CHAPTER 4

FUTURE PRODUCTION MODELS OF BIOFUELS IN BRAZIL

4.1. INTRODUCTION

As seen in previous chapters, Brazil created sustainable biofuels production models, both for ethanol and biodiesel. However, these models need to be revised or adapted to allow further expansion of biofuels. This could be done either by modifying existing ones or the development of new market models.

Sugarcane ethanol is the most important biofuel in Brazil. Its economics were heavily linked to the sugar market. During the last few decades, the success of new ethanol-built distillery, was directly associated with joint production of sugar. This model currently has its limitations.

Also, criticism related to biofuel and food competition, although not necessarily applicable in the case of sugarcane ethanol, do raise some concerns. Brazil also faces important criticism related to land use, particularly with deforestation in the Amazon region and beef cattle ranches in pastureland. Therefore, there could be a way out by reconciling all these issues by introducing different production models.

4.2. NEW PRODUCTION MODELS FOR BIOFUELS

Bioenergy, specifically biofuels, were developed from existing feedstocks together with conversion technologies. This was the case for ethanol, biodiesel, and biogas and will probably be a good start for biokerosene and other fuels. Therefore, biofuels developed from adaptations, somehow inherited positive and negative features of their "mother" raw material and their "mother" conversion technology. In other words, biofuels were not designed from zero, in which environmental sustainability criteria were of little concern. Should biofuels have been conceived with environmental sustainability in mind, the outcome would have been different.

Perhaps we need rethink the entire production and conversion process as the current situation is very different. It could be said that the difficulties presented today may also represent a great opportunity for tomorrow. For example, sugarcane is a recognized as an excellent energy crop e.g., it produces, on average, 7,000 litres of ethanol/ha/yr besides the fibres/bagasse. But some studies have demonstrated a potential of 10,000 litres/ethanol/ha/yr, if G2 ethanol is coproduced (LEITE, 2009). What this example demonstrates is the considerable potential of sugarcane as a feedstock. With the development of new energy sugarcane varieties, this potential could increase even further, at least on the long term. Also, with the bagasse and leaves and tops, electricity can be produced in large scale. For example, by using combined cycles it is possible to produce at least 787.5 kWh/ton of cane (EQUIPAV, 2009). Besides ethanol and electricity, sugarcane has also shown the potential to produce other coproducts, such as animal feed (e.g., Vale do Rosário Mill), dried yeasts (São Martinho Mill), and biomethane (several mills are implementing new projects).

Other possibility is to extract the whole cane juice and instead of producing ethanol convert the juice directly to methane by a biodigestion process. Many experts consider vinasse biodigestion as a great contribution to the environment, while others consider biomethane as a precursor of green hydrogen. The remaining fibre (bagasse and trash) could then be used to generate heat and power.

All these are potential technological scenarios or pathways. Following is a more detailed discussion.

4.2.1 SECOND GENERATION ETHANOL OR G2 (USING BAGASSE AS RAW MATERIAL); CELLULOSE-BASED ETHANOL; COGENERATION; BIO-OIL PLANTS

Sugars, starches, and protein are noble raw materials. They should be used with parsimony since they are difficult to produce from a metabolic point of view. Plants are quite successful in producing sugar, starch, and protein to recreate life. Biofuels are just one clever way to convert these raw materials into useful energy. Human beings have been using firewood for long time, and this was, possibly, the first fundamental discovery we ever made. Firewood is still very much in use today (or “traditional biomass”), and in large quantities in many areas of the world, but predominantly in countries in Africa, Asia, and Latin America. Traditional biomass is basically extracted from biomes in quantities two or three times larger than how modern bioenergy is produced. Much of the traditional use of biomass is considered unsustainable and of very low energy inefficiency, and consequently should be phased out, but this is beyond the scope of this book.

To bypass the food vs biofuels dilemma, ligno-cellulosic materials are being seriously considered, particularly in the last two decades (see Chapter 1), to produce biofuels such as ethanol. Ligno-cellulosic can be converted into ethanol by two different ways: acid and enzymatic hydrolysis. There are other ways to produce biofuels using thermoconversion technologies, including the existing Rankine cycles, pyrolysis, and gasification. The experiences of ligno-cellulosic hydrolysis and thermoconversion in Brazil are discussed below.

4.2.1.1. Production of cellulosic or G2 ethanol

The production of G2 ethanol basically consists of two steps: the first is the hydrolysis f polysaccharides forming monosaccharides and disaccharides; secondly is the fermentation of produced sugars into ethanol. The difficulty is that the hydrolysis of cellulose, hemicellulose, and lignin generates products which ultimately may inhibit the fermentation process.[1] Therefore, an additional previous pre-treatment process is necessary to change or remove the lignin or the hemicellulose, increase its surface area, and decrease the cellulose polymerization degree and its crystallinity (Santos et al., 2012).

Probably, the biggest challenge in the G2 ethanol production process relates to pre-treatment. According to Santos et al an adequate pre-treatment process needs to have the following characteristics: a) low cost and investment; b) avoid the formation of undesired by-products which can inhibit the enzymatic action; c) allow high cellulose digestibility by the enzymes; and d) high recovery of sugars (SANTOS et al., 2012)

4.2.1.1.1. Production of ethanol using acid hydrolysis

The initial research works in acid hydrolysis started at CODETEC/UNICAMP at the end of 1970s with José Carlos Campana Gerez. This project reached pilot plant scale. And in the 1970s, COALBRA company[2] was created with the objective to tropicalize the soviet acid hydrolysis technology to produce ethanol from wood and animal protein as by-product. This demonstration plant achieved 30,000 litres of ethanol/day, located at the *"triângulo mineiro"* in the state of Minas Gerais. The COALBRA plant had technical problems such as the difficulty to dehumidify the eucalyptus lignin using filter press. In addition, the heavy investments in equipment resulted in high production costs (CORTEZ, 2016).

In 2001 DEDINI started the development of the DEDINI Rapid Hydrolysis Process (HDR) with the support of a FAPESP project.[3] The initial configuration was to use the acid catalysed Organosolv saccharification, integrating the G2 and the G1 ethanol. Among the difficulties was the problems posed by bagasse feeding technology.

4.2.1.1.2. Production of ethanol using enzymatic hydrolysis

As mentioned before, the FvF debates reborn the concept of producing sustainable biofuels from ligno-cellulosic raw material to avoid food competition. Ligno-cellulosic

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[1] https://www.scielo.br/j/qn/a/9n4nqyhZ3dVtZrpHQy5thDh/?lang=pt

