

# CO-GENERATION IN THE SOUTH AFRICAN SUGAR INDUSTRY

A WIENESE

*Sugar Milling Research Institute, University of Natal, Durban, 4041, South Africa*

## Abstract

Unlike in a number of other sugar producing countries, co-generation generally has not been considered a viable option for the South African sugar industry. The main reasons for this are an abundance of generating capacity at ESKOM and the low cost of fuel in the form of coal. Although this is still true today it might well change in the near future. It is estimated that ESKOM's capacity will be fully utilised by the year 2005. At the same time new government energy policies are based not only on economic factors but place a greater emphasis on social and environmental aspects. In addition, new developments in power generation called Biomass Integrated Gasification / Combined Cycle (BIG/CC) indicate a potential increase in power yield of 50 to 80% over the best technology currently used. These developments might change the future of co-generation in the South African sugar industry.

## Introduction

In the sugar industry, the term co-generation is generally adopted for the production of electricity for the purpose of export. The feasibility of co-generation then depends on the capability to produce electricity over and above one's own needs in the presence of an export market. In South Africa the market for electricity is almost totally controlled by ESKOM, which is a government organisation, and until now the sugar industry has hardly been able to enter into that market. The main reasons are an excess of generation capacity at ESKOM and the cheap price of coal. Despite the fact that the industry is not engaged in co-generation in any significant way, all the bagasse is being used in one way or another. One might conclude from this that the industry is unable to produce a surplus of electricity or that bagasse is utilised inefficiently, at least from an electricity generation point of view. Whatever the reasons for the lack of participation in co-generation, this might change in the years ahead due to two recent developments. The first is the government's publication of a Draft White Paper on Energy in which it reveals its energy policy. A short summary of this policy will be given, with special focus on its objectives and energy markets. The second is the development of a new technology for the generation of electricity from biomass, referred to as Biomass Integrated Gasification / Combined Cycle (BIG/CC). The principles and consequences of this technology will be outlined using elementary thermodynamics.

## Government's Draft White Paper on Energy

The government's energy policy must be seen in a wider national and international context. It is based on economic, social and environmental considerations. On a national level it forms an integral part of issues such as:

- The Reconstruction and Development Programme (RDP) which includes the electrification of 2,5 million households by the year 2000.
- The government's new macro-economic strategy - Growth, Employment and Redistribution (GEAR) - aims for economic growth of 6% per annum and the creation of 400 000 new jobs by the year 2000.

South Africa has to take cognisance of international trends and pressures which will affect its energy policy. Some such trends and pressures are:

- World markets are opening up and to be competitive there is a strong move towards deregulation, commercialisation and privatisation.
- The oil crisis put greater emphasis on energy security by means of diversification and flexibility of supply.
- Attention has to be given to the environmental impact of the energy sector which goes beyond the country's boundaries.

### *Government's energy policy*

In the Draft White Paper on the Energy Policy of the Republic of South Africa (Anon, 1998) government formulates the following objectives:

- *Increasing access to affordable energy services:* Government will promote access to affordable energy services for disadvantaged households, small businesses, small farms and community services.
- *Improving energy governance:* The relative roles and functions of the various energy governance institutions will be clarified, the operation of these institutions will become more accountable and transparent and their membership will become more representative. Stakeholders will be involved in the formulation and implementation of new energy policies.
- *Stimulating economic development:* Government will encourage competition within energy markets. Where necessary, government will intervene to ensure effective delivery of energy services to consumers. Government encourages energy prices to be as cost-reflective as possible. If subsidies are required these should be implemented transparently. Energy taxation will continue to remain an option within government's fiscal policy. Government

will work towards an investor-friendly climate in the energy sector.

- *Managing energy-related environmental impacts:* Government will promote access to basic energy services for poor households in order to reduce negative health impacts arising from the use of certain fuels. Government will work towards the establishment and acceptance of broad national targets for the reduction of energy-related emissions that are harmful to the environment.
- *Securing supply through diversity:* Government will pursue energy security by encouraging a diversity of both supply sources and primary energy carriers.

