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Energy-cane and RenovaBio: Brazilian vectors to boost the development of Biofuels

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ABSTRACT

Brazil was the first country to use bioethanol in large volumes, still in the 70′s, to cope with the oil crisis. The development of vehicles powered by ethanol included the biofuel definitively in the Brazilian energy matrix, ensuring its demand. To increase the ethanol production, a new cane variety has been developed, the energy cane, which can potentially triple the productivity of biomass per hectare and reduce the production costs. Since most of the sugar produced by energy cane is insoluble, second-generation mills have been installed in Brazil, and nowadays the technology is in a consolidation phase. To increase the stability of the biofuels market and to attend the Nationally Determined Contribution at COP21, Brazil has created the RenovaBio, a program by which the biofuels producers receive financial titles, the CBIOs, in the proportion of the biofuel production volume and efficiency, and under the condition of respecting the environmental legislation. Fuels distributors will have an obligation to buy CBIOs to compensate emissions beyond their mandates, but CBIOs will also be available to any interested investor, with significant potential for a strong appreciation. As a result, the expectation is to have a substantial increase in sustainable biofuels production, mainly ethanol, which could become a world commodity to supply international markets in the bioeconomy world.

1. Introduction

The planet was formed about 4.5 billion years ago, and 0.5 billion years later there is an evidence of the first record of life (Tashiro et al., 2017). Photosynthesis then originated in between 3.2 and 3.5 billion years ago (Blankenship, 2010), bringing the possibility of using the energy of the solar photons to convert a gas, the CO_2 - which constituted more than 90% of the atmosphere - in a solid compound, the glucose. This process resulted from the transfer of electrons from the water to the carbon, also led to the release of oxygen, changing in a determinant and the evolutionary way the composition of the atmosphere (Blankenship, 2010; Lyons et al., 2014). Today, a significant part of the ancestral CO_2 of the atmosphere is sequestered in the vast reserves of coal and oil (Berner, 2003), which correspond to an amalgam of everything that has lived and died throughout the history of the planet.

Human intelligence soon realized that in fossil reserves there was a significant amount of energy that could be reused. With the industrial revolution, society replaced the human labor by machines, now fed by the carcasses, i.e., the carbon of ancestral life. The injection of these energy sources into civilization allowed an immediate increase of world population, whose growth is strictly correlated with the use of fossil energy (“Peak People, 2009”). We have been living a real energy bubble for the past 100 years, not sustainable either because of the finitude of the reserves or because of the environmental consequences of its use.

From the geological point of view, man is reversing the history of the planet, bringing back to the atmosphere extraordinary volumes of fossil CO_2, inaugurating what has been called, negatively, the Anthropocene (Crutzen, 2006). In the last 50 years, the concentration of CO_2 has jumped from averages between 250 and 300 ppm - detected in the last 800 thousand years - to levels above 400 ppm (Pachauri et al., 2014). The correlation between these data and the global temperature increase is consistent, as the increase in the frequency of the extreme environmental event (Baker et al., 2018). In spite of intense discussions about these issues, which have strong economic and ideological components (Hornsey et al., 2018), the fundamental precautionary principle, the fact that there is no plan B for the planet, leads us to the imperative need to find new sources of energy and carbonic chains for support the development of civilization.

One of the fundamental processes in this energy transition is the

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possibility of producing and transforming biomass in an economically and environmentally sustainable way. Unlike wind and solar energy, which "reduce the increase" of CO_2 emissions, biomass has the potential not only to reduce emissions but also to capture what has already been emitted, a consequence of CO_2 fixation by photosynthesis.

The production and transformation of biomass is an area in which Brazil has a competitive advantage and can develop whole value chains of great complexity, all of them based on sugarcane varieties, particularly, the energy cane. Therefore, in this review we will explore the science and technology that permeate the biofuels production chain, especially the ethanol. More specifically, we will explore the productivity potential of sugarcane varieties and Brazil's National Biofuels Policy, RenovaBio, a program that provides incentives for the development of biofuels and for the application of new technologies, including those aimed at capturing and storing of CO_2 from the atmosphere.