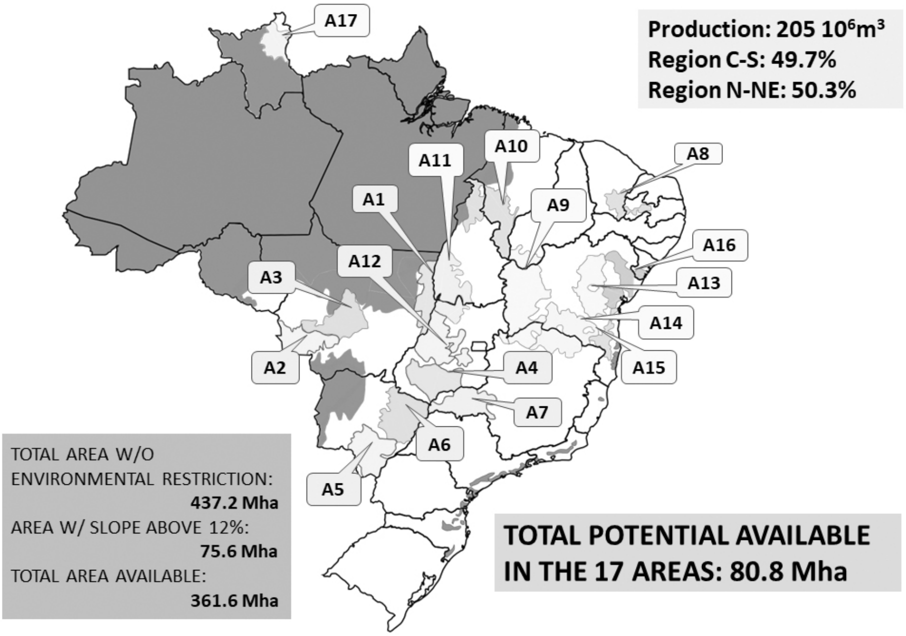
[2] The project was coordinated by Sérgio Motta, José Goldemberg, Gil Serra, and José Roberto Moreira as collaborators

[3] https://fapesp.br/3257/bioen-chamada-fapesp-dedini-para-apoio-a-pesquisa

is by far more abundant than sugars, starches, or oils and are easier materials to convert to biofuels.

In respond to the need to develop hydrolysis, several laboratories initiated research into this area. This was particularly the case of the National Research Energy Laboratory (NREL), USA, focusing the enzymatic hydrolysis. Acid hydrolysis was considered a more difficult route for the conversion of biomass into ethanol or methanol. The NREL initiative influenced Brazilian researchers, particularly at the Instituto de Pesquisas Tecnológicas (IPT), University of São Paulo (USP), and UNICAMP. A research group-- Bioethanol Network- was put together under the leadership of Rogério Cerqueira Leite. This group worked to identify the level of competence, scientific and technology barriers to cellulosic ethanol in Brazil. (CORTEZ, 2016)

Another research group, also coordinated by Cerqueira Leite, was trying to answer the question of how much sugarcane ethanol could be produced in Brazil. A group of agronomists studied soils and climate conditions in different regions, excluding ecological sanctuaries such as the Amazon, Pantanal, and the remaining Atlantic Forest. A total of 17 areas (Figure 4.1) were selected as a function of the potential shown in the maps (Figure 4.2). These maps were plotted by agronomists from the Sugarcane Research Centre – CTC from Piracicaba, SP, based on local edaphoclimatic conditions.



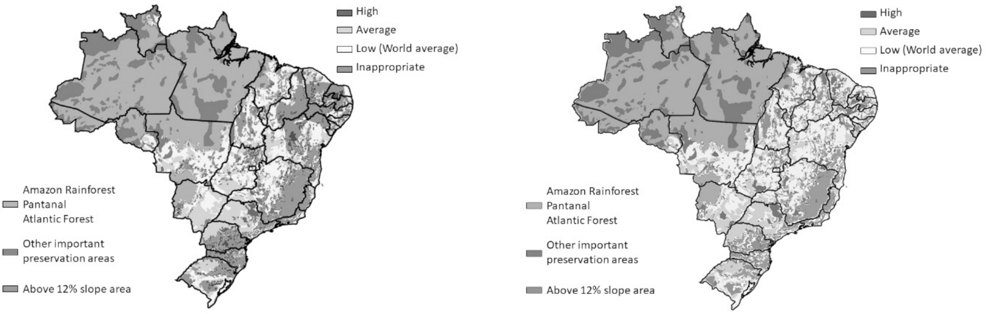
Production: $205\ 10^{6}m^{3}$
Region C-S: 49.7%
Region N-NE: 50.3%

TOTAL AREA W/O ENVIRONMENTAL RESTRICTION: **437.2 Mha**
AREA W/ SLOPE ABOVE 12%: **75.6 Mha**
TOTAL AREA AVAILABLE: **361.6 Mha**

TOTAL POTENTIAL AVAILABLE IN THE 17 AREAS: 80.8 Mha

Figure 4.1 Seventeen selected areas for potential production of sugarcane in Brazil.

Source: Leite (2009).



(a) (b)

Figure 4.2 Potential for sugarcane production in Brazil, considering soils and climates, (a) non-irrigated, and (b) with survival irrigation. Source: Leite (2009).

Then, based on these 17 selected areas and average combined sugarcane ethanol productivity, and plantation areas were then estimated. The conventional technology, based exclusively on the fermentation of sugars, were 6,000 litres/ha in 2005 and expected to go up to 8,200 litres/ha in 2015. Regarding the hydrolysis technology, it was expected to produce 1,100 litres/ha in 2015 and 3,500 litres/ha in 2025. Unfortunately, for several reasons, these yields were never achieved, although G2 ethanol is progressing well in Brazil, as discussed below.

Naturally, if hydrolysis technology was to be successfully developed in Brazil, the required sugarcane area would have been significantly smaller. For example, to produce 205 billion litres of ethanol/year using only the existing 1G ethanol technology with 7,000 litres/ha/yr, approximately 29 Mha would have been necessary. However, if G2 ethanol could contribute with an additional 3,000 litres/ha/yr, totalling an overall yield of 10,000 litres of ethanol/ha/yr, the required area would be 20.5 Mha. So, it was clear at that time that a national R&DD effort was necessary to develop hydrolysis technology.

As a result of these discussions, the Brazilian Centre for Research in Energy and Materials (CNPEM), decided to create the Brazilian Bioethanol Science and Technology Laboratory (CTBE) funded by the federal government. The new centre, the CTBE, would have to contribute to assure the leadership in sustainable ethanol production and implied basically two axes: a) redesigning the existing agriculture, particularly helping to disseminate the existing "best practices", and helping to promote adequate sugarcane mechanization; and b) helping in the developing the G2 ethanol technology. Several partnerships were signed up with both agricultural and industrial sectors. Another interesting contribution included a) a pilot plant which allows the development of experiments with the objective of reproduce industrial conditions; and b) a virtual biorefinery, a simulation platform useful to evaluate different technologies in the sugarcane bioethanol sector. Today, the CTBE operates under the name of Brazilian Biorenewables National Laboratory (LNBR).

To boost G2 ethanol the Brazilian Development Bank (BNDES) launched in 2011, together with the Brazilian Innovation Agency (FINEP), a program to support industrial technology innovation in the sugar energy and sugar chemical sectors, the PAISS.[4] One of the 35 selected business plans financed by the PAISS program, was the GranBio project to produce G2 ethanol.

In 2014 the GranBio project (60 million litres/year capacity) started operations at São Miguel dos Campos, AL. The GranBio project uses "energycane" as feedstock, which presents a higher overall productivity with a fibre/sugar ratio of 3, as compared with conventional sugarcane varieties with 2. With higher fibre content it could make sense to develop a process such as hydrolysis. The expected overall yield for the Granbio project was 10,000 litres/ton of sugarcane: nearly 45% higher than conventional sugarcane. This project received technology support from partners such as Beta Renewables, Novozymes, and DSM.

