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COGENERATION IN BRAZILIAN PULP AND PAPER INDUSTRY FROM BIOMASS-ORIGIN TO REDUCE CO_2 EMISSIONS

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Abstract

For developing countries, electricity cogeneration is quite important due to economic difficulties of local utilities, because it avoids the investments for the construction of new plants.

Moreover, electricity generation from biomass origin allows significant reductions in CO_2 emissions because even hydroelectric power plants (90% of Brazilian generation) also release greenhouse gases [1], although much less than fossil fuels.

In Brazil, biomass-origin cogeneration occurs mostly in sugar and alcohol industries [2]. However, there is a high potential in pulp and paper industries, from process by-products, using both conventional and advanced technologies (biomass-fired gasifier/gas turbine systems) as evaluated in this paper.

Pulp and paper segment is in third place among the highest energy consumers in Brazilian industrial sector and most of its electricity is purchased from the grid. Fuel oil consumption is also quite high due to the low prices of fuel oil.

More efficient technologies could allow a surplus electricity, moreover the replacement of fossil fuels. In this paper, existing data [3] are adapted to Brazilian plants and results show that electricity cogeneration could be more than twice the current values.

Although environmental benefits are evident, the main difficulties remain in economic aspects because of low prices of electricity for industrial sector. Also, proposed price to purchase electricity from self-producers is not attractive. Therefore, more efficient technologies are not economically competitive and special mechanisms are necessary to improve cogeneration in Brazil.

Keywords: biomass, cogeneration, emissions, energy, environment, gasifier, gas turbine, pulp-paper industry.

1 Introduction

The consequences of carbon dioxide emissions on greenhouse effect are evident, despite the controversy among the specialists. Recent phenomena regarding climate change over the world, as well as the melting of polar ice, reinforce the need of controlling carbon emissions, as already stated in ECO'92 Conference, in Rio de Janeiro. Although most emissions come from developed countries, also the developing ones can contribute to reduce them, improving their development through a sustainable way.

Brazil is quite efficient in carbon dioxide emissions: around 1% of total emissions, due to the large use of hydro and biomass-origin energy. Evaluations on CO_2 emissions in Brazil range from 242 Mt [4] to 269 [5] Mt[1] of CO_2 emitted in 1990. Brazilian efficiency is because most of energy consumption is from renewable sources. More than 90% of consumed electricity is produced in hydroelectric power plants, half of energy used in automotive vehicles is from sugar cane-ethanol and, in sugar/alcohol segment, all the energy needs come from sugar cane bagasse, corresponding to more than 6% of total energy consumption in Brazil [5].

Results show that Brazil is more efficient than developed countries, regarding CO_2 emissions per kWh generated (15 times more efficient than USA) and also in terms of CO_2 emissions per capita (much less emissions than Germany, Great Britain, Japan, Italy, France and USA) [5].

On the other hand, recent studies [1] show that even hydroelectric power plants also release carbon emissions (besides other well-known environmental impacts [4]), mainly as methane, from the flooded biomass, although much less than fossil fuels[2]: Tucuruí power plant, in Amazon, is estimated to release 103 Mt of CO_2 equivalent, under the form of methane, in a period of 100 years [1].

Also, a significant amount of fossil fuels - mainly fuel oil - is still used in Brazilian industry due to low international prices of oil. Because of that, 1.3 Mt of CO_2[3]are estimated, from existing data [5], as having been produced by industrial sector in 1993, only from fuel oil. From that amount, 10% corresponds to the pulp and paper industry, one of the higher energy consumers in Brazilian industry. By replacing fuel oil by process by-products (biomass residues and black liquor from Kraft process used for pulp production), and introducing more efficient technologies, these CO_2 emissions could be avoided (besides the other pollutant emissions), due to the carbon reabsortion during biomass regrowth.

