Biochemicals in Brazil:

Market assessment of five strategic product categories

Guilherme de Oliveira Marques

Nicholas S. Vonortas

Sérgio Robles Reis de Queiroz

Campinas, Brazil

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Executive Summary

This document has been prepared by the partnering team from UNICAMP on the request of the CEBRABIC consortium management. It focuses on a set of related biochemical sectors chosen on the basis of six criteria:

1. These are sectors with large global potential given the widespread environmental concerns regarding carbon-based chemicals.
2. Europe and Brazil have complementary production strengths in these sectors which makes collaboration between the two regions desirable and feasible.
3. Complementary political justifications – reducing the carbon foot print of the chemical sectors, large in both regions – and complementary comparative advantages – extensive biodiversity in Brazil that the country has been striving to exploit commercially and relatively few aggressive private sector companies in sectors such as cosmetics versus a very large environmentally-concerned fine chemical sector in Europe with extensive technological capabilities. This makes a potentially interesting recipe for collaboration.
4. The recent production of a detailed report by the Joint Research Centre (JRC), the European Commission's science and knowledge service, on bio-based chemicals which provides an excellent background and point of comparison for the discussion in this document. This report complemented an earlier technical report on the same subject, thus providing excellent background material for the interested reader.
5. Bioeconomy was one of the five areas of interest identified by experts attending the UNICAMP workshop run by the predecessor project INCOBRA (17-18 Nov 2016) through a formal technology foresight exercise.
6. Two Brazilian companies affiliated with ENRICH (Braskem and Natura) are directly linked with the story herein.

The JRC recently published a Science for Policy report entitled "Insights into the European Market for Bio-based Chemicals" (Spekreijse et al., 2019). The report provided a detailed description of a segment of the EU bio-based products sector, represented by ten chemical product categories, and its application markets:

- Platform chemicals
- Solvents
- Polymers for plastics
- Paints, coatings, inks and dyes
- Surfactants
- Cosmetics and personal care products
- Adhesives

- Lubricants
- Plasticisers (and stabilisers for rubber and plastics)
- Man-mase fibers

The JRC report identified fifty products as representative of the ten product categories (3-9 per product category). Detailed market assessments were carried out on the fifty selected products covering production in the EU, price, turnover, consumption, trade, feedstock use and agricultural land requirement. Moreover, market information on the product categories was collected, covering EU production and market share, the EU's import dependence, future market size, private investment, and the importance of Member States and the EU to production. Finally, a SWOT analysis was undertaken of these products.

The scope of the JRC studies includes non-energy and non-traditional bio-based chemicals, entirely or partially constituted by renewable raw materials from biomass and intended for a wide variety of application areas.

In this report, we chose to analyze five product categories that we believe to be among the most promising industrial biochemicals for Brazil in the next few years:

- platform chemicals;
- bioplastics;
- cosmetics & personal care products;
- sweeteners & flavors; and
- nanocellulose.

The first three appear in the 2019 JRC report. In these five product categories there are significant innovative efforts in Brazil at the commercial or pre-commercial phase. While there is a degree of arbitrariness in choosing these five specific categories, to our best knowledge they are of great strategic importance for Brazil, which was confirmed by the conducted interviews.

The following dimensions were explored for each of the five product categories:

a. Productive capabilities already present in Brazil (*supply*);
b. Market size for biochemicals made in Brazil (*demand*);
c. Innovative and productive opportunities based on Brazilian technological capabilities, skills and complementary assets.

The limited resources available allowed two steps: First, we collected, systematized and analyzed publicly available data and information from official statistics (such as the Brazilian Annual Industrial Survey - PIA), technical reports, scientific papers and patents. Second, we

carried out interviews with eight biochemicals stakeholders in Brazil to expand on the material available in the public domain.

Brazil arguably has a huge potential in the biochemicals arena, but many challenges need to be overcome in order to exploit this potential successfully. The country has important natural resources that can be developed with domestic expertise (scientific and technological competences) as well as well heeded foreign collaboration. Brazil has an advanced agroindustrial complex, with many products that could boost the development of a profitable biochemical sector. Importantly, Brazil has one of the biggest biodiversity in the world, which has only been superficially explored as of now. However, Brazil has serious problems in infrastructure and an industrial structure that is becoming rapidly obsolete in face of the rapid developments frequently referred to under the label of the 4th industrial revolution. This can be a serious obstacle for the development of the sector in question.

The country has been building technological competencies in the biochemical area. Companies like GranBio, Braskem, Natura, Beraca, Tobasa, Corbion and DSM–Amyris, among others, have invested significant resources in the past few years to create and diffuse new renewable technologies and products in the Brazilian chemical industry, with reasonable success. For this to happen, it was necessary for these companies to get closer to customers and to users for the development of new applications, which would increase the possibility of commercial penetration of their products. Brazil also has important science and technological institutes, which serve as a bridge between the scientific production that can support the development of new technologies – often located at universities - and the domestic industrial community. Academic research plays an important role too.

In addition to high relative costs, other challenges need to be overcome by biochemicals producers. The main ones are the need for changes in an already installed industrial infrastructure facing to the production of conventional polymers, the procurement of consumers to accept new products, the lack of public policies that encourage the manufacture of more sustainable products and regulatory issues, also including those related to certification and final destination of bioplastics.

All in all, we conclude that it is not a smooth way ahead, but the reward for those who travel it will be a cleaner and more sustainable future. Given the strengths of EU organizations exactly on what are Brazil's greatest deficiencies (technology, market access, industrial capabilities) and vice versa (incredibly large land for agricultural production, a very advanced agroindustrial complex for volume production, very rich biodiversity), and given that the basic bridges also exist (Brazil does not start from zero in terms of both R&D and industry), we conclude that this set of industries provide a significant opportunities for collaboration.

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1. Introduction

The world economy heavily depends on oil and gas for energy production, as well as for the manufacture of practically all types of everyday products. However, fossil resources are scarce (non-renewables) and their use is harmful to the environment and the climate. As the science and the technological community has announced for decades, fossil materials can be at least partially replaced by bio-based raw materials, which brings new features to the products, making their production more sustainable and less dependent on non-renewable resources. Encouraged by government support and major R&D programs, diverse industrial sectors have developed a variety of innovative bio-based technologies, which are expected to increasingly find their way onto the market in the next years. In the chemical sector, specifically, there are many initiatives dedicated to the development of the production of bio-based products (or, as we call in this report, *biochemicals*). However, monitoring the development opportunities in the biochemicals market is challenging, since the literature and the set of public available material are scarce[1]. This work is a step to fill this gap. It explores the market dynamics of five biochemicals products categories in Brazil, in three main dimensions: supply, demand and capabilities.

This report was strongly inspired by two previous studies of the Joint Research Center (JRC), a European Commission's science and knowledge service. Specifically, this work was based on the report 'Insights into the European market for bio-based chemicals' (Spekreijse, J. et al., 2019[2]) and on the study 'The EU bio-based industry: results from a survey' (Nattrass et al., 2016). The scope of the JRC studies includes non-energy and non-traditional bio-based chemicals, entirely or partially constituted by renewable raw materials from biomass and intended for a wide variety of application areas.

In this report, we chose to analyze five product categories that we believe to be among the most promising industrial biochemicals for Brazil in the next few years:

(1) platform chemicals;

(2) bioplastics;

[1] In 2014, the Brazilian consultancy Elabora, with funding from institutions like FAPESP, FINEP and BNDES, and well companies like Braskem and GranBio, published a report entitled "World Directory of Advanced Renewable Fuels and Chemicals", a survey of projects worldwide (Brazil included) dedicated to the development of biochemicals and biofuels production. However, it is more of a compilation of information and data about projects than a systematic and in-depth analysis of opportunities for Brazil in the biochemicals arena. Moreover, the data were collected until 2014 and, so far, its update has not been published. We should also mention the report "Diversification of the Brazilian Chemical Industry", by Bain & Company and Gas Energy and funding by BNDES; however, the focus is not on renewables.

[2] See Spekreijse, J. et al. (2019).

(3) cosmetics & personal care products;

(4) sweeteners & flavors; and

(5) nanocellulose.

The first three of these appear in the 2019 JRC report (among a total of 10 product categories analyzed therein). These five product categories were chosen on the basis of six criteria:

- These are sectors with large global potential given the widespread environmental concerns regarding carbon-based chemicals.
- Europe and Brazil have complementary production strengths in these sectors which makes collaboration between the two regions desirable and feasible.
- Complementary political justifications – reducing the carbon foot print of the chemical sectors, large in both regions – and complementary comparative advantages – extensive biodiversity in Brazil that the country has been striving to exploit commercially and relatively few aggressive private sector companies in sectors such as cosmetics versus a very large environmentally-concerned fine chemical sector in Europe with extensive technological capabilities. This makes a potentially interesting recipe for collaboration.
- The recent production of the aforementioned detailed report by the Joint Research Centre (JRC), the European Commission's science and knowledge service, on bio-based chemicals which provides an excellent background and point of comparison for the discussion in this document. This report complemented an earlier technical report on the same subject, thus providing excellent background material for the interested reader.
- Bioeconomy was one of the five core areas of interest for collaboration identified by experts attending the UNICAMP workshop run by the predecessor project INCOBRA (17-18 November, 2016) through a formal technology foresight exercise.[3]
- Two major Brazilian companies affiliated with ENRICH (Braskem and Natura) are directly linked with the story developing in this document.