Figure 4.3 GranBio G2 Ethanol plant in São Miguel dos Campos, AL. Source: GranBio.[5]

RAÍZEN ENERGIA was founded in 2011 by integrating part of the COSAN (50%), at that time the largest producer of sugar and ethanol in Brazil, with the Brazilian SHELL (50%). RAÍZEN ENERGIA amalgamated the COSAN units, responsible for sugar, ethanol, and cogeneration, together with the distribution and commercialization operations of fuels of both companies. RAÍZEN presently is the largest fuel integrated group in Brazil, responsible from sugarcane production to the fuel distribution. The group had 35 sugar mills processing 105 million tons of cane in 2019/2020 harvest.[6]

The RAÍZEN group started its industrial production of G2 ethanol in 2015. An annexed G2 distillery was installed alongside the Costa Pinto Mill in Piracicaba, SP (Figure 4.4). The main idea with the annex plant is to have synergy between the G1 and

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[4] https://www.bndes.gov.br/wps/portal/site/home/imprensa/noticias/conteudo/20130507_etanol

[5] http://www.granbio.com.br/conteudos/bioflex-biocombustiveis/

[6] https://conteudos.xpi.com.br/renda-fixa/cra-raizen-dez-2022/

G2 processes to save energy. Its production capacity is 40 million litres/year. According to the RAÍZEN group they are presently the largest global cellulosic ethanol producer and trader in a commercial scale. Just recently the RAÍZEN group signed a contract to sell 460 million litres of G2 ethanol in the next 9 years. The group has, up to now, commercialized nearly 1 billion litres of G2 ethanol.[7]

Both GranBio and RAÍZEN have faced technical difficulties mainly related to pre-treatment and lignin filtering. Although significant improvements have been achieved, both units are still operating under capacity (EPE, 2022).

Figure 4.4 RAÍZEN G2 ethanol plant in Piracicaba, SP. Source: G1 (2015).

The RAÍZEN group recently announced the construction of a second G2 ethanol plant together with the Bonfim mill at Guariba, SP. The new plant will have the capacity to produce 82 million litres of ethanol/harvest, nearly double of the first plant.[8] The G2 ethanol business is progressing well, as RAÍZEN group declares that their prices receive a premium of up to 70% in the North American market.[9] Under such conditions, the same source confirms G2 ethanol competitiveness. These high premiums are related to the renewable identification numbers (RIN) associated with the technology under the RFS program and how EPA tracks and evaluates the entire process.[10] Table below shows a comparison of RAÍZEN´s ethanol emissions reduction and fuel ethanol produced in different regions and different feedstocks.

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[7] https://www.novacana.com/n/etanol/2-geracao-celulose/raizen-anuncia-venda-460-milhoes--litros-etanol-celulosico-100821#:~:text=Atualmente%2C%20a%20Ra%C3%ADzen%20possui%20uma,milh%C3%B5es%20de%20litros%20por%20ano.

[8] https://www.udop.com.br/noticia/2021/06/25/raizen-vai-construir-sua-segunda-planta-de-etanol--celulosico.html

[9] https://udop.com.br/noticia/2021/10/26/raizen-esta-vendendo-etanol-celulosico-com-premios--de-70.html

[10] https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information

Table 4.1 Carbon footprint, reduction of emissions, and volume of ethanol produced in different regions. Source: (RAÍZEN, 2022).

G2 Ethanol	Raízen (ACV Br/KPMG)[40]	13.6	86%	Raízen 20 billion liters[10]
	Watanabe et al. 2015 [46]	12.9	85%	
Sugarcane Ethanol	Raízen (ACV Br/KPMG)[40)	19.6-20.9	78-79%	34 billion liters in Brazil and Raízen 2.5 billion liters [47]
	Pereira et al. 2019 [39]	16-24	74-83%	
Sugarcane and corn ethanol	Milanez et al. [43]	28-31.4	67-70%	Distributed between sugarcane and corn production*
Brazilian corn ethanol	Moreira et al. (2020)	18.3-25.9	72-81%	Brazil 1.7 billion liters [47]
US corn ethanol	Pereira et al. 2019 [39]	43.4-61.9	34-54%	USA 59.7 billion liters [48]
European corn ethanol	Hamelinck et al. 2019 [41]	42.5	55%	Europe 2.7 billion liters [49]
	RED II, 2018 [35]	31.4-71.7	24-67%	
European sugar beet ethanol	Manochio et al., 2017 [42]	40	57%	Europe 1.08 billion liters [49]
	RED II, 2018 [35]	34-50	47-64%	
Gasoline	ANP	85.4		
	RED II, 2018 [35]	94		

Key: The table above shows the carbon footprint of ethanol in different regions (Brazil, USA, and Europe) from different inputs (sugarcane, second-crop corn, US and European corn, wheat, and sugar beet) compared to gasoline. Some figures have been selected for methodological consistency and to facilitate comparisons, presenting carbon footprints with energy and economic allocations. Data certified by RenovaBio were not reported because the mills opted for different strategies. The pursuit of higher volumes of CBIOs can lead to the inclusion of producers with lower quality data, which increases the carbon footprint. *The volumes of ethanol produced by the "flex mills" are distributed between sugarcane and corn production.

4.2.1.2. Combustion of ligno-cellulosic materials (existing Rankine/sugarcane mills)

Sugar and ethanol mills are the largest installed facilities to produce electricity from biomass in Brazil. According to the Brazilian Ministry of Mines and Energy annual report (MME, 2021), biomass represented 9.1% of all electricity used in the country in 2020.[11] In 2021, sugarcane bioelectricity provided 79% of all biomass electricity (RE-hydro with 65.2%, wind with 8.8%, and solar with 1.7%) representing 84.8% of all electricity.

As mentioned above, the challenge refers to how the energy matrix will behave with the generation of electricity from renewables. The situation with hydroelectricity is

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[11] https://summitagro.estadao.com.br/noticias-do-campo/cana-de-acucar-gera-energia-eletrica-no-brasil/#:~:text=A%20gera%C3%A7%C3%A3o%20de%20energia%20pelo,biomassas%20com%204%2C1%25.

complicated because, although there is still significant potential to be explored, it is concentrated in the Amazon region where the topography imposes large dams and large flooded areas, with significant impacts on biodiversity and the environment. The possibilities are much better with wind, particularly in the Northeast region where there is still a significant potential to be explored, and solar, a market that is growing fast, though still making a modest contribution. Biomass-based electricity has long tradition but depends very much on how the sugar and ethanol market will behave/develops. Presently biomass electricity is growing a much slower pace than wind and solar.

Two important points to remember is that the South-East and Central-West regions suffer from chronic droughts, particularly so in the last 20 years due to increasing population and climate change. The existing water reservoirs are used both for water supply and electricity generation which results in conflicting objectives. Therefore, biomass-based electricity can play an important role, particularly because sugarcane bagasse, the main feedstock, is harvested in the drought months, typically from May to October. Sugarcane itself, although a relatively resilient crop, also suffers from the consequences of severe and prolong droughts.

In 2002-2003, during a major drought, a study was conducted to evaluate the potential contribution of sugarcane to the production of electricity, concluding that the sugar and ethanol sector can significantly contribute to bioelectricity production. For example, in 2021, only 60% of all existing 369 mills were exporting electricity to the national Grid. If all mills sold electricity to the grid, the total amount could reach 151 GWh, meaning 26% of all electricity consumed in Brazil.[12] These figures were calculated by the Brazilian Energy Research Office (EPE), published in the “Bioeletricidade em Números” report from February 2022 by the Observatório da Cana (UNICA, 2022). One the difficulties to the expansion of cogeneration using sugarcane bagasse has been the low price paid for MW, which has been based on average electricity cost in Brazil.

4.2.1.3. Other thermoconversion technologies (pyrolysis and gasification)

The pyrolysis and gasification processes are thermoconversion technologies which can transform biomass into valued-added products. They have been tested in Brazil in the last decades and are now close to commercial utilization.