Besides those environmental aspects, cogeneration improvements in industrial sector, through private investments, also present economic advantages for the Brazilian electric sector. Most of this sector is still state-owned - although there is nowadays a privatization program being started mainly in the state of São Paulo - and the utilities have significant financial difficulties. Therefore, private investments in

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[1]*In this paper, metric tones were used.*

[2]*A thermoelectric power plant releases 88 times more carbon per megawatt than a hydroelectric one [1].*

[3]*Also 10,600 t of SO_2 and 708 t of NO_x were emitted, as evaluated from [6] and [7].*

more efficient cogeneration technologies allow the expansion of this sector without the construction of new dams and their subsequent economic and environmental problems, as already discussed in [1] and [8].

In pulp/paper plants (as well as in sugar/alcohol and iron/steel ones), thermal and power profile are adequate for cogeneration systems, as already discussed in several studies [2], [9], [10], [11]. Therefore, this paper analyzes the cogeneration potential in a group of large Brazilian pulp/paper industries (corresponding to 40% of Brazilian production) to generate an electricity surplus to be sold to he grid. To achieve this aim, more efficient technologies are adopted, since those ones already commercially available in Brazil until more advanced ones, such as gasifier/gas turbine systems [3]. On the other hand, less pollutant fuels - mainly process by-products (biomass residues and black-liquor, from Kraft pulp production process) - are used to replace oil derived fuels.

The results are significant. Although conventional processes (condensing or back-pressure extraction-steam turbines) do not allow the self sufficiency of all the plants chosen, natural gas-fired combined cycles generate a surplus evaluated in more than 65,000 MWh/month to be sold (after supplying all energy needs of the plants). This surplus can become quite higher (81,000 MWh/month) with gasifier/gas turbine systems, fired only with the available biomass residues and black liquor. Almost 300,000 MWh/month is generated, more than twice the current total amount produced (the current deficit of the chosen plants is more than 77,000 MWh/month), and corresponding to almost 40% of the electricity consumption of all pulp/paper industries[4].

However, the introduction of these technologies depends on some necessary mechanisms, such as an adequate purchase price of electricity from self-producers (to be competitive with the generation costs). The electricity prices for industrial sector should be established on real levels (low tariffs does not encourage investments on new technologies) and special policies are necessary to encourage biomass-origin cogeneration (incorporation of externalities, such as carbon-avoided costs, carbon taxation, etc.[12], [13]).

2 The Brazilian pulp/paper industry

The Brazilian pulp/paper industry has produced, in 1993, more than 10 million tones of pulp and paper, divided into: plants producing only cellulose-pulp (23.81%), paper plants (30.35%) and integrated plants (45.84%), producing both pulp and paper. In the last years this sector has shown a strong growth (1993's production was 10% more than in 1991), with a subsequent rise on electricity demand (more than 9,500 GWh per year, around 8% of Brazilian industrial consumption) [14].

From that consumption, around only 40%, in average, corresponded to self-production (hydroelectric self-production and cogeneration systems). This percentage

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[4] *792,000 MWh/month, 1993 data[14].*

varies significantly according to the type of industry: pulp plants, because of the by-products' availability, cogenerate more than 80% of the electricity consumed, while paper and integrated industries produces only 10% and 40% of their needs.

Because there is no availability of by-products in paper plants (paper industries' self-production is mainly from hydroelectric power plants), improvements on cogeneration depends on the purchase of additional fuel (such as natural gas to be fired in gas turbine systems). In this case, generation costs are much higher than established electricity tariffs [15].

On the other hand, in pulp plants and in integrated industries, cogeneration is more feasible, due to the availability of biomass residues and black liquor, from pulp production process. Black liquor is a by-product from cellulose digestion in Kraft process, which is the most used for pulp production. It is consumed in recovery boilers, a technology commercialized since the beginning of this century, to recuperate chemical products and to produce high pressure steam. A chemical smelt is then produced, containing sodium carbonate and sodium sulfate, this one converted into sodium hydroxide; these chemical products are recycled for use in the pulp process [16] in [3].