The following dimensions were explored for each of the five aforementioned product categories examined herein:

a. Productive capabilities already present in Brazil (*supply*);
b. Market size for biochemicals made in Brazil (*demand*);
c. Innovative and productive opportunities based on Brazilian technological capabilities, skills and complementary assets

[3] The document summarizing the results of the extensive 2016 technology foresight exercise at UNICAMP is available upon request.

This work was compounded in two steps: First, we collected, systematized and analyzed publicly available data and information in official statistics (like the Brazilian Annual Industrial Survey - PIA), technical reports, scientific papers and patents. Second, we interviewed eight biochemicals stakeholders in Brazil to deepen and expand what was produced in the first step. The insights collected in the interviews are not presented in a separate section, but appear throughout the text as a way of illustrating and developing the information systematized from the primary sources. Citations from the interviews appear in italics. This format was also followed in order to maintain information confidentiality. The interviewees included:

a. Rafael Fabra Navarro, Head of Knowledge Management, Braskem;
b. Mateus Lopes, Innovation and Business Development Global Leader for the Renewable Business, Braskem;
c. Juliana Bernardes, Researcher, Brazilian Nanotechnology National Laboratory (LNNano - CNPEM);
d. Karina Daruich, Bioplastics Specialist, Earth Renewable Technologies;
e. Mariana Doria, Competitive Intelligence Coordinator, SENAI Institute for Innovation in Biosynthetics (SENAI CETIQT);
f. Paulo Luiz Coutinho, Director, SENAI Institute for Innovation in Biosynthetics (SENAI CETIQT).
g. Julio Espirito Santo, Industrial Biotechnology Manager, GranBio
h. João Baptista Farah Emiliano Bio Process and Technology Director, GranBio

The semi-structured guide used in the interviews can be founded in Annex 2.

Above, the lector will find a section with a biochemicals sector dynamics contextualization, with deep analysis of those five biochemicals categories, with included the result of the interviews and the dialogue between the interviews results and what we find and systematized in the step 1 of the work, finalizing with some reflections about behaviors that could be taken to booster the development of the biochemicals sector in Brazil.

2. Contextualization

The replacement of petrochemicals by renewable technologies is an important opportunity to fight against climate change and the environmental pollution caused by industrial activities. The use of biotechnology and other "bio" technologies as an instrument for the production of industrial goods is known as industrial biotechnology, which is, the modern

application of biotechnology for sustainable processing and production of chemical products, materials and fuels. The European Commission identified industrial biotechnology as one of the most promising ("key enabling") technologies and established significant respective funding mechanisms such as the Leadership in Enabling and Industrial Technologies (LEIT) actions in Horizon 2020.

In Brazil, the introduction of new advanced low carbon technologies with the addition of sugars converted from cellulosic materials has opened new technological opportunities, mainly based on the use of sugar cane by-products. The tripod second-generation bioethanol (E2G), high-biomass sugarcane (energy cane) and renewable (green) chemistry has been, in recent past, under implementation in Brazil through strong public-private partnership. One of the most successful initiative, PAISS – a government plan to support innovation in the sugar/energy and sugar/chemical sectors, led by the National Bank for Economic and Social Development (BNDES) together with the Research and Innovation Agency (FINEP), involved a number of well-established and start-up companies, as well as prominent science and technology institutions (CGEE, 2016).

Industrial biotechnology contemplates different value chains, related to different technological trajectories (Wydra, 2019). Each of these chains has its own technological and market dynamics, as well a different relationship structure between agents. Recently, around the world, biochemicals has gained a lot of attention, from public ass well private actors (US DOE, 2015).

Chemicals play an important role in modern life, with a wide range of applications, whether replacing traditional materials or creating new products. On the frontier of biomaterials are the biodegradable plastics, which can be a solution for the increasing problem of land and water pollution with conventional plastics. The main inputs to produce plastics nowadays in the petrochemical industry are natural gas and petroleum- naphtha. Biodegradable plastics are polymers that, under appropriate environmental conditions, decompose completely in a short period of time due to microbial action. Biodegradable bioplastics add an important advantage over traditional ones: to be produced from renewable sources, like starches, sugars or fatty acids. One example of a bioplastic is polylactic acid (PLA), which is composed of lactic acid monomers obtained from microbial fermentation. Another possibility is to obtain the biopolymers directly from micro-organisms as in the case of polyhydroxybutyrate (PHB), polyhydroxyalkanoate (PHA) and their derivatives; in these cases, the biopolymer is biosynthesized as energy reserve material of micro-organisms (CGEE, 2016).

Although currently the basic bioprocess is well understood, scaling-up production units and economic feasibility remain as barriers to overcome for large production of biochemicals.

There are still many obstacles to be overcome for biochemicals become an industrial alternative to petrochemicals. This work will explore the main dimensions of the biochemicals sector in Brazil, based on the National Innovation Systems (NIS) framework.

As we mentioned above, this report is focused on five product categories. Bellow, we shortly explain each one.

- Platform chemicals: "Platform chemicals are chemical building blocks and starting materials in the manufacture of a broad range of products. As an example of a platform chemical, ethylene can be used in the production of many different polymers and is also the starting material for compounds such as styrene and synthetic fatty acids. Solvents are compounds that are able to dissolve other substances without chemically changing them." (Spekreijse et al., 2019)
- Bioplastics: "comprise a whole family of polymers with various properties and applications. Plastics are usually classified by the chemical structure of the polymer's backbone and side chains."(Spekreijse et al., 2019)
- Cosmetics & personal care products: "include bath and shower products, decorative cosmetics, deodorants, perfumes, hair, skin and mouth care products, shaving products, soap and sun protection products. ."(Spekreijse et al., 2019)
- Sweeteners & flavors: renewable sweeteners and flavors are products that, besides reduce the intake of calorie in ay-by-day activities, are made from renewable, sustainable ingredients.
- Nanocellulose: Nanocellulose is a term referring to nano-structured cellulose. This may be either cellulose nanocrystal (CNC or NCC), cellulose nanofibers (CNF) also called nanofibrillated cellulose (NFC), or bacterial nanocellulose, which refers to nano-structured cellulose produced by bacteria (Wikipedia)

3. Selected biochemical product categories

3.1. Platform Biochemicals

3.1.1. Brazilian productive capabilities in platform biochemicals (Supply)

Platform biochemicals, defined as "chemical building blocks and starting materials in the manufacture of a broad range of products" (Spekreijse et al., 2019) include items with a long history of bio-based production, such as citric acid, but also products derived from relatively new

technological routes such as propylene glycol. About 90% of the global bio-based production capacity for platform chemicals is formed by seven products: lactic acid, epichlorohydrin, ethylene glycol, ethylene, sebacic acid, 1,3-propanediol and propylene glycol (IEA, 2020).

Among the platform biochemicals, ethylene is one of the most important. It is manufactured in greater amounts than any other chemical, because its molecules have very distinctive and useful properties. The majority of ethylene is produced using a process called "steam cracking", a thermal process where hydrocarbons are broken down, or "cracked" into smaller molecules that are then used to manufacture useful and valuable chemicals. In the petrochemical industry, two of the main feedstocks for steam crackers are naphtha and ethane (Caprio, 2019).

Ethylene is the basis for a range of high-volume plastics including polyethylenes (high-density polyethylene (HDPE), low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE), polyvinylchloride (PVC) and polyethylene terephthalate (PET).

From the upstream oil and gas sector perspective, the shale gas revolution[4] has triggered a wave of low-cost production of chemicals feedstock, primarily natural gas liquids (NGLs) or ethane, which directly impacted the ethylene market. NGLs/ethane-based ethylene capacity has grown by more than 3 percent per year on an average from 2008 onwards. With the arrival of ethane-only crackers in the US and the recently initiated exports of US NGLs/ethane, many new petrochemical plants are biased towards maximizing ethylene production from ethane, that comes at the cost of foregoing production of other base chemicals types (Deloitte, 2019).

