



# FLIGHTPATH TO AVIATION BIOFUELS IN BRAZIL: ACTION PLAN





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an initiative of  
Boeing/Embraer/ FAPESP and UNICAMP

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## Sponsors



## Stakeholders





## Foreword

The aviation industry is committed to reducing its environmental impact and has established ambitious goals to reach carbon neutral growth by 2020 and to reduce carbon dioxide emissions by 50% (from 2005 levels) by 2050. Currently, the aviation industry generates approximately 2% of man-caused carbon dioxide emissions; it is a small but growing share that is projected to reach 3% by 2030.

Boeing and Embraer, as leading aviation companies committed to a more sustainable future, have joined efforts to support initiatives to lower greenhouse gas (GHG) emissions derived from air transportation. These emissions represent an important global concern in the 21<sup>st</sup> century, and the growing aviation industry will need to find ways to reduce its contribution, particularly in substituting fossil fuels by sustainable biofuel.

Airlines are doing their part as well. Globally, they have created the Sustainable Aviation Fuel Users Group (SAFUG), an organization focused on accelerating the development and commercialization of sustainable aviation biofuels.

Brazil is internationally recognized for its long experience of using biomass for energy purposes beginning with wood, sugarcane ethanol, and biodiesel. Modern bioenergy represents around 30% of the Brazilian energy matrix, and has a long track record reconciling biofuel production, food security and rural development. Much of what Brazil has done in the bioenergy area was accomplished by long-term policies and investment in research and by building up human capacity.

In this context, Boeing, Embraer and FAPESP initiated this project to conduct a national assessment of the technological, economic and sustainability challenges and opportunities associated with the development and commercialization of sustainable biofuel for aviation in Brazil. UNICAMP was selected for the coordination of this study, with the charter to lead a highly qualified, multi-disciplinary research team. The project team conducted eight workshops with active participation of over 30 Stakeholders encompassing private sector, government institutions, NGOs and academia. The assessment included the most important topics from agriculture, conversion technology, logistics, sustainability, commercialization and policies. The result of this effort is this *Flightpath to Aviation Biofuels in Brazil: Action Plan* originated from the open dialogue and diverse views of the Stakeholders. The report lays out the grounds to establish a new biofuels industry to replace jet fuels. In the process, we confirmed that Brazil is a place of great promise to help the world to alleviate fossil fuel dependence in aviation.

The development of a new industry will entail the participation of different sectors of the Brazilian economy including not only research institutions and biofuels producers, but also feedstock producers, financial institutions, international relations groups, academia, the aviation industry, and environmental and social advocacy groups. In developing sustainable aviation biofuels Brazil is seen as a key player, having a unique strategic advantage worldwide.

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*The Sustainable Aviation Biofuels for Brazil Project* used a Facilitator team to implement the studies and was composed by the research team from different institutions and the support team from UNICAMP.

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## Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the participating parties. The results, analysis, conclusions or recommendations expressed in this report are based upon a series of multi-stakeholder workshops, technical presentations, data gathering, benchmarking or otherwise specified assumptions and parameters. To the extent permitted by the law, the participating parties exclude all liability to any party for any loss, expense, damage or cost incurred directly or indirectly from using this report.

## Acknowledgements

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# Executive Summary

## MAPPING AVIATION BIOFUELS FOR BRAZIL

The aviation industry has set ambitious goals to reduce carbon dioxide emissions in order to grow on a sustainable basis. While fuel efficiency can go far, achieving industry emissions reduction goals will require biofuels that are sustainably produced and comply with the technical necessities of aviation. Over the next 20-40 years, the industry will transition towards the use of sustainable biofuels to replace petroleum-based jet fuels. The use of biofuels in aviation will have to be effective, efficient, and advantageous from environmental, social and economic perspectives.

With these objectives in mind, Boeing, Embraer and FAPESP in October 2011 formally agreed to investigate how Brazil could contribute to this endeavor. The result was *Sustainable Aviation Biofuels for Brazil*, a national assessment of the technological, economic and sustainability challenges and opportunities associated with the development and commercialization of sustainable aviation biofuel in Brazil. UNICAMP was selected for the coordination of this study, with the charter to lead a highly qualified, multi-disciplinary research team. The process confirmed that Brazil has great potential to supply aviation biofuels for domestic and international markets.

The project team conducted eight workshops across Brazil, including São Paulo, Rio de Janeiro, Brasilia and Minas Gerais, with active participation of over 30 Stakeholders encompassing the entire prospective aviation biofuel supply chain, including industry, agriculture, government, NGOs and academia. The assessment covered feedstock production and delivery, conversion technology, fuel delivery logistics, sustainability and policies. In addition, there were three regional outreach workshops, facilitated by EPFL and 4CDM. The result of this effort is Flightpath to Aviation Biofuels in Brazil: Action Plan.

This roadmap lays out the pathways to establish a new biofuels industry to replace petroleum jet fuels. It includes recommendations for:

- filling research and development gaps in the production of sustainable feedstocks;
- more incentives to overcome conversion technologies barriers including scaling up issues;
- greater involvement and interaction between private and government stakeholders;
- creation of a national strategy to make Brazil a leading country in the development of aviation biofuels.

## AVIATION'S NEEDS AND VITAL ROLE

The aviation industry requires sustainable “drop-in biofuels,” meaning fuels that equal all performance characteristics of fossil fuel. While not yet cost-competitive, “drop-in” jet biofuel

has been demonstrated with a number of tests and commercial flights by airlines. Work to drive costs down to competitive levels is under way in many parts of the world. Important challenges include scaling up combined feedstock and refining technology pathways, and improvements in logistics and deployment.

Aviation is absolutely essential. According to the International Air Transport Association, the industry contributes about US\$ 3.8 trillion per year to the global economy, supporting the employment of 32 million people. In Brazil air transportation is growing faster than the global average. Brazil is forecast to become the 4<sup>th</sup> largest domestic air traffic market in the world by 2014. In 2010 the Brazilian aviation sector carried over 71 million passengers and 870 thousand tonnes of air freight to, from and within Brazil. Brazilian aviation in 2009 contributed with R\$ 32 billion to the national GDP and employed about 684 thousand people. Brazilian jet fuel demand in 2011 was 7 million cubic meters, about 2.8% of global demand, of which the Brazilian refineries produced 75% and the rest was imported.

## ENSURING SUSTAINABILITY

Not all bioenergy is sustainable energy. Fuels should be developed using strong sustainability criteria and verification to meet the needs of the aviation industry. *The Sustainable Aviation Biofuels for Brazil* assessment on the sustainability criteria for the production of feedstocks in Brazil was carried out according to the principles and criteria of the currently available and most well-known international sustainability standards for biofuels production, such as Bonsucro or the Roundtable on Sustainable Biomaterials (RSB). It is important to discuss these issues, since sustainability certification will increasingly become a requirement for accessing markets, and since the standards and certification processes are complex and require adaptations of the supply chain. It is also critical to ensure that sustainability requirements are observed in practice, through certification and verification and through appropriate enforcement of applicable laws.

## IDENTIFYING PROMISING FEEDSTOCKS

The most promising potential feedstocks for jet biofuel are plants that contain sugars, starch, and oil, as well as residues such as lignocellulose, municipal solid wastes, and industrial waste residues. Brazil is the world largest producer of sugarcane, second of soybeans and has the lowest cost of production of eucalyptus; therefore, it can competitively produce all the above listed classes of feedstock. At this stage, these three crops can be considered the natural candidate feedstocks to start a jet biofuel industry in Brazil, depending on the conversion process selected. Proper policy should ensure that feedstocks for jet biofuel do not compromise food production. In addition, sugarcane and eucalyptus can be produced with a very significant life-cycle reduction of CO<sub>2</sub> emissions. There is room for improvements even for the more established

crops to further reduce costs and improve environmental records. Pine is also a promising forest option.

Several other crops that currently are not as well positioned as sugarcane, eucalyptus, and soybeans may become feasible options. However, they will require some additional efforts in R&D to become commercial crops with high yields (jatropha, camelina, sweet sorghum), reduced costs (jatropha, camelina, sunflower, peanuts, castor beans, palm and other oil-bearing crops), as well as to solve harvesting problems (jatropha, grasses). Considerable attention is being placed by public and private institutions to improve crops such as jatropha and camelina. Logistics improvements will be needed for most crops because the transport infrastructure in Brazil is poor and most feedstock are bulky material or have low unit value. This applies to both annual crops as well as to forest products. However, logistics may be more challenging for palm, which grows well in wet tropical areas that are far away from end-use locations.

Abundant supply of crop residues such as straw, sugarcane bagasse, and forest by-products (both from the field or industry) also makes this class of feedstock a good alternative. For these, collection and transportation costs, and questions of soil preservation are the main gaps and barriers that must be overcome.

After the Brazilian ethanol program was created in 1975, it not only helped the country alleviate its fossil-fuel dependence, but it also helped to modernize Brazilian agriculture. Since 1975 Brazil has become a net exporter of agricultural goods, including grains, meat and other products. Brazil is one of the world's best examples of reconciling sustainable biofuel production with food security. Brazil only utilizes 8% of its land for agriculture. The report concludes that the country has abundant available land for bioenergy through increasing productivity on existing agricultural lands.

## DEVELOPING REFINING TECHNOLOGIES

A range of conversion and refining technologies were evaluated including gasification, fast pyrolysis, solvent liquefaction, enzymatic hydrolysis of cellulosic and lignocellulosic biomass, alcohol oligomerization to jet fuel (ATJ), hydroprocessing of esters and fatty acids (HEFA), as well as the fermentation of sugars and wastes (i.e., municipal solid waste, flue gases, industrial wastes) to alcohols, to hydrocarbons (DSHC) and to lipids. All these technologies have potential to be considered for the production of jet biofuel.

In Brazil, several of these technologies are being tested, and used in demonstration flights as possible alternatives for sustainable biofuel for aviation. Besides technical barriers, commercial hurdles also need to be addressed, such as overall techno-economics and demonstrated GHG emissions savings. Further research, development and deployment is necessary to achieve commercialization of aviation biofuel refining technologies.

## FUEL AND FEEDSTOCK LOGISTICS

Jet fuel consumption is concentrated in the country's southeast, generally in cities not far from the seashore. On the other hand, there is abundant agricultural inexpensive land available in the interior of the country, far from the consumption centers (distances larger than 1,000-2,000 km). Therefore, improvement of feedstock and of jet biofuel logistics is a significant topic need for economic competitiveness of the various pathways for production of jet biofuel. The diversity of available feedstock and specific consumption sites in different regions of the country can impel the utilization of niche solutions taking advantage of long distance and high logistics cost, depending on installed competence for testing and certification of aviation fuels. This is also true for various locations of single point industrial waste residual emissions from growing steel production throughout Brazil which are often close to urban and industrial areas.

## A POLICY AGENDA FOR BRAZILIAN AVIATION BIOFUELS

Similar to other innovative technologies, the development of aviation biofuels depends strongly on support mechanisms and proper public policies. The adoption of ethanol and biodiesel in many countries required specific and active policies in order to reduce uncertainties and risk perception among producers and promote investments, as well to protect consumers and the environment.

The basic reasons behind these measures are the differential advantages and externalities of using a renewable energy, in comparison with conventional fossil fuels, in the context of a green economy. In fact, when produced and used sustainably, a biofuel is able to foster environmental benefits, jobs generation, economic activity and energy security. Long-term biofuels policies, which integrate fuels for all motorized transportation modes and recognize the particular need of aviation for sustainable fuel alternatives, will have to be established to make aviation biofuel economically viable due to the extra cost of producing a "drop-in" fuel.

Public policies are essential to develop agro-industrial technology for aviation biofuels, as well as to implement financial and regulatory measures able to support aviation biofuels production and use. Brazil is exceptionally well posed to put forward a program of aviation biofuels, with clear targets, clear supporting mechanisms and participation of all stakeholders.

