The current situation and prospects for ethanol

ISAIAS C.MACEDO

Introduction

In the year 2006, 425 million tons of sugarcane was processed in 310 mills in Brazil, producing 30 million tons of sugar and 17 million cubic meters of ethanol. Recent estimates (Carvalho, 2006) indicate that in 2012-2013 potential markets (both external and internal) for Brazilian ethanol and sugar would consume around 685 million tons of sugarcane, produced in 6.4 million hectares; for this to be achieved, 77 new production units would be set up in the South Central region of Brazil, with investments of US$14.6 billion. In 2012-2013, around 60% of all sugarcane would be destined for the internal market; in total, as well as sugar, 35.7 million cubic meters of ethanol would be produced (7 million cubic meters for export).

- Brazil is the world's biggest producer of sugarcane (33.9%), sugar (18.5%) and ethanol (36.4%); and also the largest exporter of sugar and ethanol (2005).
- Ethanol corresponds to 40.6% of fuel for light vehicles (total of 19.2 million vehicles) (2005).

For the industrialized countries committed to the objectives of the Kyoto Protocol, the use of biofuels represents one of the most effective ways of reducing liquid emissions of greenhouse gasses associated with energy consumption in the transport sector. However, developments in recent years clearly show a great variation in the capacity for reduction of emissions between the various biofuels, indicating a substantial advantage for sugarcane ethanol produced in Brazil (Table 1) (Macedo, 2006).

Table 1 – Energy balance in the production of ethanol, from different raw materials.

Raw materials	Renewable energy / fossil fuel energy used
Maize ethanol (USA)	1,3
Sugarcane ethanol (Brazil)	8,9
Beet ethanol (Germany)	2,0
Sweet sorghum ethanol (Africa)	4,0
Wheat ethanol (Europe)	2,0
Cassava ethanol	1,0

It is very interesting to note how the technology of production and use of ethanol came about in Brazil, especially as many countries are setting off along similar paths and, here in Brazil, biodiesel may benefit from this previously acquired experience.

The Trajectory of Technological Innovation for Ethanol in Brazil

The production and use of ethanol in Brazil is today the best example (in the world) of the introduction of renewable energy on a large scale of production. Starting from the already established sugar production, a process of complete productive integration was obtained in the mills: with considerable flexibility in the attached units (for some time, with autonomous operation), the processing losses were reduced and there was an improvement in the quality of sugar produced. This strategy demanded extensive technological development (creation, importation, adaptation and transference of technology) in production (agricultural and industrial), logistics and final uses, over the last thirty years. Also important were, the specific legislation, initial subsidies and permanent negotiation between the main sectors involved: the ethanol producers, the car manufacturers, the governmental regulatory sectors and the oil industry were all party to this dense learning process.

It is important to highlight some of the main technological advances during this period (1975-2000), precisely because - in some cases - analogous developments for other biofuels may be identified.

Between 1980 and 1990:

- The wide scale introduction of sugarcane varieties developed in Brazil (mainly through CTC – Copersucar and Planalsucar programs).
- The development of the integral use of *stillage* (an effluent from the distillation process) in ferti-irrigation.
- Biological controls in the growing of sugarcane.
- Development of a milling system with four rollers.
- Technology for the operation of large scale "open" fermentation.
- Increase in production of electrical energy within the industry (self-sufficiency).
- End use: ethanol specifications; E-100 engines; transport, blending and storage of alcohol.

Between 1990 and 2000:

- Optimizatioof surplus electrical energy and sale to utility companies.
- Advances in industrial automation
- Advances in technical management (agricultural and industrial)
- Introduction of flex-fuel engines.

Results obtained in the period 1975-2000 in São Paulo can be cited as indicators of a process of intense incorporation of technological innovations and more effective management processes. The agricultural productivity figures indicate an increase of 33% in tons of sugarcane per hectare; an 8% improvement in quality of raw material measured in sugar content; and gains of 14% in the conversion of cane sugars to ethanol and of 130% in fermentation productivity measured in cubic meters of ethanol per cubic meter of reactor.day were observed.

The average values of performance parameters for the agro-industry in the South Central region of Brazil, in 2003-2004, were:

- Cane productivity: 84.3% t/ha
- Sugar % cane: 14.6
- Industrial conversion: 86%.

