KEYWORDS: Cogeneration, Electric Energy, Bagasse, Harvest.

Abstract

Electricity in Cuba is produced mainly in thermal power plants burning fossil fuel; the price of fossil fuel indicates the necessity to develop other energy sources such as sugarcane biomass. A case study is made for a sugar factory of 7000 tonnes/day crushing capacity operating all year round in order to determine the different alternatives and sources of sugarcane biomass that can be used as fuel. Sugarcane bagasse, high fibre sugar cane (HFSC), and the sugar cane crop residues (SCCR) are considered, as well as an analysis of the grinding of the whole cane (WC). There are factories where it is possible to use middle steam pressure to cogenerate and generate electric energy all year in order to satisfy the electric energy needs of close towns or the national grid. It is also possible to use high-pressure steam technology to achieve higher generation. With 110–130 kWh/tonne cane, these installations can be considered as independent power plants. In order to achieve economical results producing electric energy at sugar factories and to be able to work all year round, it is necessary to use a second fuel, and sugarcane biomass is the first alternative to be considered. The sugar cane crop residues, the high fibre sugar cane, the saved bagasse and the whole cane processing are alternatives to be considered in order to generate additional electric energy. To operate at a certain capacity of generation, sugarcane biomass can satisfy the criterion to operate year round.

Introduction

In Cuba, since the beginning of the twentieth century, electric energy has been cogenerated in the sugar industry using sugarcane bagasse as the fuel source. The electrification of the sugar industry in Cuba began with the electrification of the motors at the sugar factories.

In 1911, an electric plant was installed with a capacity that could satisfy the needs of the sugar factory and supply electric energy for other consumers, after the same sugar factory increased its generation capacity enough to serve a population of 10 000 inhabitants (Altshuler, 1999).

There were 76 sugar mills in 1925 totally or partially electrified and 200 turbogenerators installed, producing a total generation capacity of 162 MW, meanwhile, the public sector had installed only 108 MW.

Electric energy in Cuba is mainly produced in thermal plants using fossil fuel, because there are no other sources such as hydro or nuclear that can cover the needs of the country.

The price of fossil fuels—and their future increase to unknown prices—as well as their negative influence on the environment on account of greenhouse gas emissions, indicates the necessity to develop other energy sources. In the case of Cuba, sugarcane biomass offers possibilities to produce this energy with excellent environmental results.

In Table 1, the proportion of installed power and generation by the different sources is shown for the year 1959. In 1959, there were 159 sugar factories in operation and only 119 had power plants to produce electric energy; there were 292 turboalternators with 275 MW installed and 95 generators with 36 MW (JUCEPLAN, 1960). The quantity of electricity generated was 391 GWh per crop, and the potential was 664 GWh/crop using only 58% of the installed capacity with a mean generation index of 10.7 kWh/tonne of cane (Valdes, 1996).
Table 1—Installed power and generation by different sources in 1959.

<table>
<thead>
<tr>
<th>Data</th>
<th>Installed power</th>
<th>Electric energy generated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MW)</td>
<td>(%)</td>
</tr>
<tr>
<td>Thermal plants</td>
<td>429</td>
<td>50.4</td>
</tr>
<tr>
<td>Sugar factories</td>
<td>311</td>
<td>36.5</td>
</tr>
<tr>
<td>Independent plants</td>
<td>47</td>
<td>5.5</td>
</tr>
<tr>
<td>Other factories</td>
<td>65</td>
<td>7.6</td>
</tr>
<tr>
<td>Total</td>
<td>852</td>
<td>100</td>
</tr>
</tbody>
</table>

In these years, the main task of the sugar factory was to produce cane sugar, and the existing infrastructure was not adequate to cogenerate electric energy in order to supply it to a national grid. There was no national grid and due to the low oil price, there was no incentive to generate energy at the sugar factories. Many sugar factories used mainly thermal energy for power and heat. At this time, only 56% of the population of the country received electric energy.

