TECHNOECONOMIC EVALUATION OF GASIFICATION TECHNOLOGIES FOR SMALL SCALE ELECTRICITY GENERATION FROM BIOMASS

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ABSTRACT

The results of technical and economical evaluation for three different systems of low capacity (45 kWe) for electricity generation to supply isolated communities are presented: a diesel generator and two biomass gasification system, including the microturbines option. In the first part of the paper the model is evaluated for a wide range of the main parameters and a sensitivity analysis is carried out. Load factor resulted the more influential factor. In the second part some results are shown specifically for the Brazilian conditions.

Keywords: Technoeconomic evaluation, gasification, biomass, electricity generation.

INTRODUCTION

Although Brazilian urban regions are almost all electrified, in the countryside more than a million isolated communities are not supplied by electricity. Trying to tackle this situation the Ministry of Mines and Energy is carrying out an electrification program for these communities using renewable energy, mainly through photovoltaics panels. It is well known that one of the most important energy resource in Brazil is biomass, mainly as agro-forest residues, energy crops and garbage, but up to now high cost and uncertainty about feasibility of available technologies are obstacles to introduce low capacity biomass energy systems in this context. However, recent advances in energy crops productivity and biomass conversion technologies have renewed the interest on the biomass alternative.

Gas microturbines presenting low capital cost and easy operation have good perspectives for low scale decentralized electricity generation. Gas microturbines from 25 to 100 kW capacity have been appeared in the market since 1997 and were initially built from turbocompressors parts. Equipment suppliers such as Elliot Energy Systems, Capstone and Allied Signal Aerospace have been proposing this equipment for fuels such as natural gas and diesel, but intensive research is being carried out to adapt these microturbines aiming to use low calorific value gas from biomass gasification.

A paper published in the Fortune magazine about microturbines market potential (Brown, 1996) forecasts that the increasing production of such equipment for hybrid automobiles will reduce considerably their cost. So, a 24 kWe turbine, costing currently 500 $/kWe could reach 85 $/kWe. However, for utilities costs of about 250 $/kWe could be sufficiently attractive. In the same paper a commentary is made on the great future possibilities of this technology for decentralized electricity generation in developing countries. In fact, considering the difficulties for funding large thermal and the continuous increase of electricity demand, more and more the decentralized low scale electricity generation is attractive for developing countries.

Some studies about feasibility of small scale biomass electricity generation systems have been carried out. The National Resources Institute in Great Britain developed a project aimed to analyze the potential of energy crops conversion for electricity production in rural areas in the range of 100-300 kWe (Hollindale et alli, 1996). Conversion routes included in this project were: small steam engines, gasifier/internal combustion engine, bio-oils fueled internal combustion engines and indirect heating gas turbines. Two scenarios were analyzed: (1) integrated farm, where agriculture and electricity generation components are considered as one system and (2) independent process, where biomass is bought in the market. The generation cost varies in the range 0,12-0,25 $/kWh, in both scenarios resulting the lower value to the indirect heating gas turbine option.

Solantausta et alli (1996) indicate that with small scale electricity generation it is practically impossible to reach generation cost levels competitive with large power plants, because in small installations the operational costs (fuel and labor) are very high. Nevertheless, these evaluations are generally carried out assuming biomass and labor prices typical for developed countries.

Another perspective for small scale electricity generation is the utilization of biomass furnaces coupled with Stirling engines. In Denmark two sets of 30 and 150 kWe are being tested. It is expected to reach a cycle efficiency of 22 and 26 %, respectively (Carlsen, 1996). The SINTEF from Norway is planning to test an 15 kWe Stirling engine coupled with a biomass gasifier and a gas combustor (Fossum, 1997).

In the paper the results of the technical and economical evaluation of different systems for low scale electricity generation, including microturbines, are presented. The model is evaluated for a wide range of parameters and a sensitivity analysis is carried out. Some specific results for the Brazilian conditions are shown as well.

GENERAL EVALUATION OF SMALL SCALE ELECTRICITY GENERATION TECHNOLOGIES.

Three technologies are considered in this study:

- A diesel engine, fueled with conventional diesel oil (MCI),
- A biomass gasifier coupled with an internal combustion engine (G/MCI),
- A gasifier/gas microturbine set (G/MT).