Observing the nature of technological advances during this period shows that, in the initial years, preoccupations were centered on increasing production quickly (productivity of equipment and processes), even to the detriment of conversion efficiency; this can happen whenever policy incentives set excessively high implementation targets, with price guarantees. In the following years, the growth in efficiency became more important (as, in any case, the price guarantees were no longer being observed); then a third of these "phases" or periods was the advancement in production management techniques, that resulted in great cost reductions. The overall global result was a strong reduction in production costs, taking ethanol to a position in which there is practically no need for subsidies for it to compete with gasoline, considering oil prices above US$45 per barrel. The shape of this "learning curve", as shown in figure 1, has been much studied.

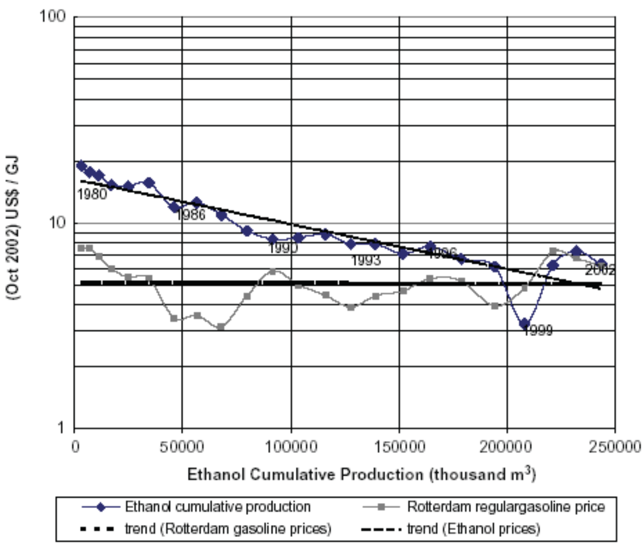

Figure 1 – Amount paid to producer (excluding taxes) and price of gasoline (Goldenberg et al, 2004)

Prospects for the coming years

A question that arises at the moment is: what are the prospects of great technological advances in the production and use of ethanol continuing to be achieved in the coming years? Put another way, it can be said that ethanol production in Brazil has reached a "mature" stage, with the lowest costs in the world and good product quality, therefore only incremental advances can be expected - or are there still areas to explore with good margins for improvement that might lead to important leaps in competitiveness?

Today it is clear that these alternatives are not exclusive, and that it will be possible, not only to continue with the gradual advances with the technologies in use, but also to achieve great gains with the advent of some of the technologies currently in development. Initially, it is necessary to consider that the joint production of sugar and ethanol will continue, among other reasons, because of Brazil's position as the biggest (and growing) world exporter of sugar; the positive synergy in joint production; and because ethanol has been the main agent in the increased level of international sugar prices in the sense that it provides a competitive alternative to sugarcane industrialization. The technological options for sugarcane products must be considered in conjunction with each other because the effects on each of their final costs (including ethanol) are related.

In this way, the possibilities of increased productivity and reduced costs in the bioenergy chain that starts with sugarcane can be considered in complementary contexts, summarized as follows:

- In the next few years, it is both desirable and possible to completely implement those technologies already available but currently still in partial use, thus widening the best agronomic, industrial and management practices. This may occur as a result of strong internal competition and with appropriate mechanisms for transfer of technology (today represented by the manufacturers of equipment and supplies themselves, the institutes, technology companies and especially by the Centro de Tecnologia Canavieira (Sugarcane Technology Center)).
- The "ongoing" technological evolution of processes currently in use could also lead to important productivity gains in the next years, through: "precision" agriculture, the development of better varieties (particularly for new areas), better harvest/loading/ transport integration, new processes for separation of ethanol, industrial automation, among other factors.
- In the medium term (from five to ten years), there should occur the development of various co-products derived from saccharose (some already being explored) and new sub-products, mainly from

bagasse and straw, such as surplus electrical energy (already initiated) and ethanol from bagasse and straw.

- In the medium and long term, the favorable prospects for the development and dissemination of genetically modified varieties of sugarcane, that are more productive and resistant, should be considered.