2. The biomass production and the energy cane

Sugarcane (*Saccharum* genus) is a monocotyledonous and perennial plant, originating in the regions of Indonesia and New Guinea. It presents the C4 photosynthesis pathway, with higher photosynthetic rate in the capture of CO_2 from the atmosphere (Silva, 2017). Nowadays, sugarcane is cultivated in 104 countries, occupying an area of approximately 26 million of hectares (“FAOSTAT, ” n.d.). Brazil stands out as the largest producer, with 40% of all world production cultivated in approximately 1% of the total area of the country (“FAOSTAT, ” n.d.). From the sugarcane biomass harvested from this area, 35.48 million tonnes of sugar and 28.16 billion liters of ethanol are produced, and 25,482 GW h of electricity are generated (“UNICA - UNIÃO DA INDÚSTRIA DE CANA-DE-AÇÚCAR”, n.d.).

Regarding the energy efficiency of sugarcane, one tonne of cane (wet basis) contains approximately 7.4 MJ of energy, equivalent to 1.2 barrels of oil (Leal et al., 2013). Considering the average of sugarcane productivity equal to 70 t/ha, from 1 ha of sugarcane crop is possible of producing the energy equivalent of 84 barrels of oil, with the advantage of being a production that is recycled, i.e. repeated every year. Although sugarcane is already considered the crop with the highest agricultural productivity on the planet, its potential could be even much higher. Sugarcane presents a high conversion of photons into chemical energy, however, the breeding programs for the improvement of sugarcane led the modern varieties to accumulate a high concentration of soluble sugar (sucrose) in their stem, to the detriment of greater vegetative growth, including the roots (Carvalho-Netto et al., 2014; Silva, 2017). Considering that sucrose is a readily hydrolyzable sugar, it is highly probable that this remobilization will ultimately reduce the photosynthetic flux since photosynthesis is highly sensitive to the accumulation and transport phenomena (Lemoine et al., 2013). Effectively, it can be observed that sugarcane is capable of much higher yields in varieties that accumulate more biomass instead of sucrose. This is the case of energy cane, a type of cane variety resulting from backcrossing between commercial sugarcane varieties and ancestral species of the genus *Saccharum*, especially, *Saccharum spontaneum* (Silva, 2017) (Table 1). The Fig. 1A shows four varieties of energy cane compared to one of the most productive variety of sugarcane in Brazil, showing the evident difference in biomass production. The Fig. 1B shows that the roots of these plants are much more abundant, creating a more dense and deep rhizosphere, which should be one of the factors responsible for the higher resistance to water and nutritional stress (Carvalho-Netto et al., 2014; Mirshad and Puthur, 2017; Silva, 2017). Besides, we have recently verified the association of possible nitrogen-fixing microorganisms in the roots of some of these varieties, a situation that was not noticed for commercial sugarcane (unpublished data).

Table 1
Comparison between sucarcane and energy cane.
Source: GranBio Investimentos S.A.

	Sugarcane	Energy Cane[b]
Fiber	17.4%	270%
Total sugars	12.6%	8.5%
Productivity (tonne/ha)[a]	92	180
Genetic gain (per year)	2%	5%
Use of fertilizers	High	Medium
Biotic and abiotic stress resistance	Low	Medium
Number of harvests	5	10

[a] Cultivated in São Paulo state (Environment E).
[b] Vertix 1 variety.

Regarding the productivity, the commercial available energy cane varieties, still with high potential for genetic gain through breeding (approximately 5% per year), are already capable of producing 2–3 times more than sugarcane, approximately 180 t/ha, with a cost of production that is half that one considered for commercial sugarcane varieties (Table 1) (dos Santos et al., 2016). Therefore, going back to the energy calculations, considering the productivity of energy cane, it allows an energy production equivalent to about 216 barrels of oil per hectare. According to the International Energy Agency, in 2017, the world consumption of oil was approximately 35,733 million barrels (“IEA - Oil, ” n.d.). If it were possible to produce the equivalent of this energy using energy cane, this would represent a planted area of about 166 million hectares. Undoubtedly, it is not small. However, it is nothing extraordinary. In Brazil, there are about 190 million hectares of pasture, much of it with very low productivity. If we associate much of the existing areas in the America, Asia, and Africa, there is probably enough area to produce the biomass necessary to replace the use of fossil sources.

Those calculations presented are a simple way only to demonstrate that it is possible, on the surface of the earth, to accumulate the amount of renewable energy that is needed to support the development of civilization. However, due to the abundance, high energy density, and low molecular complexity of oil, it has many advantages to be produced, commercialized, and transformed, which has led to the development of a whole fuel and chemical industry, deeply embedded in society. Thus, the major challenge of industrial biotechnology is to develop processes, using biomass, to generate products similar to those currently produced by the petroleum industry, and marketed for values that compensate the producer. This is not simple since the price of oil is defined by often imponderable factors, such as geopolitics, which frequently led to extraordinary variations in a short time (“IEA - Monthly oil prices, ” n.d.). To illustrate, while in 2013 the price of barrel oscillated around US$ 120.00, in 2016 it got close to $ 30.00 (“IEA - Monthly oil prices, ” n.d.), a variation of 400% in less than three years. Indeed, no renewable business, whose costs are practically stable and sales are limited by the values of the fossil references, can survive face of this instability for a long time.

