ABBI
BRAZILIAN BIOINNOVATION ASSOCIATION

Identification of Opportunities and the

Potential Impact of the Bioeconomy on the Decarbonization of Brazil

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Mateus Lopes, PhD – Raízen Energia/ Vice-Chairman of the ABBI Board of Directors
Thiago Falda, PhD – Executive President of ABBI

Authors

Alexandre Alonso Alves, DSc – Embrapa Agroenergia
Ana Karina Brambilla, MSc – Braskem
Eduardo do Couto e Silva, PhD - LNBR/CNPEM
Gerd Brantes Angelkorte, MSc - CENERGIA/COPPE/UFRJ
Gustavo Alves Soares, MSc - SENAI/CETIQT
Leonardo Teixeira, MSc - SENAI/CETIQT
Maurício Antônio Lopes, PhD – Embrapa Agroenergia
Marianne Zanon Zotin, MSc - CENERGIA/COPPE/UFRJ
Mateus Chagas – LNBR/CNPEM
Paulo Coutinho, DSc - SENAI/CETIQT
Thayse A. Dourado Hernandes, PhD - LNBR/CNPEM
Thiago Taketa, PhD - Braskem
Victoria Santos, PhD - SENAI/CETIQT
Verônica Leite Queiroz, MSc - Braskem

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EXECUTIVE SUMMARY

The energy transition and the construction of the bioeconomy are complementary processes that must be jointly encouraged. Bioeconomy offers less energy-intensive processes, biofuels with negative emissions and biomaterials for long-term carbon storage. Bioenergy production plays an important role in energy transition and has a strong connection with innovations in the sectors of agriculture, forestry, and waste management, given their need for sustainable biomass.

The bioeconomy is characterized by decentralized production, establishing, and consolidating new production chains. It differs radically from the current industrial model based on fossil sources, characterized by a few large refineries that operate on a large scale and with standardized technologies. The regionalism of the bioeconomy is an attraction for economic development, since it requires the dissemination of biorefineries and, consequently, generates investments, jobs, knowledge, and income in a decentralized way.

Brazil needs to consolidate a national bioeconomy strategy, since it depends on the interaction between different economic sectors. These sectors must be supported by public policies that encourage a sustainable supply of biomass and instigate the implementation of biorefineries, which depend on the joint production of biofuels and bioproducts with greater added value, thus creating demand that values the positive environmental aspects of Brazilian biomass.

The establishment of a carbon market that encourages the use of bioproducts is necessary to strengthen the bioeconomy. Many of the technologies and bioproducts necessary for the advancement of the bioeconomy are still not competitive with their fossil substitutes and require policies and regulations that value their environmental benefits.

Public policies and funding that allow for the sharing of innovation risks are essential. The bioeconomy is based on the advancement of technologies with different degrees of maturity, which depend on long-term public and private investments, the sharing of risks, and targeting the key sectors of the bioeconomy.

This study evaluated, within the context of the energy transition in Brazil, some bioinnovation opportunities based on the mitigation of greenhouse gas (GHG) emissions and the generation of additional revenue resulting from the bioeconomy. Bioinnovations with high economic and mitigation impact were evaluated, and the necessary investments and potential revenues generated were estimated. In addition to the bioinnovations evaluated in this study, there are still many opportunities related to Brazilian biodiversity that are yet to be studied and production chains yet to be established.

The study considers the role of biotechnology from the perspective of the multiple uses of biomass in energy, food, and materials, within the context of the energy transition and the need to develop a bioeconomy. Different trajectories for Brazil, each using a horizon of 2050, were considered: as a starting point, two scenarios previously elaborated by Oliveira et al. (2021)[1], plus a third scenario, proposed as a fundamental point of this document, to highlight the effects of a more intensified adoption of biotechnology:

- **Current Policies Scenario.** Developed by Oliveira et al. (2021), it considers the maintenance of current Brazilian policies and respects the country's Nationally Determined Contributions (NDC) under the Paris Agreement. In this scenario, fossil sources represent 62% of primary energy supply in 2050 and Brazil increases its annual GHG emissions by more than 20% in the period between 2010 and 2050.
- **Below 2°C Scenario.** Also developed by Oliveira et al. (2021), it considers that biomass becomes the main source of energy for the implementation of low-carbon technologies in the main sectors of the Brazilian economy to comply with the Paris Agreement, aiming to limit the increase in terrestrial temperature to "well below 2ºC" by the end of the century. In this scenario, biomass represents 76% of the internal supply of primary energy and, when combined with carbon capture and storage (CCS) processes, it represents the only alternative capable of delivering the negative GHG emissions necessary to achieve the decarbonization targets with the required urgency.
- **Potential Scenario of the Bioeconomy**. The principal scenario of this study, it evaluates how the bioeconomy, and the energy transition can complement each other, introducing in the *Below 2°C* scenario, promising technologies selected by companies from the Brazilian Association of Bioinnovation (ABBI), CENERGIA/UFRJ, SENAI CETIQT, Embrapa, and the National Center for Research in Energy and Materials (LNBR/CNPEM).

The *Bioeconomy Potential* scenario classifies the selected technologies into three categories, as shown in **Table 1**.

[1] The study uses the Brazilian Land-Use and Energy Systems (BLUES) model, which is an Integrated Assessment Model (IAM), widely used in IPCC assessments and recommendations, developed by the CENERGIA laboratory at COPPE/UFRJ to support decision-making in policies related to energy, agriculture, environment, and climate.

Table 1. Technology Categories selected for the Bioeconomy Potential scenario.

Technology category	Examples of technologies	Description
Solutions for sustainable intensification of agriculture	Alternative proteins, solutions for livestock confinement, carbon fixation in the soil, new vegetables varieties with high yield per hectare, biological nitrogen fixation, and biological control	Optimization of land use and biomass production with low or even negative carbon emissions
Solutions for converting biomass into energy-based products	BECCS, CCU, biogas, and second-generation ethanol (E2G)	Use of biomass for energy production with low carbon intensity or even with negative GHG emissions
Solutions for converting biomass into high added value products	Biochemicals, enzymes and biofertilizers, biomaterials, bionaphtha, advanced biofuels	Production of bioproducts with high added value that replace products of fossil origin and allow for greater economy within biorefineries

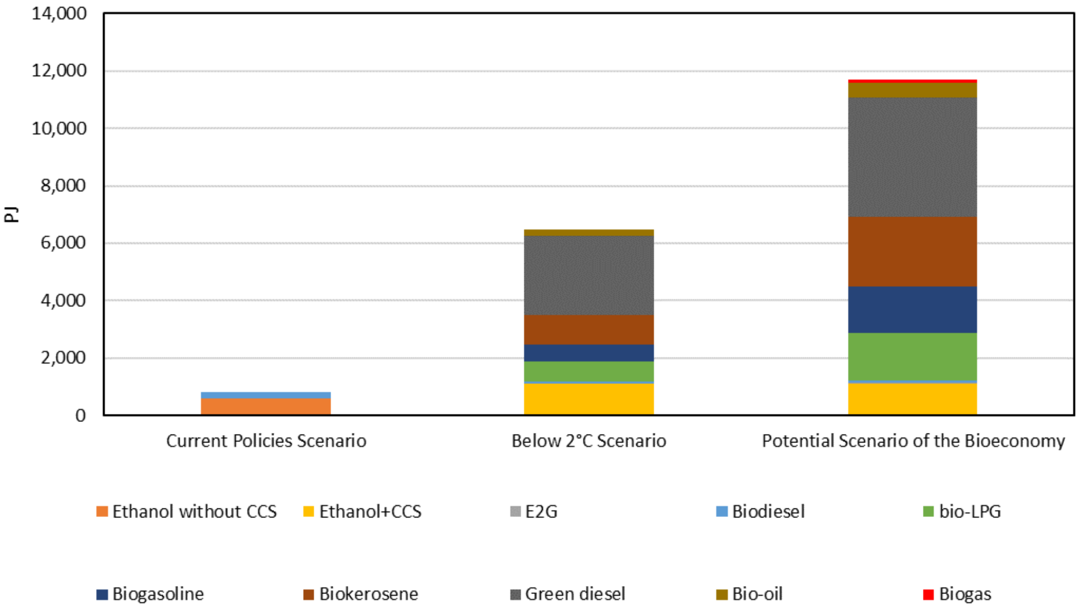
Brazil becomes a significant producer of some biochemicals with high added value – bioethene, biopropene, biobutadiene, and bioBTX – with a total production of almost 15 million tons by 2050. In 2050 the production of biopolymers will represent 53 % of the total volume of polymers produced domestically.

Biofuels reach, in 2050, a production of 373 billion liters – of which about 89% consist of advanced biofuels. This production is 75% higher than the production of the *Below 2°C* scenario for the same year. Biogas, despite having an important role in the reuse of waste and in making biorefineries viable, has low penetration compared to other advanced biofuels. Chart 1 shows the comparison of biofuel production between the different scenarios.

Around 6.1 million hectares of pasture are replaced by eucalyptus and sugarcane to support the sustainable expansion of biofuel and biochemical production. To release this area from grazing, it is necessary to replace 7% of beef production with cultured meat.

About 2 million tons of cultured meat are produced, which is equivalent to 13% of the Brazilian demand for meat in 2050. The production of cultured meat to replace traditional beef is approximately 1 million tons. In addition, the expansion of domestic meat production is considered, adding another 1 million tons of cultured meat destined for export.

Chart 1 - Production of biofuels in different scenarios in 2050



In this scenario Brazil exports 8.2 million tons of biochemicals and 159 billion liters of biofuels, generating gross revenues of around US$392 billion in 2050, US$147 billion higher than that observed in the *Below 2°C* Scenario and US$ 284 billion higher than the *Current Policies* scenario.

The *Bioeconomy Potential* scenario is just an illustration of Brazil's potential associated with biotechnology. The construction of this trajectory will only be possible through a coordinated effort to promote public policies that consider Brazil's specific characteristics and competitive advantages in the context of the transition to a low-carbon economy.