The key elements are renewable energy sources, energy efficiency, atmospheric emission, security through diversity, privatisation, restructuring of the energy sector and energy access and affordability. Government's support for these issues may well lead to an export price of electricity that makes co-generation a viable option for the sugar industry. The present buying price of electricity in South Africa varies from place to place. In the Durban area the electricity supplier (Durban Metro Electricity) pays ESKOM an average price of about 11 cents/kWh and charges its customers between 13 and 29 cents/kWh depending on tariff group and consumption pattern ('personal communication). The average price that the sugar industry pays for its electricity is estimated to be well above 15 cents/kWh. If, on the other hand, a factory manages to negotiate a contract to deliver electricity to the grid, the selling price is of the order of 3 cents/kWh ('personal communication) which is close to ESCOM's marginal cost price (see Table 1).

**Table 1: The buying and selling price of electricity**

Energy prices	cents/kWh
Selling to ESKOM	3
Buying	
- Sugar industry	15
- Industry (large)	13-29
- Residential	24
- Business (small)	29
- Durban Metro	11

#### *South Africa's energy supply*

South Africa's total primary energy supply in 1995 was approximately 1150 million GJ. Table 2 (Anon, 1998) gives an overview of this energy with regards to its source. Coal was by far the biggest supplier with 70%, but its contribution is slowly declining and is expected to continue to do so. The liquid fuels, which exclude synthetic fuel production by

Sasol and Moss gas, is about 15% and is fully imported. While the contribution of natural gas from Moss gas is presently only 1,7%, significant expansions are expected due to the discoveries of large gas fields in neighbouring Mozambique and Namibia. Koeberg is the only nuclear power station in South Africa and provides about 2,7% of the total primary energy supply. The future of nuclear energy is, however, uncertain and depends not only on economic and environmental considerations but also on its political acceptability. Renewable energy resources are presently about 10% but they are identified as those resources with the most potential for growth in the years ahead.

**Table 2: South Africa's primary energy supply in 1995**

Energy supply sectors	Percentage of total
Coal	70,6
Liquid fuels	15,0
Natural gas	1,7
Nuclear energy	2,7
Renewable energy	10,0
Total	100,0

#### *South Africa's energy demand*

As shown in Table 3 (Anon, 1998), the use of energy by end users shows a great diversity both in quality and quantity and is highly affected by social factors. Households consume 22% of the country's energy, 65% of this being in the form of fuel wood. This 22% is expected to increase substantially with government's plans for the electrification of 2,5 million households by the year 2000. Industry, mining and commerce are the biggest users of energy with 51%. The relatively cheap cost of energy has led to inefficient use by these sectors. Transport of people and goods accounts for 24% of total energy consumption. More than 90% of transport energy is derived from liquid fuels, which is largely dependent on crude oil imports. About 3% of the total energy is consumed by agriculture. Three quarters of this is met by liquid fuels and only a relatively small part is met with electricity.

<sup>1</sup> Mr M Gittings, Durban Metro Electricity (1999).

<sup>2</sup> Mr TL Boshoff, Tongaat-Hulett TMD (1999).

Table 3: South Africa's energy demand in 1995

Energy demand sectors	Percentage of total
Households	22,0
Industry	51,0
Transport	24,0
Agriculture	3,0
Total	100,0

#### The South African sugar industry

During the 1997/98 crushing season the average cane yield per hectare was about 52,5 tons per annum. With 400 000 hectares under cane the total cane delivered to the mills was approximately 21 million tons. This cane produced 7 million tons of bagasse at a nett calorific value of 6,8 GJ per ton, which amounts to a total energy of 47,6 million GJ. From this bagasse 5,5 million GJ of electrical energy can be generated in a typical conventional boiler and turbine alternator configuration as used in the South African sugar industry. This equates to 262 MJ/tc or 73 kWh/tc. 'Typical' means a boiler operating at 75% LCV efficiency to produce steam at a pressure of 3000 kPa(abs) and a temperature of 400°C, which is exhausted in steam turbines at 70% efficiency to a back pressure of 200 kPa(abs). According to Turn (1999) the energy generating capacity can be increased to 120 kWh/tc by making improvements in the form of higher pressure boilers, better boiler and turbine efficiencies and the use of a combination of back pressure and condensing turbines.

Table 4: Energy and the sugar industry

	South Africa million GJ/year	Sugar industry million GJ/year	Sugar/SAfrica percentage
Primary energy	1150	47,6	4,14
Electricity	617	2,3	0,37

In practice, however, not all bagasse and/or steam is available for the generation of electricity. Some of the bagasse is exported to be used in the production of paper, board, furfural, etc., while part of the steam is used to supply energy to prime movers such as turbines to drive shredders, mills, boiler feed water pumps, boiler fans, etc. In addition, for a well balanced factory, about 10% of the total steam is not passed through a turbine but through a letdown station to prevent or minimize the blow-off of steam as a result of swings in

process steam demand. At present the average electrical power generated in the South African sugar industry is approximately 30 kWh/tc or 108 MJ/tc. For a cane crop of 21 million tons this results in a total electrical energy of 2,268 million GJ, which is less than half its potential generating capacity. Most of this energy is used within the industry itself and very little is exported (see Table 4).