Policies should also be structured to enable the participation of small farmers and/or local communities into the production jet biofuel chain so that they can also benefit from this new industry.



## RECOMMENDED ACTIONS:

### Feedstock Production

- agronomic research, particularly on non-traditional feedstocks;
- establish policies to create adequate conditions for better use of land;
- improve logistics infrastructure for feedstock transportation;
- evaluate the long term impact of biomass collection on soil water and biodiversity;
- evaluate existing available industrial waste residue feedstocks;
- establish sites that generate long-term data to support feedstock operation methodologies as a platform for soil, water and biodiversity study. In addition, monitoring and measurement against standards must be established;
- establish more rigorous law enforcement systems dealing with sustainability aspects of biofuels production.

### Refining Technologies

- process research on different identified pathways;
- establish pilot plants for most promising alternatives;
- establish demonstration and first-of-a-kind commercialization plants.

### Biofuel Logistics and Certification

- prepare the Brazilian set of Regulations for accepting biofuels according to ASTM approval process for synthetic kerosenes;
- develop and disseminate competence for aviation biofuel certification;
- organize a long term strategy plan for the production and distribution of jet biofuels.

### Policies

- establish facilities to become the locus of scientific and commercialization activities pertaining to the goals of this roadmap;
- observe closely and anticipate regulatory actions by ICAO;
- establish or regulate sustainability criteria to be met by aviation biofuels in the country, and coordinate with emerging standards around the globe;
- establish a governmental long-term program for integrated use of biofuels in all transportation modes;
- build up high level human capacity related to biofuels for aviation;
- establish policies to include small farmers and/or local communities in the jet biofuel production chain.

In conclusion, the substitution of petroleum in aviation represents a very important niche for sustainable biofuels. Brazil has a great opportunity in this area to become a global player. There are important challenges to be overcome to create the basis for this new emerging industry. Brazil cannot afford not to participate.



# Flightpath to Aviation Biofuels in Brazil: Action Plan Report

## 1. Introduction

The aviation industry worldwide has demonstrated a strong desire to participate in a global effort to mitigate GHG emissions and, therefore, is deeply committed to reducing CO<sub>2</sub> emissions. The present goal is Carbon Neutral Growth (CNG) by 2020 and 50% reduction in net CO<sub>2</sub> emissions over 2005 levels by 2050. Several actions are being taken by the aviation industry to meet this goal. Among them are more efficient use of fuels with improved turbines, lighter airplane design, advanced airspace management and lower carbon fuels.

This report reviews the needs to create a sustainable aviation supply chain in Brazil, and establishes an action plan to make lower carbon fuels for jet travel a reality here. While fuel efficiency can go far, achieving industry emissions reduction goals will require biofuels that are sustainably produced and comply with the technical necessities of aviation.

The aviation industry wishes to develop sustainable “drop-in biofuels”. The industry has adopted the ASTM guidelines for “drop in”, meaning fuels that, when blended with petroleum derived jet fuel at no more than 50%, meet the minimum performance characteristics of petroleum produced fuel. While not yet cost-competitive, “drop-in” jet biofuel has been demonstrated with a number of tests and commercial (revenue generating) flights by airlines. Work to drive costs down to competitive levels is under way in many parts of the world. Important challenges include scaling up combined feedstock and refining technology pathways, and improvements in logistic and deployment characteristics in a way that biofuel applications become economically viable.

“Drop-in biofuels” are biofuels that when blended with conventional jet fuel up to the ratio defined by a fuel specification, can use the same supply infrastructure and do not require adaptation of aircraft or engines.

Not all bioenergy is sustainable energy, therefore the fuels should be developed using strong sustainability criteria and verification to meet the needs of the aviation industry. Producers of some crops can benefit from more mature agronomic experience, while other crops show good potential, but have not yet been put into large-scale production. At this point, no alternative can be excluded based on these arguments, justifying a careful screening of the several available supply chain routes.

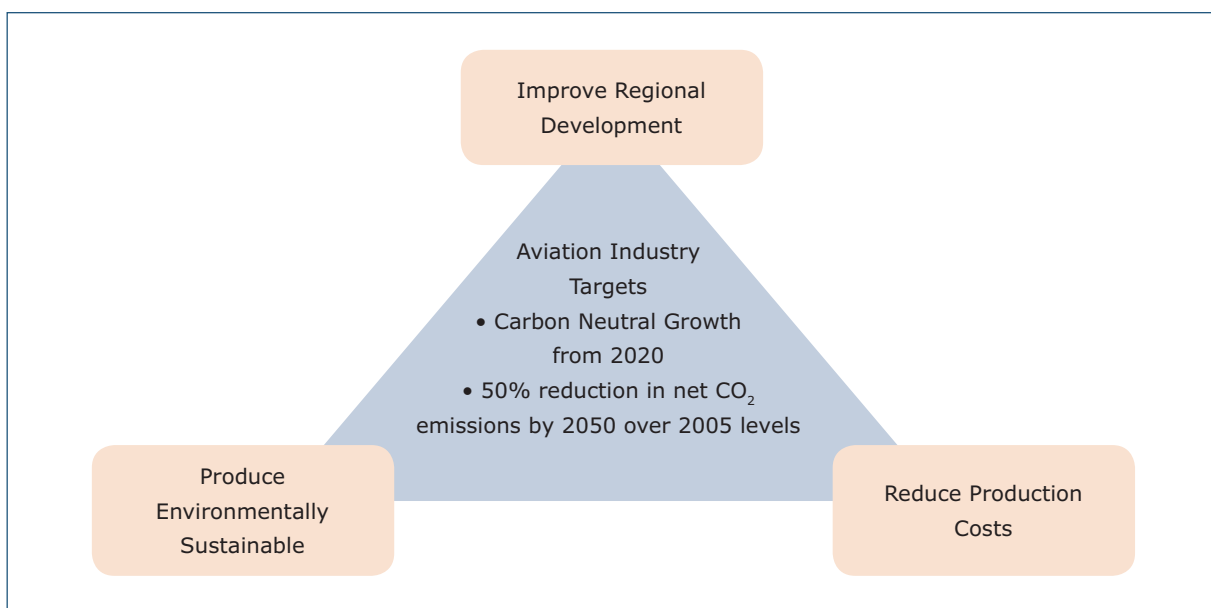
## 2. The Aviation Industry vision and the *Sustainable Aviation Biofuels for Brazil Project* objectives

**Aviation industry vision to reduce CO<sub>2</sub> emissions**  
 The aviation industry will have, in the next 20-40 years, a transition towards the use of sustainable biofuels in substitution of petroleum-based jet fuels. The use of biofuels in aviation will have to be effective, efficient, and advantageous from the environmental, social and economic points of view, in order to consolidate the expansion of the aviation industry worldwide.

Considering the aviation industry vision, the main *Sustainable Aviation Biofuels for Brazil Project* objectives are:

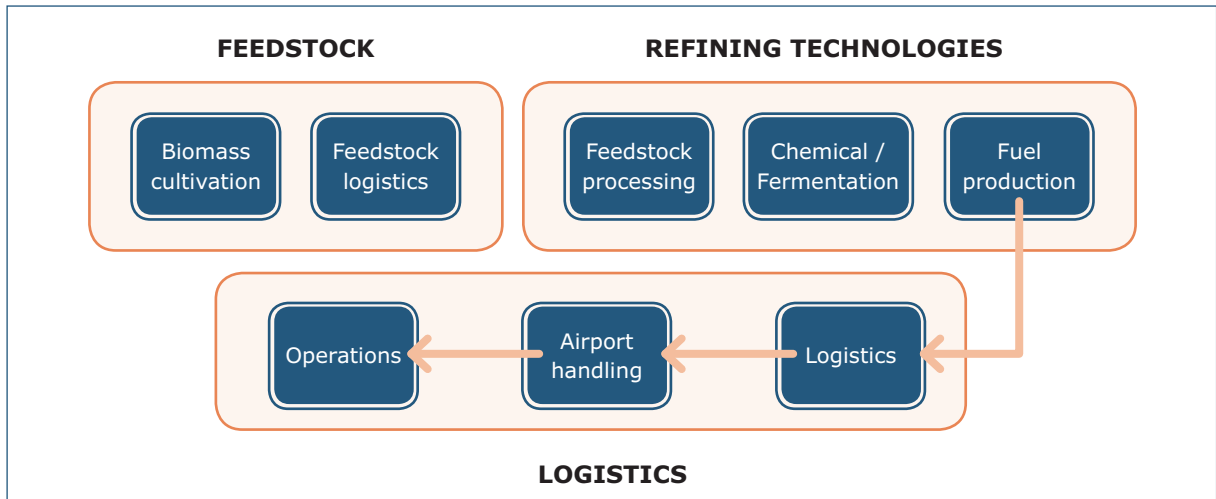
- a. to develop a Roadmap to identify the gaps and barriers related to the production, transportation and use of biofuels for aviation. Although some companies are already producing and selling biofuels for aviation to be used in mixture with fossil jet fuels, aviation biofuels have not become a standard part of the fuel supply, and a fully commercial industry has not yet been developed;
- b. to create the basis for a research and commercialization agenda to overcome the identified barriers. In short, the goal is: develop a sustainable aviation biofuels supply chain, with high GHG mitigation potential;
- c. to establish the foundation to launch a new and innovative industry in Brazil to produce sustainable biofuels for aviation.

Figure 1 presents the Roadmap targets discussed and agreed in the roadmapping process.



**Figure 1:** Strategic objectives for 2050 for the aviation industry regarding jet fuel substitution by biofuels.

This Technology Roadmap process is divided into many work fronts throughout the value chain, each with specific focus on corresponding large technological areas relevant to the aviation industry's envisioned future. **Figure 2** shows the main components of this work: Feedstock, Refining Technologies and Logistics. Sustainability is a critical issue to be considered throughout the supply chain.



**Figure 2:** Roadmap components for biofuels to the aviation industry.

### 3. Sponsors and Stakeholders

The *Sustainable Aviation Biofuels for Brazil Project* was financed primarily by Boeing, Embraer, FAPESP, and UNICAMP. In addition the Project also counted with the participation of stakeholders listed below:

AIAB, Amyris, ANAC, Andritz, ANP, APTTA, Bioeca, Byogy, Climate Solutions, CTBE, Embrapa Agroenergy, Ergostech, GE, GOL, IAC/APTA/SP, IAE/DCTA, ICONE, ITA/DCTA, LanzaTech, Life Technologies, Mount Rundle, Neste Oil, NWF, Oleoplan, Petrobras, RSB, SG Biofuels, Sindicom, Solazyme, Unifei, UOP, USP, Weyerhaeuser Solutions, WWF, 4 CDM.

### 4. Methodology and Activities

The roadmapping methodology implemented in this project was aimed at reaching a consensus on action plan priorities (gaps and barriers) in order to promote the use of sustainable biofuels for aviation. The methodology was constructed using workshops to stimulate the discussions.

A series of workshops were organized between May and December 2012:

Workshop	Venue	Date
1–Project Overview	FAPESP, São Paulo, SP	April 25-26, 2012
2–Feedstocks	ESALQ/USP, Piracicaba, SP	May 22-23, 2012
3–Refining Technologies	FEQ/UNICAMP, Campinas, SP	July 11-12, 2012
4–Sustainability	FIEMG, Belo Horizonte, MG	August 22-23, 2012
5–Policy and Incentives	Embrapa Agroenergia, Brasília, DF	September 11-13, 2012
6–Logistics & Support	ANP, Rio de Janeiro, RJ	October 17-18, 2012
7–R&D and Commercialization Gaps	DCTA, São José dos Campos, SP	November 28-29, 2012
8–Briefing to Stakeholders	FAPESP, São Paulo, SP	December 12, 2012

**Table 1:** Workshops

The workshops provided valuable information needed to develop scenarios/pathways, which were analyzed based on assessment of the likelihood of commercial feasibility in 2015-22 timeframe, while considering the long-term timeframe (2050). In addition, there were three regional outreach workshops (Cuiabá, Recife and Curitiba) organized by EPFL and 4CDM. The workshops gathered stakeholder perspectives and insights on prospective pathways.

