

RECENT DEVELOPMENTS IN SUGARCANE PROCESSING

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Abstract

Improvements in processing sugar cane are continuous as processors attempt to reduce costs. In addition, processors have been looking for new ways to increase revenue from processing sugarcane. New developments in technology are surveyed and the opportunities for revenue enhancement are explored.

Introduction

Sugar technologists continually make improvements to the way they process sugarcane. This is largely as a result of pressures on producers and operators to reduce costs, to remain competitive globally and improve profitability. The rate of change is much greater than ever before, technological change happens much quicker and the information and knowledge explosion is a reality. The future is no longer an extrapolation of the past and global competition is becoming a reality.

Most of the improvements in technology represent small but significant advances, and it is necessary to look for additional ways in which revenue can be squeezed from the sugar crop. It is largely for this reason that both ethanol production and export of electrical power are now more widely practiced. Sugarcane is an outstanding crop in terms of its ability to produce sugar and biomass more efficiently than most other crops. The sugarcane crop is one of the most productive, and is valued not only for its sugar but also for the fibrous content, which serves as a valuable fuel and in some cases also a valuable feedstock for further processing. The energy value of the whole crop can be profitably used to produce both sugar and ethanol with a low, and sometimes even a negative, carbon footprint.

Environmental issues are becoming far more important, particularly in the way sugarcane is produced. In the broader sense of sustainability, ways in which resources are used, particularly energy, water and labor, and emissions in growing and processing, are becoming important and impact on sugarcane processing.

Efforts to reduce the cost of production have focused not just on improving technology, but also on harnessing economies of scale and improving efficiencies by reducing losses and reducing power requirements. Worldwide costs of production have reduced over time, particularly as the major expansion of sugar production has occurred recently in countries with lower costs of

production. However politics, trade agreements, quotas and tariff protections all contribute to prices that producers can achieve for their products.

Overall the effect of most of these changes is to affect sugar prices and put pressure on reducing the costs of production. Assuming that trade barriers are progressively dismantled, it is expected that the high cost producers will go out of business, and continued survival or prosperity depends on having a cost of production no higher than the average and preferably below average.

This paper attempts to outline some of the significant advances in technology since the beginning of the century. These cover nearly all aspects of sugarcane processing, and show how the co-products of processing are being used to augment profitability. The production of second generation biofuels from sugarcane is being extensively investigated, with the prospect of profitable biorefineries producing a slate of products.

Developments in raw sugar production

Cane cleaning

The negative effects of cane washing are being more widely recognized, and dry cleaning of cane has become more widespread. This interest has been promoted by the change from burnt to green cane harvesting, largely with mechanical harvesting, and by the desire to use cane tops and leaves for the generation of power for export.

Systems in use are designed to remove some or all of the following: cane leaves and tops, roots and stubble, sand or field soil, clay mud balls, rocks and stones. Dry cleaning of cane could bring the following advantages:

- Cost savings in terms of reduced wear and maintenance.
- Increased factory capacity due to reduced quantities of extraneous matter.
- Reduced energy consumption.
- Higher calorific value of the bagasse.
- Lower losses of sugar in filter cake, bagasse and molasses.
- Improved sugar quality.

These generally outweigh the disadvantage of associated capital, maintenance and operational costs.

It has been shown that most of the leaves and tops can be relatively easily removed from billeted cane at the mill by blowing the leaves and tops out of the cane as it drops from one conveyor onto another (*Rein 2005*). Roughly 80 % of the leaves and tops were removed by blowing air at a velocity of about 30 m/s through a curtain of falling cane. The interesting feature is that the separation was achieved with virtually no loss of billets. Some rudimentary systems simply blow the leaves and tops out onto a large concrete slab and are managed with the use of a front-end loader. Trash is reduced from 6 % to 1 % with whole stalk cane and from 10 % to 3 % with billeted cane (*Ridge 2001*).

Pneumatic cleaning of cane in Australia has also shown that removal of tops and leaves from chopper harvested cane with a low level of billet loss is possible (*Schembri et al. 2002*). The

system was specifically designed to process cane with no trash removal in the field. Tests showed that, in order to reduce the leaf particle sizes to approximate bagasse, a relatively high power requirement for shredding of 12 kWh/t leaf material was required.

A number of different designs for trash separation are in use in Brazil, where leaves and tops are removed before crushing, to burn the material in the boilers. This is becoming attractive in a number of mills where surplus electric power generated is sold to the public grid. It is economically feasible to remove leaves and tops before crushing and send these materials to a shredder, before being mixed with bagasse and sent to the boiler station as additional fuel.

However it is generally not practical to fire only trash in a bagasse boiler, because of slagging and fouling problems caused by the higher concentration of alkali metals. The shredded trash needs to be mixed with bagasse before firing.

Diffusion

Cane diffusion has been widely adopted in Southern Africa for many years, and is increasingly being adopted elsewhere as its benefits are appreciated. Diffusers can achieve high extractions, typically 98 % in Southern Africa, and do not require more imbibition water than mills, do not necessarily require more steam and require only half the power input of a conventional mill (*Rein* 1999). Capital costs are roughly 2/3 of those for an equivalent milling tandem, while operating and maintenance costs are considerably lower. *Kumar and Rao* (2000) report these to be 44 % of the cost of running a 4 mill tandem, while *Caillier* (personal communication 2006) reports comparative annual costs from Louisiana for milling as \$9.12/t cane and \$3.17/t cane for diffusion.