Sugarcane- biomass, consists basically of the fibrous material of bagasse and trash (cane tops and leaves). Figure 4.5 shows how a thermochemical process can be integrated to an existing sugar & ethanol mill.

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[12] https://summitagro.estadao.com.br/noticias-do-campo/cana-de-acucar-gera-energia-eletrica-no-brasil/#:~:text=A%20gera%C3%A7%C3%A3o%20de%20energia%20pelo,biomassas%20com%204%2C1%25.

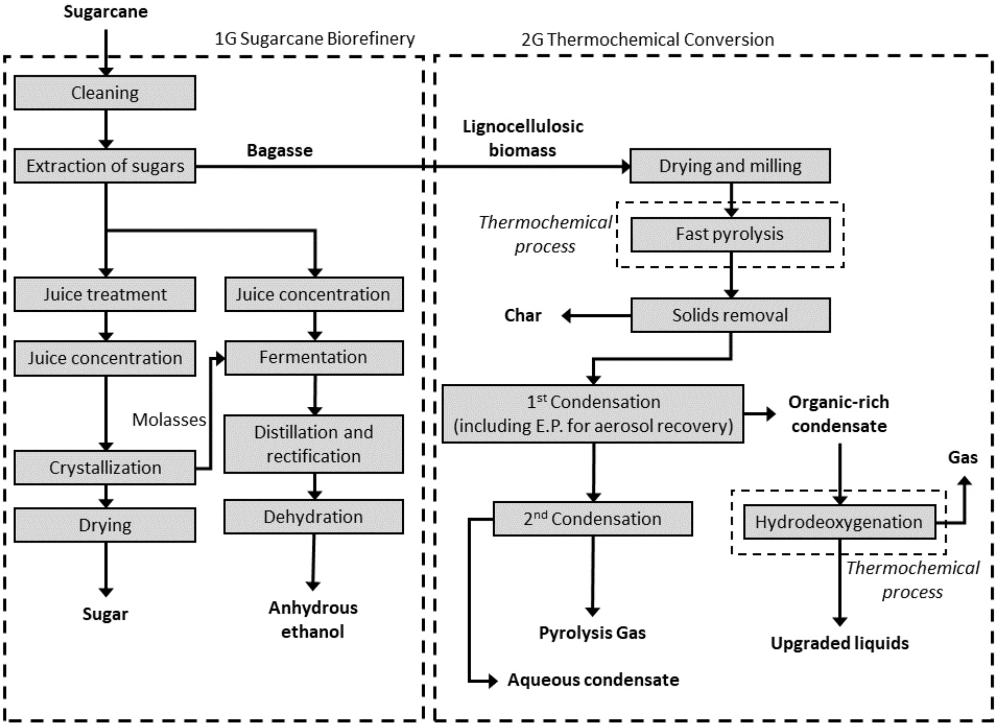

Figure 4.5 Integration of a thermochemical process with an existing sugar mill.
Source: KIT and IPT (2022).

At the end of 1970s, under the initiative of CESP and coordinated by of Eduardo Sabino de Oliveira, a wood electric gasifier was built to produce syngas for conversion to methane. The plant was installed in Corumbataí, SP, in 1987, under the leadership of José Roberto Moreira. The plant consisted of several large size gasifiers (capacity 20 tons of wood/h), but it was discontinued (CORTEZ, 2016), perhaps due to operational problems and economic viability issues.

The Institute for Technology Research (IPT) has made several contributions, both to G2 ethanol and thermoconversion processes.[13] One of the most important was a Biomass Integrated Project (PIB) coordinated by Vicente Mazzafera. This project investigated elephant grass as an alternative feedstock for bioenergy.[14] The research groups focused basically on agronomic and energy conversion studies. The prospects were positive, although no commercial application was actually made.

Also, in the early 1980s, the Brazilian company TERMOQUIP started operation in Campinas, SP, based on know-how developed at UNICAMP by Saul D´Ávila and

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[13] http://webcache.googleusercontent.com/search?q=cache:yJDWixEQqoAJ:www.ipt.br/download.php%3Ffilename%3D697-Biomassa_para_producao_de_energia_Colloquium_SAE_Brasil__Energia_Verde.pdf+&cd=26&hl=pt-BR&ct=clnk&gl=br

[14] https://sites.google.com/a/capimelefante.org/www/trabalhos-apresentados/t5

Themístocles Rocha. TERMOQUIP manufactured biomass gasifiers for clients including PETROBRAS. Also, fast pyrolysis rectors were made for experimental work using sugarcane bagasse and whole sugarcane as feedstocks (CORTEZ, 2016).

In the last decade, an important project has been conceived by the Canadian ENSYN with SUZANO (Fíbria). Production was planned to reach 110 million litres of biocrude/day.[15]

The main idea with this technology is to investigate direct conversion of biomass into a useful biofuel, not necessarily ethanol or biodiesel. If this technology works, it could provide a boost to biomass-based fuels given the large amount of bagasse and tops and leaves from sugarcane alone potentially available, not only in Brazil but worldwide. Potential candidates include “biocrude and bio-oil”. This could also have a major economic impact in existing refining process.

Just for illustration, if this viable biomass such as sugarcane, eucalyptus, or other energy crops could eventually be converted into biocrude and then enter in an oil refinery to produce the same oil derivates as gasoline, diesel, and kerosene, this will have a significant impact, just by partially using this new source.

This model could be used by PETROBRAS if it is to become, gradually, a green oil company, since the company has excellent conditions and experience to use ethanol and sugarcane as tools to innovate in this area.

Also, as mentioned in Chapter 1, Brazil used to have a small, but flourishing ethanol-based chemical sector, particularly fine chemicals. Presently, large investments are directed into biomass-based feedstocks, and away from fossil fuels-based ones. An example is the well-succeeded Braskem polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) resins. This represents a great opportunity, particularly for ethanol and its use for new green materials. See BNDES (2008) for further details on ethanol-chemical industry in Brazil.

4.3. THE EXPANSION OF CORN ETHANOL IN BRAZIL

4.3.1. LAND USE, DEFORESTATION, AND GHG EMISSIONS FROM BEEF CATTLE IN BRAZIL

Land use in Brazil is dominated by native forests (65%) and pastureland (18%).[16] These numbers are subject to some variations e.g., pastureland maybe closer 20% of the Brazilian territory, approximately 170 Mha. There is a significant controversy regarding the size of Brazilian beef cattle and the area it occupies. The 170 Mha of pastureland is, in fact, a conservative figure. The exact number is difficult to know, but it is probably anything from 150 to 200 Mha (Figure 4.6).