The bioeconomy can decouple increased production and economic growth from increased GHG emissions. Between the *Below 2°C* and *Bioeconomy Potential* scenarios, despite the huge growth in biofuel production, biochemicals and revenues, emissions would be reduced by around 550 million tons of CO_2eq.

CHAPTER I

ENERGY TRANSITION AND BIOECONOMY AS COMPLEMENTARY EFFORTS

I. THE GOALS OF THE PARIS AGREEMENT AND THE ROLE OF THE ENERGY TRANSITION

In its sixth Assessment Report Cycle (AR6), the Intergovernmental Panel on Climate Change (IPCC) shows that there is a clear relationship between temperature rise and anthropogenic GHG emissions and that mitigation policies can prevent the aggravation of the effects of global warming. In order to meet the 1.5 °C target established in 2015 (Paris Agreement), the report states that net GHG emissions must be close to zero in 2050 (IPCC, 2021). For the ongoing irreversible effects, such as the impact of increased temperature on biodiversity (Manes et al. 2021), adaptation policies are needed to reduce, as much as possible, the damage that is already being generated.

Paris Agreement signatory countries sent the revisions of their NDCs to the Conference of the Parties (COP 26) held in November 2021 in the city of Glasgow, Scotland. The conference reinforced the perception that a more ambitious collective effort at reducing emissions and stabilizing the planet's climate has never been undertaken. There is abundant evidence that human action is the main cause of the climate crisis and if we want a habitable planet in the future, countries, industries, and sectors must urgently decarbonize. In general, it is clear that there is a growing number of countries that have incorporated the IPCC recommendations and established long-term commitments to zero emissions by the middle of the century (IEA, 2021). Most of the actions present in the NDCs focus on reducing emissions from the energy sector which is responsible for about two-thirds of all GHG emissions on the planet. Such efforts are mainly focused on the search for alternative energy sources to fossil sources, which characterizes the ongoing energy transition process.

In addition to carbon dioxide emissions, methane is also an important greenhouse gas. Its short lifetime in the atmosphere means that significant cuts in its emissions can reduce warming in just a decade, at relatively low cost. That is why around 100 countries, including Brazil, announced during COP

26 the "Global Methane Pledge" - a collective goal of reducing emissions by 30%, to be achieved by 2030. The pledge imposes substantial reductions in emissions from sources such as landfills, oil and gas systems, coal mining, industrial processes, and agriculture, with a particular emphasis on livestock. The good news is that methane is a valuable gas that can be captured and used as fuel, reducing our dependence on fossil sources, and stimulating the development of the bioeconomy in various ways.

The projections made by the International Energy Agency, IEA (2021), and the International Renewable Energy Agency, IRENA (2021), for a global scenario of neutral emissions in 2050, show the great role of electrification in final energy consumption. Global projections also point to a trend in the use of biofuels, mainly to meet the demand of large vehicles as used in air, sea, and road transport, whose electrification is more complex (IEA, 2021; IRENA, 2021). In the Brazilian context, where there is already a fully established ethanol production chain, biofuels continue to be a very interesting alternative, even in the face of electrification. Hybrid and fuel cell vehicles based on ethanol combine the advantages of biofuels with electrification, representing a great national advantage. This expansion of biofuels is related to technological advances since it is based on the increase in the production of advanced biofuels – those that use raw materials that do not compete with food, such as urban and agro-industrial waste and energy crops. Many of these raw materials still need to build supply chains, overcome logistical barriers, and require the development of appropriate processing technologies.

In the large vehicle sector, the expectation is for the development of drop-in biofuels, such as green diesel and aviation and marine biofuels. These are biofuels that have the advantage of being able to replace fossil fuels, taking advantage of existing infrastructure and without requiring adaptation of equipment. Aviation biofuels, for example, must be drop-ins and meet international certifications to avoid technical problems arising from fuel supply on international flights.

Bioenergy, as a whole, will play a leading role in meeting the decarbonization targets. For the industrial sector, especially for energy-intensive segments such as steel and chemicals, electrification for heat generation is more complex, given the need for high temperatures (IEA, 2021). For these segments, the modern use of biomass and derivatives (roasted pellets, biomethane, bio-oil, hydrogen from biomass, among others) will be one of the main options for replacing fossil fuels in heat generation. By modern use, it is understood that the supply of biomass is sustainable, originating from agro-industrial or forest residues or from energy crops (IEA, 2021).

Bioenergy production is still relevant to offset residual emissions in emission-neutral scenarios. As the production of biofuel and bioelectricity generates flows of biogenic CO_2 in point sources and with a large volume of emissions, bioenergy is capable of delivering negative GHG emissions when associated with carbon capture and storage technologies. This combination of technologies is known by the acronym BECCS[2] and has been considered essential for meeting decarbonization targets (IEA, 2021; IPCC, 2019).

II. THE NEED FOR THE DEVELOPMENT OF THE BIOECONOMY AND ITS RELATION WITH THE ENERGY TRANSITION

The energy transition alone is not enough to meet the economy's decarbonization needs. According to a report by the Ellen MacArthur Foundation (2020), the energy transition would only be able to meet 55% of the need to mitigate GHG emissions (EMF, 2020). The other 45% must be mitigated in sectors such as agriculture, chemicals, and the materials industry, which emit large amounts of GHGs, such as, for example, methane from enteric fermentation in ruminants, nitrous oxide from the use of fertilizers and emissions from chemical processes, such as calcination.

The bioeconomy, defined here as any economic activity that uses bioprocesses and generates bioproducts that contribute to efficient solutions in the use of biological resources (CGEE, 2021), meets the need to decarbonize these sectors. It represents a transition to a base of renewable raw materials, moving from fossil to biomass, and to a production model that follows a circular logic, where residual flows from one chain are valuable inputs for others. It seeks to develop more efficient production processes that are less intensive in inputs and energy, strongly supported by biotechnology.

As it is important for the supply of biomass to be sustainable, moving forward with the bioeconomy also means seeking better use of the soil, recovering degraded areas, diversifying the supply of food, preserving biomes, taking advantage of biodiversity and generating jobs (D'AMATO; KORHONEN, 2021).

Support for the bioeconomy should not be understood as a parallel action to the energy transition. In fact, the two actions are complementary and the advancement of the two agendas generates synergies that must be explored. For example, the production of bioenergy, an important element in the energy transition, has strong interaction with the sectors of agriculture, forestry, and waste management. Bioenergy plays an important role in the bioeconomy as it makes biorefineries

[2] Bioenergy with carbon capture and storage

economically viable (IEA, 2017). Thus, a sustainable supply of biomass to produce bioenergy is also essential to enable the sustainable production of biochemicals and biomaterials.

Linked to biofuels, biomass will also increase its participation as an input to the production of building materials, fibers, food and feed, furniture, and textiles. It will be increasingly used, especially in innovative biomaterials such as bio-based chemicals, lubricants, and bio-based plastics, which offer high added value per unit of weight. Bioenergy will enhance residual flows of raw materials, contributing to the replacement of fossil-based energy.

The bioeconomy is characterized by decentralized production, establishing, and consolidating new production chains. It differs radically from the current industrial model based on fossil sources, characterized by a few large refineries that operate on a large scale and with standardized technologies. The regionalism of the bioeconomy is an attraction for economic development, since it requires the dispersion of biorefineries and, consequently, generates investments, jobs, knowledge, and income in a decentralized way (IEA, 2017; OECD, 2018).

The bioeconomy breaks with the already established structures, requiring a set of bioinnovations that solve the challenges of creating a sustainable supply of biomass, production processes that can compete with fossil processes, and bioproducts that add more value to biomass. While the energy transition has several technological possibilities that are already competitive, the construction of the bioeconomy represents a paradigm shift that requires a great effort of innovation from the agents and economic policies that encourage technological development and that value the benefits generated by the bioeconomy.

III. THE ROLE OF THE BIOECONOMY IN ENERGY TRANSITION SCENARIOS IN BRAZIL

The objective of this study is to evaluate the opportunities generated through the bioeconomy, in a context of energy transition in Brazil. This work focuses on bioinnovations in existing and developing industries, in which it is possible to estimate investment and revenue values. It focuses on sectors with the greatest potential for GHG mitigation.

To quantify the impact of the bioeconomy in energy transition scenarios in Brazil, different trajectories for the country were considered up to the horizon of 2050: as a starting point, two scenarios previously elaborated by Oliveira et al. (2021), plus a third scenario, proposed as a fundamental point of this document, to highlight the effects of a more intensified adoption of biotechnology:

- **Current Policies Scenario.** Developed by Oliveira et al. (2021), it considers the maintenance of current Brazilian policies and respects the country's Nationally Determined Contributions (NDC) under the Paris Agreement.
- **Below 2°C Scenario.** Also developed by Oliveira et al. (2021), it considers that biomass becomes the main source of energy for the implementation of low-carbon technologies, in the main sectors of the Brazilian economy, to comply with the Paris Agreement, aiming to limit the increase in terrestrial temperature to "well below 2ºC" by the end of the century.
- **Potential Scenario of the Bioeconomy.** The principal scenario of this study, evaluates how the bioeconomy and energy transition can complement each other, introducing, into the *Below 2°C* scenario, promising biorenewable technologies.

Oliveira et al. (2021) evaluate the role of biomass in energy transition scenarios in Brazil, from the perspective of its multiple uses – energy, food, and materials – using the Brazilian Land-Use and Energy Systems (BLUES) model, an Integrated Assessment Model (IAM) developed and constantly improved by the CENERGIA laboratory at COPPE/UFRJ to support decision-making in energy, agricultural, environmental and climate policies. It is important to emphasize that the results of IAMs represent possible future trajectories that are internally consistent with demographic, economic, and technological assumptions. They do not make predictions, but rather, elaborate plausible and cost-effective decarbonization scenarios. Scenarios generated by IAMs are used in IPCC assessments and recommendations, for example.

