CLEAN PRODUCTION: EFFICIENCY AND ENVIRONMENT *

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I- Introduction

The first documented mention about sugar cane, appeared in the Hindu sacred book, Atharva Veda, and is dated from a period estimated between the years of 5000 1000 before Christ. Christopher Columbus in his second journey brought sugar cane to the American continent and planted it in "La Española" island. However, its industrial utilization for sugar production began at the end of the 16th century in Cuba and other Caribbean islands. In 1528 copper mines were discovered in Santiago de Cuba and the first fusion was carried out in 1599 with the establishment of a Spanish Government State Company. This allowed the manufacturing of the "machinery" for the first sugar cane mill. It is not casual that Mr. Francisco Sánchez de Moya, the first "Manager" of this metallurgic company, was the owner of 3 of the first sugar cane mills in the American continent. In 1617 there were already 37 sugar cane mills between Santiago de Cuba and Bayamo, the first sugar cane mills in Jamaica and Haiti appeared at this same time.

The sugar industry enters its fifth centennial within a complex context. On one hand the reduction of the sugar prices seems to be an irrevocable tendency. On the other hand, the intensification of the use of sugar cane as a renewable energy source is vital, considering its contribution to the solution of global environmental problems and the exhaustion of fossil fuels reservatories in a near future.

The main objective is to found, the possibility of sustainable development of sugar cane industry in the 21st century and its relationship with energy efficiency and environmental management aspects in the sector.

II- The sugar cane industry and the clean production.

First, let us see the concept of clean production firstly (C+P): "it is a preventive integrated strategy applied to processes, products and services in order to increase the efficiency and reduce the risks for the human beings and the environment. For the processes, a clean production includes the efficient use of the raw materials, water and energy, the elimination of toxic products, and the reduction of emissions and residues in the source. It also deals with the decrease of the environmental impact of the products, promoting friendly designs according to the necessities of future markets." (Centro Nacional de Producción más Limpia, 1998).

Analyzing the activity of diversified sugar cane agro-industry, some important elements could be indicated in order to reach a clean production in this sector:

- Implementation of green sugar cane mechanized harvest;
- Control of soil erosion and salification;
- Implementation of alternative methods for distillation stillage treatment;
- Reduction of the sector own environmental impacts through the implementation of prevention and control programs;
- Reduction of water consumption in the mill and the use of zero-effluents type systems, with total water recuperation;
- Reduction of environmental impacts caused by the energy and fuel sectors by substituting considerable quantities of generated electricity with liquid fuels of fossil origin;
- Environmental improvement of extensive regions and sugar cane producing countries.

The attainment of a clean production in the sector is attached to the efficiency increase of several agricultural and industrial process stages:

- The increase of the agricultural yield. At Present, in the range of 40-60 tc/ha.year in the majority of the producer countries, that is equivalent approximately to 5-6 tons of sugar by hectare per year (Fry, J., 1999). As a comparison, in Australia this indicator is 9 t/ha.year;
- The reduction of steam consumption in the fabrication process. The sugar cane industry, due to the availability of a low cost residual fuel, has resulted to be less energy efficient than the sugar beet industry. The implementation of new technologies in the process such as falling film evaporators, continuous pans, steam compression and the addition of a sextuple effect in the evaporator could reduce the current consumption in 50%.;
- The Increase of the efficiency and the cost reduction in the production of alcohol. In accordance with COPERSUCAR (1989) there is a potential cost reduction of 23,1% in the alcohol production;
- The increase of the efficiency and the cost reduction in the electricity generation from sugar cane biomass. This is related to the introduction of advanced cogeneration technologies based on integrated gasification and gas turbines combined cycles.

Figure 1 shows the factors that determine the clean production attainment in sugar cane industry.

The 21st century will introduce a series of characteristics that could contribute to further development in the sugar cane industry:

- The introduction of new technological paradigms in a commercial stage such as gasifiers and gas turbines to use low calorific value gas as fuel, with gas cleaning systems to increase high efficiency in the electricity generation from sugar cane biomass;

- The reduction of petroleum production and the probable increase of its price beginning in the year of 2010 (Campbell and Laherrére, 1998);
- The necessity of taking radical measures to reduce CO_2 emissions and control the greenhouse effect and its consequences related to the climatic changes;
- The expected increase of the worldwide sugar cane market in approximately 30 million tons (Genetoux, 1999);
- Considering a growth in the electricity demand in Latin America of approximately 5% per year, the increase in installed capacity by the year of 2050 would be 250GW (OLADE, 1998). On the other hand the sugar cane biomass (bagasse and trash) availability in Latin America is equivalent to 3, 58 EJ/ year (Hall, et all., 1993);