Capital costs have been reduced even further by new developments in design in South Africa.

- A new development by Bosch Projects enables the chain and headshaft, both expensive components, to be dispensed with (*Voigt* 2010). The diffuser screen (floor) consists of 750 mm wide modules that run the entire length of the diffuser. Each of these modules moves independently of each other, and by employing the correct sequence of movement, the cane is conveyed through the diffuser. These individual modules are actuated by hydraulic cylinders.
- Tongaat Hulett Sugar have developed a new design of drive and headshaft, which substantially reduces the size of the headshaft and simplifies the mechanical structure.

Both these developments also allow for a diffuser to be expanded easily by widening the diffuser.

Over the last decade, most of the Southern African mills have started returning clarifier muds directly to the diffuser. A full evaluation of mud recycling (*Jensen* 2001) demonstrated the feasibility of recycling clarifier underflow to the diffuser, dispensing with the filter station altogether. The mud is returned at a point where the Brix content of the mud is close to that of the juice in the diffuser, so as not to interfere with extraction efficiency. To ensure that the return of clarifier muds does not affect the percolation in the diffuser by plugging the bed with fines, the mud is returned close to the first set of bed lifting screws. Details of the arrangement are shown in Figure 1. It was found that mud flow rate averaged only 4 t/100 t raw juice, largely

because of the low solids content in raw juice from diffusers. Thus the amount of sugar recycled is in fact quite small.

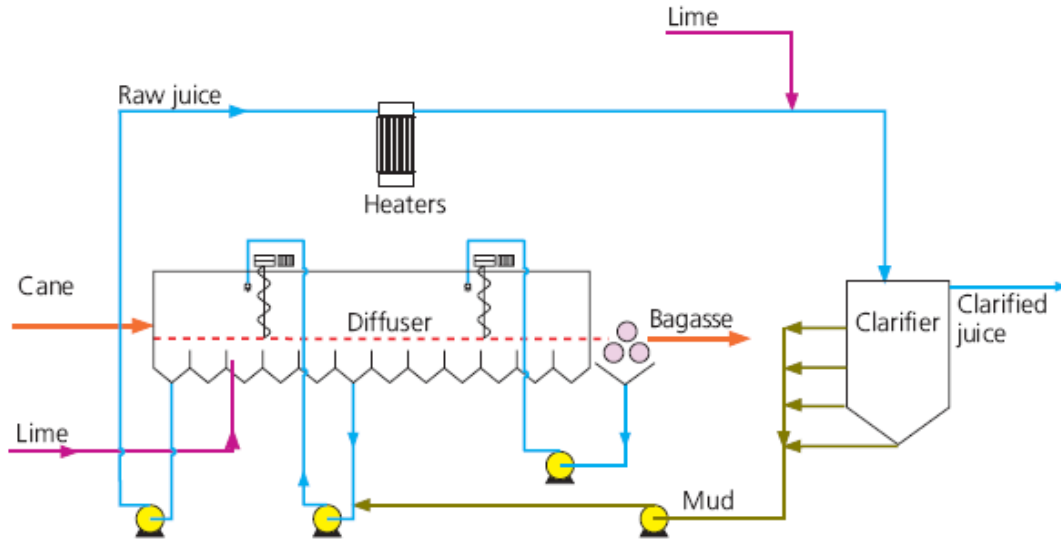


Figure 1. Schematic diagram of clarifier mud recycle to a diffuser.

Operation of mud recycling has established that extraction and percolation conditions are not affected adversely. A number of significant advantages have been identified:

- The operational and maintenance costs associated with running a filter station are eliminated.
- Loss of sugar in cake is eliminated.
- Chemical and microbiological losses associated with filter station operation are eliminated.
- The cost of disposing of the cake is saved.
- Water washing of the cake is obviated, reducing evaporation requirements.
- Equipment for bagacillo and cake conveying is not required
- The bagasse supply to the boilers is increased.

However, the amount of ash in bagasse is increased by about 10 %. This could have implications for increased boiler tube wear, depending on the boiler design and in particular gas velocities through the boiler tube banks. Gas velocities less than 10 m/s through the generating bank are low enough to obviate tube erosion. While reducing the ash (sand) content of cane delivered to the mills is the best solution, this is often not under the control of the mill operator.

Work done in Hawaii in the early sixties investigated the possibility of producing juice from a diffuser which did not require clarification. This work has been taken up again in South Africa, with some plant trials on-going (*Jensen 2013*).

Juice clarification

Trayless, so-called short retention time, clarifiers were introduced in the 1970s, but never lived up to their name. CFD (computational fluid dynamics) studies in the past few years (*Steindl 1995, 2001a; Chetty and Davies 2001*) have elucidated the liquid flow patterns in clarifiers.

These show that local velocities are higher than expected, leading to recirculation and short circuiting in clarifiers, seriously reducing their effectiveness. A modified Australian design has been developed which improves the situation significantly (*Steindl et al. 2005*).