The new technologies included in the model were selected by companies associated with the Brazilian Association of Bioinnovation (ABBI), CENERGIA/UFRJ, SENAI CETIQT, Embrapa, and the National Center for Research in Energy and Materials (LNBR/CNPEM), and act in the search for a more sustainable supply of biomass, the development of technologies capable of processing a wider range of different raw materials and the development of new bioproducts with greater added value. The construction of this trajectory will only be possible if there is a coordinated effort of public policies that consider Brazil's specific characteristics and competitive advantages in the context of the transition to a low-carbon economy. Therefore, a national strategy is needed that considers the bioeconomy in a systemic way, from the search for a supply of sustainable biomass to the incentives provided for the production and consumption of bioproducts and bioenergy. It is important to consider that a group of biomass-intensive sectors is already established in the country and that these can serve as a starting point for the consolidation of a bioeconomy with greater added value, diversifying production beyond commodities.

CHAPTER II

KEY TECHNOLOGIES FOR THE BIOECONOMY

Bioinnovation encompasses technological innovations related to the use of renewable raw materials to develop new industrial processes and new bioproducts. In turn, the introduction of these bioinnovations, followed by their dissemination, generates economic benefits, such as an increase in the level of investment, increased industrial competitiveness, and the emergence of new productive sectors. These economic advantages translate into social benefits through the creation of jobs, many of them generated in a decentralized way.

In this chapter, the 12 selected technologies will be presented as examples of how bioinnovation can contribute to the creation of a solid bioeconomy. From technologies that have already been implemented, but that need greater diffusion, to less mature technologies that still need the construction of new markets and complementary assets. Such technologies show that the construction of the bioeconomy already offers solutions to meet the demands of mitigation, mainly with bioenergy, but there is a need for continual efforts to innovate to tackle the next drivers of emissions and to adapt to the effects of climate change.

It is important to make it clear that this report is focused on technologies needed to mitigate GHG emissions and combat global warming. The focus given to the construction of biorefineries that produce biofuels as well as other bioproducts, on a large scale, is due to the GHG mitigation capacity of these bioproducts when used to replace fossil products.

I. KEY TECHNOLOGIES FOR THE BIOECONOMY

The supply of modern biomass is characterized by low emissions of GHGs, or even the removal of GHGs from the atmosphere, noncompetition with food supply, and no impact on deforestation and loss of biodiversity. Energy crops are interesting sources of this type of biomass, as they grow quickly, can be planted in association with other crops, and are often adaptable to less fertile soil (IEA, 2021; IPCC, 2019). The expansion of these crops should favor marginal areas, such as low-productivity pastures, without causing a reduction in the food supply or the deforestation of native areas. One of the selected categories of technology is characterized as presenting “solutions for the sustainable intensification of agriculture". These are technologies that have an impact on increasing agricultural productivity, enabling the release of areas that can be used for energy crops, and reduce emissions during the production process. Table 2 presents the technologies grouped together within this category.

Table 2 - Biomanufacturing solutions for sustainable intensification of agriculture

TECHNOLOGY CATEGORY	KEY TECHNOLOGIES	DESCRIPTION
Solutions for sustainable intensification of agriculture	Alternative proteins	General term covering alternatives to animal protein. It includes plant-based proteins, fermented protein, and cultured protein. In Appendix I, there is a detail on the different technologies to produce alternative proteins.
	Development of new varieties of high-yielding crops per hectare, management practices for carbon fixation in the soil, biological nitrogen fixation and biological control	They represent a wide variety of solutions that can contribute to more sustainable agricultural practices, replacing fossil-based inputs and increasing yields per hectare, which leads to a reduction in the carbon footprint of agriculture.
	Cattle confinement solutions	This livestock feedlot technology combines feed additives (chemicals, enzymes, and vitamins) to reduce enteric fermentation in livestock.

The second category of technologies evaluated in this report refers to "Solutions for converting biomass into energy-based products", which can be seen in **Table 3** together with the final category of technologies, presented in **Table 4**, "Solutions for the conversion of biomass into products with high added value", represent technologies that enable full use to be made of the of biomass and expand circularity in the bioeconomy by offering productive opportunities for waste that would have previously been discarded or used inefficiently. They show the need to adapt processing technologies to different sources of biomass, which reinforces the modular nature of biorefineries and the possibility of different organizational forms within the same production space. While the energy-based products shown in **Table 3** have a larger market scale and, in fact, are the main justification for biorefineries and constitute a solid basis for the development of a more complex bioeconomy, the high value-added bioproducts in **Table 4** are important to replace other fossil products, which emit large amounts of GHG during their life cycle and make the development of biorefineries economically viable.

Table 3- Solutions for converting biomass into energy-based products

CATEGORIES OF TECHNOLOGY FOR BIOMANUFACTURING	KEY TECHNOLOGIES	DESCRIPTION
Solutions for converting biomass into energy-based products	**BECCS**	Bioenergy with Carbon Capture and Storage (BECCS), preventing the carbon dioxide of biogenic origin, released during the processing of biomass to produce energy, biofuels, and biomaterials, from reaching the atmosphere, being captured, and permanently stored in geological reserves.
	CCU	Use of captured CO_2 as a raw material to produce chemicals.
	Biodigestion and gasification	Production of biogas and syngas using a range of technologies to make use of residual outflows from different sectors: agriculture, livestock, and municipal waste streams.
	Cellulosic ethanol	Use of biomass to produce second-generation ethanol (E2G) from the fractionation of lignocellulosic biomass, with the opportunity to use biomass fractions for other biofuels and chemical intermediates.
	Advanced biofuels: green diesel, aviation, and marine biofuels	Heavy fuels produced from biomass for sectors that are intensive in GHG emissions and difficult to electrify.

Table 4- Solutions for converting biomass into high value-added products

CATEGORY OF TECHNOLOGY FOR BIOMANUFACTURING	KEY TECHNOLOGIES	DESCRIPTION
Solutions for converting biomass into high added value products	Biochemicals, enzymes and biofertilizers	Various biochemicals and enzymes can be produced from renewable raw materials. Included here are drop-in or non-drop-in solutions that can reduce the use of fossil-based raw materials. Market segments include fertilizers, electronics, automotive, fine chemicals, construction, food additives, household cleaning and personal care products, among others.
	Biomaterials	Bioproducts such as bioplastic, building materials and fabrics. Using a similar approach to the BECCS, biomaterials can be used as a Negative Emission Technology.
	Bionaphtha	Naphtha is the main feedstock for chemicals and materials around the world. A renewable solution is the production of bionaphtha from alternative raw materials such as triglyceride residues from cattle (tallow), used cooking oil or soybean oil.
	Chemical recycling	New technologies to convert plastic waste into new raw materials.

CHAPTER III

ENERGY TRANSITION AND BIOECONOMY IN BRAZIL

I. SPECIFIC CHARACTERISTICS OF THE TRANSITION TO A LOW-CARBON ECONOMY IN BRAZIL

Brazil, in its NDC published in 2015, made a commitment to reducing GHG emissions by 37% by 2025 and, subsequently, reducing emissions by 43% by 2030, using the year 2005 as a base (BRASIL, 2015). In 2020, when updating its NDC, the country committed itself to achieving carbon neutrality by 2060 (BRASIL, 2020).

The main mitigation instrument present in the Brazilian NDC, which came into force even before the Paris Agreement, is the National Policy on Climate Change (Law 12,187 of 2009), known as the Climate Law. The Climate Law served as the basis for the creation of several sectorial policies, in addition to fixing the GHG reduction targets between the years 2010 and 2020 (BRASIL, 2009).

Brazil presents conditions that make the transition to a low-carbon economy very specific in relation to the rest of the world. Comparing the Brazilian energy matrix with the world average, it is clear that the country already has a high share of renewables accounting for around 48%[3] of its domestic supply of primary energy, compared to the 12% international average in 2020 (EPE, 2021; IEA, 2021). Looking exclusively at the electrical matrix and the industrial consumption matrix, an even greater share of renewables can be observed. In the case of electricity, the participation of hydro generation stands out, with around 65%, and wind generation, with 9%, in 2020 (EPE, 2021). The Brazilian industrial consumption matrix is also one of the most renewable in the world, with an emphasis on the use of biomass, which responds for around 45% of the energy supply in the sector (EPE, 2021; IEA, 2021). It is important to emphasize that the biomass used comes mainly from agro-industrial residues, such as sugarcane bagasse and black liquor, which constitute sustainable sources of energy.

It is in the transport sector where there is a greater predominance of fossil fuels, as the main mode of cargo transport in the country is road and, consequently, there is a large consumption of diesel. However, even in the case of the transport sector, when comparing the Brazilian matrix with the world

[3] Considering the participation of renewables in the internal supply of energy

average matrix, Brazil has a high share of renewables. Looking exclusively at the road sector, biofuel consumption is 26% (EPE, 2021).

To meet the need for decarbonization in the transport sector, the National Biofuels Policy, RenovaBio, was created, which is aligned with the NDC aiming to increase the share of biofuels in the energy matrix to 18% by 2030 (currently, the share of biofuels is 8.3% (EPE, 2021)). Its main instruments are: i) the certification of companies that produce/import biofuels, which start to generate decarbonization credits (CBIOs) proportional to the production/imports and the mitigation capacity of the biofuel compared to its fossil substitute; ii) the establishment of GHG emission reduction targets applied to fuel distributors, who need to buy CBIOs or reduce the sale of fossil fuels in order to meet the targets; iii) the creation of the carbon market, where producers and distributors trade CBIOs.

Despite being created in 2017, RenovaBio only started operating in 2020 and, after one year of operation, the number of certified companies reached 291 and the decarbonization targets for 2020 were met (ANP, 2021). In Brazil, there are also obligatory blending mandates between ethanol and gasoline and biodiesel and diesel.

In Brazil, the main vector of emissions is related to the “Agriculture” sector, followed by the “Energy” sector and the “Land Use, Land-Use Change, and Forestry” (LULUCF) sector (SIRENE, 2021). So, in addition to measures in the energy sector, the Brazilian NDC also has goals and plans for these other segments. Regarding the LULUCF, the NDC considers that the country needs to strengthen the fight against illegal deforestation since there is already wide-ranging legislation for environmental protection. In addition to the Conservation Units System, which determines areas of environmental protection, the 2012 Forest Code defines percentages of private rural areas that must be kept preserved (IPEA, 2016). Specifically, the NDC sets the goal of eliminating illegal deforestation by 2030 and reforesting about 12 million hectares (BRASIL, 2015). The NDC update in 2020 also highlights the need for international support to preserve the existing forest cover. The argument is that the costs of protecting the integrity of the forest cannot fall on just one country, since the benefits generated impact the entire globe. Therefore, the NDC considers that an annual support of about US$ 10 billion is needed from the developed countries for the maintenance of forests (BRASIL, 2020).