Global ethylene production was 150 million tonnes in 2016 and is expected to grow to 175 million tonnes in 2021 (IEA 2020). The total global capacity of ethylene for 2022 will reach around 210 million metric tonnes. This is a considerable increase from 2017, when the capacity of ethylene reached some 169 million metric tonnes (Deloitte, 2019). Around 126 planned and announced plants are scheduled to come online over the next four years around the globe, led by

[4] "In recent years, the United States natural gas industry has experiences a quiet 'revolution', thanks to development of new and innovative technologies. Investments in new extraction techniques — drilling horizontal wells and hydraulic fracturing (fracking) techniques — have made the production of gas less expensive. Fracking technology has given access to vast resources of unconventional gas, in particular 'shale gas', which is found trapped within sedimentary shale rock formations and which is extracted by injecting sand, chemicals and water at high pressure (...) The shale gas boom, combined with easier access to new and vast natural gas supplies, has led the US shale gas production to soar dramatically since 2007. By 2010 shale gas constituted 23 % of US gas production, a significant change from the previous year, during which shale gas constituted only 14% of the total country's gas production". Source: European Parliament. The Shale gas 'revolution' in the United States: Global implications, options for the EU. Available at: https://www.europarl.europa.eu/RegData/etudes/briefing_note/join/2013/491498/EXPO-AFET_SP%282013%29491498_EN.pdf

Asia and North America (ESI Africa, 2019). Evidently, this dynamic has strongly impacted the viability of the production of ethylene from alternative sources.

Using renewable resources, ethylene can be directly produced through the dehydration of bioethanol or through the cracking of bionaphtha. Bionaphtha is produced during the processing of renewable feedstock in processes such as Fischer Tropsch fuel production; it comprises molecules with a carbon chain length ranging from about five (C5) to nine (C9) carbons (Elabora Consultoria, 2014).

The production of ethylene from renewable sources is more likely to take place in countries with abundant raw materials (sugars). Two countries with great conditions are USA and Brazil, the leading producers of bioethanol. Given the large scale of ethylene plants (>300,000 tonnes) a single plant would be a considerable consumer of ethanol, depending on a reliable source of regular supply (IEA, 2020).

Brazil is a pioneer in the production of ethylene from renewable sources. In 2010, the Brazilian chemical producer Braskem commissioned a 200,000 tonnes capacity plant to produce biopolyethylene from sugarcane derived ethanol, located in the state of Rio Grande do Sul. However, as we will see in the next sections, the biopolyethylene produced in Brazil today acts as a specialty with niche applications only.

A further promising use of renewable ethylene is in the production of mono ethylene glycol (MEG) (IEA, 2020). Braskem has a demonstration MEG renewable plant in Denmark, in partnership with Haldor Topsue, using a revolutionary technology developed with co-financing from the Danish Innovation Fund. According to the interviews, Haldor Topsue's skills and expertise in process technologies was decisive in deciding the location of the plant, overcoming the advantages in terms of raw materials in Brazil. MEG is a raw material for PET, a resin widely used in the textile and packaging sectors, especially for the manufacture of bottles. The global market for MEG currently is around US$25 billion (Braskem, 2019).

"The main bottleneck in the development of biochemicals production in Brazil is in the conversion technology, that is, in the transformation of biomass into the intermediate and final products. The products that make the most sense are those that do not generate many by-products without value (or that should be dispensed with important costs), such water in the green PE production."

In 2017, Brazil produced 3,399,610 tonnes of ethylene, and consumed 623,605 tonnes, including both renewable and non-renewable (IBGE, 2018[5]).

Table 1: Ethylene production & consumption in Brazil, 2017

	Production	Consumption
Ethylene	3,399,610 tonnes	623,605 tonnes

Data Source: IBGE 2018

Another platform biochemical produced in Brazil is lactic acid. In Brazil, lactic acid is produced by Corbion, through the Purac brand, in Campos dos Goytacazes, Rio de Janeiro state, through the fermentation of sugar from sugarcane. Corbion is a global market leader in lactic acid and its derivatives, in addition to operating in the functional blends sector, containing enzymes, emulsifiers, minerals and vitamins. Producing natural ingredients through renewable resources, it operates in global markets such as bakery, meat, dairy products, beverages and food, pharmaceuticals, personal and home care, and resins. We could not find Corbion's market share for lactic acid in Brazil, but accordingly to the interviews it's about 100%.

Table 2: Lactic acid production & consumption in Brazil, 2017

	Production	Consumption
Lactic Acid	43,213 tonnes	60,965 tonnes

Data source: IBGE, 2018

While Brazil is not yet among the main global producers of lactic acid, which are Spain, Belgium, Germany and the Netherlands (Spekreijse et al., 2019), the country has a huge potential to amplify its production capacity regarding the fermentation of cellulosic sugars through sugarcane bagasse and other agroindustrial residues, as indicated by the interviews.

[5] The Annual Industrial Survey, conducted by the Brazilian Institute of Geography and Statistics (IBGE), is the main national statistical research about the industrial production, similarly to the European PRODCOM.

3.1.2. Market for platform biochemicals produced in Brazil (Demand)

Ethylene is used as a feedstock in the manufacture of a large range of products, like plastics, fibers, and other organic chemicals that are ultimately consumed in the packaging, transportation, and construction industries, as well as a multitude of other industrial and consumer markets. Packaging accounts for more than half of ethylene derivative consumption worldwide. Ethylene consumption is sensitive to both economic and energy cycles. The majority of the increased consumption over the last five years is from Northeast Asia, North America, and the Middle East. Over the next five years, global consumption of ethylene is forecast to grow faster than average world GDP growth rates. Ultimately, ethylene demand will be driven primarily by the growth of polyethylene-based consumables; increasing PET fiber, bottle, and packaging demand; and increasing requirements for PVC used in construction and pipe applications. Furthermore, the recent ban on waste material imports into mainland China[6] is bound to further support incremental demand growth for virgin plastic material (polyethylene for instance). Mainland China alone is projected to account for a large percentage of new ethylene demand anticipated through 2024 (IHS Markit, 2020). This could be an opportunity for green ethylene, mainly in niche applications like in the development of new packaging, more sustainable and with improved attributes, as in advanced cosmetics, as well as in others higher valued products.

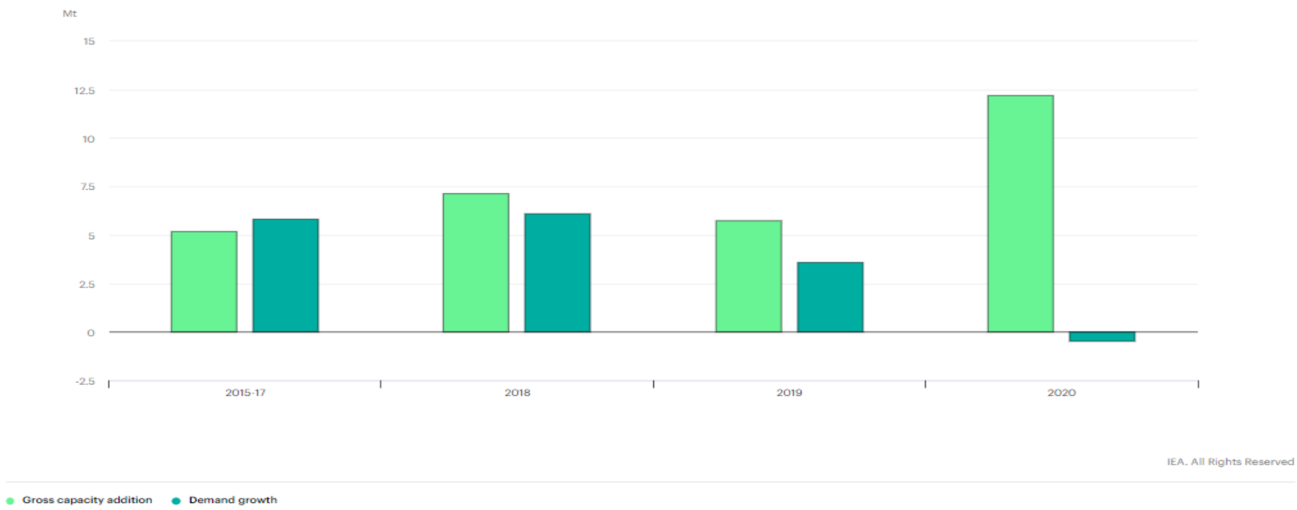
Regarding lactic acid, the consumer market has shown significant global growth since 2008 due to the use of this organic acid as a monomer for the production of PLA, a bioplastic, and the growing demand coming from the food and beverage industry. The lactic acid market was projected to reach US$ 3.82 billion by the end of 2020, with an annual growth of 18.6%. North America is currently the main consumer market for lactic acid in the world, with the USA responsible for approximately 30% of this consumption. China figures as the second largest consumer market for lactic acid, surpassing the amount consumed by Europe, the third largest (Benevenuti, 2016). According to IBGE, Brazil consumed 60,965 tonnes of lactic acid in 2017 (IBGE, 2019).