## 5. Project context and drives

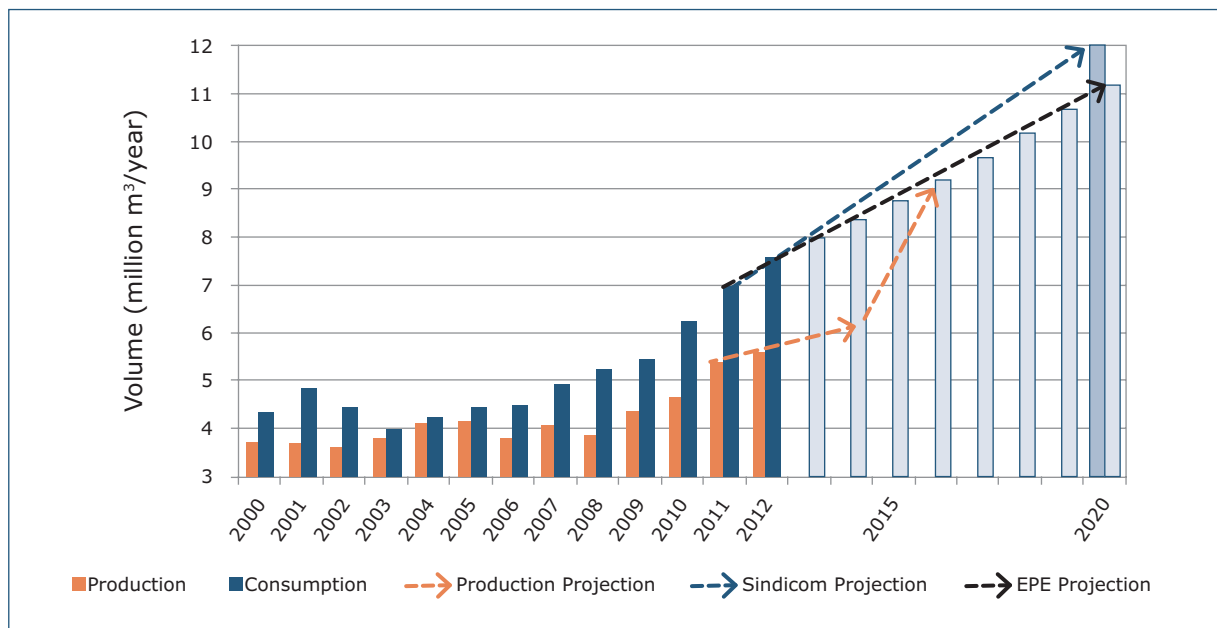
### Civil aviation perspective

The civil aviation is absolutely essential to the global economy. According to the International Air Transport Association, the air transport industry contributes about US\$ 3.8 trillion per year to the global economy, supporting the employment of 32 million people, to transport 42 million tonnes of goods and connect 2.8 billion people. One daily international long haul flight generates, in annual terms, 60 thousand passengers, 880 jobs, US\$ 26 million in GDP, US\$ 10 million in salaries and US\$ 4 million in taxes (IATA, 2012).

In Brazil air transportation is growing rapidly, higher than the global average. Brazil is currently forecasted to become the 4<sup>th</sup> largest domestic air traffic market in the world by 2014. In 2010 the Brazilian aviation sector carried over 71 million passengers and 870 thousand tonnes of air freight to, from and within Brazil. More than 62 thousand scheduled international flights depart Brazil annually, destined for 58 airports in 35 countries. Domestically, more than one million scheduled flights annually provide connections between 108 airports. In economic terms, in 2009 this activity contributed with R\$ 32 billion to Brazilian GDP and employed about 684 thousand people. In addition, it is estimated that there are a further 254 thousand people employed through activities promoted by aviation, such as tourism (Oxford Economics, 2011).

## Energy and aviation

The energy demand of the aviation industry is almost totally focused on petroleum-based jet fuel, a form of kerosene made to be used in jet turbines with efficiency and safety. The global demand of jet fuel is around 250 million cubic meters per year, close to 6% of refinery output (EIA, 2011). About 2/3<sup>rd</sup>s of that demand occurs in OECD countries. In Brazil, the demand for jet fuel in 2011 was 7 million cubic meters (about 2.8% of global demand) of which the Brazilian refineries produced 75% and the rest was imported from various countries (ANP, 2012).

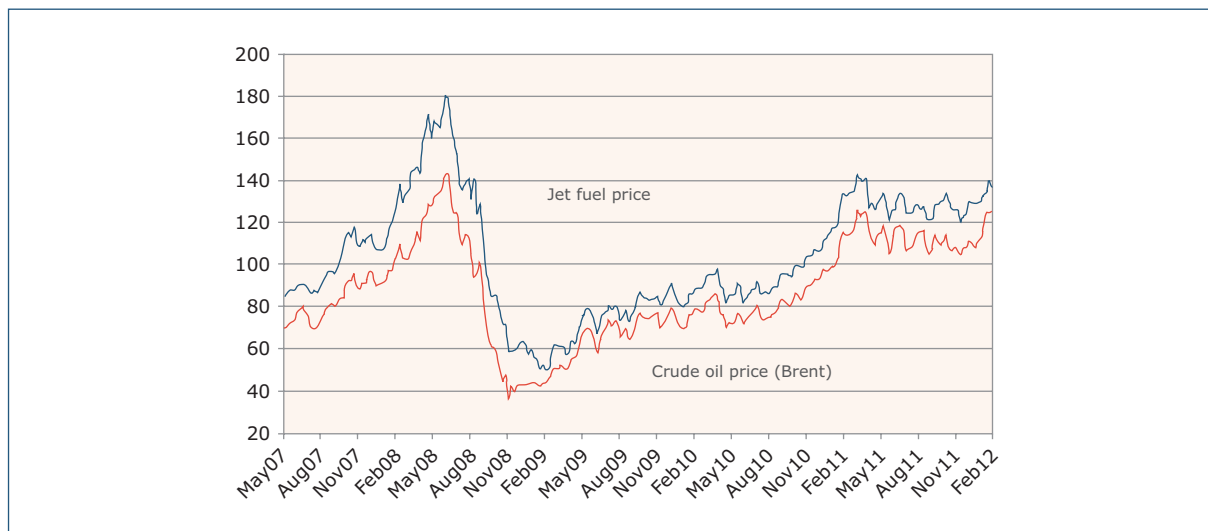


**Figure 3:** Jet fuel consumption and production in Brazil. Source: ANP (2012)

**Figure 3** represents the projected growth of jet fuel consumption in Brazil, together with the historical evolution of production and consumption in the past 12 years. According to Sindicom, jet fuel consumption is projected to reach 12 million cubic meters by the year 2020 while the number projected by EPE (EPE, 2011) is 11 million cubic meters for the same year, with an annual growth around 5%. The projected volume of production by EPE undergoes a very steep growth around 2015 because of new refineries that are planned to initiate operation by that time but, following the investment plans of Petrobras recently made public (PETROBRAS, 2012), there may be some postponement. The equilibrium between supply and demand probably will only occur several years later.

Fuel represents the most important operational cost for an airline. As a world average fuel currently represents 34% of the operational costs (compared with 10-15% in the past decade), but in Brazil it is higher, representing around 40% of the operational cost for the airlines. Besides this high share, the volatility associated to oil price variation is another concern, introducing significant difficulties for planning and management in these companies. **Figure 4** presents the evolution of oil (referenced as Brent) and international jet fuel prices in the past years.

The pricing of jet fuel is usually done according to three models: market-based formula, import parity and posted price. In market-based pricing, an average spread over crude oil is US\$ 9.6 per barrel. The jet fuel price at the producer gate in Brazil, about 1.0 to 1.2 US\$/liter in 2011, is defined by Petrobras and taxed multiple times. The domestic jet fuel price is 12% higher than the regional average and 17% higher than the global average (Ebner, 2012a).



**Figure 4:** Crude oil and jet fuel prices. Source: IATA (2012)

### Aviation and GHG emissions

Beyond the concerns on energy costs, the awareness of the environmental impact of fossil fuel utilization, mainly related to GHG emissions, has increased significantly in the context of the aviation industry. Although air transport currently accounts for approximately 2% of human-made carbon dioxide emissions, this sector is growing extremely rapidly. If fuel consumption and CO<sub>2</sub> emissions were to continue growing at present rates, CO<sub>2</sub> emissions by worldwide aviation in 2050 would be nearly six times the current figure.

Historically, significant fuel efficiency gains have been achieved by operational improvements (such as higher load factors, utilization of larger aircraft) and by technical progress (such as more efficient engines, lighter airframes). As a consequence of better efficiency, aviation fuel consumption growth can be significantly slowed to only 3% annually. Even with this efficiency improvement, aviation CO<sub>2</sub> emissions are predicted to more than triple by 2050 (EC, 2011).

To address the threat of climate change and emissions from the aviation sector, some public policies responses are being developed. In this regard, the most relevant measure is the European Union Emissions Trading Scheme (EU ETS), launched in 2005 to be introduced in progressive tiers and representing relevant additional costs to the sector (OAG, 2012). Enforcement is currently suspended while negotiations for an international aviation emissions framework are underway through the International Civil Aviation Organization.

In the Brazilian context, where jet fuel consumption is predicted to grow on average at annual rates around 5%, as depicted in **Figure 3**, and with road transportation increasingly using



renewable fuels, the aviation share of transportation sector CO<sub>2</sub> emissions could reach 12% by 2020 (Nigro, 2012). One of the main targets of the *Sustainable Aviation Biofuels for Brazil Project*, to make aviation growth carbon neutral in 2020, is aligned with aviation industry targets. If this is to be achieved directly in the sector without “open” trading or offsetting schemes for CO<sub>2</sub> compensation, and without reducing the sector growth, it would require adding around 0.6 million cubic meter of renewable jet fuel each year after 2020.

### The Brazilian experience on liquid biofuels

In Brazil, about half of the total primary energy comes from renewable sources, mainly hydro, sugarcane and wood. The importance of the sugarcane bioenergy is high; in 2011 it accounted for 15.7% of the national energy supply (42.8 Mtoe), slightly above the contribution of hydroelectric power (EPE, 2012). In the road transportation sector, biofuels were responsible in 2011 for about 19% of total energy consumption.

The extensive Brazilian experience with automotive biofuel started in 1931 with the mandatory blending (5%) of ethanol in the whole gasoline commercialized in gas stations. In 1975, the Brazilian Ethanol program induced a large expansion of production with the progressive improvement of agro-industrial productivity, use of 25% ethanol gasoline blends and introduction of pure ethanol cars. After 1985, with the decline of oil prices, the stimulus to ethanol was reduced. Production stagnated until the introduction of flex-fuel cars in 2003. These cars represent today about 93% of sales of new cars. Pure ethanol can be used by 12.7 million Brazilian vehicles (mostly cars with flex-fuel engines), around 47% of the national light vehicle fleet (ANFAVEA, 2012). In the 2010/2011 harvest season, 9.2 million hectares of sugarcane fields (approx. 1% of the Brazilian territory) produced 620 million tonnes of feedstock for sugar, ethanol and electricity. About 50% of available sugar was used to produce 22.6 million cubic meters of ethanol in 2011 (UNICA, 2012). During the last decades productivity grew at a cumulative average annual growth rate of 3.1% in ethanol production per hectare, a noteworthy gain in productivity obtained through the steady incorporation of new technologies.

**Brazil, the “biomass country”**  
Using only 0.5% of its territory to produce sugarcane bioethanol, Brazil is substituting nearly 1/3 of the fuel energy consumed by its light vehicle fleet.