In the agricultural sector, the trajectories for reducing emissions involve a transition to a more conservationist agriculture, which uses increasingly fewer chemical fertilizers and starts to use more inoculants and biological nitrogen fixation, with a more rational use of the soil, and the application of methods to integrate crop, livestock, and forestry (ICLF) and the recovery of pastures (LIMA; HARFUCH; PALAURO, 2020).

To act on these trajectories, based on the Climate Law, Brazil instituted the Low Carbon

Emissions in Agriculture Program, known as the ABC Plan. The program mainly consists of a differentiated credit system that benefits farmers who use low-carbon agricultural technologies in their production, such as those highlighted in the previous paragraph (LIMA; HARFUCH; PALAURO, 2020). The Program, which had a ten-year term, ended in 2020 and showed good results, including exceeding some initially established goals. In 2021, the ABC Plan was extended for another ten years and was named the ABC + Plan, however, the volume of funds allocated to the second phase of the plan seems to fall short of the amount needed to implement all the activities, similarly to what is reported in the first phase of the plan's execution (Lima, Harfuch and Palauro, 2020).

In general, the official data of sectorial emissions in Brazil for 2016 (SIRENE, 2022) show a significant reduction, of around 75%, for the LULUCF sector when compared to the level of emissions for the base year of the NDC (2005). In the case of the agricultural sector, emissions remained at the level of 2005, with an increase of about 10% when compared to 2005. The biggest increase was in the energy sector where sector emissions increased by 35% from 2005 to 2016, mainly driven by the water crisis and the activation of thermal plants powered by fossil fuels in later years, since, with reduced reservoir levels, hydroelectricity generation, which represents a large part of the electricity supply in the country, was compromised. So, it is clear the importance of intersectorial measures for achieving decarbonization goals through the bioeconomy, and that only coordinated and joint efforts within the bioeconomy will be effective in achieving the country's decarbonization goals.

II. THE NEED TO ADVANCE THE BIOECONOMY IN BRAZIL

To reach the emission neutrality target by 2050 and comply with the Paris Agreement, Brazil needs to extensively incorporate sustainable sources of biomass that meet the growing demand for advanced biofuels, biochemicals, and biomaterials, that are important for the energy transition. Therefore, technologies for the sustainable intensification of agriculture are essential to ensure that the bioeconomy develops and that the bioproducts generated are, in fact, sustainable.

It is important to consider that Brazil has a large availability of low-productive pastures, which could be turned over to expanding the production of energy forests, such as eucalyptus, or other energy crops, such as sugarcane, without causing deforestation. Other biomasses native to Brazilian territory, which do not yet have a fully established, large-scale production system, but have technological packages developed and validated by scientific research, such as, for example, macaúba, represent interesting alternatives for the country due to their high productive potential and adaptability to different biomes, climate and soil conditions.

In the projections of the IEA (2021), to reach neutral emissions in 2050, around 410 million hectares of land dedicated to the production of energy-crops in the world will be needed. Brazil currently has around 155 million hectares of pasture, with around 80 million hectares showing a certain degree of degradation

(MAPBIOMAS, 2021).

Brazil is a large agricultural and forestry producer and, therefore, generates a high amount of waste during the harvesting process. The country also has a solid biomass processing industry, being a major producer of biofuel, especially ethanol from sugar cane, but also of pulp and paper, meat, and other foods. Thus, in addition to having a huge supply of agricultural waste, Brazil also has a large supply of agro-industrial waste.

Biomanufacturing solutions for processing biomass are relevant so that these residues gain an economic destination of greater value and so ensure the full use of biomass, which can provide greater sustainability to the production chain. Furthermore, they allow the production units in the biomass-intensive sectors to advance even further in the concept of biorefinery, by introducing new technological routes and enabling energy self-sufficiency.

To get an idea of this potential, one can evaluate the technical potential of biogas production, given that the technology used to obtain it can be considered mature. Despite the need for efforts to scale-up and adaptation to different raw materials, Brazil could produce around 44 billion cubic meters of biogas, with 21.1 billion originating from the use of waste from the sugar-energy sector. If this biogas were transformed into biomethane, it could replace something in the order of 41 billion liters of diesel (ABIOGÁS, 2021). In 2020, Brazil consumed 57.4 billion liters of diesel (EPE, 2021).

Second-generation ethanol (E2G) is another great opportunity to use agricultural and agro-industrial waste in Brazil. The country is one of the few that have commercial second-generation ethanol production plants. In 2021, Raízen, a company from the sugar-energy sector, announced its second plant (NOVACANA, 2021), after 6 years of gaining knowledge.

Developments in technology and new capabilities to produce advanced biomaterials and biochemicals can provide energy and carbon savings compared to fossil-intensive products. For example, the use of wood and biopolymers as construction materials reduces the need for steel and concrete in buildings, as well as sequestering carbon for an extended period. Although the actual estimates of energy and carbon benefits vary widely, depending upon assumptions about lifetimes and disposal methods, these uses are generally considered to be highly efficient in terms of carbon storage, as they replace materials that are produced by energy-intensive processes. (Oliveira et al., 2021).

In the exclusive case of biochemicals, the development of biomanufacturing solutions for converting biomass into products with high-added value even has the potential to reduce the weight of imports of chemical products that negatively impacts the country's trade balance. In 2020, according to MDIC data (2021), the negative trade balance of chemical products was approximately US$ 16 billion[4]. Of these, about US$ 8 billion were chemical fertilizers (MDIC, 2021).

[4] Considering only NCM (2 digits) 28 (Inorganic chemicals), 29 (Organic chemicals), 31 (fertilizers) and 32 (Tanning and

In short, Brazil needs to think about the energy transition within a strategy to develop the bioeconomy, where incentives for biofuels and biomaterials are just one of the issues that need to be addressed. The country needs to reinforce policies aimed at sustainable agriculture, thus ensuring a supply compatible with the needs of biorefineries. Policies aimed at innovation are also needed, which help to attract resources for investments in new technologies, capable of processing different raw materials in a more efficient and sustainable way. Finally, the country must value the benefits of bioproducts, thus allowing them to compete against fossil fuels.

It is important to stress that Brazil is not starting from scratch. In addition to having demanding environmental regulations and being richly endowed in natural resources, especially arable areas, the country also has a thriving and innovation-intensive agriculture. Furthermore, it is one of the few countries with large biomass-intensive sectors, which is already accumulating the knowledge needed to build the bioeconomy.

dyeing extracts)

CHAPTER IV

A PRELIMINARY ASSESSMENT OF THE POTENTIAL OF THE BIOECONOMY IN THE TRANSITION TO A LOW-CARBON ECONOMY

I. STUDY METHODOLOGY

Attentive to the limits of biomass use from the perspective of its multiple uses – energy, food, and materials – Oliveira et al. (2021) showed that the *Below 2°C*[5] scenario, with accumulated Brazilian emissions restricted to 14 $GtCO_2$ between 2010 and 2050, not only highlights the centrality of the production of advanced biofuels in meeting climate targets, but also highlights the importance of co-production of biochemicals substitutes for fossils in biorefineries. Several studies show that the synergy between the production of bioenergy and biomaterials makes biorefineries economically viable without violating land use restrictions (OLIVEIRA et al., 2021; HERNANDES et al., 2021; KLEIN et al., 2018).

The *Bioeconomy Potential* scenario, constructed for this report based on the expansion of the study by Oliveira et al. (2021) (for more details, see Appendix II), represents how much the expansion of the bioeconomy in Brazil, taking advantage of its comparative advantages – biodiversity, consolidated agribusiness, and bioinnovation – can be an engine for economic and sustainable development. In this scenario, it was considered that the domestic production of chemicals would increase by about 50% in 2050 in relation to the *Below 2°C* scenario, exclusively from biomass and aimed at export. In order not to change the energy balance achieved in the *Below 2°C* scenario, the increase in energy demand (heat, steam, and electricity) was met by biogas, bio-oil, and solid biomass (agricultural waste and eucalyptus plantations). This incremental production followed the technological breakdown of the *Below 2°C* scenario, in which the steam cracking of naphtha accounted for 75% of ethylene production, which is also used to produce green polyethylene. To assess the emissions of the entire life cycle of bioplastics, it was considered that the final disposal (landfill and recycling) would follow the same current pattern.

The *Bioeconomy Potential* scenario considered bionaphtha as a raw material to produce ethylene, propylene, butadiene, and biologically-based BTX – biochemicals with high added value. Bionaphtha is co-produced in the biomass-to-liquids (BTL) process, using the Fischer-Tropsch process to produce advanced biofuels such as green diesel and aviation biokerosene. As a simplification, the only input considered was eucalyptus-planted forest and it was assumed that the increase in the area used would come from the recovery of degraded pasture. It was assumed that the other products of the BTL process – biokerosene, bio-LPG, and green diesel – would be exported, potentially contributing to the decarbonization targets of maritime and air transport in other countries. It is very important to point out that

[5] In Oliveira et al. (2021) the Below 2°C scenario appears named as WB2 scenario (Well-below 2°C)

this potential for decarbonization of exported products in this scenario is not accounted for in Brazil's accumulated GHG emissions up to 2050, presented in this study, and, in fact, it represents a potentially additional element for the *Bioeconomy Potential* scenario.

The changing profile of Brazilian beef production was also considered, assuming that part of Brazilian beef production in 2050 (approximately 14 million tons) (FAO, 2018) would migrate to cultured beef systems so as to increase the area for sugarcane and forests necessary to produce biochemicals. Among the possibilities of alternative proteins, cultured meat is the one that presents the greatest technological challenges and greatest energy intensity. Thus, this can be considered an underestimation of the alternative protein expansion. In addition, it was considered the production of a 7% surplus of cultured meat with a focus on export and that the energy demand resulting from the production of cultured meat would be supplied by biogas.