[6] "China's "National Sword" policy, enacted in January 2018, banned the import of most plastics and other materials headed for that nation's recycling processors, which had handled nearly half of the world's recyclable waste for the past quarter century." Source: Yale Environment 360. Available at: https://e360.yale.edu/features/piling-up-how-chinas-ban-on-importing-waste-has-stalled-global-recycling#:~:text=China's%20%E2%80%9CNational%20Sword%E2%80%9D%20policy%2C,for%20the%20past%20quarter%20century.&text=Recycled%20aluminum%20and%20glass%20are%20less%20affected%20by%20the%20ban.

3.1.3. Opportunities in platform biochemicals based on Brazilian technological capabilities, skills and complementary assets

The interviews indicated that the obstacles to the development of the platform biochemicals production in Brazil are huge, at least in commodities like ethylene and its derivatives. As we will see in the bioplastics section, the production experiences of this type of product in Brazil show that commercial penetration occurs mainly in a few market *niches*, especially in markets where the additional costs represented by the renewable version (replacing the petrochemical one) are relatively small in relation to the total cost of the product.

Figure 1: Annual capacity/demand growth for ethylene, 2015-2020



Source: International Energy Agency (IEA, 2020) (https://www.iea.org/data-and-statistics/charts/annual-capacity-demand-growth-for-ethylene-2015-2020)

Figure 1 shows the huge mismatch between the variation in ethylene production capacity (light green column) and the demand for the product, at least for the period 2018-2020. Although other variables are also relevant in determining the viability of production by the renewable route, the current excess of fossil-based supply ethylene represents an enormous barrier to projects dedicated to the production of commodity biochemicals.

However, there are opportunities in other arenas concerning platform biochemicals production in Brazil. Glycerin biorefineries deserve special attention. In Brazil, it is mandatory to mix biodiesel with fossil diesel at a level of 12% (B12). Currently, there are 64 biodiesel plants authorized for operation by the National Agency of Petroleum, Natural Gas and Biofuels (ANP),

with a total production capacity of 7 million m^3/year. In 2012, more than 2.5 million m^3 of biodiesel were produced, which corresponds to just 36% of the current installed capacity. This production placed Brazil in the third position in the world ranking of biodiesel producers (Schultz, Souza & Damaso, 2014).

The main commercial route used in the biodiesel production is the transesterification process of vegetable oils and fats with alcohols, in the presence of a basic catalyst. This reaction results in three molecules of fatty acid mono alkyl esters, which compose the biodiesel, and one molecule of glycerol or glycerin (currently, a byproduct).

It is estimated that 90 m^3 of biodiesel produced by transesterification generates approximately 10 m^3 of glycerin (Schultz, Souza & Damaso, 2014), implying that the country produced in 2012 around 278 thousand m^3 of glycerin.

Raw glycerin has a low market value. Currently, the crude glycerin produced in Brazil is mostly used to generate heat by burning it in industrial furnaces and boilers, such as in biofuel production, besides potteries and steel companies. In addition, Brazilian glycerin has been exported to China (Schultz, Souza & Damaso, 2014). One interviewee said that around 90% of the glycerin produced in Brazil is exported to Asia, without any processing.

It is unbelievable the opportunities that Brazil misses in the downstream of its agro-industrial chains, as in the biodiesel industry or in the soy oil production and refination. Brazil exports all the glycerin it produces, without any processing!

Since there is a global trend of continuing increase in the biodiesel demand – and, consequently, in the glycerin production, there would emerge a lot of opportunities to the development of biochemicals derived from the glycerin. For Brazil realized then, it will be necessary to attract investments, capable of building the capabilities (technological, included) that will be demanded. Glycerin should be the basis for new biorefineries, Glycerin may be used as raw material for the production of value-added products through chemical, biochemical, or thermochemical routes. Ethanol, hydrogen, and syngas, the intermediates generated first could be used directly as fuels or as intermediates in chemical synthesis. The products that could then be generated - chemical compounds as polyols and organic acid - are very important as building blocks. They are used in industrial sectors such as cosmetic, pharmaceutical, automobile, and chemical industries (Schultz, Souza & Damaso, 2014). The interviews showed that Brazil could also use glycerin to produce propylene glycol, butanediol and epochlorohydrin.

Glyceric acid may be used in chemical and pharmaceutical industries as a building block and for the production of polymers and surfactants. Lactic acid can be processed to make acrylic acid or 1,2-propanediol used in polyester resins and polyurethane. Succinic acid, another possible

derivative, is largely used for manufacturing health-related products and as a building block in the production of precursors that are converted into green solvents, pharmaceutical products, and biodegradable plastics. Polyols are used in food, pharmaceutical, and medical industries. They are used to improve the nutritional profile of food products due to their low caloric content, low insulin-mediated response, and non-cariogenicity. Polyols and their derivatives also have other industrial applications, including the production of polyurethanes, plastifying agents, resins, surfactants, and intermediates for producing hydrocarbons (Schultz, Souza & Damaso, 2014).

Not only does Brazil claim one of the richest biodiversities in the world, but the country has industrial and agroindustrial expertise in the use of that biodiversity. In Brazil there are more than 200 species of plants like fruits and grains that can produce different oils, with different potentialities and natural adaptations to environmental conditions, which can then compound biofuels or other value-added products. Unfortunately, until now only a few of them have been used or have even been tested for commercial applications.

Another promising platform in Brazil for biochemicals production is the use of lignin. Currently, most lignin on the market is a by-product from the pulp and paper industry in the form of lignosulfonates and Kraft lignin. It is estimated that 50-70 million tonnes of lignin is produced annually, but more than 95% of that is used internally at pulp mills for energy generation - that is, burned (IEA, 2020). Brazil is one of the main producers of cellulose in the world. Lignin is the second most abundant polymer from renewable sources in nature and can be found in the eucalyptus wood that we plant and grow.

In addition, lignin is also produced concurrently with sugars during the biochemical conversion of lignocellulosic biomasses and is therefore closely linked to the sugar platform. It is foreseen that large amounts of lignin will be available when industrial scale production of bioethanol for transportation from lignocellulosics is realized. The global market size for lignin was estimated at USD 733 million in 2015 of which lignosulfonates was by far the most important segment (IEA, 2020).

Sulfur-free lignin derived from lignocellulosic biorefineries along with the sugar platform for production of, e.g., bioethanol or chemicals could result in new forms of lignin becoming available for chemical applications. This could either be in the form of lower quality hydrolysis lignin (the residue after enzymatic hydrolysis of cellulose and hemicellulose) or high purity lignin isolated as part of the pre-treatment. An example of the latter is organosolv lignin. This process was first commercialized by the Canadian company Repap and later further developed by the other Canadian company Lignol, now part of the Brazilian company Suzano (IEA, 2020). Suzano, the giant cellulose producer, produces lignin in Brazil under the brand Egolig. We were unable to find the volume of lignin currently produced in Brazil.

3.2. Bioplastics

3.2.1. Brazilian productive capabilities in bioplastics (Supply)

Polymers, mainly produced through fossil resources, are an essential material for practically all industrial sectors and for the final consumption of a lot of products, and are difficult to replace due to its unique performance attributes.

Biopolymers could provide an alternative to fossil polymers. Biopolymers refer to industrially synthesized polymeric materials that consist of long chains of construction units repeatedly applied covalently, derived from biomass. The main biopolymers are bioplastics, biofoams, biorubbers, biofibers and biocomposites. All bioplastics are biopolymers, but not all biopolymers are bioplastics.

Concerns about the environmental damage caused by "conventional" plastics have gained ground recently. In this sense, products manufactured from renewable sources or with biodegradable properties have gained importance worldwide, Brazil included. Among the drivers for the development of the biopolymers industry one can cite sustainability issues, concerns about climate change, fossil resource scarcity, the development of a circular economy, the world population growth, regulatory risks, and digitalization and connectivity (Jaconis et al. 2019).

In Brazil, 6.6 million tonnes of plastics were sold in 2017. Today, the main polymer used in the plastic sector is polyethylene (PE). Only a small fraction came from renewable sources. Brazil produced 8,659 tonnes of ethylene polymers in 2019, and consumed 8,604 tonnes (IBGE, 2018).

Table 3: Ethylene polymers production & consumption in Brazil, 2017

	Production	Consumption
Ethylene polymers	8, 659 tonnes	8,604 tonnes

Data source: IBGE, 2018.