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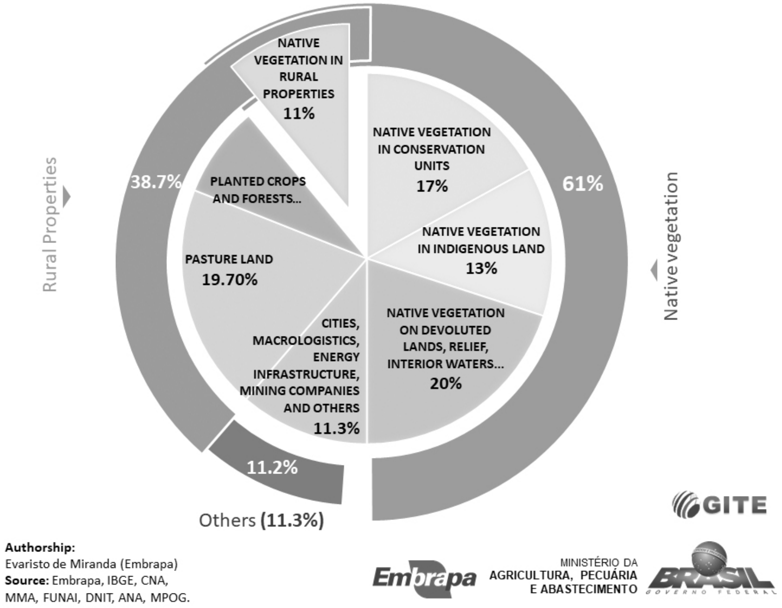
[15] https://www.gazetaonline.com.br/noticias/economia/2017/12/es-tem-99-9-de-chance-de-receber--fabrica-de-biopetroleo-diz-fibria-1014110923.html

[16] https://mapbiomas.org/infograficos-1?cama_set_language=pt-BR



Authorship:
Evaristo de Miranda (Embrapa)
Source: Embrapa, IBGE, CNA, MMA, FUNAI, DNIT, ANA, MPOG.

Figure 4.6 Land occupation in Brazil. Source: EMBRAPA.[17]

Another important issue regarding pastureland in the Amazon region refers to deforestation and its core causes. Several sources indicate that beef cattle expansion happened mainly in North and Central-West regions and are considered one of the key causes of Amazon Forest deforestation (IPAM, 2016).

As for beef cattle herd size, according to IBGE, MAPA, USDA, FAO, and Athenagro, estimates, this varies from 190 to 250 million heads, making Brazil the first or second largest herd in the world. Pastureland and beef cattle ranches are intrinsically and environmentally related, as land use is correlated with GHG emissions. This large heard represents nearly 17% of Brazilian GHG emissions. As discussed in the previous chapter, the Brazilian agriculture sector is the second most important source of GHG emissions, with 27% of total, the first being land use change. For clarity, the 27% discussed in the previous chapter, includes GHG emissions of both agriculture (10%) and beef cattle (17%).

For the Brazilian beef cattle industry, the need to reduce its GHG emissions also creates opportunities to intensify and improve the production systems, greatly benefiting the meat market. One of the largest beef cattle producers, JBS, has launched a sustainability strategy which allowed to recycle 25 thousand tons of solid residues (mainly tallow), and an additional 2 billion litres of biodiesel, plus fertilizers and organic products (Folha de São Paulo [18]). This affirmative action could be partly an answer to criticism, both domestic and international.

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[17] https://www.beefpoint.com.br/no-brasil-a-salvacao-da-biodiversidade-do-meio-ambiente-e-da-economia-esta-na-agropecuaria-diz-pesquisador-da-embrapa/

[18] Folha de São Paulo, “Terra”, JBS advertisement, April 22th, 2022, Estúdio Folha Terra, p 4-5.

Beef cattle GHG emissions are mainly methane originated from the animal's enteric fermentation[19] and nitrous oxide originated from the soil (Figure 4.7 below). The nitrous oxide may come from the application of nitrogen as fertilizer and from beef cattle manure.

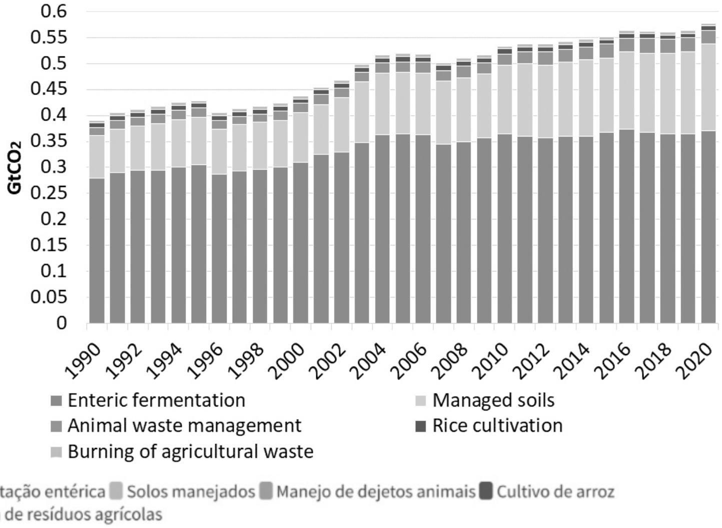

Figure 4.7 Evolution of GHG emissions by the Brazilian beef cattle, in Gtons of $CO_{2equivalent}$ (1990-2020). Source: SEEG/Observatório do Clima (2022).

The reduction of Brazilian GHG emissions is therefore very much related to improvements of the beef cattle industry. This improvement and modernization need to be accelerated, so that the country can increase beef cattle productivity and recover degraded pastureland areas. Another important measure is through genetic improvement to allow more intensive, and confined production systems and reduction of life cycle (slaughter age) and pastureland management. Naturally, it is important to make aware to cattle producers, with their particularities e.g., such as size, or production systems, of the importance of sustainable production while at the same be economically viable.

4.3.2. CORN ETHANOL IN BRAZIL

Until recently, corn ethanol did not enjoy a good reputation in Brazil. This was probably due to the relatively bad energy balance of corn ethanol[20] when compared with sug-

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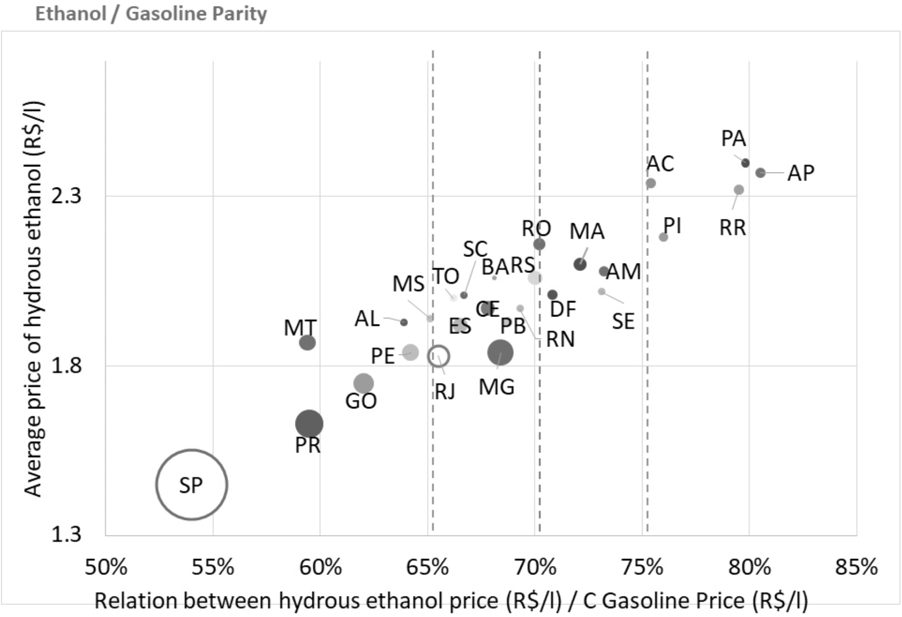
[19] Brazil is among the 100 countries which in the Conference of Climate – COP26 last Nov 2021 Glasgow, Scotland, agreed to reduce methane gases emissions in 30% until 2030. Last March 2022, the Brazilian Federal government launched a national program (Methane Zero) to reduce methane originated from organic residues.