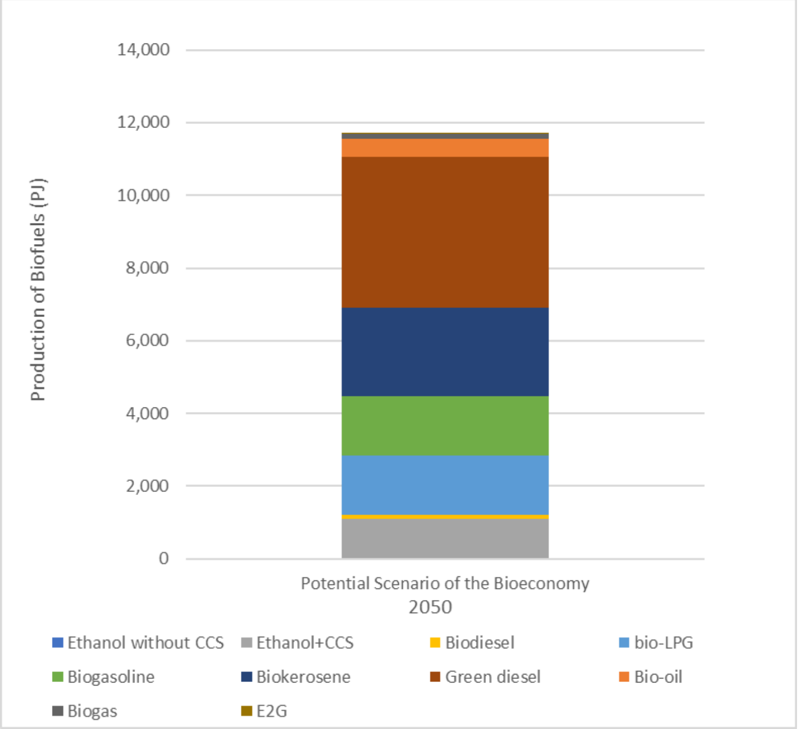
In traditional protein production, the use of additives in animal feed capable of reducing enteric CH_4 emissions from dairy cattle by 30% was assumed. Only dairy cattle were considered since this type of breeding necessarily uses the practice of confinement or semi-confinement of cattle, which guarantees adequate control of the animal feed.

In the *Bioeconomy Potential* scenario, BTL technologies proved to be key processes both to meet the domestic demand for advanced biofuels and to expand the production of green diesel and aviation biokerosene for export, with the co-production of bionaphtha, the main raw material to produce high-added-value chemicals from steam cracking. In addition, there was also a small expansion of the production of first-generation ethanol with CCS to produce ethylene. Thus, in the *Bioeconomy Potential* scenario, the share of biopolymers reached 53% of total production in 2050 (charts in Appendix II).

The electricity and primary energy matrix in Brazil did not change in relation to the *Below 2°C* scenario, except for biogas, eucalyptus, and agricultural waste, added exogenously to meet the new energy demands for the production of biochemicals and cultivated protein. Thus, there was an increase in the production of traditional (first-generation ethanol) and advanced (BTL) biofuels, both with the inclusion of CCS to reduce the carbon footprint of the production of these biofuels.

Biofuel production increased from approximately 430 PJ in 2010 (biodiesel and first-generation ethanol) to 6,500 PJ in 2050 in the *Below 2°C* scenario and to 11,600 PJ in the *Bioeconomy Potential* scenario. In addition to the production of 1G ethanol with CCS and the production of advanced biofuels via BTL, the scenario included the incorporation of the production of biogas and 2G ethanol using sugarcane bagasse from the production of 1G ethanol with CCS.

Chart 2 - Total biofuel production in the Potential Bioeconomy Scenario in 2050.



To support the sustainable expansion of the production of advanced biofuels and bionaphtha, it was necessary to expand the production of sugarcane and eucalyptus and to use agricultural residues. To this end, it was necessary to replace only 7% of beef production with cultured meat to free up the necessary area – around 6.1 million hectares. Total meat production was further expanded by 2 million tons (cultured meat), equivalent to 14% of Brazil's domestic demand in 2050 in the *Below 2°C* scenario, with a focus on exports.

The use of additives in dairy cattle feed avoided accumulated emissions of 717 thousand tons of CH_4 (20 million tons of CO_2eq) by 2050. Adding the capture of CO_2 in biofuel production technologies, the carbon stock in biomaterials for long-term applications, and also considering the emissions avoided by replacing traditional beef, fossil fuels, and fossil petrochemicals, the CO_2eq emissions were reduced by almost 550 million tons of CO_2 in relation to the *Below 2°C* scenario in 2050 (Appendix II).

Brazil also starts exporting large amounts of biofuel (3,732 PJ) and biochemicals (8,225 kt). That is, Brazil, in addition to reducing its emissions and achieving an energy matrix with negative emissions, helps the decarbonization of other countries with the export of bioproducts.

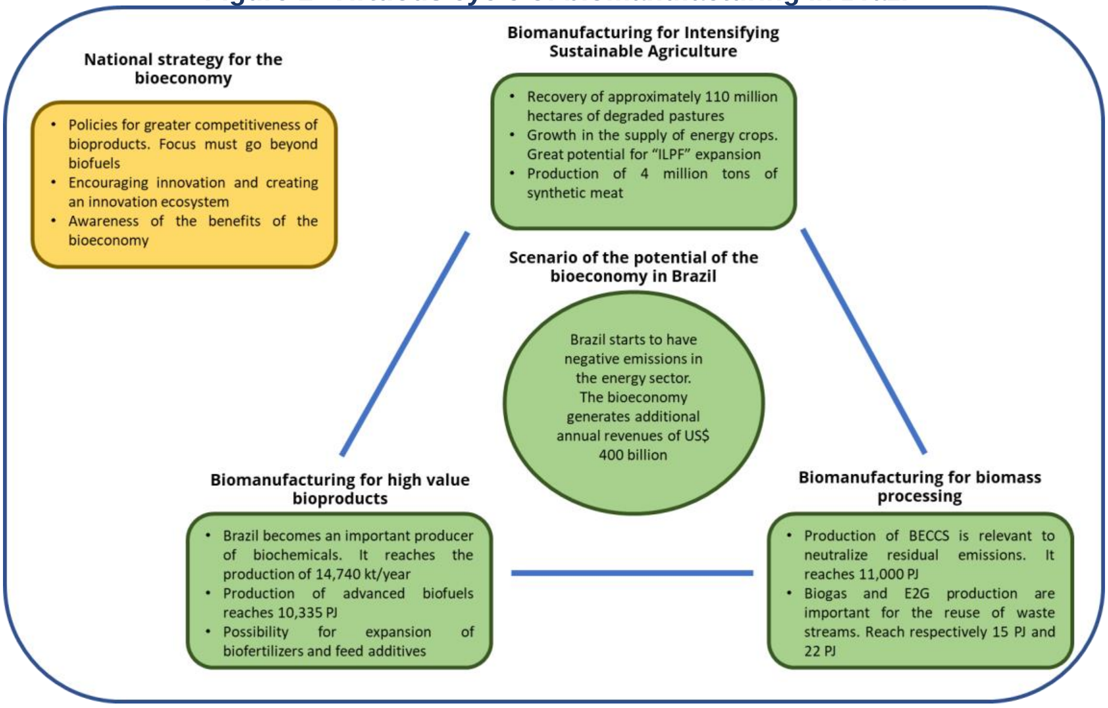
A preliminary economic assessment shows that there is an increase of around US$ 284 billion/year in the revenue of the selected technologies in relation to the *Current Policies* scenario in 2050, considering a carbon pricing scenario of US$ 50/tCO_2 (Table 5). To calculate the estimated income, the same market price was considered for fossil and renewable alternatives, so ethylene and bioethylene would have the same market value. However, a GHG mitigation bonus was granted to the renewable products by the GHG emission reduction service. This conservative premise, however, shows the potential for adding significant market value to products arising from bioinnovation. The necessary investments were estimated at around US$ 45 billion in the *Bioeconomy Potential* scenario, with 17% of the total destined for the production and conversion of biogas, and 62% destined for the new naphtha steam cracking capacity.

Table 5 - Income from the production of biomaterials, advanced biofuels, and meat in the evaluated scenarios.

BILLION US$/YEAR BY 2050	CURRENT POLICIES SCENARIO	BELOW 2°C SCENARIO	POTENTIAL OF THE BIOECONOMY SCENARIO	MITIGATION BONUS: POTENTIAL OF THE BIOECONOMY SCENARIO
Petrochemicals	23.6	16.1	16.1	
Biochemicals	0.2	7.7	17.4	
Advanced biofuels	23.5	160.9	266.1	27.4
Traditional beef	61.0	61.0	56.7	
Alternative proteins	0.0	0.0	8.5	
Total	**108.3**	**245.7**	**364.9**	**392.2**

Figure 1 summarizes, by biomanufacturing category, some of the values achieved in the *Bioeconomy Potential* scenario. It shows that the bioeconomy needs to be seen in a systemic way, involving the combination of the 3 classes of biomanufacturing to create a virtuous cycle that seeks to optimize land use in Brazil with the development of processes and bioproducts that meet the decarbonization needs of the economy. This virtuous cycle of the bioeconomy will only exist if there are adequate economic incentives for agents to adopt best practices and there are investments in new technologies. Therefore, it is necessary to establish a bioeconomy development agenda.

Figure 1- Virtuous cycle of biomanufacturing in Brazil.



It is worth remembering that, according to the *Current Policies* scenario, which considers the maintenance of the current economic policies in force, Brazil does not reach emission neutrality. For the transition to a low-carbon economy to take place, it is necessary for the government to have a greater commitment to a decarbonization agenda and, specifically in the case of Brazil, it is important to think about an agenda to build a bioeconomy.