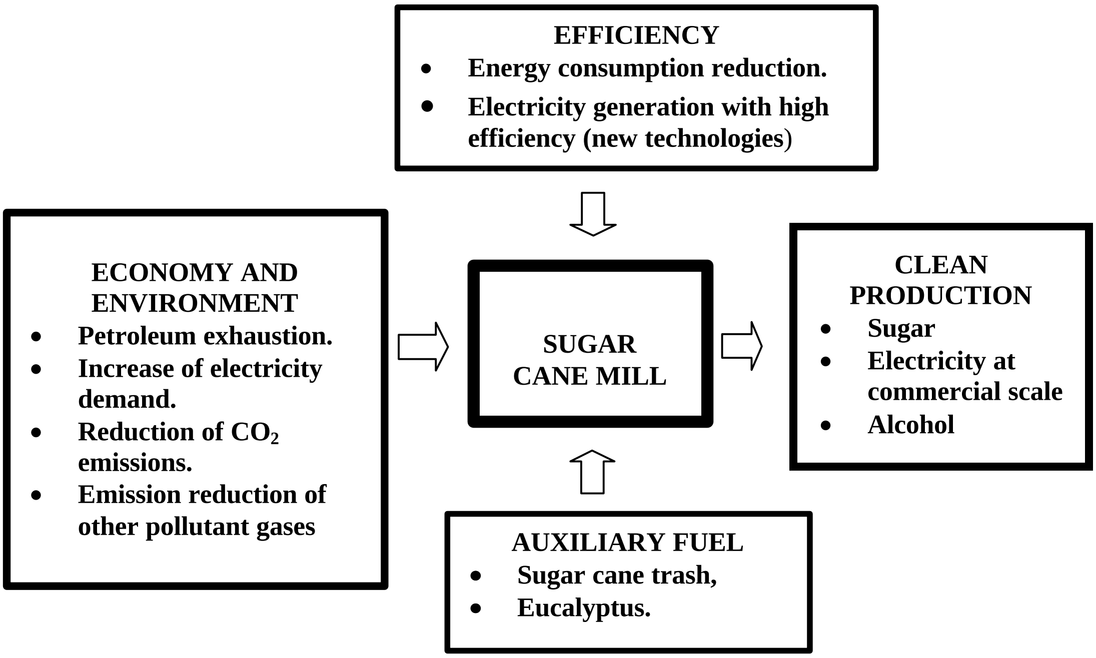

Figure 1- Factors related with the clean production in a sugar cane mill.

III- Pollution sources in the sugar cane industry.

The sugar and alcohol industry presents some negative environmental impacts. The analysis and qualitative evaluation of these impacts are shown in table 1, using an impact matrix.

The quantification of the emission of several pollutants, as well as their concentration in different environments and their final disposition are shown in table 2. Three pollutant flows that deserve special attention caused by their pollution effect can be seen:

- The distillery stillage or vinasse;
- The particulate emission as consequence of the sugar cane biomass used as fuel in the steam generation boilers;
- The water from the sugar cane washing.

Here, it is necessary to include the emission of pollutants as a result of the burning of the sugar cane for harvest. Measurements carried out by the Brazilian National Institute of Space Research- INPE, detected a considerable increase of CO and Ozone concentrations in sugar cane regions during dry seasons (Kirchoff et al, 1991). In the frame of a collaboration project between the São Paulo State Environmental Agency and the University of Tubingen (Germany) dioxins, furans, bifenils policlorates (PCB) and polyciclic aromatic hydrocarbons (PAH) concentration measurements were carried out in the smoke of the sugar cane burns. Measured values in these regions are higher than in near located cities. In the state of São Paulo a program has been defined to eliminate the burns in 8 years. One of the greatest concerns is the unemployment that could appear as a consequence of the mechanical harvest diffusion.

Table 1- Impacts qualification matrix of sugar cane production (Nature Foundation, 1990).