[20] According to RFA report, the corn ethanol energy balance is improving, basically due to more accurate estimations on the energy used in the process, particularly regarding the distillers' grains.

arcane. The main reason for this negative energy balance is based in the fact that corn, when used as feedstock, requires external use of energy to run the mill. Sugarcane, on the contrary, has abundant bagasse and fibre (representing nearly 2/3 of total energy in the plant). If energycane varieties are used, this proportion can go up to ¾. In addition, if boilers are run with maximum efficiency, this could generate large energy surpluses.

Recently, in some areas located in the country agricultural frontier (Mato Grosso and Goiás states) are more interested in ethanol production systems. This is basically due to low corn prices in that region, which at the same time are due to logistic difficulties associated with transporting corn grains to the South-East region where there is greater market demand.

Besides, in several states in Central-West and North, ethanol (E100) prices are higher making practically inviable the use of flex-fuel engines using E100. Gasoline (E27.5) are also high, but when the consumer makes his calculations,[21] the decision favour E27.5 (Figure 4.8). Therefore, it seems logical to explore the existing gap (low corn prices and high ethanol prices) and to produce corn ethanol.



Note: The bubble sizes are proportional to the ethanol consumption from July 2001 to December 2009. Prices are expressed in Reais of December 2009. The dashed red line (70%) represents the ethanol-gasoline parity, and the dashed green lines shows the 65% and 75% band.

Figure 4.8 Average price of E100 and gasoline-ethanol price parity for different states in Brazil – 2001 to 2009. Source: Souza (2010) using ANP data.

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[21] The rule of thumb: when ethanol E100 prices are higher than 70% of gasoline E27.5 prices, it is worth to use gasoline E27.5.

One important point with regard to production and use of sugarcane ethanol is that sugarcane is not a countrywide crop. In fact, sugarcane plantations are almost 80% in Central-South region (mainly in São Paulo, Paraná, Minas Gerais and Goiás states) and around 20% in the Northeast (mainly in Alagoas, Pernambuco and Paraíba states). This geographic distribution influence ethanol prices because of higher transportation costs. Typically fuels costs are nearly 50%, or even higher, compared to state of São Paulo, the centre of ethanol production and consumption and where most refineries are located. This, naturally, affects energy security and logistics since fuel needs to travel thousands of kilometres to destination. Also, often ethanol is imported from USA to supply the Amazon region. On the other hand, corn can be planted in more states and could complement sugarcane as feedstock for ethanol production (Figure 4.9 and Table 4.2 below).

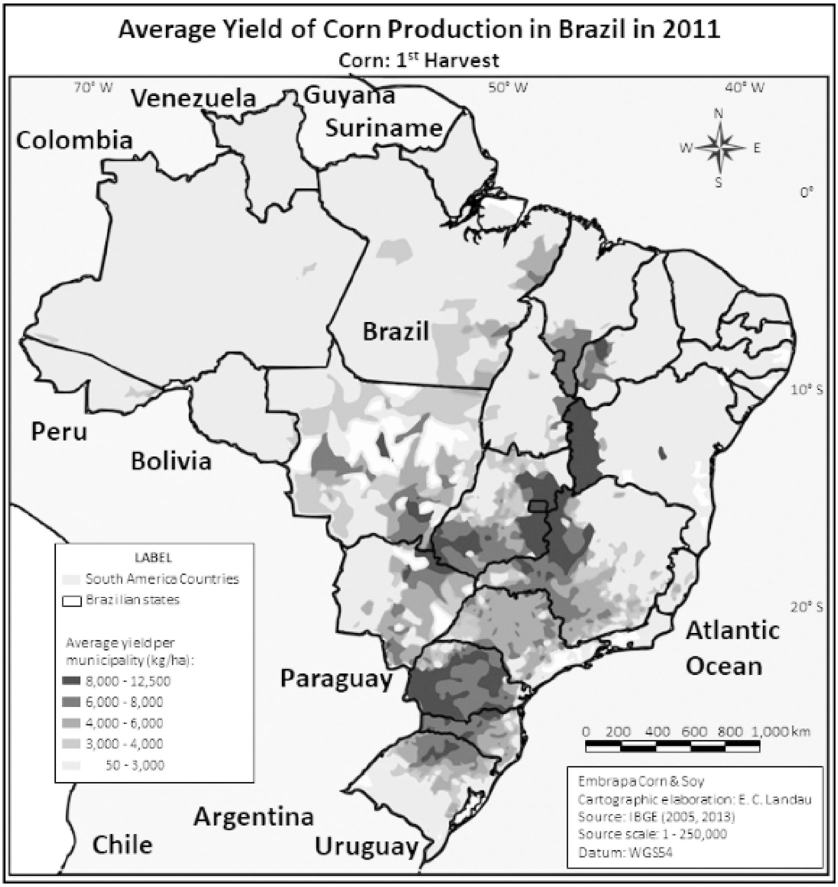

Figure 4.9 Average yield of Corn in Brazil in 2011, 1st harvest. Source: EMBRAPA[22]

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[22] http://panorama.cnpms.embrapa.br/mapas/produtividade-do-milho/mapa_milho1safra_rendimmedio2011_.jpg/view

Table 4.2 Corn Production in Brazil. 1st and 2nd crops. Source: CONAB (2022)

Year	First Crop	Second Crop
2000/01	35.8	6.5
2001/02	29.1	6.2
2002/03	34.6	12.8
2003/04	31.6	10.6
2004/05	27.3	7.7
2005/06	31.8	10.7
2006/07	36.0	14.8
2007/08	40.0	18.7
2008/09	33.7	17.3
2009/10	34.1	21.9
2010/11	34.9	22.5
2011/12	33.9	39.1
2012/13	34.6	46.9
2013/14	31.7	48.3
2014/15	30.3	64.0

One important feature of corn ethanol is the production of solid high-protein residues. There are two basic processes to produce corn ethanol in the USA, wet and dry. In the wet process the result is wet distillers' grains (WDG) and in the dry is distillers' grains (DDG). Typically, 1 ton of corn yields 425 litres of ethanol and 312 kg/ of DDG.[23] In principle the same yields are expected in Brazil.

Presently, several mills are already in operation in the country. Most of them are in the states of Mato Grosso and Goiás (Figure 4.10). In addition, Table 4.3 provides a list of all corn ethanol mills, either processing corn only or corn and sugarcane (flex mills).

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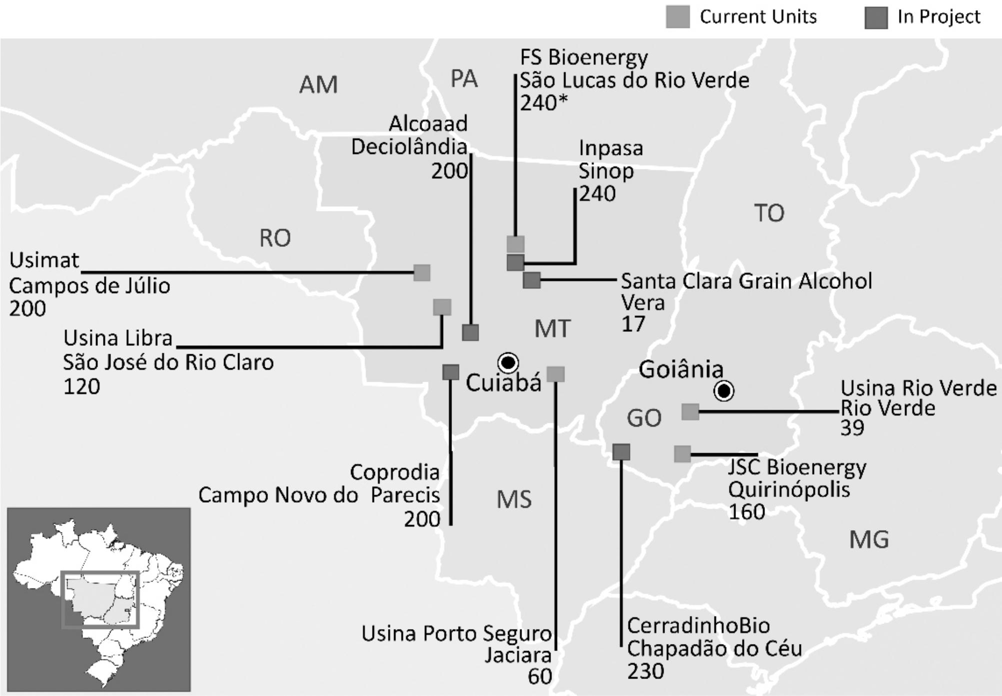
[23] https://sistemafaeg.com.br/faeg/noticias/etanol-de-milho/goias-deve-produzir-392-milhoes-de--litros-de-etanol-de-milho