National bioeconomy development strategies are already being applied in several regions of the world. As can be seen in greater detail in Appendix III, countries such as the USA, European countries, and Costa Rica have national strategies aimed at the bioeconomy. They combine industrial policies, aimed at specific sectors, policies aimed at innovation, which enable risk sharing among agents, and market policies, such as the establishment of carbon markets. As the report "Creating the Biofuture: A Report on the State of the Low Carbon Bioeconomy" shows, the construction of a national strategy focused on the bioeconomy needs to reconcile a mix of policies that involve market policies and innovation policies (BIOFUTURE PLATAFORM, 2018).

Market policies are those that seek to create an environment of greater competitiveness for bioproducts and bioprocesses by correcting market failures, that is, internalizing environmental benefits in the price of bioproducts, establishing blending mandates, or using the purchasing power of governments and public companies. In general, they are policy instruments that used for more mature technologies.

Innovation policies seek to reduce the cost of research and development for stimulating new ideas and reduce the cost of technology. They allow the sharing of innovation risks between the public and private sectors, which facilitates access to credit for innovative projects and channels capital to key sectors of the bioeconomy. In short, it helps create an innovation system.

CONCLUSIONS

Despite adopting the goal of reaching zero emissions by 2060, the current scenario of policies in Brazil is not consistent with meeting the established goals. Through the actions described in Chapter III and with the projections made in Chapter IV, it is clear that following the *Current Policies* scenario results, in 2050, in an energy matrix that is very intensive in fossil inputs and that far exceeds the Brazil's carbon budget, estimated at 14 $GtCO_2e$ by 2050, as can be seen in Chart 6 (Annex II).

When using the carbon budget as a restriction, the energy matrix changes significantly, with fossil resources going from 62% in the *Current Policies* scenario to 14% in the *Below 2°C* scenario. This substitution is mostly made with the use of biomass, which becomes the main source of primary energy in Brazil. This pattern contrasts with the worldwide trend of energy transition, presented in Chapter I, which is strongly based on electrification and expansion of solar and wind sources. In the Brazilian case, biomass and biofuels are the most competitive solution with the possibility of faster and more sustainable implementation.

As is clear in Chapters I and II, discussing bioenergy is inseparable from the bioeconomy. The challenges of building sustainable biomass supply chains and processing it at scale are common among the variety of bioproducts. The use of biomass is essential for meeting the mitigation goals, as it is the only viable option capable of generating negative CO_2e emissions. However, for this capture to actually occur, it is necessary for the supply of biomass to grow within sustainability parameters. The projections consider the recovery of around 102 million hectares of degraded pastures for the development of energy crops with the use of integrated production systems.

In addition to biofuels, the model observed that, between the *Current Policies* and *Below 2°C* scenarios, the production of biopolymers as a proportion of total polymers increases from 1%, in the *Current Policies* scenario, and reaches approximately 33%, in the *Below 2°C* scenario. In the projections, the production of biomaterials is important to reduce the use factor of oil refining, thus affecting the production of fossil fuels. They also store biogenic carbon when used in long-term applications.

The *Bioeconomy Potential* scenario represents the construction of a broad bioeconomy, with the inclusion of technologies not considered in the *Below 2°C* scenario. With it, it was possible to assess the potential of Brazil's economic development through the adoption of public policies toward low-carbon scenarios associated with an increase in the production of bioenergy and bioindustrial inputs with high added value. It is clear that, due to the domestic agricultural potential, the country has sufficient means of producing bioinputs to meet domestic demands and without needing to increase pressure on areas of native forest, rather it is only necessary to improve production systems to make them more sustainable and productive.

However, for Brazil to be able to take advantage of these opportunities, its domestic industry must seek to orient itself toward the bioeconomy production model. The sustainable use of biological resources is essential to meet both the most restrictive climate goals and the country's economic development. As has been stated, the country has the possibility of achieving additional industrial revenues of around US$ 392 billion through bioinnovation, more than US$ 284 billion/year, when compared to the *Current Policies* scenario. To that end, an investment of around US$ 45 billion is necessary. It is important to highlight that this preliminary assessment does not consider the enormous economic potential existing in other forms of bioinnovation, based on the exploration of Brazilian biodiversity.

Other studies have sought to assess the contribution of the bioeconomy or its growth potential for the Brazilian economy. Silva, Pereira, and Martins (2018), for example, estimated the value generated by the bioeconomy in Brazil in 2016 to be around US$326 billion in revenue in 2016 (SILVA; PEREIRA; MARTINS, 2018). However, the definition of bioeconomy used considers the biomass producing and processing industries without relating any criteria of environmental and social sustainability. ABBI, in 2020, in turn, made an effort to assess the contribution of industrial biotechnology, just one part of the bioeconomy, to the Brazilian economy. ABBI concluded that by 2040, biotechnology could increase Brazilian GDP by US$ 53 billion (CNI, 2021).

The present study has a more restricted definition of bioeconomy than the definition adopted by Silva, Pereira, and Martins (2018), as it considers the need to meet sustainability criteria. The projected growth of the bioeconomy is consistent with a low-carbon economy, with zero deforestation and without impacting food production.

The most impressive thing in the comparison between the *Bioeconomy Potential* and the *Below 2°C* scenarios is that, despite the enormous growth in the production of biofuels (from 6,500 PJ to 11,600 PJ), of biochemicals (from 6,516 kt to 14,741 kt) and revenues (an increase of US$ 120 million), GHG emissions dropped. Therefore, the bioeconomy is capable of decoupling increased production and economic growth from increased emissions. In fact, it reverses the relationship. The reduction in emissions is largely due to the recovery of approximately 6 million hectares of pastures and the production of biofuels associated with carbon capture and storage. Comparing the two scenarios there is an accumulated reduction of almost 550 million tons of CO_2eq in the period between 2010 and 2050in the *Bioeconomy Potential* scenario compared to the *Below 2°C* scenario.

It is important to consider that for the transition to a bioeconomy, Brazil has large biomass processing sectors that serve as a starting point for building a bioeconomy. The sugar and energy, pulp and paper and the soy complex sectors have already accumulated a set of capabilities, such as access to competitive biomass, which facilitate the expansion process of biorefineries. However, significant investments in research & development are still needed to overcome the challenges of building new supply chains, which include regional raw materials without generating deforestation, for the development of processing technologies that allow the full use of the biomass and for the development of new bioproducts, which enable the construction of biorefineries and generate greater aggregate income.

The construction of the *Bioeconomy Potential* scenario is not an attempt to predict the evolution of the bioeconomy. It presents a viable possibility that can be built. However, the construction of this trajectory will only be possible if there is an effort by public policies that consider Brazil's specific characteristics in the context of the transition to a low-carbon economy. In other words, a national strategy is needed that thinks about the bioeconomy in a systemic way, from the search for sustainable biomass supplies to encouraging the production and consumption of bioproducts and bioenergy.

For Brazil, this means deepening existing policies and developing new ones. It is necessary that the current policies, focused on biofuels, move forward and also start to contemplate other bioproducts. Also relevant are innovation policies that guide investments in the 3 classes of biomanufacturing technologies – (i) sustainable intensification of agriculture (ii) conversion of biomass into energy products, (iii) conversion of biomass into higher value-added products – which, when combined, can generate synergistic effects to ensure food production and the development of advanced biorefineries in the country.

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APPENDIX I

THE THREE WAVES OF ALTERNATIVE PROTEINS

The first wave, which now counts on the availability of competitive protein sources, is plant-based proteins, that consist of proteins of vegetable origin. Technological challenges in relation to the supply of protein are not major barriers, since it is largely a matter of replacing meat consumption with plant foods rich in protein, such as chickpeas and beans.

The biggest challenge is cultural, since meat consumption is well established and difficult to change. In this sense, there is the development of technologies that seek to mimic animal protein through vegetables processing. According to Morach et al. (2021), these technologies are already at an advanced level and should be competitive with traditional protein from 2023.

The second wave deals with the production of meat based on the use of microorganisms, which includes proteins produced with bacteria, yeasts, unicellular algae, or fungi that are flavored and textured into edible products. The process starts with a specific strain of microorganism which is then grown in a carbohydrate-rich solution to produce protein through fermentation (MORACH et al., 2021). The technology to produce this type of protein is not new, it dates from at least the 1980s. However, for the necessary scale and for the parity of texture and flavor with animal protein there are still technological challenges that need to be resolved. Cost parity with animal protein should be achieved in 2025 (MORACH et al., 2021).

Finally, the third wave encompasses the "cultured meat" or cell-based protein that is characterized by the extraction of specific animal cells and their subsequent multiplication in bioreactors that use a growth medium rich in nutrients to feed the multiplication of cells, and energy to maintain ideal temperature and hygiene conditions. In this technological option, the meat produced is of animal origin, but to become a perfect substitute, it is necessary to use 3D printing technologies so that the texture and shape of traditional meat are mimicked (REIS et al., 2020).

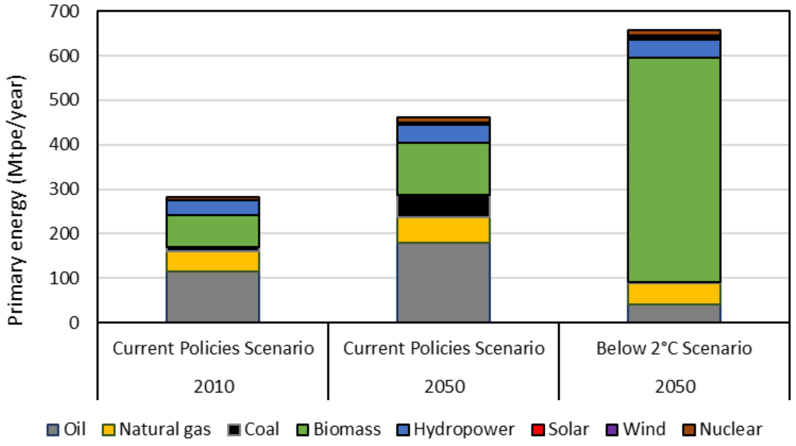
This is the most incipient technological option and has a great diversity of companies developing their own technologies and processes in an isolated way, thus, there are no dominant designs that will determine the process of industry structuring (REIS et al., 2020). However, it can already be claimed that the production pattern is disruptive in relation to the traditional way of producing meat since the non-necessity of livestock production allows productive decentralization. Even in its infancy, Morach et al. (2021) project that in 2032 cultured meat will be competitive with traditional protein.