The National Program of Biodiesel Production and Use was launched in 2005, aiming to encourage small producers and farmers from least developed regions to become involved with biodiesel production and setting a progressive use of mandatory biodiesel blends in all diesel oil sold in gas stations. This blending obligation started in January 2008 with 2% biodiesel (B2) which ramped up to reach 5% biodiesel (B5) by January 2010. Due to these factors, the production of biodiesel has increased exponentially and reached 2.67 million cubic meters in 2011, derived mainly from soybean (80%) and tallow (14%) (EPE, 2012). Although the Biodiesel Program has achieved its objectives in terms of ensuring a steady supply of biodiesel, the encouragement of small and less favorable producers is no longer a target as it was conceived when the program was launched.

### Institutional issues

Similar to other innovative technologies, the development of aviation biofuels depends strongly on support mechanisms and proper public policies. As an immediate example, the adoption of ethanol and biodiesel in many countries required specific and active policies in order to reduce uncertainties and risk perception among producers and promote investments, as well to protect consumers and the environment.

The basic reasons behind these measures are the differential advantages and externalities of using renewable energy in comparison with conventional fossil fuels. In fact, when produced and used sustainably, a biofuel is able to foster environmental benefits, jobs generation, economic activity and energy security, as main positive impacts. It is important to stress that these potential advantages of biofuels are intrinsically dependent on the production route adopted, including the feedstock productive system and the agro-industrial conversion process, which should be properly assessed by sustainability indicators.

Two basic governmental actions to support the development of sustainable biofuels are the promotion of R&D activities and the definition of a fuel specification. Regarding the first one, in the agriculture, forestry, processing and refining contexts, there are many gaps to fill, open questions to explore and processes to improve. Some feedstock proposed for aviation biofuel production, such as jatropha and algae are relatively unstudied, requiring more assessment. Venture capital can play a complementary role, and one which may be especially relevant in the case of crops such as jatropha and camelina that have a relatively small public research infrastructure but have substantial private funds for R&D, which may speed up the incorporation of such crops into the future jet fuel production chain. However, clearly it is a government responsibility to stimulate the scientific and technological development, fostering basic studies, promoting demonstration projects and, as an essential matter, preparing and motivating researchers. Only with proper resources applied in a broad research agenda is it possible to screen the large number of options for aviation biofuels production systems and choose wisely the most promising ones. That R&D effort should be permanent in order to optimize the biofuel chain.

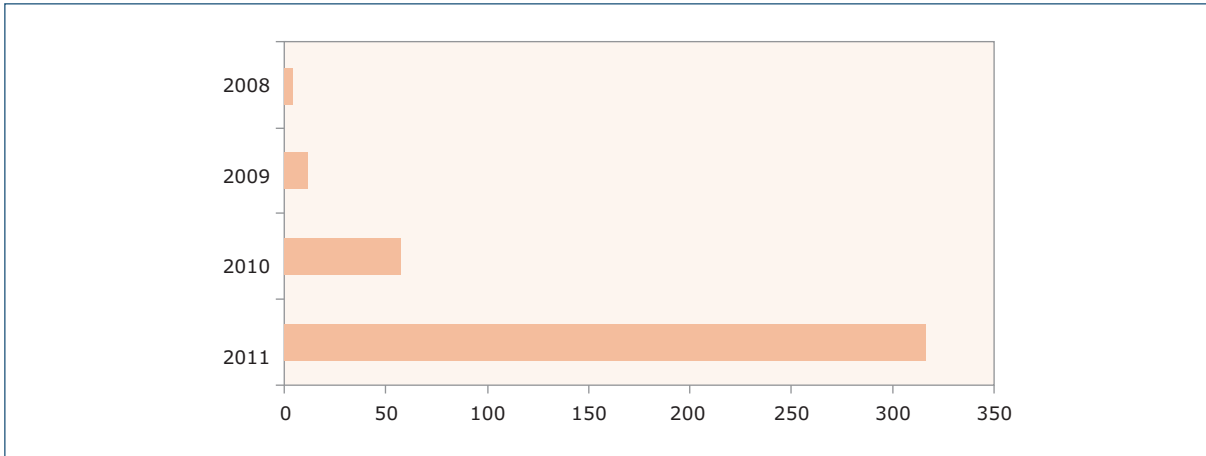
The aviation biofuel specification must attend simultaneously to the environmental, engine and producers requirements, which are in conflict in many cases, and impose a judicious analysis before the final decision. In the case of aviation, the globalization of demand and stringent conditions of use and safety standards imposes the “drop-in” concept. A widely accepted procedure for biofuel approval process is already available (ASTM D4054, *Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives*). The ASTM standards for aviation fuels are currently under review by ANP, the regulatory agency with legal mandate for setting fuel specifications in Brazil.

### Initiatives in aviation biofuels

As a clear signal of the interest and commitment of the aviation industry towards the development of aviation biofuels, there are an increasing number of initiatives promoting them, including demonstration flights. Among those initiatives, it is worth noting:

- the Center for Strategic Studies and Management in Science, Technology and Innovation (CGEE) promoted in 2010 a study about the introduction of jet biofuels in aviation in Brazil;
- the creation of the Brazilian Alliance for Aviation Biofuels (ABRABA, *Aliança Brasileira para Biocombustíveis de Aviação*) joining Brazilian companies “to discuss the various aspects of developing sustainable aeronautical biofuels driven by the growing demand to meet the requirements for reducing greenhouse gas emissions in aviation as well as to provide support for Brazil’s energy security.” (ABRABA, 2012);
- the Civil Aviation Environmental Goals definition by the International Civil Aviation Organization (ICAO), looking to minimize the adverse effect of civil aviation on the environment and including actions to limit or reduce the impact of aviation GHG emissions on global climate, using sustainable biofuels and efficiency gains as key elements. This agency launched the ICAO Global Framework on Aviation Alternative Fuels (GFAAF) (ICAO, 2012);
- the creation by the US Federal Aviation Administration of the Commercial Aviation Alternative Fuels Initiative (CAAFI), aimed to “enhance energy security and environmental sustainability for aviation through alternative jet fuels” (CAAFI, 2012), in a context where the biofuels are one prominent alternative;
- the inclusion in 2011 of aviation biofuels in the framework of the European Industrial Bioenergy Initiative, an important element of the EU’s energy and climate change policy (EC, 2011). Also under EU sponsorship was issued the study Sustainable Way for Alternative Fuels and Energy for Aviation (SWAFEA);
- in 2011 of the report Flight Path to Sustainable Aviation by the Commonwealth Scientific and Industrial Research Organization (CSIRO), focused on developing a sustainable aviation biofuels industry in Australia and New Zealand (CSIRO, 2011);
- in 2011, the report Sustainable Aviation Fuels Northwest focused on developing a sustainable aviation biofuels industry in the Northwest region of the United States (SAFNW, 2011);
- in December 2012, the European Commission postponed the full implementation of the European Trading Scheme in response to ICAO demand to treat the subject in an international forum (EC, 2012);
- Iniciativa Española de Producción y Consumo de Bioqueroseno para Aviación (bioqueroseno.es);
- Initiative Towards a Sustainable Kerosene for Aviation (ITAKA).

Many demonstration and commercial flights have been staged, involving more than 20 airlines worldwide, flying with jet fuel made out of a variety of feedstock including used cooking oil and oil crops such as rapeseed, jatropha, camelina, and palm oil (**Figure 5**). During the Conference Rio+20, two Brazilian airlines made demonstration flights employing biofuels. Azul Airlines flew an Embraer E-195 using a “drop-in” renewable jet fuel produced in Brazil from sugarcane by Amyris. GOL Airlines flew with a Boeing 737-800 using jet fuel blended with biofuel derived from inedible corn oil and used cooking oil supplied by UOP. Previously in 2010, TAM tested a jet fuel containing 50% of fuel made with jatropha seeds produced in Brazil.



**Figure 5:** Number of initiatives on aviation biofuels. Source: Hupe (2012)

### R&D in jet fuel alternatives

Presently there are several initiatives to develop sustainable jet biofuels in Brazil and in other countries. None of them can be yet considered “commercial” although several of them have received the ASTM technical certification approval.

The emphasis of the present project has been on refining technologies. Basically the identified initiatives are to develop kerosene-like molecules using feedstock sustainably produced and processed at competitive cost (even negative in case of residues) and with relevant environmental and social benefits.

Many high tech companies are connected with different players, including important airlines, with R&D following diverse strategies. The results indicate that no product is close to be economically competitive with conventional jet fuel. The results also indicate that more concentrated and integrated efforts are needed to overcome scale-up barriers. This is to be discussed in more detail further in this report.

## 6. Main outcomes of the Workshops carried out in the *Sustainable Aviation Biofuels for Brazil Project*

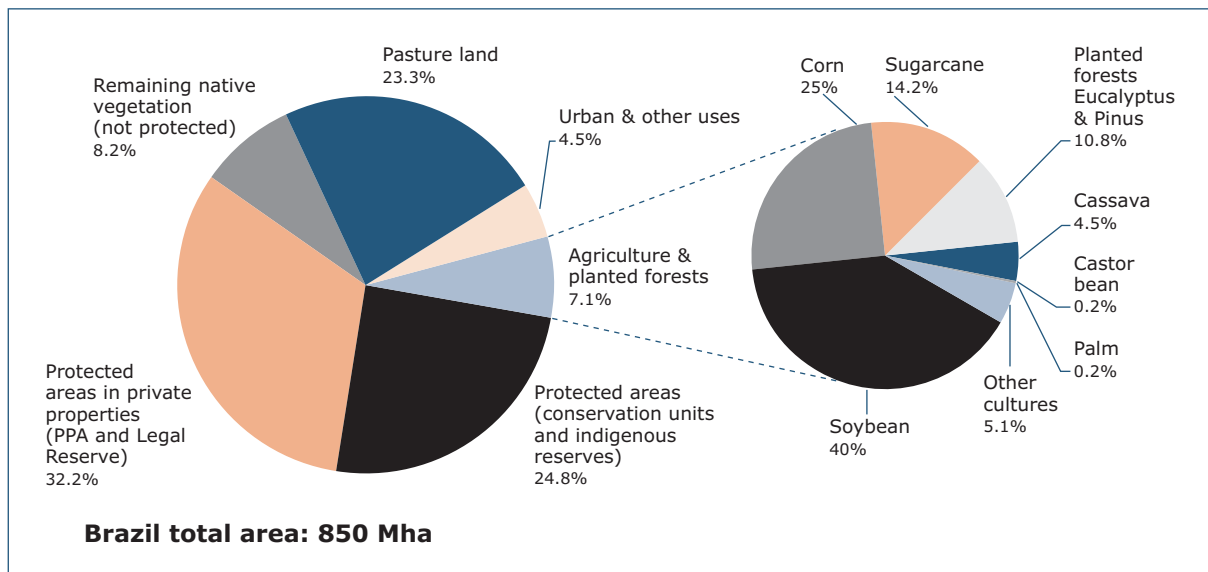
A series of workshops were organized covering the main aspects involved in the production of sustainable alternative biofuels for aviation in Brazil. A summary of the workshop findings are presented below.

### 6.1 Feedstock

Brazil has a strong agricultural tradition and is among the world's leading producers and exporters of many agricultural products such as soybean, sugarcane, coffee, cotton, maize, tropical fruits, meats, etc. This relevant position was attained due to abundant land, good climate conditions, long-term investment in research and development, and an entrepreneurial private sector. Brazil has a unique combination of significant availability of land already cleared for agriculture, a dynamic agriculture sector presenting strong productivity growth, a large amount of legally-protected native vegetation, strong conservation laws, and human health and safety regulations for rural activities equivalent to urban activities. Both sets of laws face difficulties of enforcement and low level of compliance from rural producers. This remarkable combination places Brazil, from a feedstock supply perspective, in a good position, if policies were carried out, to develop an aviation biofuel program in compliance with responsibility principles and sustainability requirements.