Taking into account the typical applications, the capacity of the power plant to be analyzed was 45 kWe and biomass price ranged from 0 to 3 $/GJ. Other considerations done during calculations are presented as follows, afterwards evaluated by a sensitivity analysis:

- Annual operation - 8000 hours
- Interest rate - 6 %
- Load factor - 0,60
- Biomass calorific value - 14 MJ/kg
- Diesel price - 0,39 $/liter
- The internal combustion engine losses due to the operation with gasification gas was supposed to be 30 % of capacity, and the diesel substitution by gasification gas was 75 % (expressed as heat).
- The gas microturbine is supposed to maintain its nominal efficiency and capacity during the operation with gasification gas.

For the microturbine option the Elliot Energy Systems 45 kWe model was chosen to be considered in calculations. The main parameters of this turbine are presented in Table 1.

Table 1 Elliot Energy Systems 45 kWe parameters.

Parameter	Value
Power	45 kWe at 15 ^{o}C and sea level
Efficiency	30 %
Exhaust gas temperature (after recuperator)	315 ^{o}C
Gas inlet turbine temperature	1010 ^{o}C
Weight	Less than 136 kg

Figure 1 shows the dependence between the generation cost and the biomass fuel price for the considered technologies. For a biomass cost of 3 $/GJ the generation cost of the G/MCI and the G/MT are the same. For biomass prices less than 2 $/GJ the generation cost of the G/MT set is considerable lower. According to Martin et alli (1995) biomass fuel prices in the range 3-5 ECU/GJ can not be considered as commercially competitive.

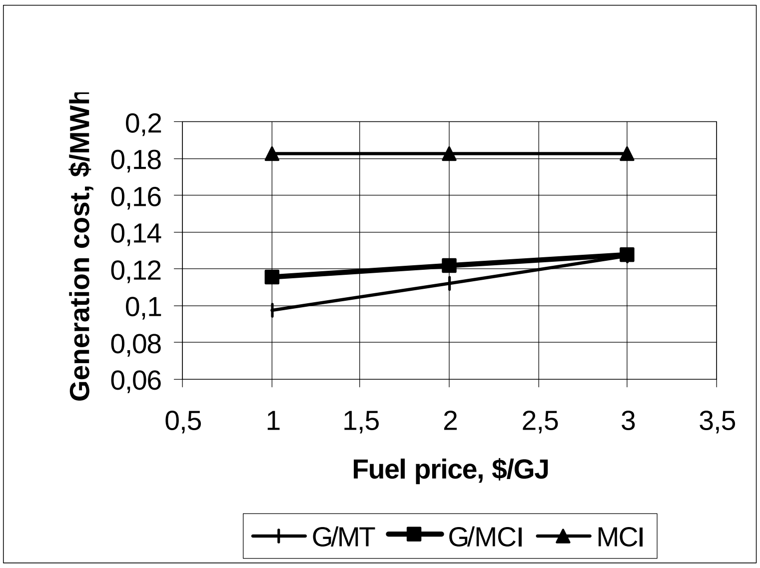

Figure 1- Dependence of the generation cost from biomass fuel price (load factor 0,60).

Figure 2 shows the influence of level of utilization on the generation cost for different biomass prices. It shows clearly that the increase in generation cost is steeper for the low values of load factor, reaching 0,25-0,30 $/kWh for an availability of 0,2. To keep the generation cost below 0,1 $/kWh is necessary to have load factor values greater than 0,7, but it should be stressed that this variable depends basically on the user side, therefore it is not alterable easily.