The country, however, is one of the major global producers of polymers of renewable origin, using sugarcane derivatives. Braskem is the main producer. The company has an installed capacity for 200 thousand tonnes of polyethylene (PE) from sugarcane ethanol (using the “I’m green” brand), which represents around 10% of the global bioplastics manufacturing capacity (Revista Pesquisa FAPESP, 2020). However, as the interviews showed, currently the green PE is only used in niche applications, especially those in which the additional cost of replacing fossil

PE with renewable PE is not significant in terms of the final cost of the product. This is the case, for example, with some high-value cosmetics, where PE is used only in packaging. In these cases, the additional gain added by the word ‘green’ on the packaging exceeds the increase in the production cost resulting from the replacement of the fossil material by the renewable one. Renewable PE also penetrates markets where there is regulation obliging producers (of packaging, for example) to adopt a certain percentage of renewable raw materials in their products, as is the case in Japan, according to the interviews[7].

Another bioplastic produced in Brazil is polyhydroxybutyrate (PHB) by the company PHB Industrial under the brand Biocycle. However, production currently is only by demand, in very low volume.

Globally bioplastics represent less than 1% of the 359 million tonnes of plastics manufactured annually, according to the European Bioplastics association. Production, however, grows year by year. Between 2018 and 2019, the expansion of installed capacity was 5%, reaching 2.1 million tonnes. The expectation of the European association of bioplastics producers is that this number will continue to evolve, reaching 2.4 million tonnes in 2024 (Pesquisa FAPESP, 2020).

In 2014, more than 55% of bioplastics were used in Asia, while the production of bioplastics predominates in Europe, North America and South America (Gao et al. 2020).

3.2.2. Market for bioplastics produced in Brazil (Demand)

Among the drivers that boost the demand for biopolymers, we can highlight new modern lifestyle, profitability of the value chain, biodegradability and other eco-friendly features, competitive cost, and possible applications (Jaconis et al. 2019)

In 2014, the global size of the bioplastics market was about 1.7 million tonnes. In 2014 that represented a tiny 0.68% of the total market for plastics (250 million tonnes). Several market analyses have showed that new lower-cost feedstocks and technologies will enable huge reductions in biochemicals production costs (and, consequently, in the prices to final consumers). There is an estimation that biopolymer demand has grown by a compound annual rate of 4.5 times

[7] “From July 1, 2020, Japan will require all retailers to charge a fee for the use of plastic shopping bags, with the exception of biodegradable plastic bags and plastic bags containing at least 25 percent of renewable plant-based materials. The exemption is expected to increase demand for biomass-based plastic bags.” Source: USDA. Available at: https://www.fas.usda.gov/data/japan-introduction-mandatory-plastic-bag-fee-creates-opportunities-bioplastic#:~:text=From%20July%201%2C%202020%2C%20Japan,for%20biomass%2Dbased%20plastic%20bags.

in the period of 2014–2019 (Galiano et al., 2018). The bioplastics market is expected to grow 7.1% by year through 2026 (Focus on Catalysts, 2020).

The global size of the biodegradable plastics demand is expected to reach $ 6.12 billion by 2023, compared to $ 3.02 billion in 2018, a CAGR of 15.1% (Plastivision, 2019). The main drive behind the growth of the biodegradable plastics market is the packaging and bags industry. Consumer awareness of sustainable and comprehensive plastic solutions to eliminate the use of non-biodegradable plastics is contributing to this tendency.

In 2017, Brazil produced 1,114,533 tonnes of high-density polyethylene (HDPE) and 747,780 tonnes of low-density polyethylene (LDPE). The consumption of these two products was, respectively, 1,001,236 tonnes and 637,635 tonnes (IBGE, 2018). This data includes renewable and non-renewable products.

Table 4: Polyethylene production & consumption in Brazil, 2017

	Production	Consumption
High-density polyethylene	1,114,533 tonnes	1,001,236 tonnes
Low-density polyethylene	747,780 tonnes	637,635 tonnes

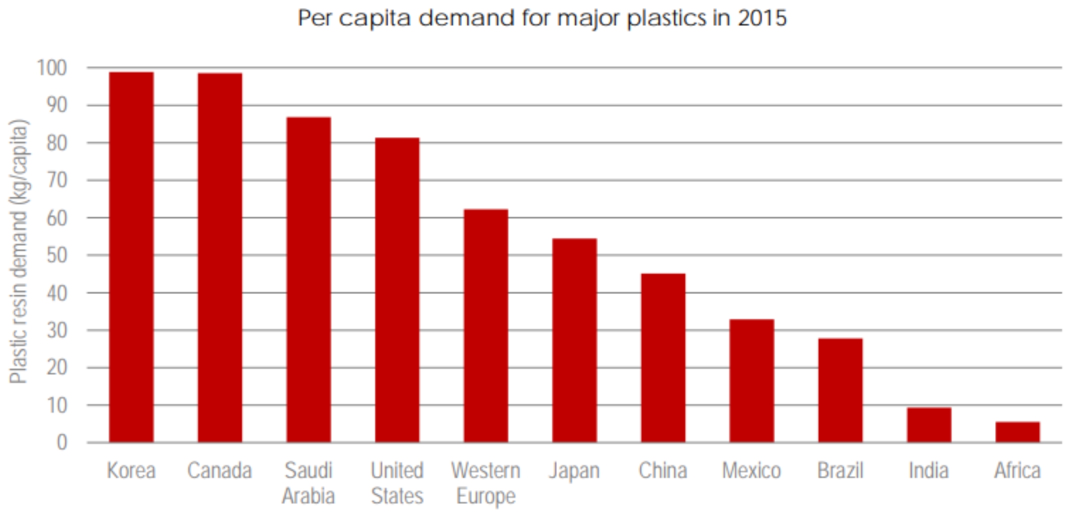
Data source: IBGE, 2018.

There are no statistics on the volume of PHB produced and consumed in Brazil, but the available information suggests that it is currently very small.

3.2.3. Opportunities in bioplastics based on Brazilian technological capabilities, skills and complementary assets.

There is much room for growth in the consumption of plastics (renewable and non-renewable) in Brazil, as can be inferred from the graph below from the International Energy Agency:

Figure 2: Per capita demand for major plastics in 2015



Source: IEA (2018) - https://ec.europa.eu/energy/sites/ener/files/documents/iea-the_future_of_petrochemicals.pdf

This could be a window for the growth of bioplastics. However, opportunities are not the same for all kinds of products. The interviews indicated that the opportunities to develop the production of drop-in bioplastics in Brazil, like PE, are very constricted. Drop-in (opposed as dedicated) are products already produced thought the petrochemical route)As in the case of drop-in platform biochemicals, drop-in bioplastics are not competitive with their fossil counterparts, and penetrate only market niches (in minor blends with fossil polymers in packages, for example). According to one interviewee, green PE is about 30% more expensive than fossil PE, an arguably quite significant cost handicap.

Biochemicals commodities have little chance of success, especially the drop-in ones like green PE. In this kind of product, the applications will be niche only.

Notwithstanding, there are opportunities in Brazil to the development of advanced renewable plastics production with new attributes compared to fossil plastics, like lactic polyacid (PLA). Many 3D printers in the country, for example, use PLA instead of conventional plastics despite the cost disadvantage because PLA fits better to heat deformation than conventional plastics (especially in unsophisticated models which predominates in Brazil, produced mainly in China), as the interviews confirmed.

Interviewees pointed out that the main reason for the low volume of the PHA and PHB production is the molecular structure of this kind of plastics and the performance attributes that derive from it. Despite being biodegradable and thermoplastic, the properties of these polymers make it brittle, which limits its applications.

In general, huge obstacles still need to be overcome to boost the development of the bioplastic industry in Brazil. There is a need for studies on the properties of the generated materials and the development of new formulations to enable the effective application of bioplastics. It is necessary to amplify the potential applications of bioplastics, which could be done in partnerships between the bioplastics producers and the developers of applications, like the packaging industry.

3.3. Cosmetics and personal care (bio-C&PC) products

3.3.1. Brazilian productive capabilities in bio-C&PC (Supply)

Some every-day habits, such as applying face cream, have always depended on fossil resources, and few non-fossil raw materials have managed to compete in these production chains. The few initiatives in the opposite direction in recent decades have been hitting high costs and the lack of viable technologies.

However, gradually the cosmetics industry has acquired new contours. Green initiatives are a hot spot in the new cosmetics formulations. The global revenue of green cosmetics in 2018 has been estimated at USD 13.33 billion**.** Natural ingredients for cosmetics can be categorized as follows (CBI, Ministry of Foreign Affairs, EU):

- Vegetable or animal derived oils, fats and waxes;
- Essential oils and oleoresins;
- Vegetable saps and extracts;
- Raw plant materials;
- Coloring matter of vegetable or animal origin.

Brazil, as a hub of agroindustrial production, and a country with some of the biggest biodiversity on earth, has many opportunities to develop the production of green cosmetics. Amyris and its main shareholder, the Dutch DSM, for example, have some initiatives to develop green ingredients for cosmetics from sugarcane. With the investment of DSM, Amyris will construct a US$ 110 million plant in Brotas city, São Paulo state, that will use sugars from sugarcane to produce specialties, included esqualane, a superior cosmetic ingredient that in nature

is found only in shark liver, olive and palm. We were unable to find the production or consumption volume of esqualane in Brazil.