#### Biomass Integrated Gasification / Combined Cycle (BIG/CC)

Sugar industries around the world are in the process of increasing their electricity generating capacity in excess of their own requirements for the purpose of co-generation. The conventional steam power plant is, however, incapable of increasing electricity generating rates much beyond 120 kWh/tc (Turn, 1999) and new technologies are being explored. The most promising of these new technologies is the Biomass Integrated Gasification / Combined Cycle (BIG/CC) which has been the subject of many publications, including Bridgwater (1995), Channiwala (1994), Hobson and Dixon (1998), Larson *et al.* (1989), Ogden *et al.* (1989) and Weeks and Rohrer (1997). BIG/CC is based on the gasification of bagasse to form a combustible gas that can be used in a gas cycle on top of the steam cycle currently employed. The projected yield of this combined cycle is in excess of 200 kWh/tc (Turn, 1999). If trash and tops were included this could even be as high as 460 kWh/tc (Larson *et al.* 1989). Table 5 shows the electricity generating potential for various scenarios. The estimated capital costs of a combined cycle plant are of the order of R10 million/MW with operating and maintenance costs of 15 cents/kWh (Turn, 1999). This compares very unfavourably with the buying price and even less favourably with the selling price of electricity (Table 1).

Table 5: Electricity generation potential

Cycle	Technology	Electricity generating fuel	kWh/tc
Steam	standard	bagasse (part)	30
Steam	standard	bagasse	73
Steam	optimum	bagasse	120
Combined	optimum	bagasse	200
Combined	optimum	bagasse, tops and trash	460

#### Steam cycle

The Carnot cycle, consisting of two isotherms and two isotropes, is the most efficient thermodynamic cycle, but for practical reasons is not suitable for most applications. A modified Carnot cycle called the Rankine cycle, as shown in Figure 1, is therefore used universally for the generation of electricity.

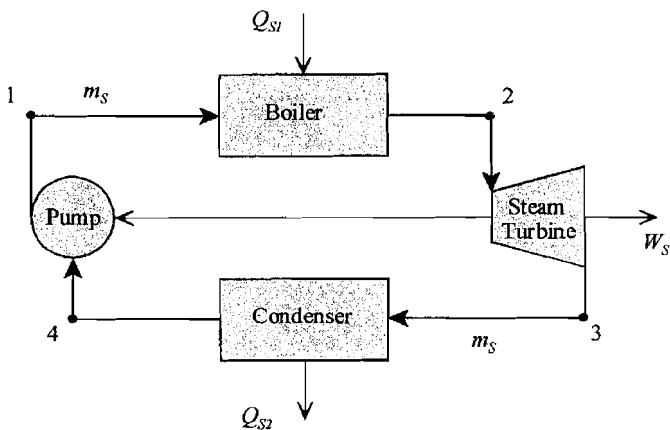


Figure 1: Steam cycle flow diagram

Under reversible conditions (i.e. no system losses) the cycle consists of the following processes. In the boiler, 1 to 2, heat  $Q_{S1}$  is supplied isobarically to the boiler feed water to produce superheated steam. In the turbine, 2 to 3, work is generated through the isentropic expansion of superheated steam. In the condenser, 3 to 4, heat  $Q_{S2}$  is given up isobarically while turbine exhaust steam loses its latent heat. In a sugar factory the condenser takes the form of process equipment such as evaporators and juice heaters. In the boiler feed water pump, 4 to 1, the condensate pressure is raised isentropically to that of the boiler by the application of work. The work produced by the turbine minus that needed by the boiler feed water pump is the net work  $W_S$  created by the cycle. This is available to the alternator for the generation of electricity. The thermal efficiency  $\eta_s$  of the cycle is defined as the net work output  $W_S$  divided by the heat input  $Q_{S1}$ . Since the net work output  $W_S$  is equal to the heat input  $Q_{S1}$  minus the heat output  $Q_{S2}$ , the cycle efficiency can be expressed in terms of its heat flows as follows:

$$\eta_s = 1 - Q_{S2} / Q_{S1}$$

Because the heat  $Q$  is equal to  $m/TdS$ , this cycle is most conveniently represented in a temperature entropy diagram (Figure 2).