3. The ethanol production in Brazil

The production of ethanol from sugarcane in Brazil was boosted by Decree No. 19,717 of 1931 which required the mixing of 5% of anhydrous ethanol with gasoline. In the 1970s, as a response to the oil crisis, the government instituted the National Alcohol Program, Proalcool, which provided incentives and subsidies for the expansion of distilleries, the development of ethanol-powered vehicles, the mixing of anhydrous ethanol with gasoline (E20) and the research and development of ethanol production. As a consequence, there was a significant development of the Brazilian sugar and ethanol sectors, and in 20 years the ethanol production increased more than 28 times, the fleet of ethanol cars reached 4.5 million, more than 9.5 million of vehicles were filled by gasoline and ethanol, and lastly, 10% of the total energy from the Brazilian energy matrix came from sugarcane products (Puppim de Oliveira, 2002). Since 2003, with the introduction of flex-fuel vehicles,

Fig. 1. Comparison between energy cane and sugarcane. In A, 5 energy cane varieties grown side by side with a top variety of sugarcane (the fourth, from left to right), at 7 months of age. In B, comparison of the root system of plants with after about 6 months of growth. On the left, sugarcane. On the right, energy cane.

the demand for anhydrous and hydrated ethanol in the country has grown, even more, reaching current production of 28 billion liters (de Freitas and Kaneko, 2011).

In 2010, with the advancement of research on enzymes and transgenic yeasts, capable of hydrolyzing the insoluble sugars of lignocellulose and its conversion into ethanol, several companies of different sizes started business plans for the implementation of the industries of second-generation ethanol (dos Santos et al., 2016). The decisive step in this direction was a sharp increase in the international price of oil, which, if maintained above US$ 80.00, would allow the feasibility of these ventures. Effectively, from 2012 various initiatives have been announced, such as the BioChemtex plant in Italy, Dupont, Poet-DSM and Abengoa in the USA (dos Santos et al., 2016). In Brazil, GranBio and Raizen built industrial units, starting production operations in 2015. However, the equipment used by these companies for the handling and processing of biomass were all adapted from the pulp and paper industry, which have been developed for wood. Virtually all companies underestimated the fact that biomass from short-cycle plants, which were the only ones with costs capable of making biofuels viable, had their characteristics, which demanded a specific development of equipment, both in architecture and metallurgy. For example, after the steam explosion pre-treatment, sugarcane bagasse and straw undergo a waterlogging and gain a consistency similar to that of a porridge, which impairs the movement of dewatering threads, used to move the material. Also, silica present in this type of biomass, which in nature has the role of avoiding herbivory, leads to abrasion and erosion of the materials, damaging equipment and significantly impairing the operation stability (Yancy-Caballero et al., 2017).

Thus, the biotechnology stages, which were considered the bottleneck for the establishment of the second-generation industry, were overcome. Unexpectedly, the problem now lies in the engineering of the mechanical process, a challenge of less technological difficulty, but which requires significant capital contributions, both to recover the investments already made and to develop equipment and processes that are appropriate for this technology. However, the sharp reduction in the price of oil since 2014 has impacted the investments in the sector, once again demonstrating the need for long-term policies to cope with the instability caused by fossil energy price changes.

4. RenovaBio – a Brazilian program for biofuels

The world is finally beginning to address climate change with concrete actions such as the Nationally Determined Contributions (NDCs) agreed in Paris during COP21 ("The Paris Agreement | UNFCCC, " n.d.). Brazil is a signatory of this agreement and has committed to reducing its emissions to 37% by 2025 and to 43% by 2030, considering 2005 emissions levels as the baseline ("iNDC - Contribuição Nacionalmente Determinada, " n.d.).

Unlike other countries, most of the Brazilian emissions in the energy sector are related to transportation (43%), given that the electricity is mainly generated from renewable sources, notably hydroelectricity ("Seeg Brasil, " n.d.). Therefore, to achieve the agreed targets determined in the NDC, it was proposed to reduce the Carbon Intensity (CI) of fuels; i.e., the amount of gases equivalent to CO_2 emitted by fuels to generate a certain amount of energy. Nowadays the in Brazil this CI is 74.25 g CO_2 eq/MJ (Brazilian Ministry of Mines and Energy).