It is apparent that in most clarifier designs, the capacity is limited by the liquid hydraulics, not the mud settling area. If all point velocities in a clarifier are kept below a threshold value (around 10 mm/s), clarifier performance is optimized. *Alvarez and Johnson (2006)* report that relatively simple modifications to conventional clarifiers to improve liquid hydraulics resulted in a 30 % improvement in capacity.

For the past few years, a modified clarifier design has been implemented in Louisiana, called the Louisiana Low Turbulence (LLT) clarifier (*Gaudet and Kochergin 2013*). It incorporates a network of juice feed pipes which introduce juice through a series of hydraulically uniform pathways. The endpoints of pathways are distributed uniformly over the clarifier. Endpoints of the distribution piping are fitted with “turbulence reduction devices” to cancel the momentum of the liquid entering the clarifier. Clarified juice overflow is collected through a series of uniformly distributed outlets at the top portion of the clarifier. Juice residence time in these clarifiers is reported to be about 35 minutes compared with something closer to an hour in conventional clarifiers.

It is anticipated that new designs will be able to achieve significantly lower retention times, closer to 10 minutes, the theoretically achievable value.

Filtration

Vacuum belt press filters have become more widespread, replacing rotary vacuum filters in many instances, particularly in South and Central America. A comparison undertaken in Reunion reported that the loss of sugar in cake could be reduced, but the filter feed required conditioning with lime and flocculant and used more water. However it does not require bagacillo and shows some other advantages. Some comparative performance data are given in Table 1.

	Rotary drum vacuum filter	Vacuum belt press filters
Retention	98.7%	86.2%
Pol % filter cake	1.1	1.1
Purity drop between clear juice and filtrate	0.56	2.0
Bagacillo (dry kg /t cane)	2.6	0.0
Lime (kg/t cane)	0	255
Flocculant (kg/t cane)	0	1.7
Electric consumption (kWh/t filter cake)	18.4	9.6

Water consumption (m ³ /t filter cake)	2.1	5.2
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Table 1. A comparison of filter types at two mills in Reunion (*Petit 2013*)

Experience with the first unit installed in Australia indicates that the pre-conditioning of the feed mud stream to the filter was found to be critical to the performance of the filter.

Trials have been in progress in Florida over a number of years to assess the performance of solid bowl decanter centrifuges to replace rotary vacuum filters for mud treatment. Wear problems have been overcome with the use of ceramic and hard wearing materials, and the decanters show a number of advantages:

- Individual machines can have high capacity; a single Broadbent decanter is roughly equivalent to a rotary filter of 180 m²
- The power installed is marginally less than a rotary filter, without the need of a vacuum system
- The decanter has a smaller footprint
- No bagacillo is required, giving a saving in bagasse
- The decanter produces less cake, at a lower moisture content
- No microbiological losses occur, since the temperature remains over 90 °C
- Physical as well as microbiological losses of sucrose are lower
- Maintenance requirements are minimal
- The centrate is not cooled, so less reheating is required
- The decanter has good turndown - 3:1 ratio

However the decanter does require conditioning of feed with flocculant and lime addition, and uses more water for dilution of the feed. However recycle of centrate could reduce the water usage. The installation is clean and compact, as shown in Figure 2.



Figure 2. Broadbent decanter handling clarifier muds

Syrup clarification

Flotation clarification of syrup is becoming more widespread, particularly where improved sugar quality is required. It can remove about 85 % of the turbidity, gives a small ash and color improvement and reduces massecuite viscosity. Its effect on sugar quality is generally greater than the improvements measured in syrup quality suggest (*Steindl and Doherty 2005*), largely because high molecular mass impurities are removed.

The area required for syrup clarification should ideally be determined by the rise time of the aerated floc particles. The terminal velocity of the floc particles is expected to be in the range of 2 to 10 m/h by calculation. Liquid surface loadings may be determined by dividing the volumetric throughput by the surface area. A syrup clarifier is usually sized to have a retention time of around 20 to 25 minutes (*Bennett et al. 1977, Rein 1988*). If the depth of the clarifier is 1 m, the surface loading based on these times is 2.4 to 3 m/h.

In practice liquid surface loadings in the range 2.5 to 15 m³/(m².h) or m/h are used in dissolved air flotation (DAF) in treating water. *Haarhoff and Edzwald (2001)* report that practical surface loadings greater than calculated rise rates are not uncommon. This is ascribed to further agglomeration of the aggregates due to differential rise rates.

Syrup clarifier loadings are at the lower end of the loadings used for DAF. A breakthrough in flotation water treatment was the introduction of lamellas, which prevent recirculation patterns and reduce the Reynolds number, and consequently the turbulence, leading to a more efficient separation and higher capacity (*Hedberg et al. 1998*). Flotation units on water treatment provided with lamella plates can achieve higher load rates (30-40 m/h). Numerical simulation of the flow in a hypothetical syrup clarifier provided with lamellas suggests that a surface loading of 40 m/h appears feasible (*Echeverri and Rein 2006*). A unit based on these considerations has been installed and operated in Nicaragua. This has achieved a surface loading of 20 m/h, with a residence time of just 6 minutes, and achieved the same or better turbidity removal as commercial units operating in parallel. Further testing is expected to improve on initial results.