Since the middle of the sixties, there has been an increase in the power installed at the sugar factories and also in the quantity of electric energy generated. At present, around 26 kWh/tonne of cane is generated, which is more than double the quantity generated in 1959. The situation in 1999 is shown in Table 2.

Table 2—Installed power and generation by different sources 1999 (Valdes, 1997).

<table>
<thead>
<tr>
<th>Data</th>
<th>Installed power</th>
<th>Electric energy generated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MW)</td>
<td>(%)</td>
</tr>
<tr>
<td>Thermal plants</td>
<td>3182</td>
<td>76.2</td>
</tr>
<tr>
<td>Sugar factories</td>
<td>818*</td>
<td>19.6</td>
</tr>
<tr>
<td>Independent plants</td>
<td>160</td>
<td>3.8</td>
</tr>
<tr>
<td>Other factories</td>
<td>14</td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td>4174</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* From them 684 are interconnected to the National Grid

Sugar cane biomass

Sugar cane can provide biomass to be used as fuel. One source, sugarcane bagasse, is obtained at the factory. The high fibre sugar cane (HFSC), the sugar cane crop residues (SCCR), and the grinding of the whole cane (WC) are other fuel sources that could be available from this plant.

High fibre content sugar cane

Crossing Saccharum officinarum with Saccharum spontaneum can produce a high fibre content sugarcane, sometimes called an energy cane. It normally has more than 22–24% fibre on cane, meaning that it has practically double the biomass of normal sugarcane and can be used mainly as fuel for energy purposes (Zabala, 1998).

It is claimed that its agricultural yield is higher than 100 t/ha and, if harvested as whole cane, yield can be increased by 15–20%. It can be harvested at 10 to 12 months of age, has a high resistance to smut and rust, and adapts well to different soil conditions. An analysis of this type of sugarcane at a sugar factory is shown in Table 3.

Sugar cane crop residues

Sugar cane has other components apart from the stalk such as the green and dry leaves and the tops. They represent around 25% of the weight of the whole cane. At harvest, 50% of these components are removed and, in Cuba, another 25% is separated at the dry cleaning centres, and the rest goes to the sugar factory with the cane stalk as extraneous matter (Valdes, 1995).

Table 3—Data of high fibre content sugar cane (Peña and Perez, 1999).

<table>
<thead>
<tr>
<th>Fibre(%)</th>
<th>Bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane</td>
<td>Bagasse</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>Cane (%)</td>
</tr>
<tr>
<td>22.34</td>
<td>43.63</td>
</tr>
</tbody>
</table>

A sugar factory that grinds 1000 tonnes of cane per day can have 76 tonnes of SCCR as an additional fuel. Of the 76 tonnes, some goes to the factory with the cane and the rest stays in the field. The SCCR obtained from each million tonnes of sugar produced amount to more than three millions tonnes of a biomass fuel, of which around 750 000 tonnes are directly available.

The harvest of sugarcane in Cuba employs a system that separates some of the extraneous matter from the cane. For this objective, 915 dry cleaning stations are located throughout the country and process more than 85% of the cane that goes to the factories, with unitary capacities of 500 t/d. This cleaning of the cane produces 30–40 tonnes SCCR per day (Valdes, 1998a).

The feasibility of using these residues for generating electric energy, or rather the definition of the quantity of energy that is consumed in their preparation, manipulation and transportation in relation to the energy that can be produced, is an important factor in specifying the best process to use these residues.

The available net energy indicates figures of 67% to 93%; also, there is an increase of 7% to 14% of the biomass fuel obtained from this agro industry when these residues are used. From an environmental standpoint, the usage of these residues allows the substitution of fossil fuels and, as a consequence, less greenhouse gases are sent to the atmosphere (Valdes, 1998b).

The composition of these residues is shown in Table 4.