Given this scenario, Brazil realized that could develop a policy that contemplated the commitment assumed at COP21 with the need to promote mechanisms that would increase the price stability of biofuels and thus their economic attractiveness. To this end, in December 2017, the Brazilian Government instituted the National Biofuels Policy, named RenovaBio. The first step of the program was to define the target of reducing CI of the fuel matrix, which must be obtained by the combination of the use of fossil fuels and biofuels. For example, gasoline emits 87.4 g of CO_2 eq per MJ of generated energy. Meanwhile, hydrous ethanol emits 20.8 CO_2 eq per MJ on average. Therefore, the more ethanol is used, the lower will be the Carbon Intensity of the fuels.

On June 5, 2018, the Brazilian authorities set a reduction target of 10.1%, to be achieved in 10 years, equivalent to a reduction of emissions of 591 million tonnes of fossil CO_2. To achieve those numbers, individual Carbon Intensity targets were defined and applied for fuel distributors. In order to achieve these goals, the distributors will need to acquire bonds equivalent to carbon credits, called CBIOs, on the Stock Exchange (B3) (Fig. 2). Each CBIO corresponds to one tonne of CO_2 that is no longer emitted, and it is generated from the production of biofuel. For example, hydrous ethanol emits 20.8 g of CO_2 eq/MJ against 87.4 of gasoline, thus failing to emit 55.9 g of CO_2 eq/MJ. Considering that 1 L of ethanol has 21.35 MJ, each liter of ethanol mitigates approximately 1.2 kg of CO_2; therefore, considering these parameters, 1 t of fossil CO_2 is mitigated when 833 liters of ethanol are produced.

In the example above, the ethanol producer would be entitled to 1 CBIO when he sold 833 liters of ethanol (considering that each liter mitigates 1.2 kg of CO2). However, it may be that another producer generates biogas from the vinasse (resulting from the distillation of ethanol) and uses that biogas in its agricultural machinery and trucks, replacing diesel oil. Thus, for each liter of ethanol produced, this second producer emits less CO_2 in the process, thus being entitled to a larger number of CBIOs per volume of marketed biofuel. If we consider the