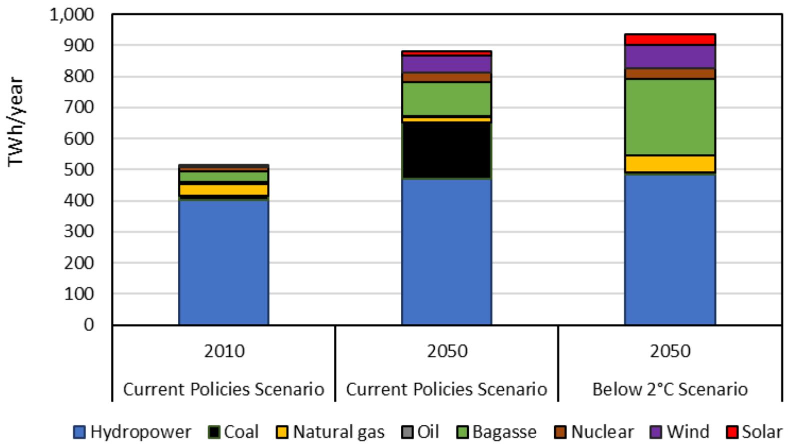
APPENDIX II

BUILDING SCENARIOS

The initial results of the BLUES model scenarios showed a clear need to replace fossil energy sources such as coal and oil with renewable sources, mainly from biomass. Regarding primary energy, the participation of fossil sources dropped from 62% in the *Current Policies* scenario to 14% in the *Below 2°C* scenario. As a result, there was an expansion from 35% of the share of renewable sources in the *Current Policies* scenario to 84% in the *Below 2°C* scenario. This increase was due to the expansion in the use of biomass and sugarcane to produce electricity and biofuels associated with carbon capture and storage (BECCS).

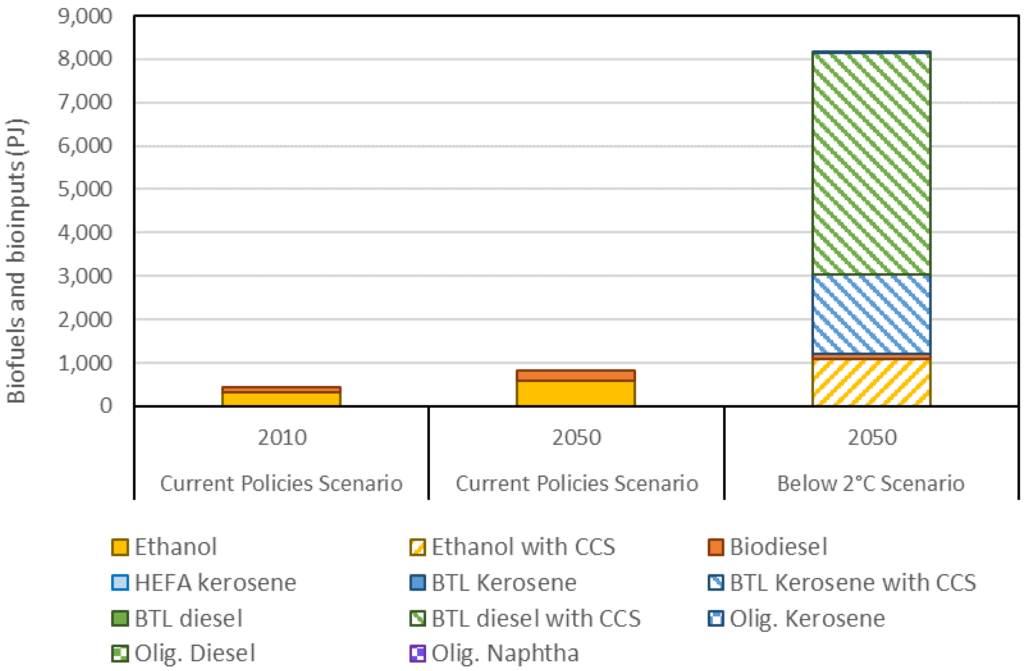
Chart 2 - a) Primary energy in the BLUES scenarios; b) Electric generation in the BLUES scenarios.





This change in the profile of Brazilian energy production was necessary given that the restriction of the carbon budget in 2050 (14 $GtCO_2$) generates the need to implement mitigation measures both in the electricity sector, as well as biofuels and land use. In the *Current Policies* scenario, accumulated Brazilian emissions from 2010 to 2050 reached the level of 41 $GtCO_2$ while the *Below 2°C* scenario only 14 $GtCO_2$. As a result, the model had to adopt several CO_2 mitigation measures associated with BECCS, such as the production of advanced biofuels including BTL and 1G ethanol, changes in soil cover to covers with a greater carbon stock above the ground (recovery of pastures, planted forests, and integrated systems) and production of polymers from agricultural feedstocks (planted forests, soy, and sugarcane) for carbon storage. It is important to point out that these changes in the energy profile for biomass-based sources result from the fact that it is the only possible means of obtaining negative CO_2eq emissions, given that CO_2 is captured during the vegetative development of the biomass and later there is a new capture during the industrial process to produce this energy source. This does not happen when using fossil sources associated with CCS.

Chart 3 – Production of biofuels in the BLUES scenarios.



In this context, the model observed the increase in the production of polymers from renewable sources as being important, increasing the share of biopolymers from 1% in the *Current Policies* scenario in 2050 to approximately 33% in the *Below 2°C* scenario (in both cases the demand is the same in 2050). This increase in share was mainly due to the large-scale use of bionaphtha (BTL) to produce ethylene, propylene, butadiene, and BTX, ethanol dehydration for the productio of ethylene and catalytic reforming for the production of BTX.

Chart 4 - Total production of beef and synthetic meat in the evaluated scenarios

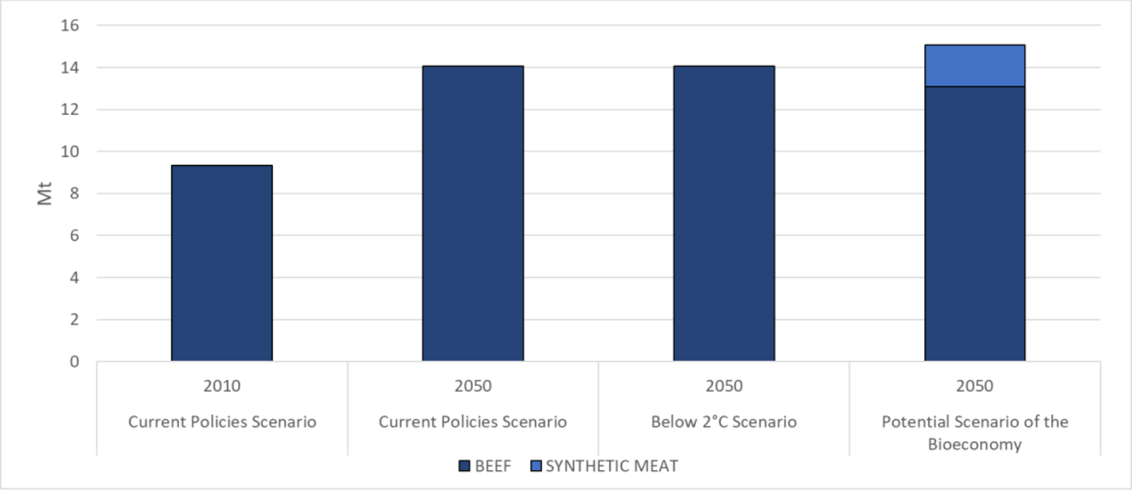


Chart 5 - Balance of CO_2 emissions from the "Potential Scenario for the Bioeconomy in Brazil" in relation to the Below 2ºC scenario