Besides the use of 5 Mt of black liquor and 2.4 Mt of biomass[5] (1993 data), the consumption of other fuels is also quite high: fuel oil's consumption is 811,000 cubic meters per year, corresponding to 10% of the whole industrial sector, together with 257,000 tones of charcoal (15% of industrial sector) and 794,000 tones of oil equivalent (toe) in other oil-derived fuels (8% of industrial sector)[14].

Despite the fact that the thermal and power profile in pulp/paper plants is favorable for cogeneration systems, investments in more efficient technologies - even those already commercialized in Brazil (high pressure boilers and condensing extraction steam turbines) - are not made by the industries due to the low prices of electricity established by Brazilian utilities.

However, with the lack of equilibrium between demand forecasts and electricity offers (forecasts show figures as 20% for deficit risks [9]) due to the financial difficulties of the utilities, cogeneration appears to be a promising option to Brazilian industrial sector to guarantee the electricity needs without shortage risks.

3 Cogeneration potential in pulp/paper plants

The group of selected pulp/paper plants produces around 12,000 tones per day of pulp and paper (40% of Brazilian pulp/paper production); these are quite large industries, producing more than 1,500 tones per day of pulp and paper. Their current total consumption of electricity is around 216,000 MWh/month, 65% of which is self produced (cogeneration systems), a higher efficiency than the Brazilian average. To produce this electricity, as well as the steam needed for process, all the available black

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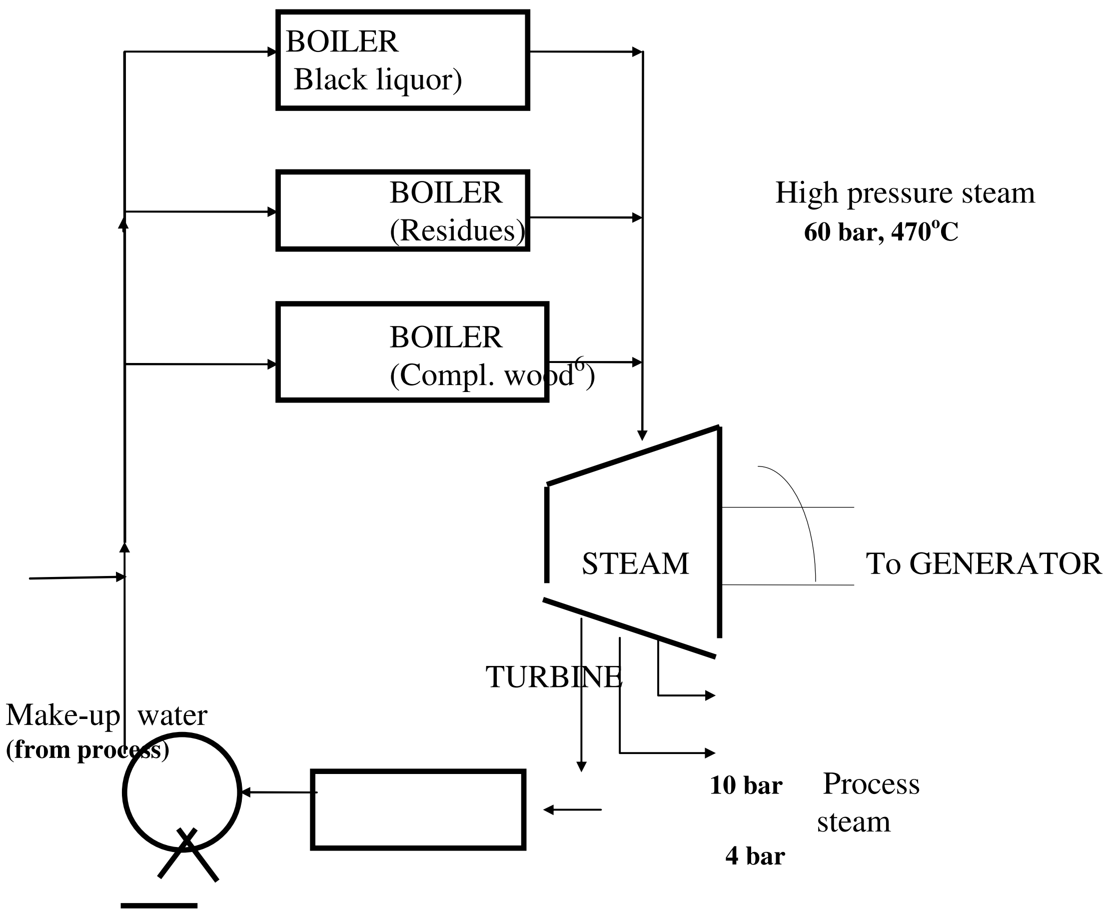
[5] *Hog fuel and bark, including a small amount of purchased biomass, like firewood and sugar cane-bagasse*