IDENTIFIED ENVIRONMENTAL IMPACT	APPEARANCE	NATURE OF THE IMPACT	D.	AREA OF INFLUENCE	INTENSITY	TYPE OF EFFECT
Air Pollution	Production processes. Energy Production.	Air pollution with soot.	P.	Regional	Moderate	Direct
Reservatories of Contaminated water	Production processes. Energy Production.	Water contamination by liquid industrial effluent. Loss of soil quality by irrigation with these effluents.	P.	Regional	High	Direct
Water contamination	Production processes.	Mill mud deposition with high DBO causes water contamination.	P.	Local	Moderate	Direct
Changes in soil use	Soil Transformation. Solid residuals disposition. Production processes.	Industrial installation, mono-culture, soil contamination.	Per.	Regional	Moderate	Direct
Changes in the flora and fauna	Soil Transformation. Production processes. Energy production	Damage to the flora and the fauna of the reservatories receiving liquid effluents.	Per.	Regional	Moderate	Direct
Social and economical effects	Soil Transformation. Resources extraction. Production processes. Handle of raw material. Energy production. Residuals.	Gastrointestinal diseases caused by water contamination Noise disturbs. Increase of traffic accidents. Change in the behavior patterns in a community, can improve life conditions	Per.	Local	Moderate	Indirect

D., duration; P., periodic; Per., permanent.

Table 2- Main residuals from the sugar and alcohol production (Da Silva Salles, 1993, Bichara e Filho, 1991).

Residuals and/or subproducts	Main characteristics	Disposition
Water from cane washing	Vol.: 2-7 m^3/tc DBO: 200 - 1200 mg/l PH = 4,8	Land irrigation; Recirculation; Treatment or discharge.
Secondary condensates	Vol.: 0,55 m^3/tc DBO: 500 - 1000 mg/l	Land irrigation; Recirculation; Treatment or discharge.
Water from barometric condensers and multistream	Vol.: 10 - 20 m^3/tc DBO: 100 - 300 mg/l t = 35 - 40 ^oC	Land irrigation; Recirculation; Treatment or discharge.
Boilers condensate and blowing down.	Low pollutant potential.	Recirculation.
Water from floor washing and equipments.	High concentration of solids sedimentation DBO: 400 – 15000 mg/l	Land irrigation; Discharge.
Domestic residuals water	75 - 120 l/ day per worker Presence of coliforms.	Fosses/Drain.
Distillery stillage	≈ 156 l/tc (annex distillery) and 910 l/tc (autonomy distillery). High potential pollutant.	Land irrigation, anaerobic fermentation, boilers combustion, others uses.
Mill mud	30 – 40 kg/tc High DBO	Fertilizing, wax production.
Particulate material from sugar cane bagasse combustion	Particulate: 4000 - 6000 Mg/Nm^3 ≈ 6 kg/tc. NO_x	To the atmosphere with or without control equipment.

IV- Standards for the emission of pollutant gases and effluent discharges.

In order to maintain the environmental impacts of the sugar cane industry in acceptable levels several international financing institutions have established limits for the emission of pollutant gases in several countries, specifically for particulates (Table 3). The present tendency for these emission levels is to become more and more rigorous, this way, forcing the use of high efficiency and high cost technologies.

In Brazil the São Paulo State Environmental Agency (CETESB, 1986) carried out a study about the value that should be included in a norm that regulates the limits of particulate emissions in boilers that use bagasse as fuel, finally proposing 120 mg/Nm^3. Other studies of the same organization show that a clear plume corresponds to concentrations of approximately 85 mg/Nm^3.

In relation to liquid effluents most of the sugar producing countries have already got standards concerning effluent discharges that establish a limit for the organic concentration between 15 and 60 mg/l of DBO, with the exception of India, where the limit is 100 mg/l (Purchase, 1996). The treatment of effluents is carried out in anaerobic or aerobic pools. Activated sludge systems have the tendency to the “bulking” phenomenon due to the presence of saccharose in the effluents.

Table 3- Particulate emission standards in bagasse boilers, in force in several countries or established by financing institutions.

Country or institution	**Particulate emission standards, mg/Nm^3**	**Observations**
South Africa	120	-
India Mauritius	250 850	Inclined grate boilers Spreader stoker boilers
Mauricio Island	400	-
Malaysia	400	-
Brazil	70 100 120	Preserved metropolitans areas. New boilers Existing boilers
World Bank	100 150	In general Small capacity boilers

The World Bank requires determined levels of pollutant concentration in the effluentsto be reached, as shown in table 4 (World Bank, 1997). Furthermore, as a pollution prevention measure the specialists of this institution recommend the flow of effluents to be reduced to 1,3 m^3/tc, with the tendency of reaching the level of 0,9 m^3/tc with the implementation of water recirculation.

Table 4- The World Bank requeriments regarding the level of pollutants in sugar cane mills effluents (World Bank, 1997)

Parameters	**Maximum**
PH	6-9
DBO_5	50 mg/l
DQO	250 mg/l
Total suspension solids	50 mg/l
Oil and greases	10 mg/l
Total nitrogen	10 mg/l
Total phosphor	2 mg/l

V- Prevention and control of pollution in the industry.