The agricultural sector occupies 30.4% (23.3% pasture land and 7.1% agriculture and planted forests) of the Brazilian territory, while 65% of the territory is covered with native vegetation (**Figure 6**). Legally-protected native vegetation (conservation units and indigenous reserves) represents 40% of the total remaining vegetation. Although this is a significant amount of land protected, but it is highly concentrated in the Amazon Biome. The other 60% are located in private properties, from which 50% of total remaining vegetation is protected by the National Forest Code, considering the definition of the legislation approved in 2012. Annual and perennial crops, however, have a small share of the total agricultural land: only 23% (7.1% of the total Brazilian territory). The majority of the agricultural land is occupied with pastures, used mainly for beef cattle production.

Pasture-fed cattle based on extensive systems still characterize the pattern of beef production in Brazil. There still are large amounts of degraded and low-intensity pasturelands that can be utilized more effectively to grow and harvest crops for advanced biofuel production, improving the environmental and financial value for these lands. The intensification of cattle production will be important to allow the growth of agriculture avoiding pressure for conversion of natural vegetation.



**Figure 6:** Land Use and planted area with some biofuel feedstock in Brazil and potential for expansion. Sources: Minister of Environment- MMA; IBGE – PAM (2010) and Agricultural Census (2006); INPE – TerraClass; Agricultural Land Use and Expansion Model Brazil - AgLUE-BR (Gerd Sparovek, ESALQ-USP). [Notes: 1) The data on Conservation Units exclude the areas called Environmental Protection Areas (APAs); 2) The PPAs data include buffer strips along rivers, high slopes areas and top of hills; 3) The data for other natural vegetation areas include Quilombola's areas, public forests non settled and other remaining natural vegetation areas; 4) The protected areas in private properties were estimated based on the new Forest Code, approved in 2012].

Annual and perennial crops are expanding mainly over pastures, though clearing of natural vegetation still occurs. We estimate that around 3/4 of cropland (annual and perennial crops) expansion in the last 10 years had been directly over pastures and the other 1/4 through conversion of native vegetation. Most of expansion over natural vegetation is related to cattle expansion. Annual and perennial crops production expansion, on the other hand, is primarily caused by yield increase, and only secondarily by area increase.

Availability of feedstocks for aviation biofuels, in terms of both production quantities and diverse sources, is not a major concern in Brazil. Most of the crops in Brazil are rain-fed and do not require irrigation. The extensive territory has areas of temperate, subtropical and tropical climates, which allow the cultivation of different crops suitable for jet biofuel. Brazil also has a long experience in agricultural-based biofuels with the sugarcane ethanol program. Around 50% of the sugarcane produced is used for ethanol. More recently, Brazil implemented the biodiesel blend program, which now uses around 26% of soy oil production. In contrast to some regions in the world that are adopting biofuels based on agricultural products, evidence in Brazil shows that the agricultural sector has been able to meet the increasing demand of both food and energy (see **Box 1** on page 31).

The most promising potential feedstocks for initial development of jet biofuel in Brazil are plants that contain sugars and starches, for longer term feedstocks such as plant oils, lignocelluloses, municipal solid wastes, and industrial waste residues. Brazil is the world's largest producer of sugarcane, second of soybeans, and has the lowest cost of production of eucalyptus; therefore, it

can competitively produce these classes of feedstock today. At this stage, these three crops can be considered the natural candidate feedstocks to start a jet biofuel industry in Brazil, depending on the conversion process selected. Proper regulation may be required to meet international restrictions, to ensure that feedstock for jet biofuel do not compromise food production, although in Brazil historically food and biofuel production have increased steadily in parallel. In addition, sugarcane and eucalyptus can be produced with a very significant life-cycle reduction of CO<sub>2</sub> emissions; oil crops may raise greater concerns. It is important to recognize that even for the more established crops there is room for improvements to further reduce costs, and improve environmental performance. Pine is also a widely grown forest plant that can be used in addition to eucalyptus.

Several other crops that currently are not as well positioned as sugarcane, eucalyptus, and soybeans may become feasible options. However, they will require some additional efforts in R&D to become commercial crops with high yields (jatropha, camelina, sweet sorghum), reduced costs (jatropha, camelina, sunflower, peanuts, castor beans, palm, and other oil-bearing crops), as well as to solve harvesting problems (jatropha, grasses). Logistics improvements will be needed for most crops because the transport infrastructure in Brazil is poor and most feedstock are bulky material or have low unit value. This applies to both annual crops as well as to forest products. However, logistics may be more challenging for palm, which grows well in wet tropical areas that are far away from end-use locations.

Abundant supply of crop residues such as straw, sugarcane bagasse, and forest by-products (both from the field or industry) also makes this class of feedstock a good alternative. For these, collection and transportation costs, and questions of removal rates to preserve soils are the main gaps and barriers that must be overcome.

The plant material removal from fields must also take into consideration its long term impact on soil and water quality, including biodiversity. Therefore, long-term feedstock sustainability research platforms need to be established to study the impact of forest and agricultural practices on soil, water and bio-diversity. The data from these sites will be the benchmark for environmental metrics and productivity models.

Municipal solid wastes, tallow and used cooking oil are options for biofuel production, not only to recycle products that would otherwise require costly disposal, but also because they avoid food security concerns. Tallow is already widely used to produce biodiesel in Brazil (15% of the non-fossil oil used to make biodiesel), but the other residues require considerable efforts to solve collection and/or separation problems.

Other suitable non-food crops include industrial waste residues. These residues are widely found in the Brazilian steel industry, which is one of the world's largest and growing at 5%

**Direct "LUC" Land Use Change** is caused by land clearing to produce bioenergy crops themselves; and **indirect land use change, or "ILUC"** is caused by the need to expand production on new land, to make up for crops diverted to biofuels from the original use. These are concepts used to estimate CO<sub>2</sub> emissions derived from land use change.

annually. These single point source residue feedstocks are inherently low-value, do not compete with food, or affect land use. Gas fermentation technologies can utilize these industrial residues to capture carbon, reducing overall GHG emissions and produce ethanol input for jet fuel.

Although all the feedstocks considered have already a market that, in many cases, pays a price that may inhibit their use for jet biofuel, the general consensus in this roadmap study was that significant quantities of additional sustainable biomass can be produced in Brazil. In view of the favorable conditions for agriculture and forestry, production of feedstock in Brazil probably will be at a comparable cost, or lower than anywhere. In this sense, the processing and conversion phases will have an important weight in defining the best feedstock options.

As important as the availability of feedstocks for jet biofuel production is the capacity of the feedstocks to comply with sustainability requirements. In line with the international debate, it is well recognized in Brazil that the expansion of agricultural-based feedstocks for jet biofuel production can promote land use changes and impacts on markets for food crops. However, due to the specific characteristics of the dynamic of the Brazilian agriculture (as discussed in **Box 1** on page 31), evidence suggests that the indirect effects caused by the expansion of biofuels, in terms both of emissions associated with land use change and of impacts on food prices and food security, can be dealt with in Brazil, if adequate precautions are taken.

There are reasons to believe that the future expansion of agricultural-based biofuels can be stronger than the historical expansion. Therefore, ILUC and competition with food can potentially have an increasing relevance in the future, especially when the process of intensification and conversion of less productive land (notably pastures) has reached its potential. Thus, an option to be considered is development of instruments and policies for making sure expansion of biofuels feedstocks production is done sustainably.

## 6.2 Conversion and Refining Processes

Current technologies allow conversion of agricultural feedstocks to “drop-in” jet fuel. In the workshops a range of conversion and refining technologies were evaluated including gasification, fast pyrolysis, solvent liquefaction, enzymatic hydrolysis of cellulosic and lignocellulosic biomass, alcohol oligomerization to jet fuel (ATJ), hydroprocessing of esters and fatty acids (HEFA), as well as the fermentation of sugars and wastes (i.e., municipal solid wastes, flue gases, industrial waste residues) to alcohols, to hydrocarbons (DSHC) and to lipids. All these technologies have potential to be considered for the production of jet biofuel.

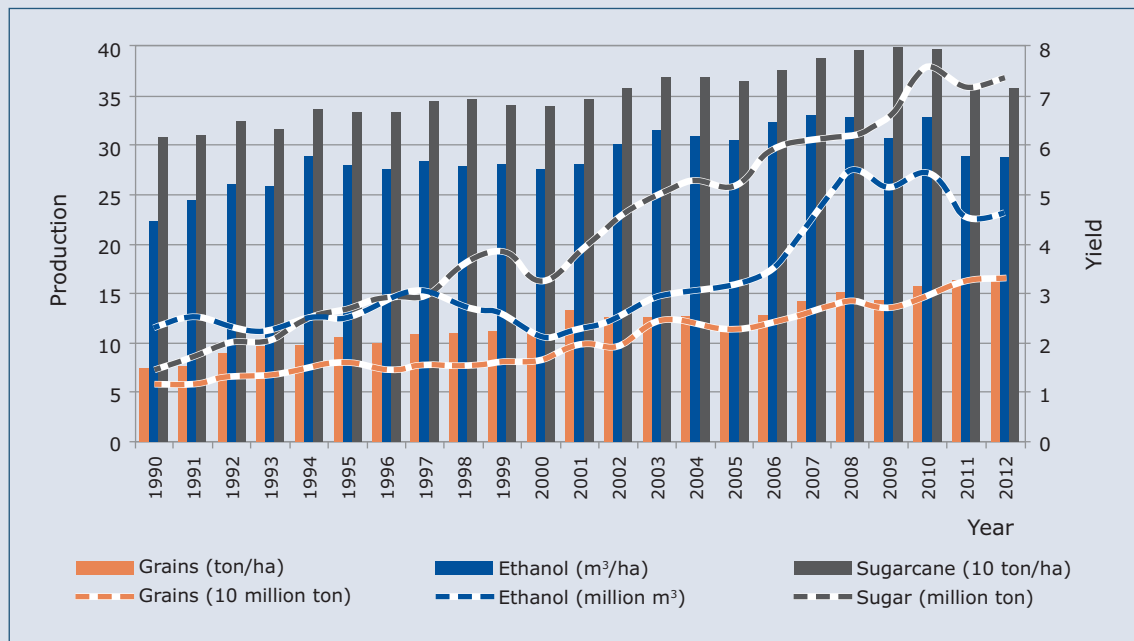
In Brazil, fermentation of carbohydrates (sugars) to hydrocarbons or to lipids is reaching commercial stage, with first-of-a-kind installations getting into operation (Amyris, 2013 and Solazyme, 2012), generating two main different products. The hydrocarbon obtained is an unsaturated C15 product with four double bonds, would need 4% hydrogen (weight basis) to produce jet biofuels (DSHC). The second product is microbial oil, which typically, can be a very good feedstock for HEFA conversions.



**Box 1: Why indirect effects of sugarcane ethanol is low in Brazil**

ILUC and food versus fuel are the two most relevant indirect effects raised as concerns in the biofuels debate. Several pieces of evidence indicate that the expansion of cane ethanol in Brazil have not undermined food production. The same evidence also shows that concerns regarding a direct causal relationship between ethanol expansion and native land conversion is not supported in reality. The evidence is based in the following facts:

- Brazilian agriculture is facing a process of intensification and efficiency gains with increasing yields in crops and livestock;



- there still is a lot of space for intensifying cattle production in Brazil. Technical yields such as slaughter age, calves’ birth rate and meat produced per hectare are still low in Brazil;
- Brazil has developed a double-cropping system allowing the integration of soybean and corn in the same year. The double cropping is already responsible for half of the total corn production in Brazil and since the year 2000 most corn production expansion has taken place as a second crop;
- the expansion of sugarcane for ethanol, although very strong, has not undermined the expansion of other annual and perennial crops. Therefore, rather than food-versus-fuel, the reality in Brazil shows a food-and-fuel situation;
- the cultivation of oilseeds in rotation with sugarcane is also generating food and fuel in the same systems;
- deforestation has been reduced since 2004. Decreased deforestation levels in 2011 and early 2012 have been very encouraging, at around 75% lower than 2004 levels.