liquor is burned in high pressure boilers producing steam to be fed in steam turbines. Complementary process steam is produced in other boilers, burning biomass residues and firewood (4,300 tones per day), fuel oil (1,800 tones per day) and some charcoal (less than 200 tones per day).

To evaluate the cogeneration potential for this group of pulp/paper plants, aiming their energy-self-sufficiency and the generation of a surplus electricity, the following technologies already commercialized are considered:

1. *System 1*: This configuration (figure 1) aims only the thermal self-sufficiency of each plant; electricity production is defined by steam flow needed to process, aproximately as the existing situation. The proposed system includes high pressure (and more efficient than existing ones) boilers (60 bar, 470°C), burning the current consumed amount of black liquor and of biomass, from each plant's availability. When it is needed, complementary firewood replaces fuel oil previously consumed to supply the thermal needs of the plant. For this group of plants, firewood consumption in these additional boilers corresponds to 10% of current biomass consumption. High pressure steam goes to steam turbines with steam-extractions to process (10 bar and 4 bar).



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[6] *If necessary.*

CONDENSER[7]

Figure 1: Steam turbine cycle with boilers fueled with available black liquor/residues and additional boiler firing complementary wood (*system 1*).

A condenser is necessary when the amount of generated steam is higher than the needs of the plant; otherwise, back-pressure/extraction steam turbines are employed[8] and all produced steam is needed to process.With this system, energy balance (evaluated separately for each plant) shows a global electricity deficit of more than 16,000 MWh/month (almost 8% of global consumption of the group).

2. *System 2*: This configuration aims both thermal and electrical self-sufficiency of each plant. A natural gas-fired gas turbine (figure 2) is adapted to the steam turbine cycle of system 1 and the additional firewood-boiler is replaced by a heat recovery steam generator (using the exhaust gases from the gas turbine). With this combined cycle, authors'calculations show that energy self-sufficiency of all selected plants is obtained, with a small surplus (around 65,000 MWh/month). However, the natural gas consumption is evaluated in more than 220 million cubic meters per year, more than twice the global consumption of Brazilian pulp/paper sector and corresponding to almost 12% of our whole industrial consumption. Because the current availability of natural gas in Brazil is not so high (4,820 million of cubic meters in 1993 [14]), processes with high consumption of this fuel depend on the construction of the gas pipeline Brazil-Bolivia, still under negotiations nowadays.

For systems 1 and 2, data related to availability and heating values of black liquor and biomass residues are assumed equal to the real ones, for each plant. Also process steam flows are assumed the current ones, without any energy conservation measure adopted. As it was considered in System 1, for the plants where there is no steam surplus, it is adopted a back-pressure extraction steam turbine (return water from process to the boiler is assumed at 120°C); also, when it is needed, a condensing-extraction steam turbine is used.

For both proposed systems, higher thermodynamics efficiencies are assumed as follows: 80% for black liquor recovery boilers, 90% for biomass residues' boilers[9], 90% for isoentropic efficiency of the steam turbine; 90% is the capacity factor. Condenser temperature is assumed equal to 40°C.