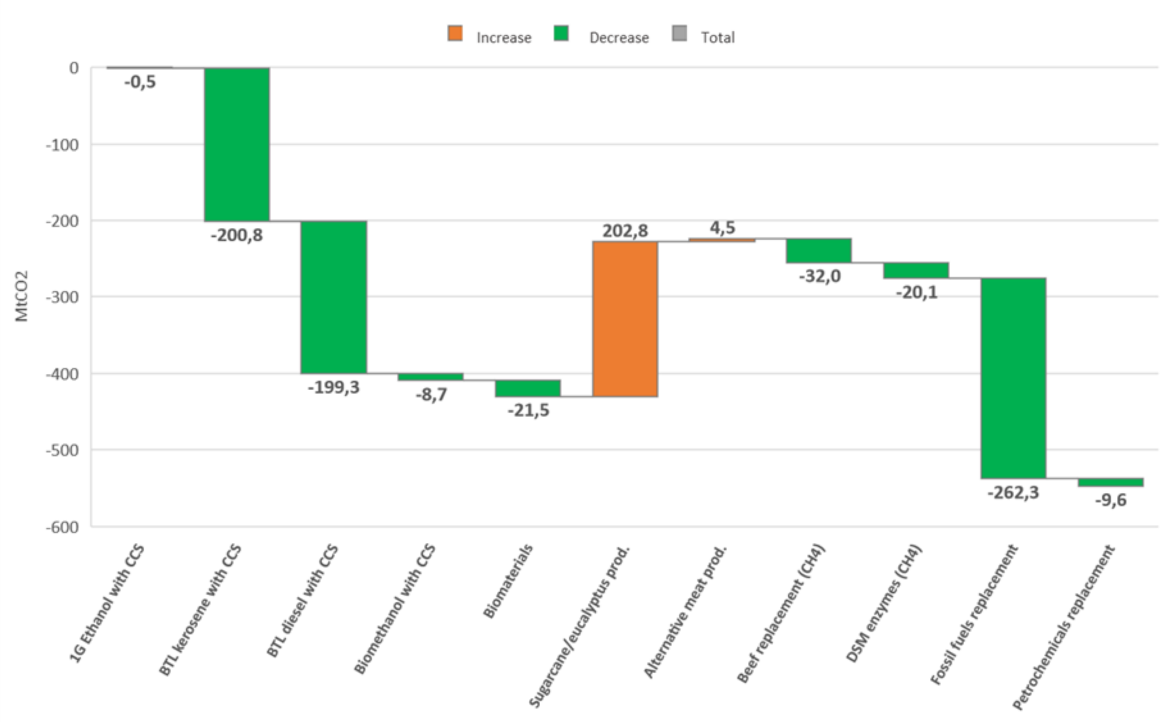
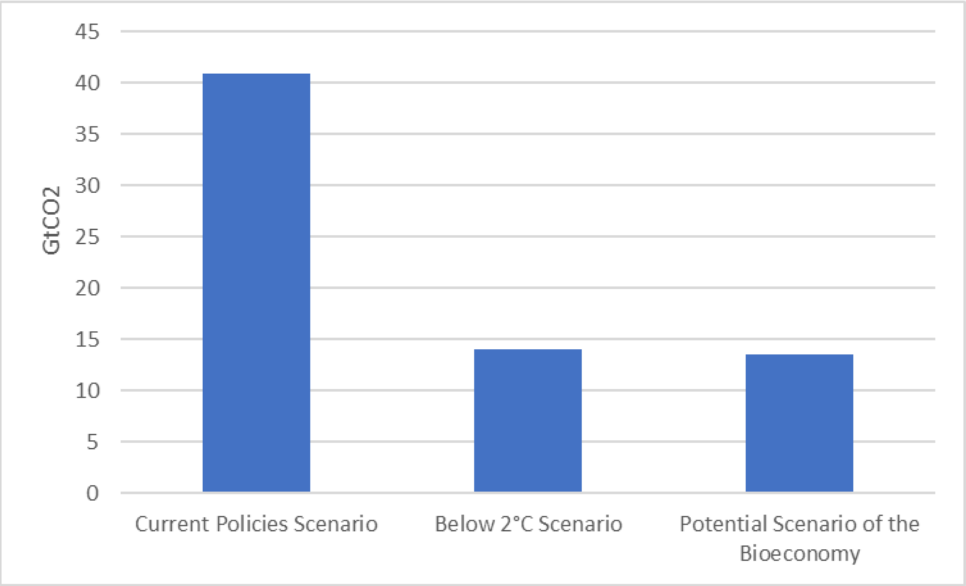


Chart 6 – Accumulated CO2 emissions between 2010-2050 in the evaluated scenarios



APPENDIX III

CARBON MARKETS AND NATIONAL BIOECONOMY DEVELOPMENT STRATEGIES

Carbon markets are increasingly present globally. According to the World Bank (2021), in 2021, about 21.5% of global GHG emissions were covered by carbon pricing mechanisms, a value 6.4% higher than that recorded in 2020. There are currently 61 carbon pricing initiatives either in existence or programmed for implementation, consisting of 31 carbon credit trading mechanisms (ETS) and 30 that levy a carbon tax (WORLD BANK, 2021).

In Brazil, the Climate Law, cited in Chapter IV, provides for the implementation of a carbon market in the country, however, it was only in 2021 that a Bill (PL nº528 of 2021) seeking the creation of a regulated domestic carbon market started its passage through congress (BRASIL, 2021). RenovaBio, established by the National Biofuel Policy (Law No. 13,576, of December 26, 2017), presents a concrete initiative to create a carbon market in Brazil. The mechanism successfully adopted by this policy for the transport sector could be expanded to also include other low-carbon bioproducts and processes and so promote the replacement of conventional alternatives based on fossil sources.

At the international level, the Kyoto Protocol of 1997 created the guidelines for the construction of the international market for carbon credits. Despite the non-adherence of major countries, the protocol served to establish the Clean Development Mechanisms (CDM), a voluntary carbon market that has increasingly relied on the participation of countries and institutions, such as companies committed to ESG principles. At COP 26, a proposal was presented to create a carbon market, managed by the UN to replace the CDM (WORLD BANK, 2021), capable of transforming reductions in greenhouse gas emissions into more reliable assets. Although carbon markets already exist, their formats are fragmented and lack transparency, hence defects in search of solutions with criteria that strengthen their robustness, credibility, and reach.

The development of carbon markets is one of the significant ways for building the bioeconomy, since they are means of pricing the environmental benefits generated by the production chains of bioproducts. It is important to note that these benefits must be quantified in an appropriate and comprehensive manner, addressing aspects other than greenhouse gas emissions and mitigating risks associated with the transition to a bioeconomy. Thus, the valuation of the different ecosystemic services provided by the production chains of the bioeconomy enables ventures that, under normal conditions of competition, would not be competitive in relation to the substitutes of fossil origin. The markets have a transversal action, that is, they impact different sectors and different links within the production chains. Therefore, they provide a broader incentive, going far beyond biofuels, which generally enjoy greater public support.

The advancement of the bioeconomy needs to reconcile a mix of policies that vary from market incentive policies to technological incentive policies. It is essential to establish a national strategy for the development of the bioeconomy that coordinates the different policies and creates a predictable environment for private investments (BIOFUTURE PLATAFORM, 2018). At least 50 countries already have policies that are somehow related to the bioeconomy, however, the number of countries with national strategies for building the bioeconomy is small (OECD, 2018).

The US is one of those countries with national strategies for building the bioeconomy. The country has a set of policies that seek to develop new raw materials and new technologies with varying degrees of technological maturity. Regarding incentives for innovation, the US has an aggressive policy of subsidizing research and development for pilot and demonstration plants through grants. As an example, the Biomass Program and the Bioenergy Program for Advanced Biofuels are thematic programs that annually provide millions of dollars in grants for R&D projects and for scaling-up new technologies (PEREIRA; BOMTEMPO; ALVES, 2015; USDA, 2021a).

In addition to grants, the US has an aggressive policy of guaranteed credits for the construction of biorefineries or the retrofit of old oil refineries into biorefineries. The Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program has guaranteed lines of credit of up to US$ 250 million (USDA, 2021b). Through this instrument, the government guarantees the payment of the debt of companies that invest in biorefineries if they are unable to honor their obligations with financial intuitions. As there is no risk of default, companies get lower interest rates and easier access to credit lines.

As for market incentives, the Renewable Fuel Standard in the US establishes mandates for blending biofuels with fossil fuels. The program is interesting because it establishes different and progressive mandates for different biofuels in different stages of maturity, including for advanced biofuels (PEREIRA; BOMTEMPO; ALVES, 2015). The objective is to create secure markets for new ventures to gain scale and reduce costs. In addition to biofuels, in the US there is the BioPreferred Program, which requires federal agencies and other government bodies to give purchase preference to bioproducts that meet a minimum percentage of biological content, verified by an external laboratory. The program is important because it uses the immense purchasing power of the US government to leverage the production of bioproducts. The program also created voluntary labeling for bioproducts (USDA, 2021c).

In Europe, several countries such as Germany, France, and Finland have national bioeconomy strategies. However, in the regional context, what draws attention is the European Green Deal, which includes a broad set of policies aimed at meeting the goal of reaching zero emissions on the continent by 2050. It involves GHG reduction targets, the creation of a European ETS, and innovation promotion programs, which include the provision of grants and other forms of incentives, such as Horizon Europe (WYRWA, 2020).

Europe has also launched a sustainable taxonomy that serves to categorize investments according to their environmental impact, thus facilitating the directing of private investments towards projects that really contribute to the advancement of the bioeconomy. In the European case, the European Investment Bank (EIB), a regional development bank, is an important instrument in the transition to the bioeconomy. It acts as a catalyst for long-term financing for the bioeconomy, as it provides technical and financial support for commercial banks to be able to offer long-term credit lines and low interest rates for investments related to the bioeconomy and the circular economy. The EIB is also the main stakeholder of the European Circular Bioeconomy Fund, an investment fund dedicated to investing in other investment funds that operate in the bioeconomy area (EIB, 2021).

Closer to Brazil, Costa Rica is the country with the most ambitious strategies for building the bioeconomy. In 2018, the country launched its National Bioeconomy Strategy 2020-2030, which operates in five thematic areas: (1) rural development, (2) biodiversity, (3) biorefineries and residual biomass, (4) advanced bioeconomy (focus on biotechnology), and (5) “green” cities. The strategy is currently at the stage of identifying a set of strategic projects to boost the bioeconomy and creating a legal framework that will allow the development of the bioeconomy (MICITT, 2018).

The strategies herein mentioned show that countries and regions understand the bioeconomy in a systemic way, going far beyond biofuels. They realize that it is not possible to advance the bioeconomy without reinforcing the idea of the biorefinery, where synergies between biofuels and bioproducts are harnessed, and without building a sustainable supply of biomass. Another point that is clear is the need to create means to facilitate the development of technologies with different degrees of maturity and, therefore, reconcile policies aimed at innovation with market policies.

The realization of the projections in this report indicates the need for carbon pricing, thus providing competitiveness for technologies, especially those already mature, which will produce biofuels to replace fossil fuels. It also shows that the transition to a carbon-neutral economy will only occur if there is an advance in the production of bioproducts, such as bioplastics, which reduce the need for oil refining, can capture carbon, and promote the feasibility of biorefineries. Another point, more disruptive technologies, present in the *Bioeconomy Potential* scenario, which are important to deliver a more sustainable supply of biomass and increase income in the country, require policies to encourage innovation, which allow them to leave their niches and advance on the markets.

That is, the realization of the scenarios put forward requires a national strategy that looks at the bioeconomy as a whole. Currently, Brazil has important policies aimed at biofuels, but it leaves out other bioproducts. Another significant point is that policies aimed at low-carbon agriculture are few in relation to policies aimed at traditional agriculture and are unrelated to policies for building biorefineries and harnessing biodiversity.

ABBI
BRAZILIAN BIOINNOVATION ASSOCIATION

www.abbi.org.br

+55 11 3569-3564

contato@abbi.org.br

Rua Gomes de Carvalho, 1581 Conj. 901|902
04547-000 - São Paulo, SP - Brasil