Air pollution caused by the sugar cane industry is classified in two main types: the contamination because of the sugar cane burns before the harvest and the one originated by the sugar cane biomass combustion in steam generation boilers. Different technologies can be used for the particulate control in the boilers (figure 2). Only the gas scrubbers and the electrostatic precipitators allow reaching levels of particulate emission lower than the emission standards now effective, for example, in Brazil: 100-120 mg/ Nm^3.

A technical and economic analysis was carried out in order to compare several options of particulate separators for the sugar cane biomass boilers. The specific cost of particulate separation expressed in US$/Nm^3, and also the specific investment and the operational specific cost was calculated and used as an analysis tool. Three boilers capacities, 40, 80 120 t/h, were considered in the calculations representing the typical commercial range for sugar cane biomass boilers. The exhaust gas temperature of 250 °C and 1,45 of excess air were assumed.

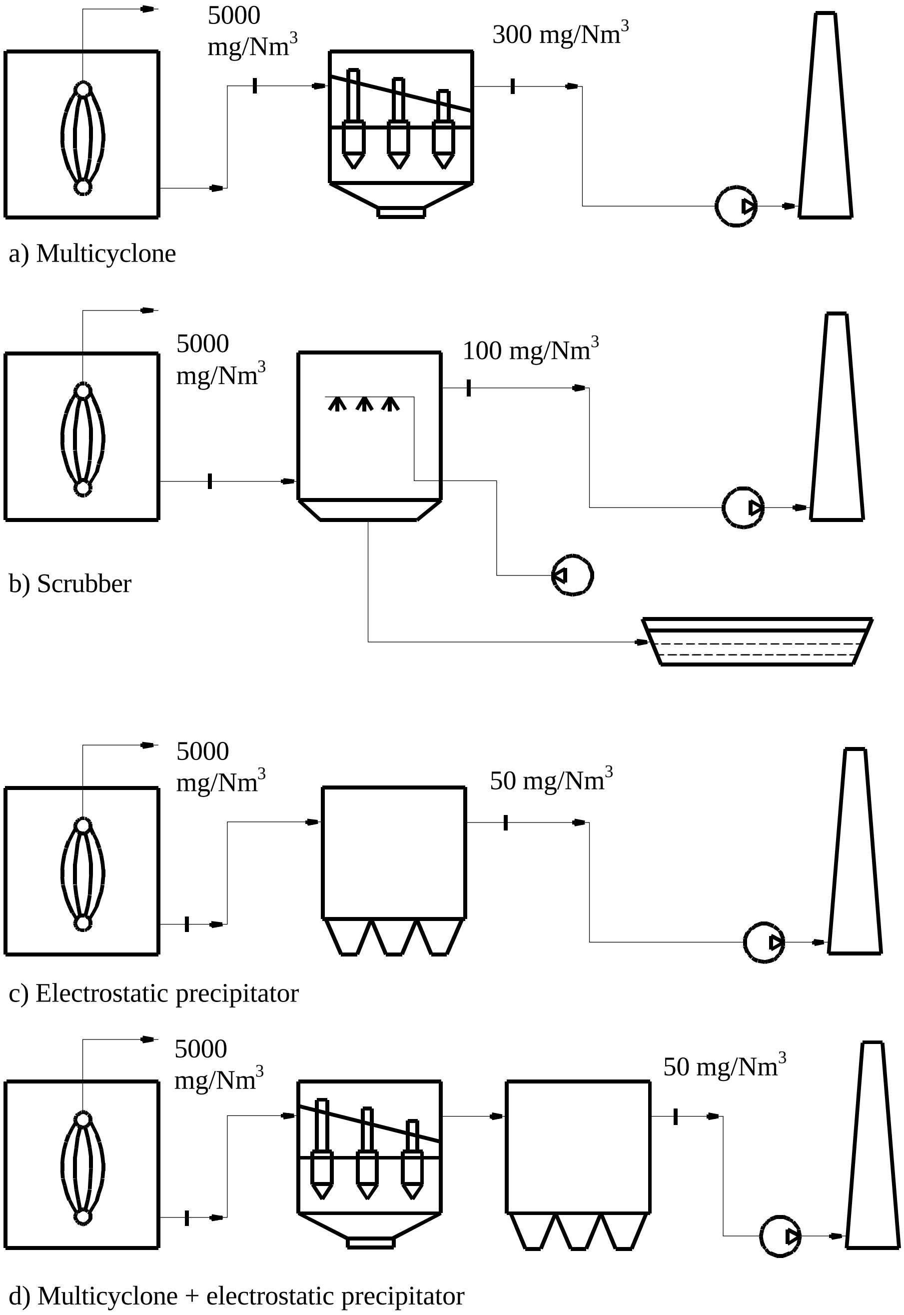

Figure 2- Particulate control technological variants in sugar cane biomass boilers.