### Table 4—Composition of the SCCR.

<table>
<thead>
<tr>
<th>Components</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tops and green leaves</td>
<td>8.44</td>
</tr>
<tr>
<td>Dry leaves</td>
<td>19.74</td>
</tr>
<tr>
<td>Clean stalks</td>
<td>71.82</td>
</tr>
</tbody>
</table>

### Whole cane

The processing of the whole cane makes it possible to have a direct increase in the quantity of bagasse at the sugar factory that can be used as fuel. One topic of discussion among the sugar technologists is that processing the whole cane will increase the final molasses losses due to the presence of non-sugars, and can also increase the starch content in the sugar produced.

An analysis made of the increased losses from molasses and bagasse on account of the processing of tops and the increase of the biomass content, considering the prices of sugar and fuel oil, indicated that it can be economically feasible to process the tops. Nevertheless, it is necessary to make an industrial test in order to obtain more accurate information. An economic analysis of the increase of the starch content and the application of α-amylase enzyme to decrease it must be made.

### Case study

In order to achieve economical results from the electric energy generation at the sugar factories and to be able to work the year round, it is necessary to use a second fuel. This second fuel: petroleum gas, fuel oil, coal or biomass as wood or from sugarcane can depend on the availability of these fuels. From an environmental standpoint, undoubtedly biomass can be the first alternative.

In the sugarcane industry in Cuba, 30–40% of the factories have the best conditions to cogenerate and generate electric energy all year round. There are factories that can cogenerate and generate electric energy all the year with minimum investment in order to satisfy the electric energy needs of nearby towns, or it can be supplied to the national grid. Using high-pressure steam technology, it is possible to generate 110–130 kWh/t of cane (Anon., 1994). These are installations that can be considered as independent plants.

The price paid for the electricity to the sugar factories is an incentive for its production. A price of 4.0 USc per kWh is paid to those factories that supply electricity to the grid; to be incorporated in this system, it is necessary that the factory be self-sufficient and does not acquire electricity from the grid.

For this type of installation, for a sugar harvest of 150 days, there will be cogeneration for that period and 180 days of generation of electric energy. In order to operate the whole year 7920 hours (330 days), it is necessary to use the second fuel such as sugarcane crop residues, the cane variety of high fibre content, and/or the sugarcane bagasse. These alternatives must be analysed.

The data considered for the case study are as follows:

- Cane milled: 292 t/h.
- Bagasse % cane: 28.
- Sugarcane crop residues available: 575 t/d.
- Number and capacity of installed boilers: 4 boilers of 45 t of superheated steam per hour.
- Boiler steam pressure: 42 kg/cm².
- Back pressure steam: 1.8 kg/cm² Process steam consumption: 420 kg/ton cane.
- Steam generation index: 2.2 t of steam per t of bagasse.
- Number and capacity of installed turboalternators: 3 turboalternators of 4 MW each with 70% efficiency.
- Electric energy consumption: 30 kWh/t cane.
- Installation of a new electric energy generator: condensing type.

**Electric energy cogenerated**

It has been considered that 10% of the steam generated is sent to the technological process through the steam pressure-reducing valve.

The electricity generation is 11.8 MW using three boilers, the sugar factory consumption is 8.7 MW, and there is an electricity surplus of 3.1 MW. The total quantity of energy that can be supplied to the national grid during the sugar campaign by cogeneration is 11.2 GWh.

**Electric energy generated**

**During sugar season**

The quantity of available bagasse during the cane grinding season and the capacity and steam pressure of the installed boilers are enough for the factory requirements. Making an investment in a turbogenerator of the condensing type, it is possible to generate 10 MW with the installed energy infrastructure. The total quantity of energy that could be supplied to the national grid during the sugar season by generation is 36.0 GWh.

**During the off-season**

Using the steam condensing turbo-alternator at its nominal capacity, 43.2 GWh will be generated. In Table 5, the total quantity of electric energy that can be supplied to nearby towns or to the national grid is shown.