Crystallization

CFD work on attempting to elucidate massecuite flow patterns in vacuum pans has been reported by *Rackemann and Stephens (2002)*, and *Echeverri et al. (2005)*. Recent work by *Echeverri (2007)* has shown that shorter tubes give higher circulation rates, important in natural circulation pans, and that there is no benefit to be gained in having sloping calandria tube sheets. This work has also shown why flared batch pans (with conical enlargements in diameter above the calandria) circulate more poorly than straight sided pans.

Sugar handling

New forms of sugar cooler have been developed, where the sugar is cooled by gravity flow of the sugar between a bank of vertical closely spaced hollow stainless steel plates. Cooling water flows through the bank and heat is transferred by conduction, eliminating the need for fans and scrubbers. The coolers require less room, have reduced maintenance requirements and use less energy (*Reichling 2005*).

Since the severe sugar dust explosion occurred at the Imperial sugar refinery in Savannah, more notice has been taken of the need to ensure that the correct provisions are in place to prevent or mitigate the consequences of white sugar dust explosions. The steps to be taken are well known, but need to be applied universally (*Rein 2007*).

Boilers

In general, larger size boilers are being installed, and often with steam at higher pressure and temperature where export of power is practiced. Many of these newer large boilers are being installed as single drum boilers. Sloping pin-hole grates have become popular in cases where coal is not used as supplementary fuel, because of mechanical simplicity.

CFD modeling has been applied with success in improving the design and operation of boilers. The technique can be used to identify high velocities and potential tube erosion problems, to reduce emissions, increase capacity and improve boiler efficiency (*Mann et al. 2006*). Bagasse is essentially a gaseous fuel; less than 15 % of its dry ash-free mass is solid. CFD studies have confirmed that it makes sense therefore to introduce a large proportion of the combustion air into the furnace as overfire air. This helps to keep emissions down, improve furnace stability and optimize combustion.

A recent innovation is the use of bubbling fluidized bed boilers, with a number installed in Brazil by HPB Simisa. A fuel inert material (e.g. sand) is mixed with the bagasse in the fluidized bed. Heat transfer is good, excess air requirements are reduced and the lower combustion temperature reduces the NO_x emissions. However additional complexity involving fans and screens is incorporated.

Refining

There has been a slow but steady improvement in raw sugar quality provided to refineries over the years. This has enabled some refineries to abandon their affination stations, with significant capital and operating cost savings.

Todd (1997) has shown that the average cost of production of refining in attached refineries is about 55 % of the cost in stand-alone refineries. In order to compete, autonomous refineries have to be larger to achieve economies of scale and lower unit production costs. A trend in the US sugar industry, both beet and cane, has been an increase in vertical integration from field to white sugar output. White-end refineries have been built at raw sugar mills both in the US and elsewhere.

The first new stand-alone refinery to be build for 25 years was constructed in 1990 in Dubai. Since that time, over a dozen new refineries have been built, existing refineries have been expanded and a number of new refineries are being built. One of the driving forces is the lower quantity of white sugar available from the European Union following the reform of the EU sugar policy. This has reversed the relationship between white and raw exports; the proportion of whites traded on the world market increased over many years but this has changed with raw sales now increasing relative to whites. Freight differentials, between the costs of shipping raw sugar

in bulk and bagged white sugar, are partially responsible, particularly with larger vessels now shipping bulk raw sugar. In many countries too the tariff protection for import of white sugar is higher than for raw sugar.

Sugar quality has a major impact on refining costs and an interesting example of a refinery working together with a raw supplier was reported by *Hikmat and Oliveira (2006)*. Improvements in sugar quality to achieve a polarization of over 99.6 °Z resulted. This study validated their statement: “Reducing the impurities in raw sugar is a governing factor in improving performance of the sugar refinery and can be achieved easily and economically in the sugar mill”. This effort has resulted in the Dubai refinery being among the lowest cost refiners in the world.

The threats to the refiners are a reduction in the white premium, a new higher sustained level of energy costs and the prospect of direct white sugar production technology developed to a feasible stage (e.g. *Fechter et al. 2001; Rossiter et al. 2002; Kochergin et al 2000; Oliverio and Boscaroli 2006; Rein et al. 2006*).

Membrane systems have been used with success on salt regenerant from ion exchange plants. Otherwise advances in cane sugar refining have been minimal. The potential exists to reduce refining costs through the use of hydrogen peroxide to prolong resin decolorization cycles (*Bento 2004*) and the chemical regeneration of granular activated carbon (*Bento 2006*).

A reduction in the cost of refining may be possible with new designs for ion exchange decolorization employing shallow resin beds. This approach has been used in beet sugar processing, both for molasses desugarization and for softening thin juice. It is based on “Fractal Short Bed” designs developed by ARi, but has had limited application in the cane sugar industry. Resin beds would be about 1 m in depth, much shallower than conventional ion exchange systems. Flow rates are higher, pressure drops lower and resin is used more efficiently. This results in a smaller inventory of resin, and the system produces less sweet water and effluent. (Fractals may be defined as “self-similar objects whose pieces are smaller duplications of the whole object”).