"Brazilian biodiversity is perhaps the main (untapped yet) source of opportunities for the development of biochemical production."

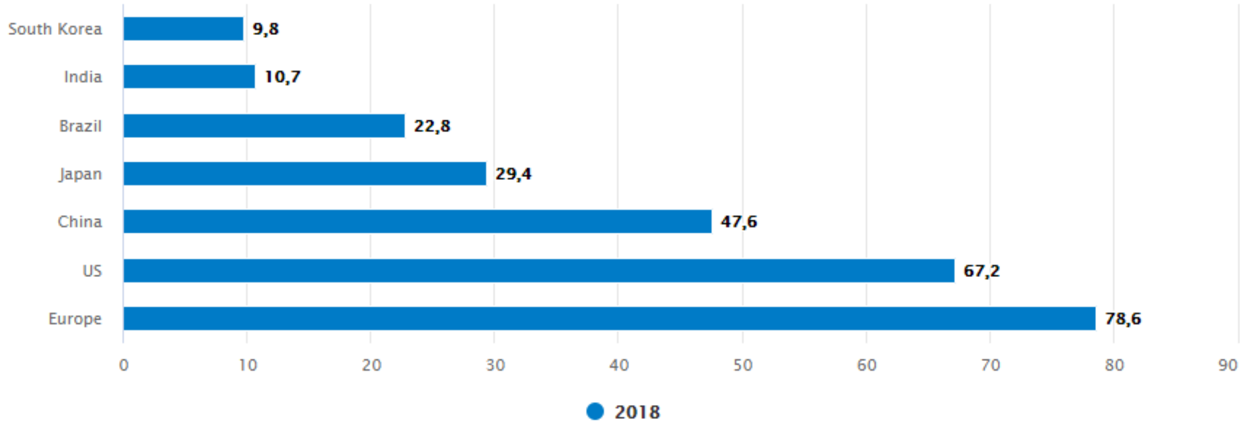
Another important company in Brazil in the green cosmetics arena is Beraca (beraca.com). This company specializes in the production of ingredients for cosmetics using natural resources from the Brazilian biodiversity. The company supplies over 40 countries with natural and organic ingredients extracted from the Amazon Forest and other Brazilian biomes, including oils, butters, clays and multifunctional assets. Another interesting company that produces ingredients for cosmetics from Amazonian biodiversity is Tobasa Bioindustrial (tobasa.com.br), mainly from babassu coconut (Orbignya Phalerata). Both companies (Beraca e Tobasa) were cited by respondents in the interviews. These companies, among others, could be global leaders in the supply of advanced, renewable ingredients to the cosmetics & personal care industry, exporting to countries where there exists growing consumer awareness for natural products and the desire of cosmetics companies to replace synthetic ingredients with natural variants.

3.3.2. Market for bio-C&PC produced in Brazil (Demand)

Natural cosmetics and skincare were estimated to be worth $33 billion in 2015, accounting for 13% of the overall global beauty market, and was predicted to have hit $50 billion by 2019 (Franca & Ueno, 2020). The global organic personal care market size is projected to reach USD 25.11 billion by 2025. It is anticipated to register a CAGR of 9.4% during the forecast period (Grand View Research, 2019).

Brazil has the fifth largest market for cosmetics in the world (renewable and non-renewable), as we can see in Figure 3 below. It was not possible to find specific data on the consumption of renewable cosmetics in Brazil.

Figure 3: Main markets for cosmetics in the world, 2018 (€ billion)



Source: CBI EU

The main cosmetics categories in Brazil by market size (renewable and non-renewable) are listed on Table 5:

Table 5: Main cosmetics products categories, Brazil, 2017

Product	Market size, 2017 (R$)
Deodorant, liquid	4,279,248
Non-medicinal soaps	2,785,644
Shampoos	1,610,096
Toothpaste	1,501,461
Deodorant, non-liquid	1,187,879
Sunbeds and sunscreens	1,043,780
Production service for cosmetics, perfumery and personal care products or related services	1,039,786
Hair dyes and bleaches	782,28
Hair conditioner	652,81
Perfumery, toilet and cosmetic preparations, unspecified	629,49
Hair preparations	610,24
Skin creams	507,25
Hygienic wipes	447,23
Makeup products for lips	397,22
Hair Creams	284,42
Manicure or pedicure preparations	284,32
Cologne	265,55
Preparations for oral or dental hygiene	263,54
Makeup products for eyes	253,49
Scented salts and other bath preparations	210,52
Hair fasteners	201,84
Makeup powders, talc and powder	194,83
Medicinal soaps	188,56
Dental floss	65,24
Shaving creams	61,69
Permanent waving or straightening preparations for hair	35,88
Perfumes (extracts)	11,98

Data source: IBGE (2018)

3.3.3. Opportunities in bio-C&PC based on Brazilian technological capabilities, skills and complementary assets

Xanthan gum is a polysaccharide obtained naturally by fermenting the bacteria Xanthomonas campestris, which synthesizes gum to prevent dehydration. It is an additive widely used as a stabilizer, thickener and emulsifier. “Brazil should have been producing xanthan gum for a long time " observed one interviewee. The product is considered strategic in the oil industry, as it is used in the lubrication of drilling bits and also in the secondary recovery of oil wells, processes already used in Saudi Arabia and China and which are also adopted by Petrobras. As a stabilizer and thickener, the product is also used in the food, cosmetic, pharmaceutical, textile, agrochemical, ceramic and cleaning areas.

The main raw material for xanthan gum production is corn glucose. Currently, Brazil imports 100% of the xanthan gum consumed internally. In 2006, the Brazilian National Development Bank (BNDES) financed a plant for the production of xanthan gum in the state of Rio de Janeiro at R$ 25 million, which should be operated by the company Policam. The technology that would be used was pioneer, because it would be based on the sugarcane sucrose, instead of corn glucose. The plant never ran.

In the production of cosmetics itself, Natura (www.natura.com.br) is the main producer of products with renewable or natural properties in Brazil[8]. The company has a long history of synergistic behavior with local and traditional communities (mainly in the Amazon region), which brings a recurrent flux of innovation opportunities based on natural ingredients. The company is one of the most active in terms of research and development investment in Brazil.

Brazil has a lot of opportunities to develop the production of renewable ingredients for the cosmetic industry. The country has one of the biggest biodiversity in the world, which could provide many new solutions to the cosmetic manufacture. Another great potential for the development of renewable, revolutionary ingredients to the cosmetics industry is through the use of agroindustrial residues. Limonene, for example, is obtained as a byproduct of orange juice production. Brazil is one of the most important producers of orange juice in the world.

[8] According to the company, 80% of its formulations are vegan. Source: Natura’s Annual Report 2019. Available at: https://static.rede.natura.net/html/home/2020/br_07/relatorio-anual/natura_annual_report_2019.pdf

Table 6: Limonene production & consumption in Brazil, 2017

	Production	Consumption
Limonene	1,204,818 kg	1,001,978 kg

Data source: IBGE, 2018.

3.4. Sweeteners & Flavours (bio-S&F)

3.4.1. Brazilian productive capabilities in bio-S&F (Supply)

Obesity is, nowadays, one of the greatest public health concerns worldwide, with consequences beyond esthetic issues, as it is considered a risk factor for many different diseases, such as cardiac conditions, hypertension, and diabetes. To limit the prevalence of diseases related to the excessive consumption of sugar, researchers have worked on the isolation of naturally occurring compounds and the development of synthetic sweeteners. Unlike sucrose, most sweeteners exhibit undesirable off-tastes as concentration increases, and are also associated with severe side effects, including psychological problems, mental disorders, bladder cancer, heart failure and brain tumors. Some of the most commonly used non-caloric sweeteners include saccharin, aspartame, cyclamate, sucralose and acesulfame K. (BELTRAMI, DÖRING & DE DEA LINDNER, 2018). A study carried out at the University of Campinas revealed that the artificial sweetener sucralose - the most consumed in the world and, until now, considered by health agencies to be the safest - can become unstable and release potentially toxic compounds when heated to 98 ºC (Toledo, 2016). Besides these health impacts, the traditional sweeteners production methods are often costly and, in many cases, involve the use of petrochemicals or high-fructose corn syrup.

The development of new sweeteners, made from other raw materials, could be a great opportunity, sinceince over 16% of global soft drinks launched in 2016 used either no added sugar, low sugar or sugar free claims. Along with the interest in sugar reduction, there has also been a continuing focus on clean label formulations, such as stevia and monk fruit. Soft drinks accounted for 20% of recent launches featuring stevia (BELTRAMI, DÖRING & DE DEA LINDNER, 2018).