Lignocellulose is the cheapest feedstock among the studied ones and can be processed as a whole. However its conversion into synthesis gas (Syngas using Fischer-Tropsch process<sup>1</sup>), bio-oil and biochar requires expensive equipment and high temperature conditions. Conversion of lignocellulosics should be important in the near future as the costs of equipment decline.

Enzymatic hydrolysis of lignocellulosics does not require such expensive equipment; however the process is still slow and needs substantial improvement to provide good quality hydrolyzates

### “Second Generation Biofuels”

also known as advanced biofuels, are “drop-in” fuels that can be manufactured with no adverse impact on food security.

to supply the large potential demand for fermented biofuels. Besides this, cheaper and more efficient enzymes are necessary in order to make enzymatic hydrolysis economically viable. Improvement of the microorganisms to excrete larger amounts of enzymes, synergistically working, would be very advantageous. It is desirable to have enzymes with higher turn-over number and more affinity for their substrates, as increased robustness to biofuel process conditions.

Fermentation of sugars to alcohols (i.e. bioethanol) is well developed and commercially executed around the world.

Brazil has a long tradition in producing bioethanol and this biofuel is currently used as a building block to generate polyethylene in a commercial chemical plant, which is a successful example for other upgrading processes such as ATJ technology. These alcohols can be easily deoxygenated to jet biofuel by the ATJ processes. Naturally, second-generation sugars would improve the sustainability of sugar-derived alternative jet fuel, such as ATJ, DSHC and some HEFA pathways (i.e., algae oil derived from sugar).

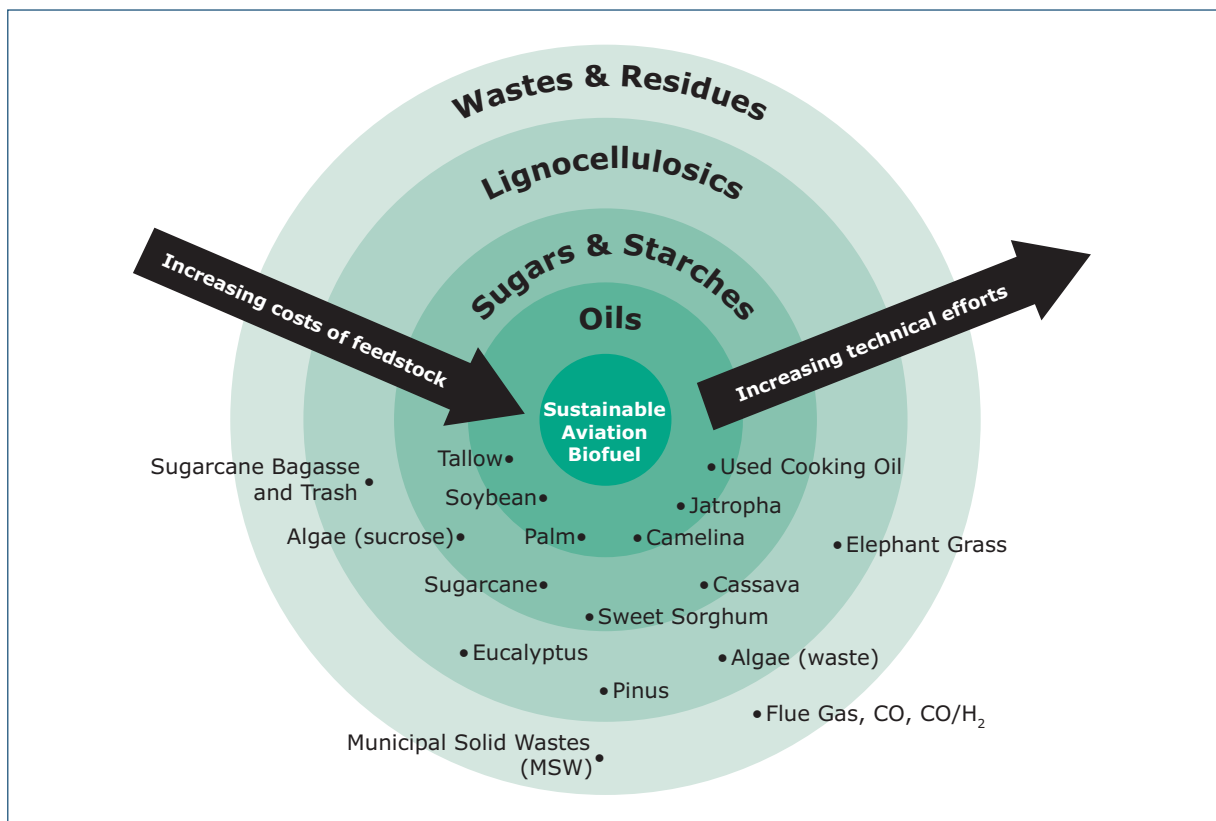
Conversion of vegetable oils to hydrocarbons (HEFA) is a commercial process. However, feedstocks are generally expensive, compared to fossil materials, even though their costs can be shared with other co-products such as soy protein in Brazil. The integration of this plant to an existing refinery/power plant would lower costs for the hydrogenation step of the process. Petrobras has developed a similar concept for the HBIO Process which could be applied for existing diesel hydrotreating units to process a blend of up to 10% of vegetable oil in the feedstock. This requires a process engineering evaluation to check important operational parameters like hydrogen consumption. The HBIO process is waiting economical opportunities when it can be operational at some Petrobras HDT units where tests have been performed. The final product has a chemical composition similar to the fossil fuel.

Conversion of municipal solid wastes and industrial waste residues by biochemical processes, therefore avoiding the high-temperature conditions of the thermochemical processes applied for cellulosic materials, is being developed and commercial viability for certain routes remains unproven. However, bacterial conversion of flue gases (rich in CO) to ethanol was scaled up to two demonstration plants in China by LanzaTech and commercial plants are currently in development. Wastes are often available at negative costs and transforming wastes into useful

<sup>1</sup> “Fischer-Tropsch process” is a set of chemical reactions that converts a mixture of carbon monoxide and hydrogen into aliphatic hydrocarbons (fuels like gasoline or kerosene).

products should be encouraged, even though their future price may increase to reflect their value. More research is required to know the costs of separation and processing of the different constituents, mainly for municipal solid wastes. Conversion of tallow and yellow greases is possible using the HEFA process, but the limited availability and opportunity cost of these feedstocks are driving them to biodiesel production under Brazilian conditions.

In summary, feedstocks can be discussed according to how close they are and can be converted to the target “sustainable aviation biofuel”. **Figure 7** shows, in a simplified way, that closer to the center more costly the feedstock is, but easier or less costly is the conversion technology.



**Figure 7:** Feedstocks and their relative position according to costs and technical efforts to be converted to aviation biofuel. For illustrative purposes only. *Feedstock prices and technical efforts will vary significantly. This Figure does not represent the views of all stakeholders in the Project*

### 6.3 Sustainability indicators

Sustainability is a fundamental topic to be addressed in the establishment of a market for the production and use of jet biofuels in Brazil. There has been much criticism, directed especially towards agriculture, regarding practices that, in the context of the biofuels market, would be considered non-sustainable with respect to social and environmental issues. Furthermore, there is increasing pressure, especially from the European market, for the adoption of more sustainable practices in biofuels operations. Due to this, stakeholder-driven, international sustainability standards and certification schemes have become common over the past years as a way of demonstrating sustainability of the production chain.

The sustainability assessment for the production of feedstocks in Brazil was carried out according to the principles and criteria of the currently available and most well-known international sustainability standards for biofuels production, namely Bonsucro, Roundtable on Sustainable Biomaterials (RSB) and the International Sustainability and Carbon Certification System (ISCC). These principles and criteria are in line with those suggested by Goldemberg (2011) when analyzing sustainability aspects of biofuel production. It is important to discuss these issues, since sustainability certification will increasingly become a requirement for accessing markets, and since the standards and certification processes are complex and require adaptations of the supply chain.

The Sustainability requirements analyzed were:

(i) Laws and International Conventions	(ii) Waste production and disposal
(iii) Land Rights	(iv) Crop Management and Agrochemical Use
(v) Employment, Wages and Labor Conditions	(vi) Direct Land Use Changes
(vii) Human Health and Safety	(viii) Social and Environmental Impact Assessment
(ix) GHG emissions	(x) Rural and Social Development
(xi) Biodiversity and Ecosystems	(xii) Contractors and Suppliers
(xiii) Soil conservation	(xiv) Engagement and Communications with Stakeholders
(xv) Water use and contamination	(xvi) Economic Viability and Production and Processing Efficiency
(xvii) Air pollution	(xviii) Food Security

Although there are important differences among the four groups<sup>2</sup> of feedstocks, some general common conclusions can be made regarding biofuels production and the gaps to comply with sustainability requirements.

In the social sphere, the main positive impacts are the high potential for job creation, income generation and regional development. Regarding the gaps for compliance with sustainability

<sup>2</sup> Sugars and starch, oil, lignocelluloses, and wastes

requirements, the following aspects were common to all groups: great number of laws and rules, sometimes stricter than sustainability standards; different interpretations and lack of knowledge on how to apply laws; uneven enforcement and certain labor laws not adapted to the rural context. There is also a need for qualification and training of workers.

Regarding environmental aspects, the main potential positive impact generated by compliance with requirements is GHG emissions reductions compared to fossil fuels, especially in the sucrose and cellulose groups, although there are still some difficulties with calculations and data.

Brazilian legislation establishes that at least 20% of the land of individual farms (50% to 80% in the Amazon region) be set aside under Legal Reservation in order to preserve natural resources, water sources, biodiversity, and shelter for the native fauna and vegetation. In addition, stretches of land along water bodies as well as those with slopes above 45° are Areas of Permanent Preservation and cannot legally be converted to production. Aspects of Brazilian legislation on sustainability issues and considerations about difficulties of law enforcement are discussed in **Box 2** below.

### **Box 2: Law Enforcement & Sustainability**

Environmentally sustainable production of jet biofuel is a strategic objective of the aviation industry, therefore meeting sustainability standards is of great importance.

Brazilian laws are quite strict to protect natural resources, water and biodiversity. The Brazilian Forest Code is among the most restrictive legislation on land use. Labor laws are equally severe. However, complying with legality principles of sustainability standards is regarded as challenging, in some circumstances. Many laws and rules are complex, prone to different interpretation, and sometimes, as in the Forest Code, demand expensive investments to make up for land clearing done in the past under other legislation. Generally small and independent producers have even more difficulty to comply with the rules because of the high costs involved. In addition, the extensive Brazilian territory makes it difficult to enforce some laws. Under these conditions the legal framework in place, which could be quite effective to guarantee high sustainability standards, often falls short of its objectives.

The Action Plan for implementation of aviation biofuels in Brazil must firmly emphasize that companies, institutions, or farmers that receive any incentive or benefit from public policies that involve public funds, abide by the laws related to the sustainability of processes in the whole production chain. Proof of compliance must be tied to receiving any benefits.

Macedo and Seabra (2008) analyzed the GHG emissions and mitigation for ethanol from sugarcane in Brazil for the 2002-2008 period and the expected changes in the expansion from 2008-2020. Regarding the land use changes (LUC) effects, ethanol expansion started in 2002 led to a very small use of native vegetation lands (less than 1%), and a large use of low productive pasture lands and some crop areas (soy and maize). The relatively small area used

for the expansion was due to land availability<sup>3</sup>, environmental restrictions, and local economic conditions. Growth scenarios for 2020 (reaching 60 million cubic meters of ethanol) indicate the need for relatively small additional areas (approximately 5 million hectares) as compared to the availability (non-used arable lands or degraded pasture lands). Thus if policy and law enforcement are implemented so as to ensure optimal land use for biofuels, they found that very little impact (if any) from LUC on GHG emissions is expected. Considering the local conditions in Brazil, Macedo and Seabra (2008) found the area needed for the expansion to be very small when compared with the areas available with increased cattle raising efficiency (30 million hectares) and other non-used arable land. They showed that sugarcane expansion has been independent (and much smaller) than of the growth of other agricultural crops. In all sugarcane expansion areas the eventual competition products (crops and beef production) also expanded.