Energy issues

Cogeneration and export of power

A number of sugar producing countries now provide financial incentives for the production of energy from a renewable resource like sugarcane. Extensive power exports are common place and expanding in countries like Mauritius, Guatemala, Brazil, Thailand and India.

Sugar mills are able to start exporting power on a small scale, and increase sale of power in steps. Most mills have the ability to produce more power than they need. The most effective means of increasing the amount of power available is through the use of high pressure boilers. If the amount of power exported can be increased to about 40 kW/t cane, it is possible to produce sugar with a negative carbon footprint (*Rein 2010*). The amount of power that can be exported depends on a number of factors, which are summarized in Table 2.

Boiler conditions	Process steam (kg/t cane)	Production period	Trash used	Power surplus (kW/t cane)
21 bar, 300 °C	500	harvest	no	10.4
42 bar, 400 °C	500	harvest	no	25.4
42 bar, 450 °C	500	harvest	no	28.3
65 bar, 480 °C	500	harvest	no	57.6
65 bar, 480 °C	350	harvest	no	71.6
65 bar, 480 °C	500	all year	50 %	140
65 bar, 480 °C	350	all year	50 %	153

Table 2. Estimated electric power production as a function of boiler conditions and process steam usage (BNDES and CGEE 2005)

In order to maximize energy exports, the transport of cane leaves and tops to the mill to supplement the bagasse supply has received considerable attention. Transporting the whole cane to the mill and removing trash at the mill has been compared with leaving the trash in the field and transporting it separately in bales. The latter option has the advantage that the trash has the opportunity to dry out in the field before baling. Many factors influence the optimum system, including transport, capital and operating costs. There is an opinion that at least 50 % of the tops and leaves should remain in the field, so that the carbon content of the soil is not adversely affected.

However trash only cannot be burnt in the boiler because of the high alkali metal content of the trash. Potassium content of trash is about three times that of bagasse, and the ash fusion temperature is lower by about 100 °C (*Linero and Neto 2013*).

Although the trend to higher pressure boilers is evident to maximize power production, pressures much above 80 bar (8 MPa) lead to an area of diminishing returns, as shown in Figure 2.

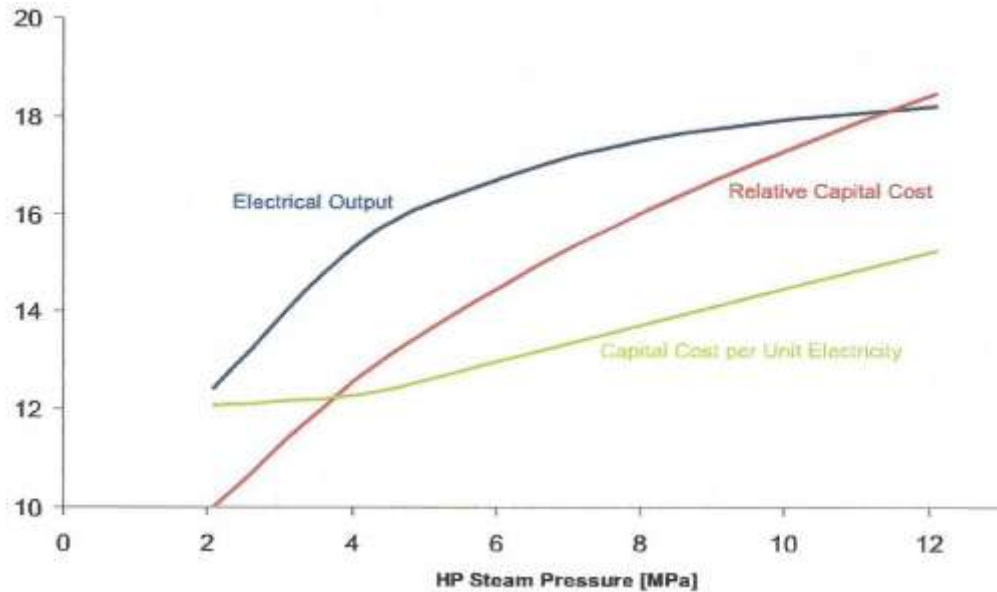


Figure 2. Electrical power output as a function of boiler pressure, and relative capital costs (Inkson 2010)

Capital costs for cogeneration depend largely on the cost of boilers and turbo-alternators, but there are also the costs of possible modifications to the bagasse handling system, grid interconnection, electrical control and protection equipment and drive electrification.

Hodgson and Hocking (2006) list the following criteria for successful cogeneration projects:

- A group mill with access to bagasse from nearby mills.
- Site specific operating factors, such as supplementary year-round energy sales to a co-located processing plant.
- Existing site specific plant configurations or underutilized plant, which can lead to significant capital cost reductions.
- Power purchase agreements (PPAs) that recognize avoided capital costs
- Ability to offset cogeneration capital costs by other avoided capital, such as the need for steam capacity increase, the need to replace an aging boiler, or the need to improve stack particulate emissions from old boilers.