The relation between the gas cleaning specific cost expressed as US$/(1000 Nm^3), and the boiler capacity is shown in figure 3. It is evident that the electrostatic precipitator and the Ventury scrubber present the highest specific cost of gas treatment, which becomes lower with the increase of the boiler capacity. It is also observed, that the specific cost of gas cleaning by multi-cyclone and atomization tower scrubber doesn't rise with the increase of the boilers capacity. The specific cost of gas treatment with different particulate separation technologies tends to converge for capacities higher than 120 t/h.

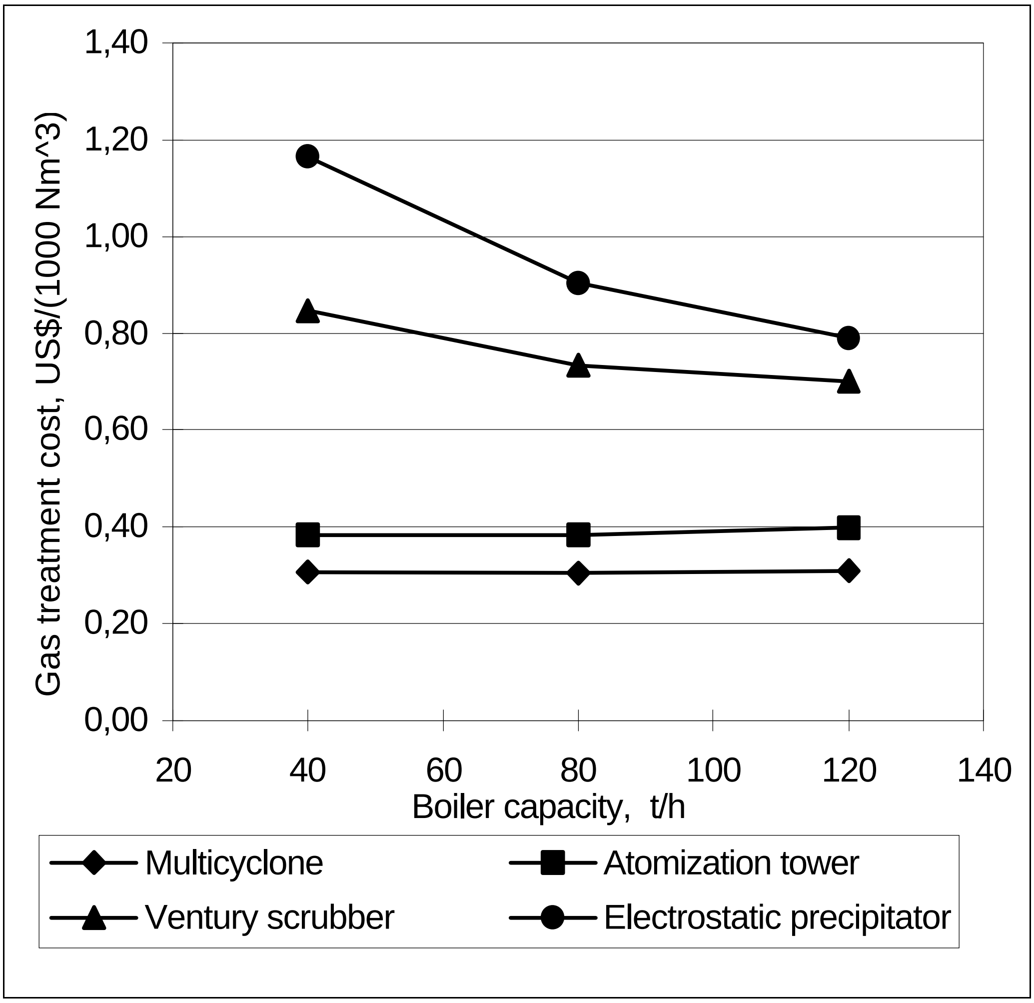

Figure 3- Influence of the boiler capacity on the specific cost of gas cleaning expressed as US$/(1000Nm^3).

VI- Cogeneration, efficiency and environment.