Another globally discussed topic in the sustainability of biofuels is the food vs. biofuel debate. According to Rosillo-Calle (2012) “*biofuel production and food security needs to be complementary.*” It is important to assess food security impacts from biofuel production, but without disregarding the positive impacts the additional income has on agricultural productivity. It is equally important to remember the benefits that these alternative fuels generate if they meet their most important function, which is to reduce GHG emissions from the whole supply chain when compared to fossil fuels. In Brazil, there is enough available land for the production of food and biomass for biofuels (CGEE, 2012; Goldemberg, 2008; Goldemberg et al., 2008; Nassar et al., 2011). Agricultural expansion has increasingly been taking place in degraded pasture areas and productivity of livestock production has increased significantly, from 0.92 heads/hectare in 2000 to 1.15 heads/hectare in 2010 (IBGE; Outlook Brazil 2022).

So far, there is no widely accepted methodology and not enough data to calculate ILUC in a robust way. However, both Europe and the US have regulations in place related to indirect land use change emissions of biofuels. Only the US has defined a methodology to measure ILUC. In Europe, the Renewable Energy Directive (RED) states that all relevant indirect effects must be considered, but the concept and methodology to measure ILUC are still being discussed.

On April 2009, the California Air Resources Board (CARB) approved the specific rules and carbon intensity reference values for the California Low-Carbon Fuel Standard (LCFS), which included ILUC. For some biofuels, CARB identified land use changes as a significant source of additional GHG emissions. Sugarcane ethanol from Brazil was considered as an advanced biofuel, due to its verifiable 90% greenhouse gas emission reduction.

On February 2010, the U.S. EPA issued its final Renewable Fuel Standard (RFS2) regulation for 2010 and beyond. It incorporated direct and significant indirect emissions including ILUC. EPA's analysis accepted as renewable fuels both ethanol produced from corn starch and biobutanol from corn starch. Ethanol produced from sugarcane was classified as an advanced fuel based on its GHG performance. Both diesels produced from algae oils and biodiesel from soy oil and diesel from waste oils, fats, and greases fell in the “biomass-based diesel” category. Cellulosic ethanol and cellulosic diesel met the “cellulosic biofuel” standard.

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<sup>3</sup> See Brazilian Sugarcane Agroecological Zoning (ZAE Cana) [http://www.cnps.embrapa.br/zona-mento\\_cana\\_de\\_acucar/](http://www.cnps.embrapa.br/zona-mento_cana_de_acucar/)

### Box 3: Regional Outreaches

Regional Outreach workshops provided regional views on challenges and opportunities that helped broaden the range of perspectives and stakeholders represented in the Sustainable Aviation Biofuels for Brazil roadmap. EPFL (Victoria Junquera and Sébastien Haye) and 4CDM (Cristiane Azevedo) joined local stakeholders including producers, NGOs, academic experts and public agencies in three workshops. The main roadmap had the greatest concentration of stakeholders (and most of its workshops) from the Southeast region so the Regional Outreaches provided input from three regions: Northeast (Recife), Center-West (Cuiaba) and South (Curitiba). The North Region was not included in the Regional Outreaches due to the fact that it is predominantly composed of Amazonian forest therefore it was not considered a likely candidate for sustainable aviation fuel development.

The major findings and recommendations of the Regional Outreaches are listed below:

**FEEDSTOCKS** - Explore the potential of feedstocks adaptable to each region such as: **Northeast** - native palm species (Babaçú - *Attalea speciosa*, Catolé - *Syagrus cearenses*, Licuri Palm - *Syagrus coronata*, and Macaúba Palm - *Acrocomia intumescens*), castor seed, cotton, oiticica - *Licania rígida*, other oils, and microalgae; **Center West** – camelina, cotton, non-edible sweet potato, and soy; **South** - camelina, castor bean - *Ricinus communis*, cártamo - *Carthamus tinctorius*, crambe - *Hochst abyssinica*, forestry, forrage turnip - *Raphanus sativus* L., jatropha, macaúba, microalgae, peanut, rapeseed, sunflower, tungue - *Aleurites fordii*, and woody residues. Very little agronomic information is available for most, so agronomic studies must establish producing guidelines and best practices.

**FOCUS** - In the short term, focus on medium- to large-sized producers since they can produce at the scale needed.

**COLLABORATION** - Develop a model enabling structured collaboration between universities, national and state research organizations, government agencies and industry that stimulates innovation and dialogue while minimizing bureaucracy, leveraging capabilities across the country and transferring technologies to industry. Provide mechanisms for funding from national and international investors, as well as government. Drive productivity and regional development with mechanisms such as the “rural extension” program to transfer knowledge of best practices between state agronomic institutes, local Embrapas and research entities.

**SUSTAINABILITY** – A common definition frames sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” It is critical to address economic, social and environmental aspects of sustainability in developing supply chains for aviation biofuels. It makes business sense to avoid creating unnecessary impacts and triggering controversies over land, water, labor conditions, food prices or deforestation, and to demonstrate long-term financial viability in a world that may be dominated by climate change effects on agriculture. International sustainability standards and voluntary certifications, such as the RSB or Bonsucro, allow producers to demonstrate to their whole supply chain that they are using good practices, giving them an advantage in the market, especially for aviation biofuels, where the buyers are interested in proving the sustainability of their fuel supplies

**POLICIES** - Establish policies that incentivize and consider the whole supply chain and the biofuels industry as a whole, not policies specific to a particular feedstock or process. Apply smart incentive policies over time, at regional and national levels, to eventually make production economically sustainable. Expand investment in infrastructure, especially road and rail, is a fundamental condition for acceleration of sustainable regional biofuels industries as well as overall development of Brazil.

## 6.4 Logistics of jet fuel

Discussions about the logistics of production and distribution of jet fuel in Brazil included quality control requirements and safety procedures associated with jet fuel handling, and the impacts of jet biofuel commercialization on the distribution system. Several conclusions were reached. The main stakeholders of the conventional jet fuel distribution chain in Brazil, future jet biofuel producers, airlines association, international specifications boards and Brazilian regulatory agencies participated in the discussion process.

The main conclusions about logistics are:

- a. the logistics of conventional jet fuel in Brazil is fairly organized. Although consumption is very concentrated in large international airports close to oil refineries, a small fraction goes to regional airports that sometimes can only be reached regularly by air or by water ways during part of the year. Furthermore, some regions of the country are supplied almost exclusively by imported jet fuel. All these important aspects will have to be considered in the implementation of a national policy promoting jet biofuel;
- b. by adopting the international concept of “drop-in” jet biofuel, the essential anticipated barriers for the distribution logistics of jet biofuels, like recertification of aircrafts, changes of airports infrastructure, establishment of quality control, traceability and auditing requirements compatible with aviation, are surpassed. After approval of the blend according to ASTM D7566, attested by the batch Certificate of Quality, the biofuel is re-identified as satisfying ASTM D1655. It becomes interchangeable with any approved jet fuel and subject to the same requirements as conventional jet fuel;
- c. certainly, some commercialization gaps and barriers remain, mainly in the logistics of the biofuel before the blending point and with the establishment of technical and legal requirements the “blender” will have to fulfill. According to ANP, this issue is going to be regulated through the process, in course, of revision of Resolution Nr 37/2009;
- d. of the 13 largest airports responsible for 85% of jet fuel consumption in the country, 10 are mainly supplied by nearby oil refineries, 2 are supplied through imports by sea (7%) and only Brasilia International airport (6%) is supplied via tank trucks from a refinery 700 kilometers away.

### Jet fuels: required technical specifications

- Net heat of combustion (min 42.8 MJ/kg)
- Density at 15 °C (between 775-840 kg/m<sup>3</sup>)
- Adequate volatility (atmospheric distillation temperature between 200 and 300 °C)
- Freezing point (max -47 °C, for Jet A-1)
- Viscosity at -20 °C (max 8 mm<sup>2</sup>/s)
- No water dissolved
- Chemically stable and with low corrosion potential
- Additives are used in jet fuels in order to achieve the desired specifications, for example: anti-oxidant; anti-corrosive; dissipation of electrostatics charge; anti-freezing
- Technical specification needs to follow IATA and ASTM specifications.



Therefore, the best alternative for finishing the biofuel, preparing the blend and issuing a certificate of quality for the batch of jet biofuel is a terminal nearby the airports and suppliers. On the other hand, an airport like Brasilia's which consumes approximately 0.5 million cubic meter of jet fuel a year, is distant from refineries and close to agricultural feedstock production sites, could economically benefit if the "drop-in" point was nearby;

- e. because the initial processing of agricultural feedstock should be made nearby the fields for economic reasons, the logistics of the jet biofuel production deserves detailed studies for each type of feedstock and applied processes to maximize economic benefits.

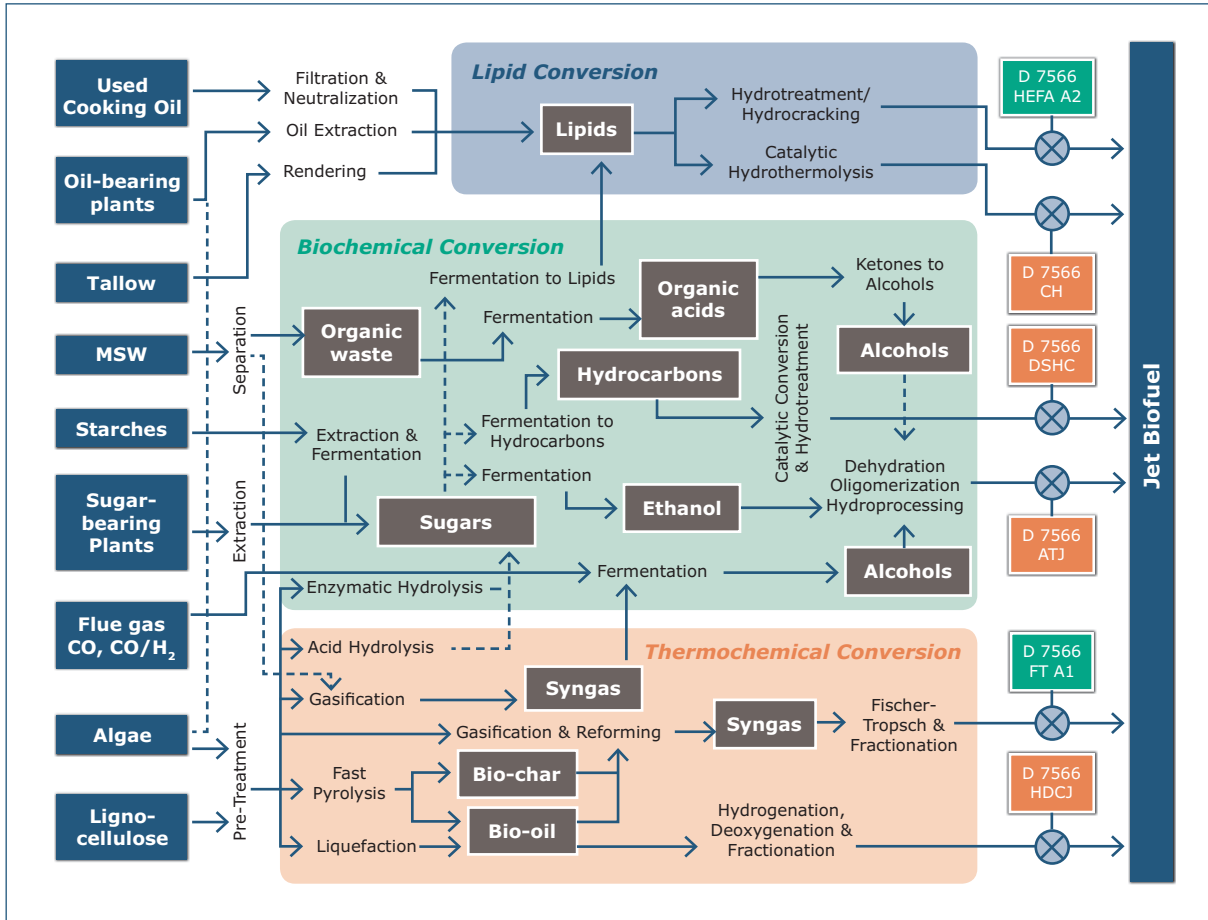
## 6.5 The Identified Pathways and R&D Gaps

### Identified Pathways

After discussing the feedstocks and refining processes for producing renewable jet fuel, multiple possible pathways were identified during the project. Certification requirements for use in commercial aviation are established internationally according to ASTM D7566, which contains one special annex for each approved alternative jet fuel production process. **Figure 8** presents an overview of all identified pathways pertinent to Brazil, including the denomination and status of the ASTM approval process. As depicted, two of the final jet fuel production processes are already approved (green boxes in **Figure 8**) and several others are still under analysis in ASTM's Emerging Fuels Committee.