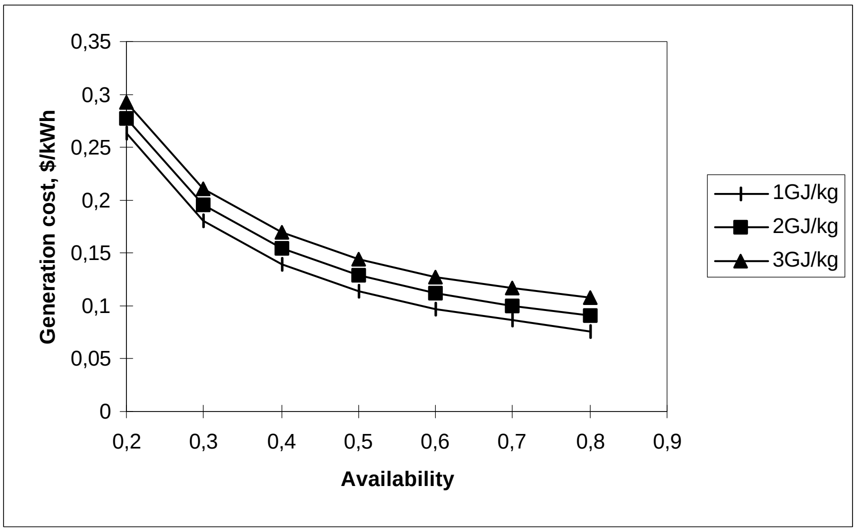

Figure 2 Influence of availability and biomass fuel price on generation cost for the G/MT case.

As the expected level of utilization is generally low, the ratio (operational cost/total cost) tends to decrease for low capacity generation systems. So another important parameter to evaluate is the capital investment, in $/kWe. A value of about 1000 $/kWe can be considered a target to reach. Figure 3 shows the influence of the capital investment value on the generation cost. In this figure capital investment is expressed as relative investment - the relationship between actual investment in \$/kWe and the "target" of 1000 \$/kWe. For a 45 kWe G/MT and a microturbine cost of about US\$ 15000, the gasifier cost must be lower than US\$ 30000. So, for this systems is necessary to design a simple, efficient and reliable gasifier. As shown in figure 3 for the G/MT system and 0,60 as load factor, generation costs lower than 0,1 \$/kWh are achieved for a relative investment ranging from 0,7 to 0,8.

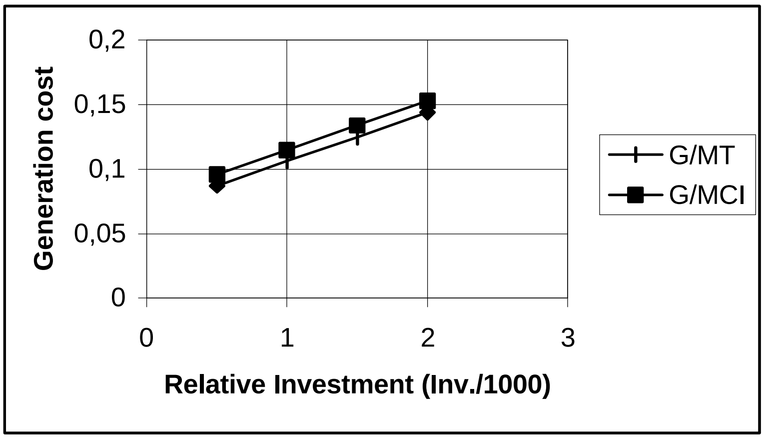

Figure 3 Influence of the specific investment on the generation cost for the G/MT case load (factor availability 0,60, biomass price 2 \$/GJ).

In many countries, including Brazil, diesel price is subsidized, according a controversial policy which distorts the energy costs. Thus, it is interesting to evaluate the influence of the ratio between diesel and biomass prices (D/B) and the generation cost for the three analyzed technologies. It is considered that the diesel price changes in the range 0,39-1,0 \$/l. As presented in Figure 4, it is clear that for D/B values near 2,5 the power generation cost is the same for diesel and biomass gasification based technologies. For diesel prices currently adopted in the Developing Countries (D/B ≈ 10-15) diesel electricity generation is considerable more expensive.

Table 2 shows the results of the model sensitivity analysis. It can be concluded that for biomass gasification systems load factor is far the most influential factor, followed by capital investment and labor. For the diesel generation the same parameter is also the main influencing factor followed by diesel price and engine efficiency.