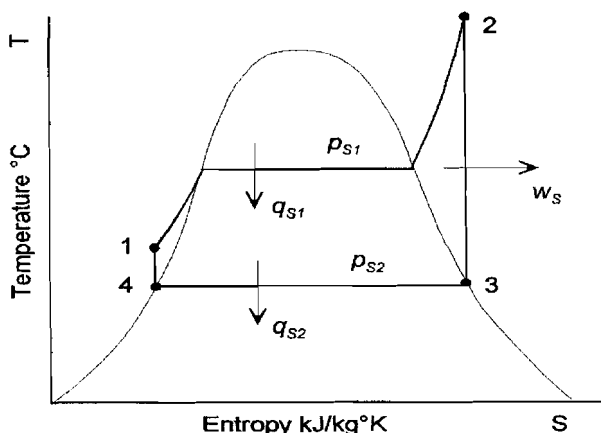


Figure 2: Steam cycle temperature entropy diagram

In this diagram, the heat input per unit mass  $q_{S1}$  is equal to the area between 1, 2 and the horizontal axis. Similarly, the heat output per unit mass  $q_{S2}$  is given by the area between 3, 4 and the horizontal axis. The net work per unit mass  $w_S$ , which is the difference between these two, corresponds to the area 1234. Since the mass flow  $m_S$  is constant throughout the cycle, the efficiency can alternatively be formulated as:

$$\eta_s = 1 - q_{S2} / q_{S1}$$

In order to raise the efficiency  $q_{S2}$  needs to decrease and/or  $q_{S1}$  must increase. This translates into a drop of the 3-4 line and/or an elevation of the 1-2 line. The 3-4 line is fixed by the condensing pressure, which is determined by process requirements and cannot be altered freely. The 1-2 line corresponds to the boiler pressure and superheat temperature. A rise in either of these is possible and will indeed result in an improvement in efficiency. Ultimately, however, the boiler pressure is limited by the triple point of water which is at a very high pressure of 22 100 kPa and a relatively low temperature of 374°C.

Gas cycle

The most basic gas cycle is an open system. A compressor supplies air to a combustion chamber where it is mixed with fuel. The chemical reaction between air and fuel results in high temperature gases which expand through a turbine and exhaust to the atmosphere. However, when it is assumed that the chemical energy released on combustion is equivalent to the transfer of heat from an outside source to a fixed quantity of gas as the working fluid, the system can be treated as a closed gas cycle (see Figure 3).

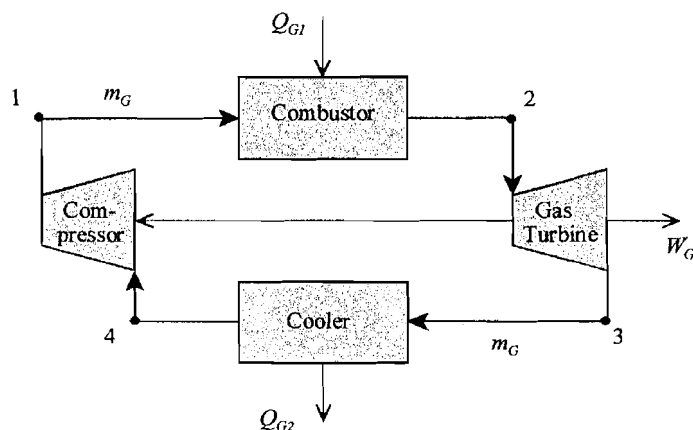


Figure 3: Gas cycle flow diagram

Under ideal conditions the cycle processes are identical to those of the steam cycle. In the combustion chamber, 1 to 2, the heat  $Q_{G1}$  is provided for the isobaric elevation of the gas temperature. In the turbine, 2 to 3, work is generated through the isentropic expansion of the hot gas. In a cooler, 3 to 4, the temperature of the turbine exhaust gas is lowered isobarically while heat  $Q_{G2}$  is rejected. In a compressor, 4 to 1, the gas pressure is increased isentropically to its original level. The

nett work  $W_G$  available to the alternator is the difference between the work done by the turbine and that required by the compressor. As for the steam cycle, the thermal efficiency  $\eta_G$  of the gas cycle is given by:

$$\eta_G = 1 - Q_{G2} / Q_{G1}$$

Again this cycle can be usefully illustrated in a temperature entropy diagram (Figure 4) in which the various areas are associated with heat and work.