<table>
<thead>
<tr>
<th>Table 5—Total quantities of electric energy that can be supplied to nearby towns or to the national grid in GWh.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Season</td>
</tr>
<tr>
<td>Off-season</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Using higher steam pressures, there can be a substantial increase in the generation for the same studied case but a higher investment will be required. As mentioned, there are alternatives for the necessary second fuel, considering sugarcane biomass. In relation to the case study, these alternatives are described.

**Sugar cane crop residues:** In this case, there are 574 t/d available, which means a quantity of 86 250 tonnes per crop, and 84 672 tonnes are needed. The use of the SCCR can satisfy the fuel requirements for this project.

**High fibre sugar cane:** It has been stated that energy cane has around 25% of fibre on cane, which means that it will be necessary to have 169 344 tonnes of this type of cane. Considering an agronomic yield of 100 t/ha, some 1693 ha will be needed. The quantity of land needed for the cane used in sugar production is 15 000 ha, for a yield of 70 t/ha. The energy cane will require an additional 11.3% of land. However, higher yields can be expected and excellent soils are not required.
Saved bagasse at the sugar factory where the alternator is installed is not an alternative to be considered in this project, because it will change the defined parameters of the case study, basically the quantity of energy that can be supplied to the electric grid.

The possibility of obtaining surplus bagasse from nearby factories could be analysed. An analysis must be made to determine the economic distance that the bagasse can be delivered.

The whole cane alternative indicates that there can be a positive economic result. It is necessary to research the effects on sugar production to define its technological availability. This alternative will allow bagasse surplus at the sugar factory.

**Sugarcane potentialities**

The potential using actual developed technologies and technologies that are in a developing state is described as follows:

1. Cogeneration possibilities using all actual installed capacity:
   \[800 \times 24 \times 150 \times 0.90 \times 0.85 = 2205 \text{ GWh/year}\]

   With a time of operation of the sugar factory of 85% and 90% for the alternator, that is the maximum that can be obtained with the actual technologies, signifying a supply of 885 GWh/year to the National Grid, if there is a consumption at the sugar factories of 1340 GWh/year.

   Considering the needs of all the sugar sector, this means that it will still be necessary to use 120 GWh/year from the national grid.

2. Considering an increase in the generation on the base of a selection of 55 sugar factories with the best conditions and using recent technologies that have been transferred to the sugar industry or are in a developing state.

   The quantity of cane that can be crushed in these 55 factories with a daily capacity of 390 000 tonnes, operating 150 days/year and with 85% of operating capacity, is: 390 000 \times 150 \times 0.85 \times 0.90 = 45 900 000 tonnes

   (a) Using an actual technology with high steam pressure, 100 kWh/t of cane can be generated. It will be possible to generate around 4590 GWh/year (42% of the quantity generated in the country in the year 1990), and supply 2263.5 GWh/year to the national grid after satisfying all the needs of the sugar sector.

   (b) Using combined cycles gas-steam, it is estimated that electric energy will be generated at a rate of 200 kWh/t of cane (Odgen *et al.*, 1990).

   It will be possible to generate around 9180 GWh/year (84% of the quantity generated in the country in the year 1990), and supply 6853.5 GWh/year to the National Grid after satisfying all the needs of the sugar sector.

   (c) Using combined cycles gas-steam and all the sugarcane crop residues as fuel, it is estimated that electric energy will be generated at a rate of 400–800 kWh/t cane (Odgen *et al.*, 1990; Williams and Larsen, 1991, 1992; Larsen *et al.*, 2000).

   It will be possible to generate around 18 360–36 720 GWh/year (167%–334% of the quantity generated in the country in the year 1990), and supply 16 033.5–34 393.5 GWh/year to the national grid after satisfying all the needs of the sugar sector. In this case, also all the country’s requirements will be satisfied.

**Conclusions**

There is a high potential to generate and cogenerate electric energy in the Cuban Sugar Industry, and there are possibilities to prepare and implement projects for the generation and cogeneration of electric energy at the sugar factories.

Case studies can be made in order to determine technical and economic feasibility for different scenarios during and after the crop harvest.