Gains from the first of these items – the greater implementation of technology - could have a considerable impact (for example, according to estimates from 2000, for a group of mills in South-Central Brazil, a wider spread of technology already in use could bring a 12% reduction in costs). The prospects for the final item - transgenic varieties - are also particularly good; today in Brazil, several groups are working with dozens of transformed varieties (still on laboratory scale and some in greenhouses) and looking at improving various characteristics (resistance to disease, early ripening, saccharose, total biomass etc.). It is difficult to estimate the time necessary for the implementation of these new varieties because it is not simply a technical matter. Their eventual release depends on many other factors, including political factors.

In the medium and long term, the advances in co-products should lead to the installation of "bio-refineries" with a more efficient use of saccharose and sugarcane residues (bagasse and straw), representing important technological "leaps". When assessing the prospects of the efficient use of lignocellulose residues of sugarcane, their enormous potential to produce energy or materials should be considered. For example, in 2006, sugarcane in Brazil corresponded to around 60 million tons of saccharose (used for sugar and ethanol, in approximately equal proportions) and to 120 million tons of lignocellulose material, bagasse and straw. Assuming that 30% of the bagasse produced is available as surplus (the rest would correspond to the agro-industry's consumption, with some surplus electricity generation, depending on the technology adopted) and recovering 50% of the straw, 48 million tons of lignocellulose material (in dry base) could be made available, already collected and with certain preparation, with an approximate cost of 1 /GJ. Average biomass costs in these conditions for industrialized countries[1] are set between 2 and 3 /GJ, with plans to reach 1.5 /GJ, in future. It is clear that the sugarcane agro-industry, processing a highly competitive resource, because of its high photosynthetic performance, will be able to achieve great diversification with the efficient use of these two thirds of its basic raw material.

Two processes and their many variants are considered "key" to the promotion of these "bio-refineries" of the future, especially for the energy value of the lignocellulose material; they are both still under development, with prospects of becoming viable in the next few years, depending on more efficient technologies and cheap biomass:

- Biomass hydrolysis: allows for the conversion of cellulose into sugars and from there to the production of ethanol and other products. It is hoped that the first units will be operating commercially between 2010 and 2020.
- Biomass gasification: allows for obtaining appropriate fuels for efficient generation of electric energy and synthesis of liquid fuels. The expectations for commercial viability are placed between 2015 and 2025.

Biomass gasification has been developing in two directions: the generation of electrical energy through integrated high efficiency cycles (gasification and combined cycles with gas turbines) or, alternatively, the synthesis, from this gas, of various fuels (ethanol, DME, gasoline, diesel). For both these routes, the necessary research and development involve: biomass feeding systems, gasification for gas of medium calorific power, with air; and advanced synthesizing reactors (for example, reactors in liquid phase for DME synthesis, dimethyl ether).

The hydrolysis of cellulose, leading to sugars of the cellulosic material, is going through huge research efforts (in pilot phase, though some already pre-commercial) to reduce costs and increase profits (Oliverio, 2005). It is expected today that future pre-treatments will be mainly physical (steam explosion, use of supercritical water); the hydrolysis and fermentation processes for ethanol may be combined, in the same way as fermentation would include sugars of five or six carbon atoms.[2] These processes may recover 52% of biomass energy, as against 35% recovered today. The programs being used include a demonstration of physical pre-treatments, biomass feeding and the selection of micro-organisms and enzymes appropriate for the consolidated bioprocessing (CBP) or simplifications.

In turn, these bio-refineries may incorporate various other co-products of sugars. Over the last 15 years, a significant expansion of demand for products derived from saccharose (and which may also be produced from the sugars from hydrolysis) has been taking place in the world; some have already passed the one million tons per annum mark. Considering figures observed at the beginning of this decade, the more significant are:

- Sweeteners (23% of the market, in 2002; fructose, glucose, polyols)
- Organic acids (citric, gluconic, lactic, ascorbic): used in the food and pharmaceutical industries, with a demand of 0.7 million tons per annum.
- Aminoacids (MSG, lysine, treonine): used basically for animal foods, with a demand of 1.5 million tons per year.
- Polyols: compounds used mainly in the food and chemical industries, with a demand of 1.4 million tons per annum, mainly as sorbitol and glycerol.