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[7] *If necessary.*

[8] *Those differences among the plants are due to the (different) thermal needs and to the (different) availability of by-products pf each plant.*

[9] *It is assumed the most efficient boilers for biomass firing (high pressure boilers), under development now in Brazil [2]. There are recovery boilers and biomass boilers in some of chosen pulp plants working with efficiencies up to 86%.*

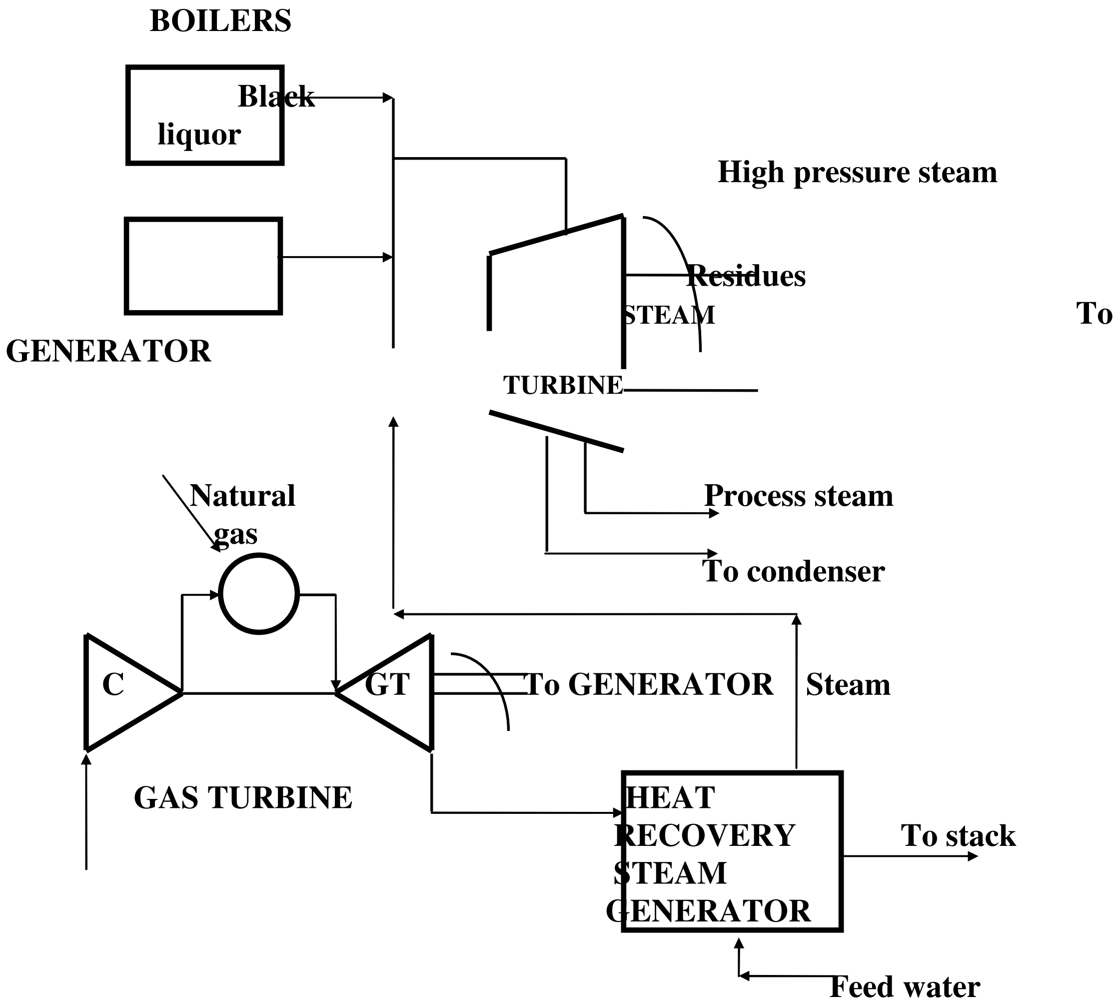

Figure 2: *System 2* - Natural gas fired-combined cycle with gas turbine adapted to the steam turbine of *system 1*