To overcome the disadvantage of the traditional sweeteners, Amyris developed a technology to produce a new, renewable product from non-GMO yeast and sugarcane, under the brand Purecane, also known as fermented sugarcane Reb M. It is a no calorie and zero glycemic sweetener that can be used to reduce the intake of sugar, calories and carbohydrates. It is made

through a patented fermentation process that starts with sugarcane and then converts it to a sweetener without any petrochemicals.

The new sweetener was approved by the National Health Surveillance Agency, ANVISA, which is responsible for the approval and supervision of food in Brazil, and by other similar agencies abroad. Brazil is one of the world's fastest growing markets for natural sweeteners. Also, Amyris established a commercial deal with Linea, the consumer market share leader in Brazil.

The Chinese company Layn (https://layncorp.com/), the leading global producer of plant-based sweeteners, is also present in Brazil. The company processes more than 90 million tonnes of biomass per year and has more than 50 patents. Layn works in partnership with sustainable farms, offers innovation in the field (with traceability) and a potentially large production capacity. Despite being in the Latin American market for just one year, the company already has a large number of projects in progress and some products for yoghurts and nutritional supplements. The company has an agreement with the Swiss company Firmenich under which Firmenich will become the exclusive distributor of Layn's natural sweetener ingredients for all international markets outside China as well as for key customers in China, while Layn will continue to service its existing clients for the duration of those commitments.

The company has a project to develop a new sweetener from extracts and juices made from monk fruit (siraitia, in Portuguese). While waiting for the product approval process, which is very similar to the process stevia went through, the company offers a platform called Lovia, which combines stevia and monk fruit to offer market solutions that combine the two products.

The Brazilian production of sweeteners (renewable and non-renewable) in 2017 was 15,252 tonnes (powder) and 250,149 thousand liters (liquid).

Table 7: Sweeteners production & consumption in Brazil, 2017

	Production	Consumption
Powder sweeteners	15,252 tonnes	15,246 tonnes
Liquid sweeteners	250,149 thousand liters	218,135 thousand liters

Data source: IBGE, 2018.

3.4.2. Market for bio-S&F produced in Brazil (Demand)

The global sweeteners market is still dominated by artificial sweeteners such as aspartame, saccharin, sucralose, and cyclamate. Stevia is a natural sweetener, but has limited applications (high-intensity sweeteners market). There has been growing tendency over the past few years to focus on the development of naturally derived sweeteners and food additives on account of rising consumer awareness regarding ill effects of artificial additives on human health (Grand View Research, 2018)

These new sweeteners, made from renewable and natural sources, could replace sugar and the other sweeteners available in the market today, improving palatability and making it more healthy. L-arabinose, for example, as a sucrose neutralizer, could have a potential global market of up to $10 billion/year (SBIR). Generally speaking, the global natural sweeteners market was approximately USD 27.04 billion in 2018 and is expected to generate around USD 37.6 billion by 2025, at a CAGR of around 4.6% between 2019 and 2025 (Zion Market Research, 2019). The Brazilian consumption of sweeteners (renewable and non-renewable) in 2017 was 15,246 tonnes (powder) and 218,135 thousand liters (liquid) (IBGE, 2018).

3.4.3. Opportunities in bio-S&F based on Brazilian technological capabilities, skills and complementary assets

Revolutionary methods are emerging for the development of new, unknown molecules that could be used as sweeteners. The challenge of food manufacturers is to develop low or calorie-free products without compromising the real taste of sugar expected by consumers. With the discovery of the genes coding for the sweet taste receptor in humans, entirely new flavor ingredients have been identified, which are tasteless on their own, but potentially enhance the taste of sugar. These small molecules known as positive allosteric modulators (PAMs) could be more effective than other reported taste enhancers at reducing calories in consumer products. PAMs could represent a breakthrough in the field of flavor development after the increase in the knowledge of safety profile in combination with sucrose in humans (BELTRAMI, DÖRING & DE DEA LINDNER, 2018).

PAMs were approved by the Flavor and Extract Manufacturers Association (FEMA)[9] as flavoring substances that have been described to be used in food and beverage applications, such as soft drinks and powdered beverages. It is apparent that the sweetener PAM technology is an exciting approach to calorie reduction of products with a taste quality which is impossible for HP sweeteners. A lot of work remains until PAMs become commercially used. PAMs do not have minimal toxicology data published by, for example, EFSA or WHO. Moreover, safety human tests of PAMs in combination with sucrose has not been adequately performed (BELTRAMI, DÖRING & DE DEA LINDNER, 2018). Other challenges for PAMs include: (i) identification of more efficacious PAMs that could enhance the taste of sugar up to 20-fold in order to cut beverage calories and enable the labeling of zero-calorie discovery of different enhancers for each sweetener, increasing specificity and therefore efficacy; (ii) isolation of PAMs with a broader spectrum of activity that are able to improve taste qualities of synthetic and natural HP sweeteners; (iii) identification of PAMs from natural origin with strong enhancement effects that are cost-effective because of the consumers' search for natural ingredients (BELTRAMI, DÖRING & DE DEA LINDNER, 2018).

Brazilian biodiversity could be an enormous source of opportunities to the development of new food ingredients, including sweeteners and flavors. The agroindustrial complex already installed in the country could also be a provider of raw materials that could be used to sustain the fabrication of these products. One of the companies acting in this direction is Amyris. After selling the Brotas 1 (farnesene) plant to DSM, Amyris turned its focus to the construction of its new plant, also located in Brotas (Brotas 2). Amyris is accelerating the construction of this second facility dedicated to specialty products, while maintaining the manufacturing process development and business support capability located in Campinas, São Paulo state. This new plant will be the main responsible for the production of advanced renewable sweeteners, between other specialties.

[9] The Flavor and Extract Manufacturers Association of the United States (FEMA) is comprised of flavor manufacturers, flavor users, flavor ingredient suppliers, and others with an interest in the U.S. flavor industry. Founded in 1909, it is the national association of the U.S. flavor industry. Source: FEMA website (https://www.femaflavor.org/about)

3.5. Nanocellulose

3.5.1. Brazilian productive capabilities in nanocellulose (Supply)

Nanocellulose is a high-impact nanomaterial derived from natural sources. It is a light solid substance obtained from plant matter, which comprises nanosized cellulose fibrils. This new material is a pseudo-plastic and possesses the property of specific kinds of fluids or gels that are generally thick in normal conditions. The lateral dimensions of nanocellulose range from 5 to 20 nanometers (nm), and the longitudinal dimension ranges from a few 10's of nanometers to several microns (Soutter, 2012).

The crystalline form is transparent and gas impermeable, characteristics that make it attractive for the development of new materials. It can be produced in large quantities with non-prohibitive costs. It has a very high tensile strength – eight times that of steel. It is highly absorbent when used as a basis for aerogels or foams. The raw material – cellulose – is the most abundant polymer on earth – and Brazil is among the main producers.

Table 8: Cellulose production & consumption in Brazil (R$), 2017

	Production	Consumption
Cellulose	R$ 38,935,222	R$ 5,242,478

Data source: IBGE, 2018.

Applications of nanocellulose range from vehicle manufacture to more secure and more efficient medicines. This new material can sometimes replace petrochemical-based products and is very likely to be cheaper than most other kinds of high-performance nanoscale materials (Soutter, 2012). The interviews indicated that nanocellulose could also be used in the cosmetics industry replacing polyacrylate as a thickener. Nanocellulose also could be used to replace carbopol in the production of alcohol-based hand sanitizers, used in sanitation and in the prevention of diseases like COVID-19. This is the subject of an ongoing project of the Senai Institute for Innovation in Biosynthetics (ISI CETIQ). The institution has assembled a team of researchers dedicated to prospecting and testing material options, such as microfibrillated nanocellulose (MFC), to replace Carbopol. In the short term, the project increased the availability of gel alcohol in the country (Lopes, 2020).

The US firm American Process (API) had developed a technology to produce nanocellulose from palm oil with MYBiomass. The project was using oil palm empty fruit-bunches and converting them into nanocellulose additives for use in automotive parts, paper and textiles. API was focused on the technical and material development aspects while its partner, MYBiomass, was using its oil palm biomass supply and market strength to help bring the project to fruition. American Process also had signed a joint development agreement with India's Aditya Birla Carbon Group to explore the synergistic use of nanocellulose and carbon black to reduce rolling resistance in tires.

In 2019, the Brazilian company GranBio acquired American Process, as well as the affiliate companies including AVAPCO LLC and API Intellectual Properties Holdings. The acquired assets include the Alpena Biorefinery in Alpena Michigan, the Thomaston Biorefinery and R&D center in Thomaston, Georgia, operations, research, and business development staff and an extensive intellectual property portfolio in the biorefinery, biofuels, biochemicals, and nanocellulose fields with over 200 granted and pending patents.