Source: Companies, Unem, Sindalcool-MT. *With expansion, capacity goes to 530 million litres per harvest.

Figure 4.10 Localization and production capacity of few corns' ethanol plants in Mato Grosso and Goiás.

Table 4.3 Main corn ethanol distilleries in the states of Mato Grosso and Goiás, Brazil. Source: Compiled by the authors.

	Localization	**feedstock**	**Production capacity of ethanol and DDG**
USIMAT	Campos de Júlio, MT	Corn/Cane	480-520 thousand litres/day + DDG
Grupo Safras	Sorriso, MT	Corn	13.86 million litres of ethanol/year
Destilaria Libra	Diamantino/São José do Rio Claro	Corn/Cane	600 thousand litres/day
Fiagril/Summit FS Bioenergia	Lucas do Rio Verde, MT	Corn	210 thousand litres ethanol, 180 thousand tons of feed, 6 thousand tons oil/day
Usina Pantanal/Porto Seguro	Jaciara, MT	Corn/Cane	16,9 thousand litres/day+9.102 tons of DDG
Santa Clara Álcool de Cereais	Vera, MT	Corn/Sorghum/Rice	50 thousand litres/day
Ethanol S.A. Bioenergia	Nova Mutum, MT	Corn	200 million litres/year
ETAMIL (Coprodia Group)	Campo Novo do Parecis, MT	Corn/Cane	300 thousand litres/day

<table>
<tr><th colspan="2"></th><th>Localization</th><th>feedstock</th><th>Production capacity of ethanol and DDG</th></tr>
<tr><td colspan="2">Cooperativa Agroindustrial Deciolândia (Alcooad)</td><td>Tangará da Serra, MT</td><td>Corn</td><td>200 million litres/year</td></tr>
<tr><td colspan="2">INPASA</td><td>Sinop, MT</td><td>Corn</td><td>6 million litres/day</td></tr>
<tr><td colspan="2">VMG Bioenergia</td><td>Jataí, GO</td><td>Corn</td><td>7 million litres/month</td></tr>
<tr><td colspan="2">GEM Alimentos</td><td>Acreúna, GO</td><td>Corn</td><td>140 million litres/year</td></tr>
<tr><td colspan="2">Grupo São Martinho</td><td>Quirinópolis, GO</td><td>Corn/Cane</td><td>200 million litres/year</td></tr>
<tr><td colspan="2">CerradinhoBio</td><td>Chapadão do Céu, GO</td><td>Corn</td><td>230 million litres/year+150 thousand tons of DDG</td></tr>
<tr><td rowspan="2">São João-Cargill (SJC Bioenergia)</td><td>Usina São Francisco</td><td>Quirinópolis, GO</td><td>Corn/Cane</td><td rowspan="2">500 million litres/year + FlexyPro, FlexyDDG, FlexyDDG Plus</td></tr>
<tr><td>Usina Rio Dourado</td><td>Cachoeira Dourada, GO</td><td>Corn/Cane</td></tr>
<tr><td colspan="2">Santa Helena</td><td>Santa Helena de Goiás, GO</td><td>Corn</td><td>400 thousand litres/day</td></tr>
<tr><td colspan="2">Caçú</td><td>Vicentinópolis, GO</td><td>Corn/Cane</td><td>500 thousand litres/day</td></tr>
<tr><td colspan="2">Usina Rio Verde (Decal)</td><td>Rio Verde, GO</td><td>Corn</td><td>55 million litres/year</td></tr>
</table>

Production of corn ethanol reached 262.3 million litres in Goiás and 1.98 billion litres in Mato Grosso in 2021/22 season, about 2.2 billion million litres in both states.

Corn ethanol offers several advantages. According to Ricardo TOMCZYK, Director of the União Nacional do Etanol do Milho (UNEM), one of the greatest advantages of corn ethanol is that the production capacity can be quickly scale up e.g., it can be put into production in 1.5 years while sugarcane needs 4 years to implement a new plantation (NOVACANA, 2019).[24] According to the same source corn ethanol production can reach 8 billion litres in 2028 in Brazil.

4.3.3. POSSIBLE LAND USE CHANGE ASSOCIATED WITH CORN ETHANOL INTEGRATION WITH BEEF CATTLE IN BRAZIL

The most important issue concerning corn ethanol production are the possible impacts on land use. Such impacts will depend on how this integration takes place, or how much land will be spared e.g., the greater the animal density the greater land

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[24] https://www.novacana.com/n/eventos/ricardo-tomczyk-unem-desafios-etanol-milho-mato-grosso--brasil-030719

availability.[25] In addition, the correct localization of new distilleries will also affect the economics of this integration

What is necessary is to investigate the potential of the final indirect land use change (iLUC). Searchnger et al. (2008) introduced the land use change and the indirect land use concepts. According to the author, when a biomass is planted it will ultimately cause two effects: a LUC and an iLUC.

The LUC can be defined as the change in land use when another crop is grown. It is the direct effect; one crop substitutes the other crop. For example, LUC happens when a given crop, such as biomass "pushes" a previous crop or pasture. This is the "direct" land use change.

The iLUC refers to the second effect, the "land whose ultimate purpose is essentially changed from its previous use".[26] An "indirect" land use change can be and understood as a kind of "domino effect". According to the same source: "an example would be a forest land that was cleared for the cultivation of biofuel crops". Figure 4.11 illustrate the LUC and the iLUC.

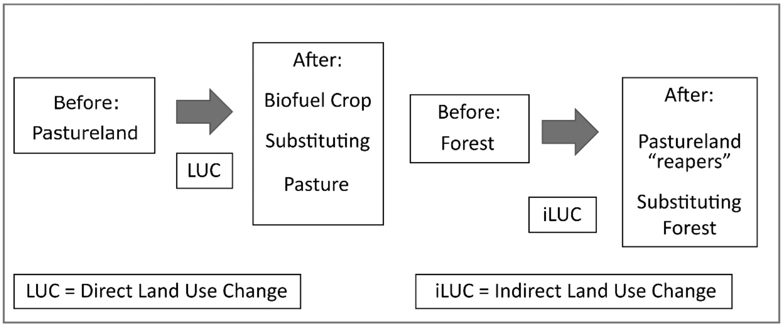

Figure 4.11 Schematic view of LUC and iLUC processes. Source: by the authors.

