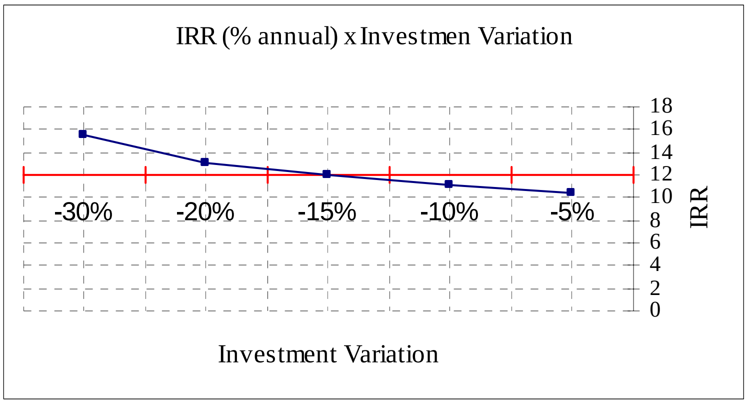

Figure 3. Values to combined cycle reducing investment up to 30%

9. Cash Flow

The cash flow facilitates the visualization of a financial problem involving revenues and expenses that happen in different instants from the time. “Recent work (Casarotto Filho, 2000)”.The cash flow that follows shows clearly the financial results for Rankine and combined cycle plant. The net present value, the internal rate of return and the discounted payback are shown in color predominant yellow for biomass price 25US$/Ton. The Tab. 3 and Tab.4 show the cash flow of the project.

Table 3.Cash flow to Rankine cycle

YEARS	AG R (1)	TRIBUTES (2) 0,0403 X AGR	ANR (3) (1) – (2)	CO&M (4)	BIOMASS COST (5)	ADM COST (6)
0	-----------------	---------------	-----------------	---------------	-----------------	------------
1	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00
2	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00
3	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00
4	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00
5	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00
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25	$6.576.022,65	$265.013,71	$6.311.008,94	$273.119,31	$2.719.754,21	$82.080,00

(Table 3. Cont.)

YEARS	DEPRECIATION (7)	NPBIT (8) (3)-(4)-(5)-(6)	I T (9)	NPAIT (10) (8) – (9)	FINAL BALANCE (10) + (7)
0	---------------	-------------	--------------	-------------	($18.207.954,27)
1	$728..318,17	$2.507.737,24	$0,00	$2.507.737,24	$3.236.055,42
2	$728..318,17	$2.507.737,24	($827.553,29)	$1.680.183,95	$2.408.502,12
3	$728..318,17	$2.507.737,24	($827.553,29)	$1.680.183,95	$2.408.502,12
4	$728..318,17	$2.507.737,24	($827.553,29)	$1.680.183,95	$2.408.502,12
5	$728..318,17	$2.507.737,24	($827.553,29)	$1.680.183,95	$2.408.502,12
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
25	$728..318,17	$2.507.737,24	($827.553,29)	$1.680.183,95	$2.408.502,12
26			($827.553,29)	($827.553,29)	($827.553,29)

IRR (% annual)	13,12%
PAYBACK(years)	9,48
NPV(Mil. US$)	$1.377.686,05

Table 4. Cash flow to combined cycle.

ANOS	AG R	TRIBUTES	ANR	CO&M	BIOMASS COST	ADM COST
0						
1	$6.575.939,65	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
2	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
3	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
4	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
5	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
6	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
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23	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
24	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00
25	$7.718.067,05	$265.010,37	$6.310.929,28	$816.194,42	$1.719.856,04	$82.080,00

(Table 4. Cont.)

YEARS	DEPRECIATION	NPBIT	I T	NPAIT	FINAL BALANCE
0					($27.206.480,82)
1	$1.088.259,23	$2.604.539,59	$0,00	$2.604.539,59	$3.692.798,82
2	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
3	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
4	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
5	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
6	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
23	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
24	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
25	$1.088.259,23	$2.604.539,59	-$859.498,06	$1.745.041,52	$2.833.300,76
26			-$859.498,06	-$859.498,06	($859.498,06)

NPV(Mil. US$)	($4.262.241,40)
IRR (% annual)	9,61%
PAYBACK (years)	18

AGR = Annual gross revenue (US$)
ANR = Annual net revenue (US$)
NPBTI = Net profit before income tax (US$)
NPAIT = Net profit after income tax (US$)
IT = Income tax
FB = Final balance (US$)
NPV = Net Present Value
IRR = Internal Rate of Return

10. Conclusion

With the analysis done can conclude that the Rankine plant is viable economically in relation the combined cycle because the economic measures show that the internal rate of return, the net present value and the time of return of the capital indicate the economic viability of the Rankine plant are results that proof the economical superiority of the Rankine power plant. Considering that Amazonian region is abundant in biomass, the biomass price around 20US$/Ton (1,36US$/GJ) is possible of being practiced that turns the project more attractive economically. The table 2, show the result for both plants and show the advantage of the Rankine plant power. The Rankine cycle is a technology fully dominated and this is more one reason for choosing this power plant for generation of energy in Brazil.

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