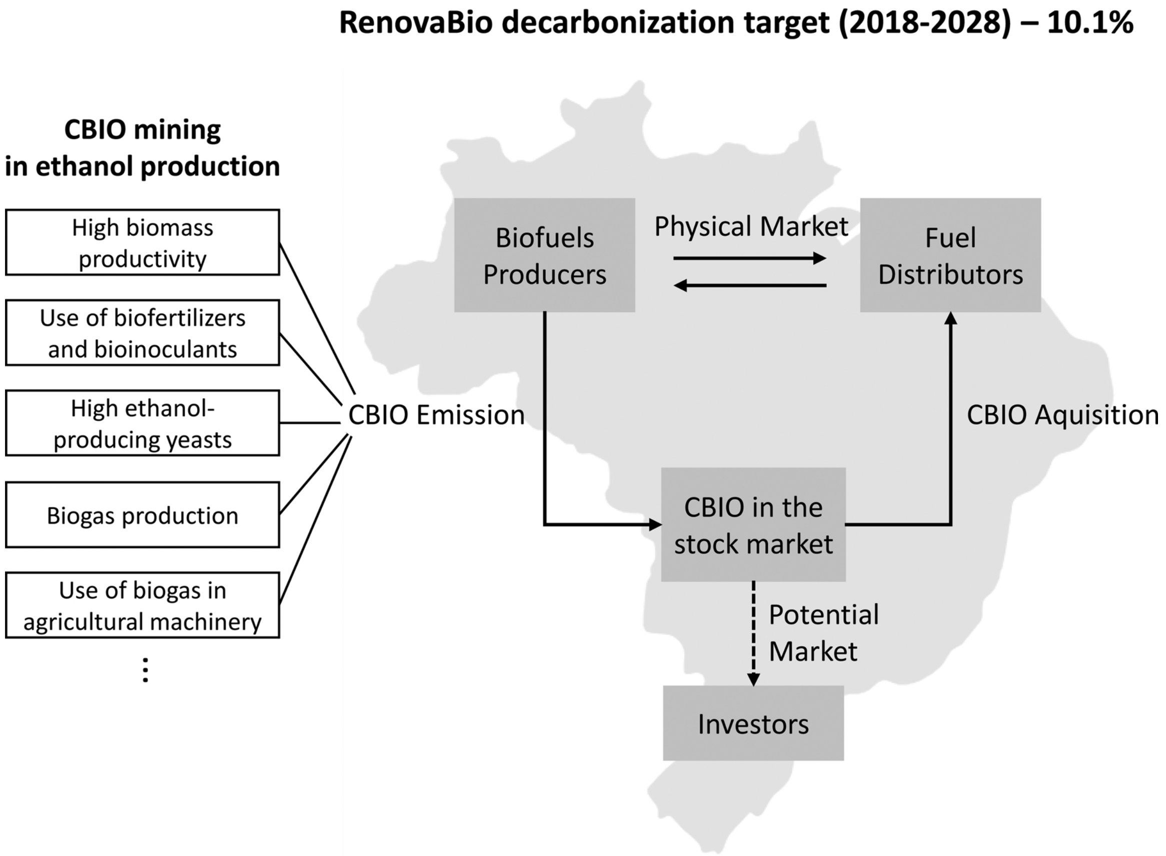

Fig. 2. The RenovaBio Program. A schematic and simplified view of the National Biofuels Policy from Brazil, the RenovaBio.

second-generation ethanol production, one CBIO would be obtained with the commercialization of only 484 liters of ethanol, which can significantly increase the attractiveness of this type of technology.

To perform the calculations of CO_2 equivalent emissions, the program has developed an environmental calculator base on Life Cycle Assessment (LCA), named RenovaCalc, from which each producer will be able to define the Carbon Intensity of their biofuel. This mechanism encourages producers to be more efficient, and this will require the development and incorporation of new technologies to increase agricultural productivity, the efficiency of machines, replacement of fertilizers and so on and so forth. In this way, the RenovaBio has enormous potential for generating new business, specially technology start-ups, which usually originate from universities. This program should also lead to the use of Carbon Capture Technologies (CCS) (Rahman et al., 2017) and, in the limit, it will be possible for each sugarcane mill, in producing biofuel and bioelectricity, to be simultaneously sequestering CO2 from the atmosphere.

The major innovation of RenovaBio, compared to equivalent programs in other countries, was to consider in the system various biofuels, allowing the producers "mine" CBIOs. The CIs of these biofuels are obtained from the comparison with the CI of the reference fossil fuel. For example, biodiesel and biogas have diesel as the reference. At the same time, these bonds, instead of being directly negotiated between biofuel producers and distributors, will go to the stock exchange where it will be freely traded. That is, the CBIO is a kind of currency, which can be highly valued in the secondary market, like the virtual currencies, but with the advantage of having a virtuous ballast, which is the mitigation of greenhouse gases in the atmosphere. Thus, the appreciation of this currency will increase the value of biofuel, which would now be calculated by adding the physical product plus this financial product, and this will be a great incentive factor to produce larger volumes of biofuels. Although market forces will define the price of CBIOs as it comes to market, the international carbon market experience offers some clues as to the values that it can achieve. For example, in California, bonds tied to the metric ton of carbon have been marketed between US$ 100 and US$ 180 (“Weekly LCFS Credit Trading Activity Reports, ” n.d.). If the CBIO reaches similar values, which is highly probable, this will represent an increase of approximately 40% in the value received by the producer, which makes the activity highly attractive to investors.

However, this mechanism could lead to an incentive to overuse of the natural resources and deforestation. Therefore, to avoid the environmental impacts, the law makes clear that only producers who are in compliance with environmental legislation may receive the CBIOS. Besides, as CBIO will be in the international market, which is attentive to environmental issues, the producer will have an incentive both to comply with the laws and to have other producers comply with it, thus maintaining the title's credibility. Therefore, RenovaBio, in addition to creating an important mechanism to increase the predictability of the price of biofuels and its economic attractiveness, generates a powerful tool to mitigate climate change on the planet and to preserve the environment at the national level.

5. Conclusion

The world is undergoing an energy transition and biofuels, in particular ethanol, are a consistent option for large-scale fuel substitution. In tropical countries, crops like energy cane have an energy density that rivals oil. The consolidation of second-generation technologies will allow the utilization of all plant tissues, increasing ethanol productivity per hectare and allowing all countries in the world to be able to produce ethanol from crop residues or specialized energy crops developed for different climates. With global awareness of climate change, programs such as RenovaBio increase economic security to produce biofuels, reducing volatility caused by oil price changes and increased attractiveness to the sector.

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