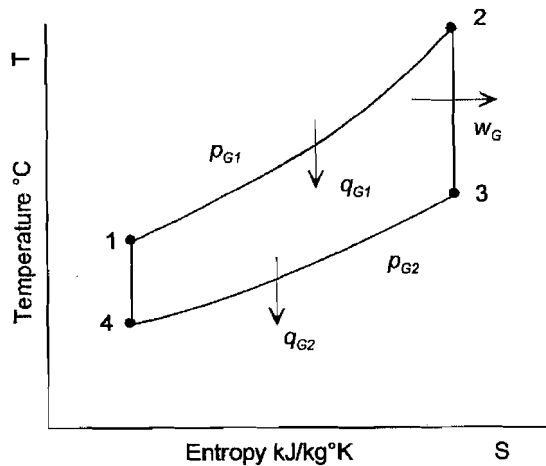


Figure 4: Gas cycle temperature entropy diagram

The heat input per unit mass  $q_{G1}$  is equal to the area between 1, 2 and the horizontal axis, the heat output per unit mass  $q_{G2}$  is given by the area between 3, 4 and the horizontal axis and the nett work per unit mass  $w_G$  coincides with the area 1234. It is assumed that the gas mass flow  $m_G$  is constant throughout the cycle and therefore the efficiency can be rewritten as:

$$\eta_G = 1 - q_{G2} / q_{G1}$$

Usually one has little control over the cooling pressure selection which means that the heat output  $q_{G2}$  is virtually fixed, i.e. the line 3-4 in the temperature entropy diagram is set. The cycle efficiency is therefore mainly determined by the magnitude of the heat input  $q_{G1}$  which should be as high as possible. In other words, in order to increase the efficiency the combustion pressure must be raised. This means a shift of the 1-2 line in the upwards direction. The maximum pressure and associated temperature is limited by the metallurgical limits of the materials used. This limit is substantially higher than the temperature of the triple point of water which is only 374°C.

**Combined cycle**

In the combined cycle the gas cycle is placed on top of the steam cycle. This means that the gas cycle supplies the heat for the steam cycle, i.e.  $Q_{G2} = Q_{S1}$ . For this heat transfer to take place, the temperature of the gas in the cooler must obviously be higher than the steam temperature in the boiler. The cooler pressure is therefore dictated by the boiler pressure and the temperature of the superheated steam. Because  $Q_{G2} = Q_S$ , the only heat input into the combined cycle is  $Q_{G1}$

and the only heat output is  $Q_{S2}$ . The thermal efficiency of the overall cycle  $\eta_C$  is therefore:

$$\eta_C = 1 - Q_{S2} / Q_{G1}$$

The heat output is equal to the mass of exhaust steam  $m_S$  multiplied by the heat output per unit mass  $q_{S2}$ . The heat input is derived from the bagasse and, if the heat transfer from bagasse to gas was without losses, this heat input is the mass of bagasse ( $m_B$ ) times its nett calorific value ( $NCV_B$ ). The thermal efficiency of the combined cycle then takes the following form:

$$\eta_C = 1 - (m_S * q_{S2}) / (m_B * NCV_B)$$

As mentioned earlier, the condenser pressure, and thus the value of  $q_{S2}$ , is dictated by process requirements. Tons of bagasse is directly proportional to tons of fibre in cane. The nett calorific value of bagasse ( $NCV_B$ ) is a function of its brix, moisture and ash and depends mainly on operating conditions. Hence an improvement in cycle efficiency at constant cane throughput, operating conditions and exhaust pressure results in a drop in exhaust steam. It is estimated that the combined cycle provides process steam at a level well below 40% on cane (Hobson and Dixon, 1998). This is in direct contrast with the present situation in South African sugar factories, which have a consumption closer to 55%. If the process steam cannot be reduced, part of the bagasse has to be used in the conventional steam cycle and only some of it is available to be employed in the gas cycle. This hybrid detracts greatly from the overall efficiency of the combined cycle. Alternatively, the steam production can be increased by the inclusion of tops and trash in the fuel.