Now-a-days, it is observed the tendency of cogeneration encouragement in the sugar cane industry in several countries. There has been studies and progresses reported about this issue in Brazil, India, Thailand, Costa Rica, Jamaica, Guatemala, Honduras, etc. In Brazil competitive prices are expected to be defined for the electricity sale for the recently privatized electric companies. In September 1999 the government of the state of São Paulo approved a price of 80 R$/MWh for the purchase of the electricity produced by sugar cane mills as one of the measures for the Brazilian Program of Alcohol Fuel- PROALCOOL reactivation.

The most diffused electricity generation technology in sugar cane mills is the back pressure steam turbine. The main disadvantage of this system is the little flexibility of load variation and its technical and economic limitation in relation to the increase of the steam parameters. The condensing-extraction steam turbines with high steam parameters allows, a better flexibility between the electricity and heat production processes as well as a higher index of surplus electricity generation and low specific costs (Albert- Thenet, 1991).

A considerable amount of electricity can be generated by using advanced technologies with high efficiency conversion. In this sense introducing the technology with Integrated Gasification and Gas Turbine (Biomass Integrated Gasifier Gas Turbine, BIG GT) in sugar mills with a low steam consumption is very attractive. The BIG GT technology is still being tested in several demonstrative projects in Europe and the United States.

Hobson and Dixon (1998) carried out a study about the possibility of BIG GT systems implementation in Australian sugar mills conditions. The main conclusions were:

- For an specific steam consumption value of 520 kg/tc (52 % of steam in sugar cane) the gas turbine exhaust gases energy is not enough to generate the process steam. For this steam consumption level, 70 % of bagasse must be by-passed from the gasifier and fed directly into the steam generators. Even in this case the amount of electricity produced is 230-250 times greater than a conventional steam cycle could produce.
- The reduction of the steam consumption from 520 kg/tc to 400 kg/tc, increases the BIG GT system available power from 88 to 148 MW. A further reduction in steam consumption up to 320 kg/tc leads to a moderate power increase of 153 MW. In the same range of analysed values a conventional steam system increases the available power from 37 to 43 MW.
- The annual generation efficiency using the BIG GT technology and considering trash recovery (37 %) is almost four times greater than when using the present available technology.

Turn (1998) presented the results of a study considering the integration of a BIG GT system to the Okelele Sugar Company mill with a milling capacity of 120 tc/h and a steam consumption of 420 kg/tc. The gas turbine net power is 18.8 MWe corresponding to 4.5 MWe to the "bottoming" 41 bars pressure steam cycle. During the after harvest period the BIG GT system operates as a 25.4 MWe thermal plant with 28.5 % efficiency by using an auxiliary fuel.

Another study considering the utilisation of steam injected gas turbines (STIG type) was carried out by using technical data from the Monimusk Jamaican sugar mill (Larson et al., 1987). As a result a surplus electricity production potential of 220 kWh/tc was obtained, with a steam consumption reduction up to 300 kg/tc.

A comparative study of different cogeneration options for the sugar industry was also carried out by Walter (1996).

So much in the case of condensing extraction steam turbines as well as for advanced BIG GT systems, it is important to reduce the steam consumption in the fabrication process in order to increase the electricity generation. In the case of the BIG GT systems this is a necessary condition, for they characterize a small steam production. Table 6 summarizes recently published studies about the minimum process steam consumption that could by achieved by different technological modifications in the sugar fabrication process.

Table 6- Minimum values of the steam consumption process in the sugar cane industry as a result of the evaluation of different variants of high efficiency systems.

Steam Consumption kg/tc	**Comments about technology and parameters assumed for calculations.**	**References**
295	Sextuple effects evaporator, sugar cane mill totally electrified, steam pressure 8 MPa and condensing extraction steam turbine.	(Chang et al., 1999)
270	Quintuple effect with two falling film evaporators (4^{th} and 5^{th} stage), steam parameter 8,5 MPa and 525 ^{o}C, mill steam driving.	(Wunch and Arram-Waganoff, 1999)
258	Quintuple effect with falling film evaporators, juice heater using condensate and continuous pans. Calculations done at the Monimusk sugar cane mill in Jamaica, 175 tc/h.	(Ogden et al., 1990)
280	Sugar cane mill with attached distillery. Quintuple effect. Steam extraction from 1^{st}, $2n^{d}$, 3^{rd} y 4^{th} effects for heating juice. Regenerative heat exchangers juice/molasses and juice/juice. Mechanical agitation in the pans. Flystel technology and molecular sieve in the distillery. Extraction from 5^{th} effect to the pan.	(CTC, 1998)

It is interesting to compare the specific emissions of CO_2 and other pollutants, for different cogeneration technologies in the sugar cane industry, with the corresponding values for the case of electricity generation in a power plant that uses fossil fuels. Table 7 shows the main parameters of the analyzed cogeneration technologies: CEST40, CEST60 and CEST80 - Condensing Extraction Steam Turbines with 40, 60 80 bars of steam pressure; BIG GT- Combined Cycle with bagasse gasification and gas turbines.