4 Cogeneration potential from gasifier/gas turbine systems

System 3 adopted in this paper (figure 3) is a biomass-gasifier/steam injected gas turbine cycle (BIG-STIG), according to existing data [3]. A steam injected gas turbine is proposed to be fired with the gases produced in a fluidized bed gasifier, with two possibilities: one single gasifier is fed with black liquor or two gasifiers are fed respectively with black liquor and biomass residues available in the plant. Results for black liquor gasification are estimated [3] from experimental data in wood gasifiers. In the same way, STIG cycles' efficiencies correspond to theoretical assumptions[10].

[10]*Most of development effort is now on combined cycles. However, despite the fact that STIG's efficiencies are lower than combined cycles' ones, overall cost and performance characteristics of both technologies can be assumed almost equal (LARSON, E., 1996.* ***Personnal communication****).*

Electricity production with this proposed technology is evaluated in 1,320 kWh per tone of pulp, if only black liquor is gasified, rising up to 1,703 kWh/t of pulp, if biomass residues are also gasified [3].

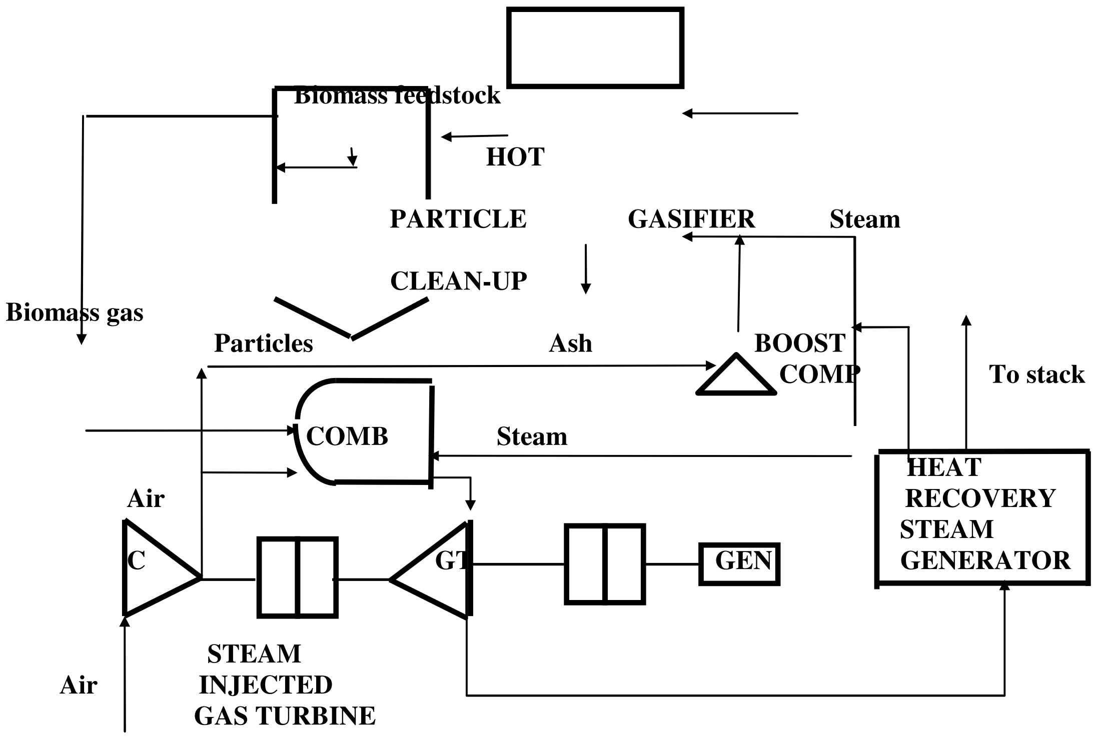

Figure 3: *System 3* - Biomass gasifier/steam injected gas turbine (BIG/STIG), fueled with available black liquor and residues from the pulp plant [3].