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L’OPTION CANNE À SUCRE POUR LA PRODUCTION D’ÉLECTRICITÉ
DANS LES USINES SUCRIÈRES CUBAINES

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MOTS CLÉS: Cogénération, Énergie Électrique, Bagasse, Récolte.

Résumé

A CUBA, l’électricité est produite principalement à partir d’un combustible fossile dans les centrales thermiques. Le prix élevé de ce combustible est une indication de la nécessité de développer d’autres sources d’énergie telles que la biomasse de la canne à sucre. Une étude de cas a été effectuée dans une usine sucrière d’une capacité de broyage de 7000 tonnes par jour et opérant toute l’année, afin de déterminer les différentes options et les types de biomasse de la canne à sucre qui peuvent être utilisés comme combustible. La bagasse, la canne à forte teneur en fibre et les résidus de la canne après la récolte sont considérés dans cette étude, ainsi qu’une analyse du broyage de la canne entière. Dans certaines usines, il est possible d’utiliser la vapeur à moyenne pression pour la cogénération et de produire l’énergie électrique toute l’année afin de satisfaire les besoins en électricité des villes avoisinantes ou du réseau national. Il est également possible d’employer la technologie de vapeur à haute pression pour réaliser une production plus élevée ; avec 110 à 130 kWh/toune de canne, ces usines peuvent être considérées comme des centrales thermiques indépendantes. Pour que la production d’électricité dans les usines sucrières soit rentable et pour pouvoir opérer toute l’année, il est nécessaire d’utiliser un deuxième carburant et, dans ce contexte, la biomasse de la canne à sucre est considérée comme la meilleure option. Les résidus de la canne après la récolte, la canne à sucre à forte teneur en fibre, la bagasse économisée et le traitement de la canne entière sont autant d’options à considérer pour produire de l’énergie électrique additionnelle. La biomasse de la canne à sucre peut satisfaire le critère pour une opération à une certaine capacité de génération et ce durant toute l’année.

ALTERNATIVAS DE LA CAÑA DE AZÚCAR PARA LA GENERACIÓN ELÉCTRICA
EN LAS FÁBRICAS DE AZÚCAR CUBANAS

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PALABRAS CLAVES: Cogeneración, Energía Eléctrica, Bagazo, Cosecha.

Resumen

La electricidad en Cuba se produce en plantas termoenergéticas quemando combustibles fósiles; el precio de los combustibles fósiles indica la necesidad de desarrollar otras fuentes de energía tales como la biomasa de la caña de azúcar. Se elaboró un estudio de caso para una fábrica de azúcar de 7000 toneladas por día de capacidad de molida operando a lo largo de todo el año, con el fin de determinar las diferentes alternativas y recursos de la biomasa que pueden ser empleados como combustibles. Se consideraron el bagazo de caña, la caña de azúcar de alto contenido de fibra y los residuos de la cosecha de caña, así como la alternativa de molida de la caña integral. Existen fábricas donde es posible emplear vapor de presiones medias para cogenerar y generar energía eléctrica todo el año con el fin de satisfacer las necesidades de energía eléctrica de las poblaciones cercanas o el Sistema Electroenergético nacional. Es posible también utilizar tecnologías de alta presión para alcanzar altas generaciones: con 110–130 kWh/toune de caña molida; estas instalaciones pueden considerarse como Plantas Energéticas Independientes. Con el fin de alcanzar resultados económicos produciendo energía eléctrica en las fábricas de azúcar y posibilitar operar a lo largo de todo el año, es preciso emplear un segundo combustible; la biomasa de la caña de azúcar es la primera alternativa que debe ser considerada. Los residuos de la cosecha de la caña, la caña de Alto contenido de fibra, el bagazo y el Caña Integral resultan alternativas a considerar con el fin de generar energía eléctrica adicional. Para operar a una determinada capacidad de generación, la biomasa de la caña de azúcar puede satisfacer el criterio de operar a lo largo de todo el año.