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Other issues that could improve project viability include:

- Compensation from transmission and network bodies for the full benefits of an embedded sugar mill generator.
- Firm export and renewable energy certificate quantities in a PPA in return for premium payments.
- Multiple (or joint) projects where economies of scale can be achieved.

Large scale export of energy also requires that provision be made for storage of large quantities of bagasse. Because bagasse has a low bulk density and its handling is associated with a potential dust nuisance problem, it can be a challenging task. Many different approaches have been taken. Most successful operations involve the use of bulldozers to manage the bagasse pile, and

compact it to the extent possible. Ideally the piles will be shaped for natural runoff of rainwater, or else a dewatering device is required on the bagasse reclaim system.

Ethanol production

Production of ethanol from cane is expanding quite rapidly. It has been a major activity in Brazil for many years, and many of the Central American countries are following suit. Production has been spurred on by the production of flexible fuel vehicles. A sugar mill with an ethanol plant attached, producing sugar and ethanol, or only ethanol, is the norm in Brazil. The ability to produce both sugar and ethanol is the preferred option, for a number of reasons.

- It retains some flexibility to alter within limits the proportions of sugar and ethanol produced, to maximize revenue.
- There are processing advantages, enabling good quality sugar to be produced more cheaply by diverting lower purity streams to ethanol production.
- The ability to produce A molasses and/or B molasses enables fermentable sugars to be stored in this form for operation of the distillery in off-crop.

The trend to continuous fermentation seems to have reversed with a preference for batch systems. Other initiatives are focused on reducing the steam requirements. One of these aims to be able to run fermentation at 16 % ethanol, using special yeasts.

Adding value through the production of by-products.

The production of by-products from a sugarcane processing plant is a way of reducing the net cost of production or increasing revenue. Adding value to residues such as filter cake and boiler ash for return to the fields is quite widely pursued.

The stillage produced is returned as a fertilizer to the cane fields in countries like Brazil, Australia, Zimbabwe and Swaziland. It is particularly rich in potash, and has often been shown to have a beneficial effect on the soil and cane crops, providing the potassium content of the soils is monitored. This may not be practical in some countries, and anaerobic digestion producing biogas for use in the boilers is likely to be the most common treatment option. On average, 185 m³ of biogas, containing 60 % methane is produced per m³ of ethanol; this is roughly equivalent to the energy value of 0.69 t bagasse (*Silva Lora et al. 2006*). This helps to maintain low energy costs in off-crop processing periods.

Evaporation of vinasse to reduce the quantity and lower the cost of transport to the fields is practiced in some mills. However energy usage and heating surface scaling continue to be problematical.

There has been little other development in the field of by-products, although there has been considerable research undertaken into the use of sugarcane biomass lignocellulose in a biorefinery for the production of fuels and chemicals. Sugarcane bred for biomass and not sucrose production represents a great opportunity to augment even further the production of biofuels from biomass.

There is an essential difference between the economics of a lignocellulose ethanol plant and a conventional plant using corn or sugar. The economics of the latter are highly dependent on the cost of the feedstock, whereas with a lignocellulose feed, the feedstock cost is low and the capital and processing costs determine its economic viability. The cost of producing bioethanol is overwhelmingly associated with processing and novel processes to reduce costs are essential for this option to become viable. An inherent advantage of a biorefinery is the diversified and perhaps more flexible nature relative to a single product plant.

Although enzyme hydrolysis of bagasse fiber has received the most attention, gasification is also being investigated. What seems to be an option gaining more support is slow pyrolysis, whereby a gasified stream is taken for further processing to fuels and chemicals, and biochar remains as a co-product which has been shown to be most beneficial when returned to the soil (*Quirk 2010*). Since the ash remains in the char, the problem of trash causing fouling and slagging in the boiler is obviated.

Torrefaction of bagasse is also being investigated. It is a mild form of pyrolysis at temperatures typically ranging between 200 and 320 °C. During torrefaction, the bagasse properties are changed to obtain char in a form that provides a much better fuel quality for combustion and gasification applications. Torrefaction leads to a dry product with no biological activity and if pelletized leads to an energy-dense fuel of 20 to 25 MJ/kg lower heating value.

Sustainable production

Sustainability has been identified as a megatrend, which requires businesses to adapt and innovate or be swept aside (*Lubin and Esty 2010*). It is suggested that companies can no longer afford to ignore sustainability as central to long term competitiveness. Energy use, production efficiency, elimination of wastage, a range of social and labor issues and the effect on global climate change need to be carefully monitored.

In the sugarcane industry, Brazil has been the most active in embracing and reporting sustainability performance. This is largely due to the need to meet sustainable standards in producing biofuels for export to first world countries. In the absence of agreed standards for sugarcane, a number of mills are reporting their results based on the Sustainability Reporting Guidelines proposed by the Global Reporting Initiative (GRI 2011).

Most mills in Brazil are very conscious of environmental issues. Intensive reforestation with indigenous trees is evident at a number of mills. Nurseries are maintained by the milling companies in Brazil and many other countries, and thousands of trees are planted each year, restoring degraded and riparian areas.