There are two main types of biomass gasifiers under development nowadays: fixed bed and fluidized bed gasifiers, both using air-blown (instead of oxygen blown). Experimental results (with wood) [3] are quite recent but they are promising and show that this technology shall be commercially available in a near future.

A pilot plant is being developed in Northeastern Brazil [17] for electricity generation from wood plantations using gasifier/gas turbine cycles (BIG-STIG). In this project both types of gasifiers are being evaluated to choose the most convenient one. Another pilot plant, for bagasse[11] gasification, has started, in 1995, in Hawaii (Manoa Island) [18], with a pressurized fluidized bed gasifier (air blown) producing bagasse gas to be fired into a combined cycle. In another proposed system, biomass residues feed a pressurized gasifier for a combined cycle in pulp plants [19]. There are also significant researches under development now in black liquor gasification; therefore, experimental results shall allow a more accurate evaluation on the potential for black liquor gasifier/gas turbine cogeneration[12].

The (theoretical) electricity generation data for System 3 correspond to a steam injected gas turbine (STIG), firing gases produced in atmospheric fluidized bed gasifiers. These gasifiers are proposed to be fed with black liquor and biomass

[11] *Bagasse is a sugar cane by-product after juice extraction, that is fired in boilers for electricity cogeneration in sugar plants, in Hawaii, and in sugar/alcohol plants, in Brazil.*

[12] *LARSON, E. (Princeton University),1996.* ***Personnal communication.***

residues, available from the pulp plant (MTCI technology, in [3]). A pilot plant (120 t/d of black liquor) for this technology is being built in North Carolina [20].

Obtained forecasts, when assuming BIG/STIG efficiencies to the selected plants, indicate an electricity generation up to 230,000 MWh/month (only with black liquor gasification) or 297,000 MWh/month (from black liquor and biomass residues), almost three times their current self-production. There is a surplus evaluated in up to 81,000 MWh/month, corresponding to more than 10% of the whole electricity consumption of Brazilian pulp/paper sector, withthe benefit of no fossil fuel's consumption.

However, to achieve these results, steam consumption in the plants must be reduced to 9.8 GJ/t of pulp [3], what requires significant improvements on energy conservation; nowadays, average steam consumption for the selected plants is 14.9 GJ/t[13] (16.3 GJ/t in a typical pulp plant in USA [3]). This reduction appears to be possible with the introduction of energy conservation measures [3].

5 Carbon emissions avoided with cogeneration improvements in pulp/paper industries

Because fuel oil is replaced by natural gas and biomass in the suggested systems, pollutant emissions can be reduced significantly. It is assumed here CO_2 emissions as follows [21]:

1. fuel oil: 73 g of CO_2 per MJ
2. natural gas: 49 g of CO_2 per MJ

Also CO_2 net emissions from biomass origin are almost null due to carbon reabsorption during biomass regrowth; so, the replacement of current technologies by more advanced ones, as proposed here, is highly favorable under environmental aspects.

Table 1 ahead illustrates the avoided carbon emissions with the introduction of the proposed systems.

Table 1. Electricity cogeneration and carbon avoided emissions for a group of pulp/paper plants:

Proposed cogeneration system	Electricity production (MWh/month)	Electricity deficit/surplus (MWh/month)	CO_2 emissions (tones per month)	
			emissions	avoided emissions
1.Biomass fired steam turbine cycle	199,868	- 16,355	almost null	8,660
2.Natural gas fired				

[13]*This consumption includes the steam for the paper production.*

combined cycle	281,368	+ 65,145	2,144	6,516
3.Black liquor and biomass residues-fired BIG/STIG	297,089	+ 80,866	almost null	8,660

From Table 1, we conclude that with BIG/STIG system, fired only with available by products from the plant, around 104,000 tones of CO_2 emissions are avoided per year, besides the electricity surplus generated to be sold to the grid.