Considering that corn ethanol integration with beef cattle will shrink pastureland and free up land, there will be a "negative iLUC". In this case, the mitigated GHG emissions should be added and not subtracted. UC impact on sugarcane LCA results in mitigation to drop from 80-90% to about 60%. This is still in makes sugarcane ethanol as "advanced fuel" according to EPA.

What it is being proposed is a reverse strategy in which corn integration with beef cattle can result on the opposite effect, freeing up land, rather than causing deforestation. Naturally, this will benefit corn ethanol new LCA, improving the potential benefits when compared to the LCA corn ethanol produced in the USA.

To demonstrate this possible benefit, it is illustrated on Table 4.4 by the following example, based on a 335 M litres/year distillery installation. There are two options:

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[25] Of course, we are aware that when animal density is large, this also presents problems. Bit this is not necessarily the case in Brazil,

[26] https://farm-energy.extension.org/what-is-direct-land-use-or-direct-land-use-change/

100% sugarcane or 100% corn as feedstock. Some assumptions are made to ensure a rough estimation of the installation of this fictitious ethanol plant. The investor is keen to know which option will be best e.g., LUC and expected iLUC.

Table 4.4 Comparison on sugarcane and corn ethanol indirect land use (iLUC) for a 335 M litres/day ethanol distillery. Source: by the authors.

	Sugarcane	Corn
Planted area for the raw material	50 thousand ha + reform area	140 thousand ha
Planted area for extra fuel (eucalyptus)	No area needed since sugarcane produces abundant fibre (bagasse)	25 thousand ha
Total planted area	67 thousand ha	165 thousand ha
Impact on land use	67 thousand ha will need to be open to cultivate sugarcane	214 thousand ha of pastureland will chance use (LUC)
Balance of areas (iLUC)	(–) 67 thousand ha of deforestation	(+) 49 thousand ha of land is freed to other uses

* Sugarcane: 335 M litres/year x 1t/85 litres x 1 ha/70 tons = 56 thousand ha
Corn: 1 M l/d x 335 d/year x 1t/400 l x 6 tons/ha = 140 thousand ha

** In Brazil 2/3 of corn is planted as 2nd crop, sharing the land use with soybeans, therefore only half of the land is to be considered

*** Eucalyptus: 1 M litres/d x 335 d/year x 7.4 tons of wood/l x 500 tons of wood/ha = 5 thousand ha/yr x 5 years = 25 thousand ha of plant area of eucalyptus

**** 335 M l/year x 1 t/400 l x 0.28 t DDG/t = 235,000 t DDG/year
235,000 t DDG/year x 1UA/1.1 t DDG/year x 1 ha/head of animal = 214 thousand ha

4.3.4. SUGARCANE WITH CORN (FLEX DISTILLERIES)

As discussed in the previous sections, corn does have advantages but also disadvantages when compared with sugarcane as feedstock to produce fuel ethanol.

A comparative analysis of such the advantages and disadvantages are given in Table 4.5.

Table 4.5 Comparative advantages and disadvantages of corn and sugarcane as feedstock to produce ethanol. Source: composed by the authors.

Parameter	Sugarcane	Corn
Crop cycle	Semi-perennial crop Once planted, occupies the soil during 5 cuts, or ~7 years	Annual crop Can be planted as 1st crop or 2nd crop. Crop cycle ~4 months
Plantation/plant implementation time	~4 years	~1.5 years

Parameter	Sugarcane	Corn
Productivity	~7,000 litres of ethanol/ha/yr in Brazil	~4,000 litres/ha/yr in the USA ~2,500 litres/ha/yr in Brazil (crop 2nd crop)
Feedstock price volatility	Relatively low. Subject to be influenced by sugar demand	Relatively high since corn is in greater demand
Investment in agricultural machinery	High (needs to harvest large volumes per hectare)	Low (harvesting of small volumes per hectare)
Capacity to store raw material Raw material highly perishable. Needs to be processed within ~24h Can be stored and used all year around		
Capacity to be transported	Sugarcane is composed by 70% water, therefore severe difficulties to be transported limiting logistics	Low water content. Corn can be easily transported to long distances
Industrial conversion	Relatively low. ~80 litres of ethanol/ton of sugarcane stalks	High. ~425 litres of ethanol/ton of corn
Investment in industry to process/convert	Requires bigger equipment because season is shorter	Processing season can last all year long
	High (heavy equipment for crushing)	Medium (needs extra tanks for saccharification but uses the same equipment after that)
Extra fuel	Large quantity of fibre (bagasse) is produced. Ratio 2/3 for sugarcane, ¾ for energycane	Low fibre. Needs extra fuel. In USA natural gas. In Brazil eucalyptus if only corn is used as feedstock
Residues utilization	Very low protein in the cane. Extra bagasse is typically used for energy in the mill. Electricity can be exported (cogeneration)	DDGW or DDGS can be produced and used for beef cattle feeding

Maybe a good solution could involve integrating a corn ethanol plant with an existing sugarcane sugar mill, as explained bellow. Typically, all the after-harvest corn dry matter remains in the field and is incorporated as organic matter during the tilling process for soybeans planting. There is a controversy about how much corn stover can be left on the field and how much should be removed.

Flex distilleries is a new concept developed in Brazil using both feedstocks, sugarcane, and corn. This allows taking maximum advantage of both feedstocks, as indicated in Table 4.2 above.

Flex distilleries operates all year round, with sugarcane plant operating from April to October. The plant then saves bagasse for corn operation from November to March. Several flex mills report operation of 6 months for each feedstock.

Typically, a corn annexed distillery is built alongside an existing sugarcane ethanol plant. Normally this occurs in existing sugarcane plants built by traditional producers of sugarcane from Central South Brazil.

In addition, projects mentioned in the Table 4.1, three other flex projects are currently being constructed in Goiás.

Besides Mato Grosso and Goiás, there is also a good potential to install corn ethanol distilleries in São Paulo state where more than a hundred mills are already in operation and where there is more than 9 Mha of pastureland for beef cattle. São Paulo state offers an excellent opportunity for flex distilleries because of potential use of DDGW to promote beef cattle integration. Around 5% of beef cattle is produced in feedlots, and large part of this already occurs in São Paulo state.

A traditional sugarcane equipment manufacturer, the DEDINI company, is already installing flex distilleries in Brazil.[27]

FINAL REMARKS

As can be appreciated from previous pages, Brazil has considerable R&D capacity and know-how to develop new feedstocks, particularly from woody biomass, and process technology. Significant R&DD has been underway for many years in universities, research institutions and industry. Many routes are being investigated and it can be said it is an invigorating and promising research field.

With the right policies and support, this area could advance rapidly. This chapter has looked at potential and realistic models and strategies, taken into consideration environmental sustainability. It has considered process technology for new feedstocks and problems posed by land use and food production. It is a rapidly evolving field. It is also clear that there is considerable room for improvement, away from current unsustainable economic and environmental models.

For example, a better management of cattle ranches can easily result in freeing considerable amount of land while being environmentally more friendly. The combined production of sugarcane-corn presents an excellent social, economic, and environmental benefits while making better use of existing natural resources.

These are, therefore, realistic alternatives to current unsustainable production models, ranging from process technology to develop sustainable feedstocks, to economic models that make better use of existing resources with considerable economic, social, and environmental benefits.

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[27] https://www.dedini.com.br/index.php/noticias-eventos/noticias/92-usinas-flex-cana-milho-e-destilaria-modular-dedini-de-etanol-de-milho

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