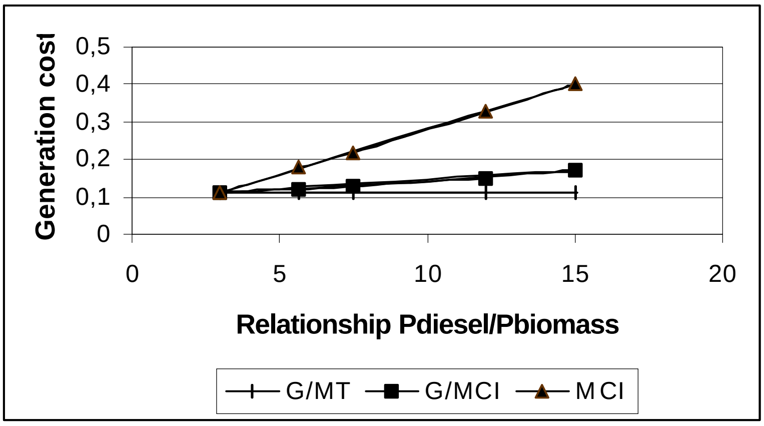

Figure 4 Dependence between the generation cost and the diesel/biomass prices ratio (D/B) (load factor 0,60 and biomass price 2 $/GJ)

Table 2- Sensitivity analysis: impact on generation cost.

Parameter	Variation range	G/MT	G/MCI	MCI
Gasifier Efficiency	+ 20 % - 20 %	-4,6 % +6,4 %	-1,6 % +2,4 %	- -
Engine or Turbine Efficiency,	+ 20 % - 20 %	-4,9 % +6,6 %	-4,1 % +4,9 %	-14,3 +14,7
Labor	+ 20 % - 20 %	+6,4 % -7,3 %	+5,7 % -6,5 %	+4,4 % -3,8 %
Investment	+ 20 % - 20 %	+6,4 % -7,3 %	+6,5 % -6,5 %	+1,1 % -0,5 %
Biomass Price	+ 20 % - 20 %	+4,6 % -5,5 %	+1,6 % -1,6 %	- -
Diesel Price	+ 20 % - 20 %	- -	+4,1 % -4,1 %	+14,7 % -14,7 %
Load factor	+ 20 % - 20 %	-12,8 % +17,4 %	-13,9 % +17,2 %	-16,4 % +25,6 %

SMALL SCALE ELECTRICITY GENERATION FOR BRAZILIAN CONDITIONS

<u>Biomass cost and yields in Brazil</u>

According to data published by Couto et alli (1993) the plantation cost of eucalyptus in the Brazilian States of São Paulo and Minas Gerais varies in the range from 0,54 to 2,19, being the mean value 1,16 $/GJ. Mimosa (Bracatinga) plantation cost are much lower and reach in the Paraná State 0,33 $/GJ (Couto et alli (1993). Logging and transport cost varies from 51 to 70 % of total delivered wood cost (Perlack et alli, 1995). So, final cost of eucalyptus must be in the range 2,2-3,6 $/GJ. An estimate of average cost of eucalyptus in Northeast Brazil shows a mean value of 2,11 $/GJ (Carpentieri et alli, 1994). Data from the Electricity Company of the Minas Gerais State CEMIG have an average price value of 2,19 $/GJ (CEMIG, 1997). It is assumed a biomass price of 2,3 $/GJ as an average value for present Brazilian conditions.

Resulting basically from forestry practice improvements, from 1970 to 1993 the productivity of the large scale Brazilian plantations increased in some cases from 35 m^3st/ha to 70 m^3st/ha (Perlack et alli, 1995), m^3st meaning cubic meter as round wood apparent volume. Figure 5 presents the average yield values of energy forest from eucalyptus, pinus, Acacia and Araucaria in Brazil (Associação Nacional de Fabricantes de Papel e Celulose, 1994).

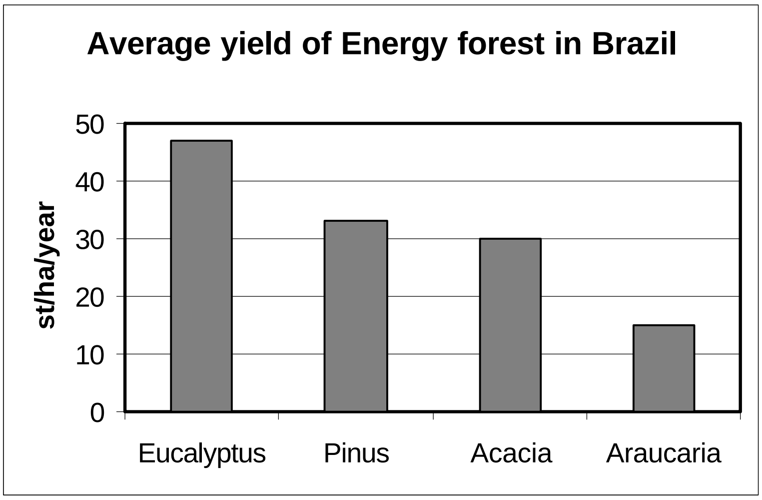

Figure 5- Average yield of different forest species in Brazil (Associação Nacional de Fabricantes de Papel e Celulose, 1994).