Table 7- Characteristics of the electricity generation technologies from sugar cane biomass (Mill capacity of 300 tc/h).

Technology	**Index of surplus/generated electricity kWh/tc**	**Specific investment, US$/kWe**	**Generation cost, US$/kWh**	**Steam Parameters, MPa/^{o}C**
CEST 40	68,42/79,42	517,0	0,032	4,1/ 450
CEST 60	74,87/85,85	523,0	0,029	6,0/450
CEST 80	79,90/90,90	581,0	0,027	8,0/450
BIG GT	162,0/217,0	1700,0	0,033	8,0/450

* Specific steam consumption in process, 300 kg/tc.

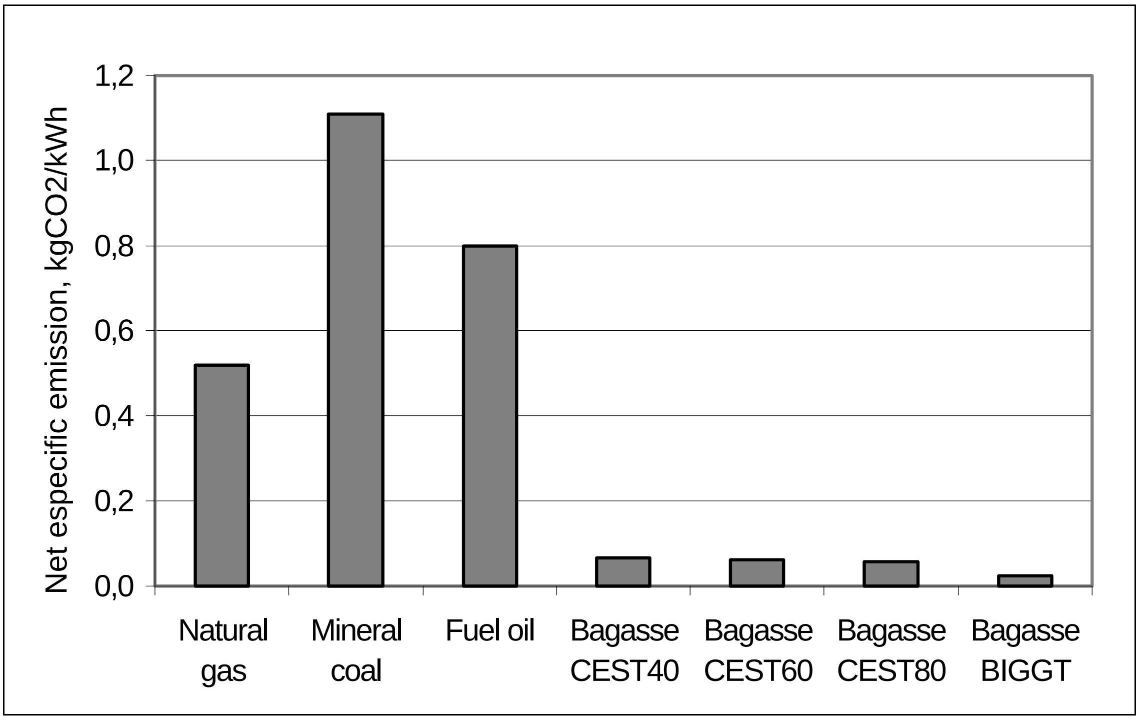

Figure 4- Specific net emissions of CO_2 during electricity generation using fossil fuels and bagasse.

Calculations for the specific net emissions of CO_2 (figure 4) and for specific emissions of SO_2, NO_x and particulate (table 8) were carried out on the basis of the following data:

- Specific emissions of CO_2 for natural gas, fuel oil and bituminous coal (based on thermal energy) are 0,19; 0,29 and 0,4 $kgCO_2/kW_{th}$ respectively (Hein, 1995);
- The power plant efficiency operating with fossil fuel was assumed to be 36 %;
- The sulfur content in the bituminous coal and the fuel oil was assumed to be 1,9 %;
- The emission factors of SO_2 and NO_x for fossil fuel combustion were taken from EPA (1996) and the corresponding factors for the emission of particulate from Philips et al, (1998). The sugar cane bagasse emission factors were taken from EPA (1995).