It is important to notice that these results corresponds only to the chosen group of plants. Moreover, although those plants produce 40% of Brazilian pulp/paper production, their CO_2 emissions from fuel oil origin corresponds to almost 80% of the total emitted by the sector from fuel oil origin. The avoided carbon emissions appears therefore to be extremely significant.

6 Economic aspects of electricity cogeneration in pulp/paper plants

Previous studies [8] have already analyzed economic feasibility of cogeneration in integrated pulp/paper plants. Results show that more efficient cogeneration technologies (systems 1 and 2, as proposed here) are not economically competitive with the current electricity tariffs in Brazil (around US$ 20/MWh for this sector).

Such technologies would be feasible only for higher tariffs (US$ 50 or 60/MWh) and assuming the sale's price of surplus electricity (sold to the grid) equal to US$ 55/MWh. This should be the marginal cost for expansion/transmission of electric sector in South/Southeast Brazil, as evaluated by many specialists, despite other higher evaluations[14], up to US$ 70/MWh. However, the existing examples[15], in this region, for the purchase of surplus electricity by utilities are not promising. The (state-owened) utilities, in the state of São Paulo, can offer only US$ 38/MWh for the purchase of electricity from self-producers, because this is the official expansion/transmission marginal cost for the South/Southeast Brazil.

In the BIG/STIG system, it is assumed [3] an installation cost of US$ 1,360/kW (the first commercial plant should cost from US$ 1,600/kW to US$ 1,700/kW [3]). This is an estimate for biomass-gasifier/gas turbine systems; there is not yet commercial black-liquor fired systems. Similar pilot plants under development (bagasse gasification in Hawaii and wood gasification in Brazil) estimate installation costs aproximately the same[16]. From these assumptions, BIG/STIG generation costs are evaluated in US$ 40/MWh [3]. By consequence, neither this system would be economically competitive with current Brazilian electricity tariffs. For a private

[14]*HUKAI, R. (IEE/USP, 1992).* ***Personnal communication.***

[15]*Brazilian sugar and alcohol sector.*

[16]*A second plant, similar to that one in Hawaii, would have an estimated installation cost of US$ 2,000/kW (KINOSHITA, C., University of Hawaii, 1995.* ***Personnal communication****). A commercial plant for wood gasification/gas turbine system, in Brazil, shall present a cost equal to US$ 1,300-1,500/kW [18].*

ownership, the internal rate of return is attractive (10%-13% per year), but only if the surplus electricity could be sold by US$ 50/MWh to local utilities[17], what is not feasible nowadays.

Therefore, those difficulties do not allow cogeneration improvements in Brazilian industrial sector. On the other hand, the financial situation of Brazilian utilities being quite hard, the privatization of the electric sector in Brazil (under development now) appears to be a first step to solve these problems. Also willing procedures (not allowed until today in Brazil) could improve electricity sales to other industries and would collaborate to make cogeneration economically feasible.

7 Conclusions

Despite the large benefits from environmental aspects (avoiding carbon emissions responsible for the greenhouse effect) and despite the advantages of allowing the expansion of electricity offer through private capital, biomass-origin cogeneration improvements are not economically feasible. Electricity tariffs are quite low for the industrial sector, specially for pulp/paper industries and therefore cogeneration costs are not competitive. Also the purchasing price established by the utilities for the electricity surplus is not attractive to encourage this process.

Brazilian utilities present significant financial difficulties due to the low prices of electricity established during many years by the previous Federal Government (used as a strategy against the high inflation rates of that period). Because of that, privatization process, as being started now in the Brazilian electric sector, appears to collaborate to reduce these problems. The participation of private capital in the sector's expansion and in the electricity distribution, as well as the willing, allowing the surplus electricity to be sold directly to other industries, are adequate mechanisms to achieve those proposed objectives.

On the other hand, the participation of international agencies could also collaborate to develop this process faster, reducing carbon emissions through the implementation of biomass-origin cogeneration, as discussed in [12].

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[17] *Surplus electricity self-producers can be sold only to local utilities, according to current Brazilian legislation.*

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