The outline given above is a great simplification of the actual combined cycle process. As far as the gas cycle is concerned, this process involves drying of bagasse, gasification

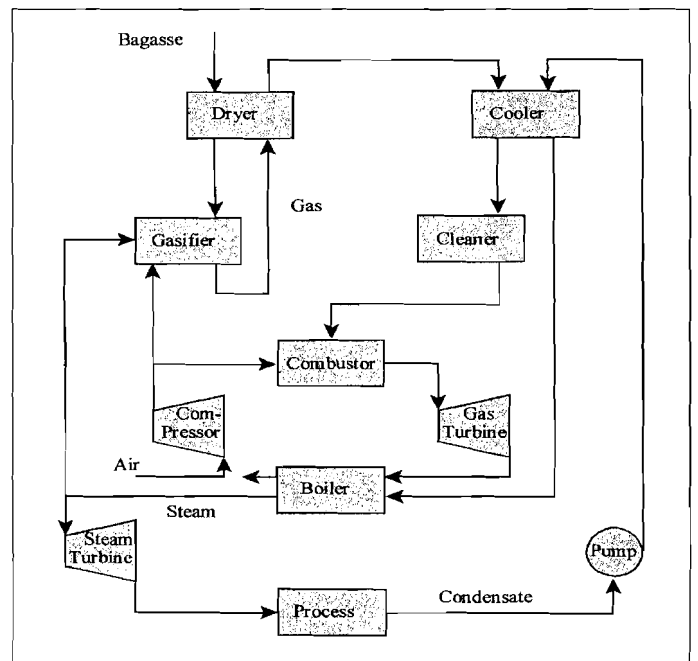


Figure 5: Combined cycle flow diagram

of bagasse, cooling of the products of gasification, cleaning of the cooled gases, combustion of the clean gases, expansion of the hot combustion gases and the compression of air for both the gasification and combustion processes. This process is shown in Figure 5. The gasifier is fed not only on air but on a mixture of air and steam to reduce the nitrogen content of the products of gasification and thereby increase their heating value in terms of  $\text{kJ/m}^3$ . Technical problems are experienced with virtually each of these unit operations. The combined cycle technology is still very much under development and is far from being commercially available.

### Conclusions

At the present selling price of electricity there is little incentive for the sugar industry to get involved in co-generation. However, government's new energy policy includes many elements which are encouraging for future participation in the energy sector by private enterprise. At the same time a new technology is being explored to increase the electricity yield from biomass. If this new technology materialises and the selling price of electricity is sufficiently attractive, the sugar industry has a tremendous potential for the export of electricity. If the industry wants to exploit this potential to the maximum it has to change its operating conditions by including tops and trash in the fuel and reducing its use of process steam.

### REFERENCES

- Anon (1998). Draft White Paper on the Energy Policy of the Republic of South Africa 1998. Department of Minerals and Energy.
- Bridgwater, AV (1995). The technical and economic feasibility of biomass gasification for power generation. *Fuel* 74(5): 631-653.
- Channiwala, SA (1994). Modelling of bagasse gasification process and study of parametric influence on gas quality. ISSCT combined factory/energy workshop on efficient production and utilisation of steam in sugar factories, held 28 November to 2 December at Pune, India. 35-48.

- Hobson, PA and Dixon, TF (1998). Gasification technology – prospects for large-scale, high-efficiency cogeneration in the Australian sugar industry. *Proc Aust Soc Sug Cane Technol* 20: 1-9.
- Larson, ED, Williams, RH, Ogden, JM and Hylton, MG (1989). Biomass gas turbine cogeneration in the cane sugar industry. *Proc Int Soc Sug Cane Technol* XX: 427-439.
- Ogden, JM, Hochgreb, S and Hylton, MG (1989). Process energy efficiency and cogeneration in cane sugar factories. *Proc Int Soc Sug Cane Technol* XX: 441-451.
- Turn, SQ (1999). Biomass Integrated Gasifier Combined Cycle Technology: Status of Commercial Development Efforts and Application in the Cane Sugar Industry. *Int Sugar J* (in press).
- Weeks, ST and Rohrer, JW (1997). Commercial demonstration of biomass gasification. *Tappi Journal* 80(5): 147-152.

### NOMENCLATURE

$\eta$	Thermal efficiency of a cycle
$S$	Entropy
$T$	Temperature
$Q$	Total heat flow
$W$	Nett work by a cycle
$NCV$	Nett Calorific Value
$q$	Heat flow per unit mass
$w$	Nett work by a cycle per unit mass
$m$	Mass flow
<i>Subscripts</i>	
s	Steam cycle
G	Gas cycle
c	Combined cycle
B	Bagasse