Table 8- Specific emissions of SO_2, NO_x and particulate during electricity generation from the sugar cane bagasse and fossil fuels using different technologies.

Fuel type and technology	**Specific emission* (g/kWh)**		
	SO_2	**NO_x**	**Particulate**
Bituminous coal	24,26 / 0,72	3,69	302,52 / 1,51
Fuel oil	7,92 / 0,23	1,76	0,29
Natural gas	0	1,07	0,02
Bagasse CEST 40	0	3,77	22,29 / 1,86
Bagasse CEST 60	0	3,49	20,62 / 0,49
Bagasse CEST 80	0	3,30	19,47 / 0,47
Bagasse BIG GT	0	1,38	8,16 / 0,19

* Without control equipments/with control equipments.

Data from table 8 show that the electricity production from sugar cane biomass has lower environmental impacts than when mineral coal or fuel oil are utilized. Only natural gas succeeds in competing with sugar cane biomass in this sense.

Let us see what could be the contribution of the electricity generated from sugar cane bagasse specifically Brazil. During the calculations, it was assumed that the sugar production growth would be 0,8 % per year and the alcohol 4,5 %. So in the year of 2025 the amount of harvested cane would be 346,6 milions tons. The thermodynamic potential for this case is presented in table 9. The increase of the installed capacity in Brazil by the year 2025 may be approximately 80 GW, so that 23,4 % of this value could be obtained from sugar cane biomass.

Table 9- The prognosis of cogeneration thermodynamic potential in the sugar and alcohol sectors of Brazil in the year of 2025 with the implementation of several cogeneration technologies.

Technology	**Cogeneration thermodynamic potential in Brazil with sugar cane bagasse, GW**	**Cogeneration thermodynamic potential in Brazil with 50 % of trash recovery, GW**
CEST 40	5,46	9,16
CEST 60	5,90	9,91
CEST 80	6,25	10,49
BIG GT	11,14	18,7

The modernization of the sugar cane industry energy base will demand huge investments which are difficult to imagine at the present moment of governmental crisis in developing countries. Possible sources of financial resources could be:

- International funds for development;
- Resources from petroleum and energy companies in search of new business opportunities;
- Resources from taxes over the emission of pollutants when fossil fuels are used;
- Loans from international banks;
- Private Initiative;
- Funds from the Kyoto Protocol imposed commitments (CDM- Clean Development Mechanism);
- Financial sustainability of the sugar cane sector.

VI- Project: "Optimization of the sugar cane energy potential with the minimization of pollutants emission".

This project is being developed by the Thermal Systems Study Group from the Federal Engineering School of Itajubá, in Minas Gerais and the COPERSUCAR Technology Center (CTC). It is financed by the Brazilian Ministry of Science and Technology and the CTC with an approximately total value of 700,000 dollars.

The objective of this project is to develop tools and methodologies for the optimization of the use of sugar cane available energy with the purpose of generating considerable surpluses of electricity with acceptable levels of pollutant emission.

The project includes the following activities:

1. Analysis of cogeneration systems;
2. Particulate emission control in bagasse boilers;
3. Efficiency improvement in bagasse boilers;
4. Theoretical and experimental evaluation of a combined gasifier/gas micro-turbine system for electricity generation;
5. Simulation of BIG GT plants in sugar cane mills;
6. Publication of a book with the results of the project.

Through this project we are planning to offer a modest contribution to the technological sustainable development of the sugar cane industry in the first years of the next millennium.

Other similar projects are being developed in Brazil, Mexico and Australia. It is important to develop projects aiming the construction of advanced technology pilot plants with integrated gasification and gas turbines. This would allow solving existing technological problems and accelerating the commercialization of this technology.

VII- Conclusions.

The current levels of the emission of pollutants in sugar cane industry, even though they are lower than in other industrial sectors, can be reduced with existing prevention control technologies down to the levels required by the standards in force.

The introduction of advanced cogeneration technologies in the sugar cane industry would allow the generation of appreciable amounts of electricity with a lower environmental impact than the electricity generated from fossil fuels.

One of the important aspects in order to achieve a clean production is a high energy utilization efficiency in the sugar manufacturing process.

A clean production and efficiency could make the sugar cane industry recover its economical importance and constitute one of the bases of sustainable development of extense regions and countries where sugar cane is cultivated.

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