Fibria (nowadays Suzano Papel e Celulose), the leading Brazilian company in the sale of pulp, became in 2016 a partner of the Canadian company CelluForce, the first commercial producer of cellulose nanocrystals. Fibria invested around US $ 4 million to acquire a 8.3% stake in CelluForce, a startup of FPInnovations, a Canadian forestry research center. Formed in 2010, CelluForce opened its pilot plant in Montreal, Quebec, in 2012. Today, with the capacity to produce 300 tonnes per year, its production is also aimed at samples supplied to potential customers.

3.5.2. Market for nanocellulose produced in Brazil (Demand)

The tire industry accounts for about 70% of global carbon black consumption and makes up about a quarter of tires by weight. Birla Carbon, a subsidiary of the Indian conglomerate Aditya Birla Group, is one of the largest carbon black suppliers in the world and has 16 factories in 12 countries and two technology centers, one in the United States and the other in India. In Brazil, the company has a plant in Cubatão and a commercial office in São Paulo, both cities in São Paulo state.

Nanocellulose is a potential substitute for carbon black in tires production. A renewable material with strength comparable to carbon fiber, nanocellulose has unique synergistic effects with filler materials like carbon black in improving the performance of composites.

Table 9: Carbon black production & consumption in Brazil, 2017

	Production	Consumption
Carbon black	371,532 tonnes	367,840 tonnes

Data source: IBGE, 2018.

3.5.3. Opportunities in nanocellulose based on Brazilian technological capabilities, skills and complementary assets

Brazil is among the most promising countries for nanocellulose production. First, because the country is the main world producer of cellulose. Extracted from cellulose, the raw material of papermaking, nanocrystals may originate from reforestation wood, but also in leftover wood, sugarcane bagasse, coconut shells and rice, residues from soybean and palm oil production, that are abundant materials in Brazil. Second, the country has technological capabilities to act in the sector with the acquisition of API by GranBio and the Fibria research dedicated to the topic.

Universities also play an important role in nanocellulose R&D in Brazil. For example, in the Lorena School of Engineering (EEL), at the Biocatalysis and Bioproducts Laboratory, University of São Paulo (USP), new routes for obtaining and applying nanoparticles from cellulose fibers are being researched from 100% renewable sources (sugarcane bagasse and eucalyptus).

The distinctive characteristic of the research carried out at EEL is the development of technology based on biotechnology for scalable processes. Advances in this area may make it possible for these nanoparticles to be used in new ways, for example, resulting in materials with countless application possibilities.

4. Final remarks

Brazil has a huge potential in the biochemicals arena, but many challenges need to be overcome. The country has important natural resources that can be developed with domestic expertise (scientific and technological competences) for the development of energy manufacturing and renewable products. Brazil has an advanced agroindustrial complex, with many products that could boost the development of a profitable biochemical sector. Importantly, Brazil has one of the biggest biodiversity in the world, which has only been superficially explored as of now. However, Brazil has serious problems in infrastructure and an industrial infrastructure

that is becoming rapidly obsolete in face of the rapid developments frequently mentioned as the fourth industrial revolution. This can be a serious obstacle for the development of such a sector.

The country has been building technological competencies in the biochemical area. Companies like GranBio, Braskem, Natura, Beraca, Tobasa, Corbion and DSM – Amyris among others, have invested hard (money and neurons) in the last years to create and diffuse new renewable technologies and products in the Brazilian chemical industry, with reasonable success. For this to happen, it was necessary for these companies to get closer to customers and users for the development of new applications, which would increase the possibility of commercial penetration of their products.

Brazil also has important science and technological institutes, which serve as a bridge between the scientific production that can support the development of new technologies – often located at universities - and the domestic industrial community. In the biochemicals field, we can mention the ISI Innovation in Biosynthetics (https://senaicetiqt.com/inovacao/). The Brazilian Agricultural Research Corporation (EMBRAPA) and the Brazilian Center for Research in Energy and Materials (CNPEM) also play important roles in the basic research involving renewable chemicals technologies, as well as public universities.

"Brazil has excellent competencies allocated to science and technology institutions to the development of biochemicals production. The Senai Innovation Institute (ISI) in biosynthetics is worth mentioning, which bridges research carried out at universities and companies."

In addition to the current high relative costs, other challenges need to be overcome by biochemicals producers. The main ones are the need for changes in an already installed industrial infrastructure facing to the production of conventional polymers, the procurement of consumers to accept new products, the lack of public policies that encourage the manufacture of more sustainable products and regulatory issues, also including those related to certification and final destination of bioplastics. It is not a smooth way ahead, but the reward for those who travel it will be a cleaner and more sustainable future.

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Annex 1 - Data for selected biochemicals from the Brazilian Annual Survey, 2018 (PIA IBGE)

Brazilian Annual Industrial Survey, 2018		NA = Not Available	
Biochemical	**Type**	**Production (R$ 1,000)**	**Sales (R$ 1,000)**
Chemical Platform			
Ethylene	Drop-in	314 697	420 576
Acetic anhydride	Drop-in	NA	NA
Ethylene glycol	Drop-in	NA	NA
Sebacic acid	Dedicated	NA	NA
Propylene glycol (1,2-propanediol)	Drop-in	450 887	260 597
Lactic acid	Dedicated	147 049	213 269
1,3-Propanediol	Drop-in	NA	NA
Epichlorohydrin	Drop-in	NA	NA
Acetic acid	Drop-in	11 222	5 030
Solvents			
Isobutanol	Drop-in	NA	NA
Acetone	Drop-in	171 230	171 202
Ethyl acetate	Drop-in	450 564	449 831
Wood turpentine	Dedicated	307 969	301 940
Ethyl lactate	Dedicated	NA	NA
Polymers for plastics			
High density polyethylene	Drop-in	6 079 719	5 324 311
Low density polyethylene	Drop-in	3 772 978	3 181 672
Linear polyethylene	Drop-in	4 721 708	4 270 737
Polyhydroxyalkanoate	Dedicated	NA	NA
Polyethylene terephthalate	Drop-in	2 444 597	2 268 200
PLA	Dedicated	NA	NA

Starch used for plastics	Dedicated	NA	NA
Paints, coatings, inks and dyes			
Alkyd resins	Drop-in	138 080	135 042
PUR	Drop-in	NA	NA
Ricinoleic acid (12-hydroxyoctadec-9-enoic acid)	Dedicated	NA	NA
Surfactants			
Glycolipids (other than sophorolipids)	Dedicated	NA	NA
APG	Dedicated	NA	NA
Esterquats	Dedicated	NA	NA
Carboxy methyl starch	Dedicated	NA	NA
Sophorolipids	Dedicated	NA	NA
Cosmetics and personal care products			
Limonene	Dedicated	NA	NA
Xanthan gum	Dedicated	NA	NA
Lauryl alcohol	Drop-in	749 329	519 472
Ethoxylated fatty alcohols	Drop-in	749 329	519 472
Stearyl alcohol	Drop-in	749 329	519 472
N-acetyl glucosamine	Dedicated	NA	NA
Vanillin	Drop-in	NA	NA
Adhesives			
Methacrylates	Drop-in	NA	NA
Epoxy resins	Drop-in	206 481	195 235
Furfuryl alcohol	Dedicated	NA	NA
Tall oil resin	Dedicated	NA	NA
Lubricants			

Alkanes (iso-)	Drop-in	NA	NA
Tall oil fatty acids	Dedicated	NA	NA
FAME (e.g. methyl palmitate, stearate, laurate)	Dedicated	NA	NA
Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate)	Dedicated	NA	NA
Plasticizers			
Azelaic acid (nonanedioic acid)	Dedicated	NA	NA
Succinic acid	Drop-in	NA	NA
ESBO	Dedicated	NA	NA
Man-made fibres			
PTT	Dedicated	NA	NA
Polyamide-11 (nylon-11)	Dedicated	877 200	855 303
Rayon	Dedicated	NA	NA
Cellulose acetate	Dedicated	NA	NA
Polyamide-4,10 (nylon-4,10)	Dedicated	213 889	158 322

Annex 2 - Guide used at the interviews

1. We have identified the following five biochemicals products categories as very promising to Brazilian organizations, or organizations based on Brazil, in the next years: platform biochemicals, bioplastics, cosmetics & personal care, sweeteners & flavours and nanocellulose. Do you agree? Please, justify your answer.
2. Inside those categories, which products do you consider most promissor to Brazil? What ones? Please, justify your answer.
3. In recent years, have you engaged yourself (or your institution/company has) in innovative projects aimed at the development of the commercial production of biochemicals in Brazil? Could you describe the project(s) (objectives, actors, milestones, financing, etc)?