Industry environmental leaders have also been accredited to ISO 14001 for environmental management, including some mills in Brazil and Thailand. The ISO 14001 standard requires facilities to set up objectives and targets, and to establish, implement and maintain programs to achieve these objectives and targets. The following issues should be considered in the process:

- Legal requirements
- Significant environmental aspects
- Technological options
- Financial, operational and business requirements
- Views of interested parties.

Biodiversity and High Conservation Value areas are also among the main concerns of many stakeholders. Some disagreement on what constitutes such areas and how they should be measured still exists. These are natural habitats where conservation or biodiversity values are considered to be of outstanding significance or critical importance. In addition, standards require that crops must not be obtained from land with a high carbon stock, including wetlands, continuous forest, highly diverse grasslands and peat lands. This generally excludes what has historically been in use as croplands, and applies to land changed to cropland after a cut-off date.

Bonsucro

Bonsucro is a collaboration of sugar retailers, investors, traders, producers and NGOs who are committed to sustainable sugar production by establishing principles and criteria that can be applied in the sugarcane growing regions of the world.

Bonsucro has developed a Certification Protocol for members and auditors that describes the process and procedures for certification against the Bonsucro standards. The certification protocol incorporates two standards, the Production Standard and the Chain of Custody Standard. This is illustrated in Figure 3.

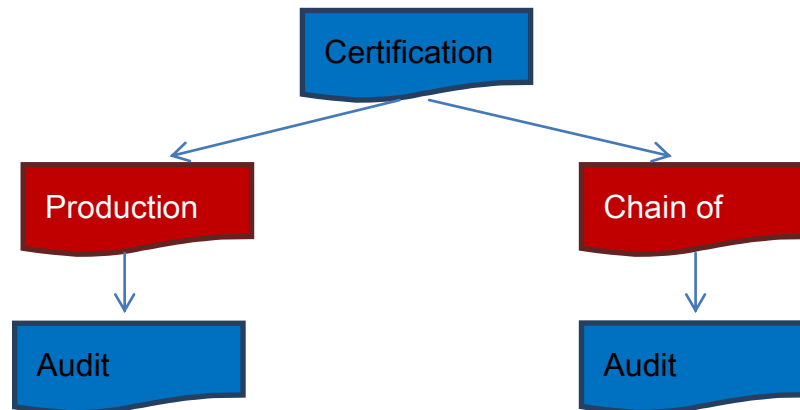


Figure 3. Bonsucro Certification Standards (*Viart and Rein 2013*)

Bonsucro has chosen to develop a metric-based standard rather than a best practice based standard. This means that most of the indicators are measurable targets which companies must achieve. It turns the focus onto outcomes rather than means of achievement. An advantage of the use of metrics is that they can be used as a means of assessing ongoing improvement, by monitoring how the values of the metrics change over time. It facilitates comparisons and benchmarking amongst producers but also reduces the risks involved with working with auditors, whose skills might be very disparate across companies and/or regions. Because it is crop

specific, it can be made simpler and more appropriate than other standards. The standards have not been set up to be “best achievable” but true reflections of what experts define as a minimum acceptable impact that can realistically be achieved by responsible operators across the globe.

It is important to differentiate between the Standards and Best Management Practices (BMPs). BMPs are a means to an end and not an end in itself. BMPs have been drawn up in many regions of the sugarcane world and are often locally adapted to support and improve efficiency of local producers. They do not identify or measure the impact of the activity considered. By nature, BMPs are constantly renewed by improvement delivered by research and development and availability of new techniques. BMPs do not belong in standards; they belong in workbooks and guidance documents (*Clay, 2008*).

The Bonsucro standards are consistent with ISO 14040 which incorporates Life Cycle Analysis (LCA). Indeed, the calculation of emissions using the techniques of LCA is incorporated in the Bonsucro standards. However, ISO 14040 looks only at environmental impacts, while the Bonsucro standards cover all sustainability issues including social and economic aspects.

There are now nine accredited certification bodies approved to certify companies against the Bonsucro standards. In a system that relies on third party independent verification, it is critical that assessments are carried out rigorously and that the assessors are trustworthy. To achieve this, Bonsucro focuses on training and verification. Training of auditors and producers has been actively undertaken in the most important sugar producing countries. Bonsucro acts as the accreditation body and has started controlling the activities of certification bodies by carrying out office audits and witnessing certification audits.

The first mill’s production was certified in June 2011. At the time of writing, 31 mills already have their production certified, representing just over 2.9 % of the global area planted to sugarcane, producing 43 million tonnes of sugarcane, 3.0 million tonnes of certified sugar and 2.2 million m³ certified ethanol.

Carbon footprint of sugar

The aspect of sustainability standards which perhaps attracts the most attention is the GHG emissions. This is derived together with estimates of energy used. In this respect both direct effects and indirect effects need to be taken into account. The latter include the energy required for the production of chemicals, fertilizers and other materials used, emissions from land use change, and in some cases the additional energy necessary for the manufacture and construction of farm, transport and industrial equipment and buildings. Direct land use change has to be taken into account, but indirect land change is generally excluded, largely because the effects of these are difficult to estimate and subject to too much uncertainty.