Results of the techno-economical analysis for Brazilian conditions.

Table 3 presents the basic data adopted in the technoeconomical analysis carried out to evaluate small scale electricity generation in the Brazilian conditions. In Table 4 are presented the main results of these calculations. In Figure 6 is shown the composition of the total annual cost of generated electricity for the case G/MT for Brazilian conditions. It is clear that investment and salaries are the components with greater specific weight.

Table 3- Data for the technoeconomical analysis of small scale electricity generation technologies.

Data	Units	MCI	G/MCI	G/MT
Gasifier cost	$	-	32500	32500
Engine or gas turbine cost	$	9000	15000	13500
Gas cleaning system cost	$	-	6500	6500
Engine or microturbine capacity	kW	45	75	45
Gasifier efficiency	-	-	0,8	0,8
Engine or microturbine efficiency	-	-	-	0,3
Biomass calorific value	kJ/kg	-	13000	13000
Diesel price	$/l	0,47	0,47	-
Availability factor	-	0,6	0,6	0,6
O & M tax	1/year	0,022	0,022	0,022
Interest tax	1/year	0,06	0,06	0,06
Average yield of eucalyptus	m^3st/ha.year	-	47	47

Table 4- Results of the technoeconomical analysis of small scale electricity generation technologies for present Brazilian conditions.

Calculated parameter	Symbol	MCI	G/MCI	G/MT
Total Investment	$	9000,0	54000,0	52500,0
Biomass fuel consumption	kg/hour	-	19,5	51,9
Diesel consumption	kg/hour	9,5	2,5	-
Annual fuel cost	$/year	35605,4	8644,5	8300,0
Labor annual cost	$/year	8300,0	8300,0	8300,0
Total annual cost	$/year	45543,4	26772,5	24449,0
Generation cost	$/kWh	0,21	0,12	0,11
Average area of planted eucalyptus required	ha	-	1,99	5,33

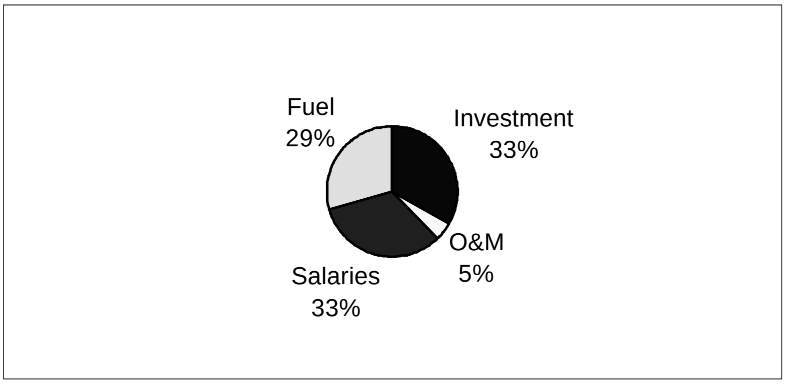

Figure 6 Share of the total annual cost (G/MT technology, load factor 0,65).

CONCLUSIONS

From the studied cases, it was possible to draw the following main conclusions:

1 For a biomass price of 3 $/GJ, the G/MCI and G/MT systems generation costs are the same. For biomass prices lower than 2 $/GJ the G/MT system generation cost is considerable lower.

2 For a ratio between diesel and biomass prices (D/B) near 2,5 the generation cost is the same for diesel and biomass gasification based technologies.

3 For Brazilian conditions (forest productivity and biomass prices) the G/MT technology has the lower generation cost (0,11 $/kWh).

4 For biomass gasification systems, the load factor is the more influential factor, followed by capital investment and labor.

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