As well as these products, there are enzymes, with a high market value that is expected to double by 2008; and also special plastics, at this time still only a promise (PLA, PHAs, 3-GT), but with markets of great potential.

The sugarcane industry in Brazil already regularly produces l-lysine, MSG, leavening extracts, citric acid and sorbitol; and on a pre-commercial basis, PHB. The possibility of introducing high production capacity (above a million tons per year) and specific high value added processes (between 10 and 50 thousand tons per year) is being evaluated by many mills. Also, products derived from alcohol chemistry (more than 30 different types were produced in the beginning of the 1990s, including synthetic rubber) are being re-evaluated under today's conditions; in particular, polyethylene (using ethylene resulting from the dehydration of ethanol). The introduction of these new products in the mills goes through careful evaluation processes, that involve:

- Availability of the process: patents, acquisition or internal development of technology.
- Quality of sugar required (juice, raw or refined sugar, HTM); sugar cost/total cost ratio.
- Investment and annual operation needs.
- Nature of the process (complexity, associated costs, effluents, environmental protection).
- Production scale and suitability to the mill.
- The economy; the export markets (almost always necessary) and the exchange rates.
- Commercial arrangements: partnerships?

Sugarcane appears to be an ideal raw-material for these future "bio-refineries", because of its relatively low biomass cost, its high availability in the world, and its interesting *mix* of one third saccharose and two thirds pre-processed lignocellulosical material. These integrated developments may help very much to bring even greater competitiveness to Brazilian ethanol.

The industrial (1/t sugarcane) and agro-industrial (1/ha) productivity gains associated with the technological developments discussed may lead, given best conditions, to great increases in ethanol production per hectare.

In relation to end use, one can expect a greater development of flex-fuel engines, with better performance and a reduction in emissions. This is an expected development, as has already been indicated in a preparatory study for the National Energy Plan 2030, that mentions American government estimates that specific consumption (light vehicles that are flex-fuel driven) would go from 14.4 kilometers per liter in 2015 to 15.3 kilometers per liter in 2030 (MME, 2006).

Conclusions

The sugarcane ethanol production technology in Brazil has advanced in a very important way over the last thirty years. In the next ten to twenty years, the more efficient use of sugarcane biomass (and possibly of genetically modified varieties) may increase significantly the range of products and their value.

Energy (electricity and liquid fuels) may come to form an even greater proportion of these products.

Some technologies under advanced development (principally abroad) may be the key to this transformation: the hydrolysis of biomass (with its various fermentations into other products) and the gasification of biomass for production of electrical energy or fuels.

Sugarcane appears to be an ideal raw-material for these future "biorefineries" because of its relatively low cost, great availability and its *mix* of one third saccharose with two thirds pre-processed lignocellulosical material.

Notes

1 Current values estimated for "energy farms" in the northern hemisphere.

2 Hydrolysis of cellulose produces hexoses, sugars with six carbon atoms, and hydrolysis of hemicellulose produces pentoses, sugars with five carbon atoms. Only the hexoses are utilized today for ethanol production.

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Abstract – In the last 30 years, the production of ethanol from sugar cane in Brazil reached 17 million cubic meters and it is expected to achieve 35.7 million cubic meters by 2012-2013. This growth has taken place due to great technological support by means of production, imports, adaptations and internal transferences. An analysis of the different phases of this development, with the evolution of its technological parameters and the great competition of the sector, is presented in the article. Nowadays, foresights state that the sector may keep evolving with continuous improvements, but sudden technological boosts are also possible through the development of technologies directed towards a better use of the residual biomass of sugar cane (which represents about two thirds of the total biomass). Studies in progress indicate that the sugar cane contribution to energy supply may be superior and more diversified than the current one. They also affirm that this may happen together with bio-refinery development, which will result in products of higher aggregate values.

Keywords: Ethanol, Biofuel, Technological development, Bio-refinery.

Isaias C. Macedo is a researcher at Núcleo Interdisciplinar de Planejamento Energético (Interdisciplinary Nucleus for Energy Planning), of Unicamp, Campinas (SP). @- isaiasmacedo22@terra.com.br

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