Climate change is rapidly becoming a serious issue and one which will increasingly demand the attention of sugar and ethanol producers. Estimation of the greenhouse gas emissions in production, otherwise known as the carbon footprint, is an essential part of any sustainability study. A method of estimating net energy usage and greenhouse gas emissions has been developed, based initially on work done on biofuels (*Rein 2010*), developed for use in the Bonsucro standards.

Carbon dioxide (CO₂) from sugarcane emitted in combustion and in ethanol fermentation is considered zero CO₂ emission to the air, because this is the carbon taken in from the air during sugarcane growth. Carbon monoxide and volatile organic compounds (VOCs) emitted in combustion are assumed to be converted to CO₂ fairly rapidly, but methane (CH₄) and nitrous oxide (N₂O) from burning bagasse must be accounted for in GHG emissions. CO₂ emissions arising from biogenic carbon sources are excluded from the calculation of GHG emissions from the life cycle of products, except where the CO₂ arises from direct land use change. Methane and N₂O have global warming potentials 25 and 298 times that of CO₂ respectively (IPCC, 2007). The carbon equivalent value is calculated by multiplying the mass of one of these gases by its global warming potential. This is added to the CO₂ evolved and expressed as CO₂ equivalent (CO₂eq). Therefore even small amounts of CH₄ and N₂O need to be considered in arriving at GHG emission estimates.

A number of studies have been undertaken to estimate the net energy ratios and carbon emissions associated with bioethanol production. Different estimates of GHG emission savings relative to fossil fuels are obtained if different assumptions are made in the calculation procedure. Wang *et al.* (2008) estimate a reduction of 78 % relative to gasoline for ethanol transported to the US from Brazil; they estimate this will increase by up to 9 percentage points if cane burning is phased out (the CO₂ is not regarded as a GHG emission since it is derived from plant material, but emissions of CH₄ and N₂O are). Data produced in Brazil indicates that bioethanol produced and used in Brazil shows GHG emissions savings of 89 % (BNDES 2008).

The EU has compiled a Renewable Energy Directive which sets out how the emissions should be calculated for the production of a biofuel from any particular feedstock. In addition some GHG emission saving default values, assuming no land use change, are given to be used in the absence of primary data required for its calculation. Ethanol produced from sugarcane has the best default value of 71 % emission saving relative to gasoline; emission savings using corn, wheat or sugar beet are significantly lower, varying between 16 and 52 %, depending on the feedstock and the process used.

The EU RED also focuses on land use change. Any land use change after 1 January 2008 needs to take into account the change in land carbon stock as a result of any expansion of cane growing areas. Depending on the status of the new land before conversion, the change in carbon stock can make a huge impact on the carbon footprint, particularly if any natural forest is involved. Estimates are given elsewhere (*Rein 2010, Rein 2011*).

The main issues to be considered in estimating the carbon footprint are as follows (*Rein 2010*):

- *System boundary.* It is essential to describe accurately the boundary of the system being examined, indicating clearly what is included and excluded.
- *Direct and indirect effects.* Direct inputs are mainly fuel and power inputs, expressed in terms of the primary energy value (taking into account, for example, the efficiency of conversion of fuel to power, and the energy in producing gasoline and diesel). Indirect inputs include, in addition, the energy required for the production of chemicals, fertilizers and other materials used. In some cases the indirect inputs also include the additional

energy necessary for the manufacture and construction of farm, transport and industrial equipment and buildings.

- *Direct land use change.* The effect on the carbon stock of planting cane compared to its previous status needs to be accounted for.
- *Indirect land use change.* This concerns secondary effects induced by large scale expansion. This displaces existing crops, leading to expansion of cropland elsewhere, either in the same country or in other parts of the world. The effects of these changes are very difficult to estimate, and have therefore been neglected in any analyses, largely because of the uncertainty in modeling the effects.
- *Handling of co-products and multiple products.* The method of allocating emissions to products can affect the estimates.
- *Default and secondary data.* It is always necessary to make some assumptions in the absence of direct measurements. The value and source of the data used can have a substantial effect on computed emissions.

The carbon footprints of sugar and ethanol are very small when compared with other foods and fuels. *Rein* (2010) has shown that particular improvements can be achieved by focusing on the following, in roughly the following order of importance:

- Cogenerate and export power to the maximum extent possible
- Maximize cane yield and factory recovery
- Reduce the amount of fertilizer and chemical inputs, particularly N fertilizer
- Reduce the extent of cane burning
- Reduce the quantities of any supplementary fuels purchased
- Minimize irrigation power input
- Reduce cane transport distances
- Recycle water to reduce water intake.

The water footprint of products is now also receiving attention (*Klenk et al. 2012; Gerbens-Leenes et al. 2009*). Preliminary results indicate that cane sugar has twice the water footprint of beet sugar, and that the water footprint of bioelectricity is about a factor of 2 smaller than that for bioethanol.

Conclusions

Because of expansion in the low-cost producing sugar countries and the potential reduction in import tariffs, the cane sugar industry will have to continue to reduce costs of production. This is likely to be achieved through economies of scale, incremental advances in technology and efficiency improvements. Increased attention will be given to securing more value from the sugarcane crop, particularly in the short term through ethanol and electric power sales, and in the longer term through exploitation of the total cane biomass. These efforts will need to be made all in the context of sustainable production guidelines.

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