#### "Pathway"

A combination of a feedstock, pretreatment, conversion and specific jet fuel production process.



**Figure 8:** Identified pathways for the production of sustainable jet biofuel in Brazil [Note: HEFA – Hydroprocessed Esters and Fatty Acids; CH – Catalytic Hydrothermolysis; DSHC – Direct fermentation of Sugars to Hydrocarbons; ATJ – Alcohol to Jet; FT – Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene; HDCJ – Hydrotreated Depolymerized Cellulosic to Jet].

After pretreatment, the possible feedstocks are submitted to different conversion processes classified here as: lipid, biochemical and thermochemical. The final jet biofuel production processes are usually oil-refinery-like processes.

While lipids and thermochemical conversion processes have already some routes approved by ASTM, the various biochemical conversion routes still require approval.

**R&D and Commercialization Gaps**

In broader terms, R&D programs need to be created having defined objectives that take into consideration aviation biofuels goals and the large number of pathways to be considered. The R&D aviation biofuels program must meet following objectives to overcome existing gaps:

- make the pathway technically feasible, when there is a need to demonstrate technical-commercial feasibility;
- reduce GHG emissions from a full life cycle analysis perspective when the biofuel net GHG emissions is still too high to justify its use;

- reduce biofuels production costs, when the biofuel final production price (cost + profit margin) is still above the jet fuel market price; and
- improve the environment and socio-economic indicators, when its benefits are still not significant.

Commercially, it is important to recognize that successful biofuels have built their economic viability on co-products. This was the case of Brazilian sugarcane ethanol with sugar, American corn ethanol with dried distiller's grain used as feed, and soybean biodiesel in different countries, where soybean cake was commercialized as feed. Of course the co-product market size and characteristics will also determine how the biofuel-co-product economic equation will be built. However, it is recognized that when aviation biofuel is considered, certainly an important strategy to obtain a lower cost biofuel is by developing high-value co-products. It is worth mentioning that generally the processes produces not only jet biofuel but also renewable diesel and gasoline, which should be considered together in an integrated biofuel program.

Besides the above drivers for R&D program definition, it is also essential to define an R&D strategy (approach) to be followed. This will determine the efforts, translated as the amount of financial and human resources to be invested, and future accomplishments and benefits.

### R&D for Identified Pathways

The lipid conversion route is well established and approved by ASTM as HEFA – hydro-processed fatty acid esters and free fatty acids. Investment cost for hydro-processing is considered to be low, but the cost of feedstocks can represent more than 70% of total cost (EC, 2011). The availability of inexpensive hydrogen can significantly affect the final cost. The main gap in this case is a commercial one. The Brazilian Biodiesel Program, well established in the market since 2005, competes for the same feedstocks — plant oil, tallow and used cooking oil. Eventual niche markets for supplying airports distant from refineries but near agriculture fields could be promoted by the production of hydrogen from biomass, an aspect that needs to be better developed in Brazil. The high oil productivity of palm has to be better explored for Brazilian conditions, and R&D on its agriculture side needs to be incentivized. R&D on other oil-producing plants can help to improve agriculture gains on lands that are not presently used for agriculture, but it is necessary to treat Brazilian biofuels in an integrated way to avoid the competition for feedstock between jet biofuel and biodiesel. Another possibility of feedstock is microbial lipid produced by fermentation of soluble sugars (heterotrophic) or directly produced by algae (phototrophic). The R&D gaps for these pathways range from applied biology to improve microbe stability, to construction of demonstration units large enough to obtain competitive prices. If cellulose can be used as feedstock some cost benefits are expected on the long run.

The biochemical conversion route actually includes diverse feedstocks such as municipal solid waste, flue gas (industrial waste residue) rich in carbon monoxide and fermentable sugars,

### "LCA"

Stands for Life Cycle Analysis, a methodology that allows calculation of the GHG emissions throughout the entire supply chain of a given product, in our case aviation biofuels.

either from plants, starch conversion or hydrolysis of cellulosic material. Most of the pathways produce alcohols as intermediate products that are transformed into jet biofuel through the ATJ process, which may be the next annex approved by ASTM. The other possible route is DSHC – Direct Sugar to Hydrocarbon, which is also submitted to ASTM and uses genetically modified microbes to convert the sugar, followed by a soft hydrogenation to obtain the jet fuel.

There are several R&D gaps to be filled according to the development stage of each particular pathway, as for example: to develop more selective catalysts to convert alcohols more efficiently to jet fuel; to improve the conversion efficiency of sugars to hydrocarbon; to develop microbes more resistant to contamination by synthesis gas produced through gasification; to advance municipal waste separation and to improve fermentation of the organic fraction; to reduce the cost of enzymatic hydrolysis to produce fermentable sugars or ethanol; to overcome the phase of demonstration units and reach commercial ones for all the pathways.

The main commercial gap for the pathways that go through sugars or ethanol is that the market price of these intermediate products is high due to possible uses as food or road biofuel. Due to the large Brazilian experience in producing sugar and ethanol from sugarcane and the existence of a well-established agro-industrial sector dedicated to the field, the natural reference price for liquid biofuels probably will be ethanol. In energy terms, the actual ethanol consumption in Brazil as road biofuel is more than one-and-a-half times all aviation fuel consumption (ANP, 2012). Once again, it is necessary to establish a governmental program to treat Brazilian biofuels in an integrated way to avoid the competition for feedstock between aviation and road biofuels.

The main feedstock for the thermochemical route is lignocellulose that is available in sufficient amounts to substitute all conventional liquid fuels in the country. An ASTM approved pathway using this route to produce jet biofuel using the Fischer-Tropsch process already exists. The origin of the lignocellulosic material can be sugarcane bagasse, wood or forestry residues.

Although the cost of the raw material in the field can be very low, the transportation cost is important and limits the size of the processing plant, with large implications on investment cost. Another possible route using lignocellulosic biomass is to start with pyrolysis, obtaining bio-oil and biochar, intermediate products that could be transported economically through longer distances, to be then submitted to gasification and synthesis by the Fischer-Tropsch process. The cost of the process is still considered high due to the very special conditions required by the reactions (high temperature & pressure), demanding large reactors to decrease cost.

The main development gap in this pathway is the gasification and gas-cleaning processes that are not designed for the available Brazilian biomass.

A promising pathway alternative to Fischer-Tropsch, which has been investigated mainly outside Brazil, is to obtain a bio-oil through fast pyrolysis or solvent liquefaction, which could be upgraded in an existing refinery infrastructure, reducing costs of upgrading.

The transformation of the bio-oil to biojet fuel is done by deoxygenation processes. The main R&D gap in this case is that hydrodeoxygenation of bio-oils needs extreme conditions of temperature and pressure, with specific catalysts and expensive hydrogen.

## 7. Conclusions and Recommendations

The *Sustainable Aviation Biofuels for Brazil Project* proposed and implemented an enriching experience involving important stakeholders from different sectors of society: government sector, agriculture, aviation industry, regulatory agencies, NGOs, universities and research institutions. The *Sustainable Aviation Biofuels for Brazil Project* proved to be an endogenous creative output, a Brazilian contribution to a sustainable aviation industry.

The following conclusions and correspondent actions were drawn from the several activities of the *Sustainable Aviation Biofuels for Brazil Project*. They can be grouped as:

### Why Brazil?

Past Brazilian experience on feedstock for modern and sustainable production of biofuels has shown the fundamental importance of large scale for economic competitiveness with fossil fuels. Brazil has accumulated technical experience in agriculture and industry, institutional capacity, and great popular acceptance. This makes it an excellent environment to begin the new jet biofuel industry worldwide.

After the Brazilian ethanol program was created in 1975, it did not only help this country to alleviate its fossil-fuel dependence, but it also helped to modernize Brazilian agriculture. Since 1975, Brazil has become a net exporter of agricultural goods, including grains, meat and other products. Brazil is one of the world's best examples of the potential for reconciling sustainable biofuel production with food security.

The current production of bioenergy in Brazil is much larger, in energy terms, than the total jet fuel consumption in the country, a fact that will compel jet biofuel to conform to feedstock prices already established in the market.

Brazil only utilizes 7% of its land for agriculture (60 million hectares out of a total 850 million hectares), much below industrialized nations such as USA's 15%, and the 30-40% of most European countries. The report concludes that the country has abundant available land for bioenergy through increasing productivity on existing agricultural lands, which could be an example for the world, if land use is optimized in this way.

### Aviation industry goals

The Brazilian aviation industry, including Embraer, Brazilian main airlines, Petrobras Aviation and all involved regulatory agencies and related institutions, has demonstrated deep commitment to the introduction of jet biofuels in aviation in Brazil.

Air transportation is indispensable in modern life, so a stable and safe supply of jet biofuel at competitive cost is crucial for the aviation industry to grow in an environmentally sustainable manner, meeting industry goals for carbon emissions reduction.

Aviation biofuel processing will possibly have to be integrated at least with liquid biofuels for road, rail and water transportation, if it is to be competitive in economic terms with fossil fuels.

Scale and chain optimization are crucial for the fuel business and the cost of “drop-in” jet biofuel is higher than that of road biofuels.

Although expensive, the ASTM certification procedure and the associated “drop-in” concept reduce barriers to introduce aviation jet biofuels and should be taken into account strictly.

#### Which feedstocks to use in Brazil?

There is no single, perfect feedstock to produce a jet biofuel in Brazil. The stakeholders agree that work should continue on a variety of feedstocks to ensure the greatest likelihood of adequate availability and getting to scale.

A diversity of feedstocks is available for different growing conditions. Eucalyptus can use land with high slopes. Sugarcane grows in the tropical and subtropical zones while different crops are suitable to different latitudes such as palm in south Pará State; starch and oil crops can be grown in most of Brazil, and these includes non-food crops such as camelina and jatropa, and other feedstocks with promising futures, if more R&D is implemented.

Brazil’s past experience with biofuels also shows that crops which can supply feedstock for diverse applications, for instance food, fuel, pulp, have a larger chance of success.

Just to demonstrate how important agricultural productivity is, sugarcane bioethanol uses only 0.5% of Brazilian territory and represents around 35% of all fuels used for light vehicles in Brazil, besides bioelectricity production. Sugarcane total contribution to primary energy used in Brazil is almost half that of the petroleum. Using ethanol or sugar from sugarcane to produce jet biofuel, less than 0.3% of Brazilian territory would be enough to substitute all jet fuel currently used in Brazil.

Considering the 2020 horizon, the most productive sources of bioenergy from the standpoints of crop yield and energy balance are sugarcane and forestry. These would be the option of choice for aviation biofuels if this was the final criteria. But the problem is much more complex, and the optimization of the country’s ample land resource may contemplate other crops as well.

Therefore the following methodology is proposed to evaluate feedstock substitution:

For each promising feedstock (for diverse applications or only for biofuel), and applicable refining process, one should choose the best identified site for producing enough feedstock to substitute, let us say, 2% of jet fuel consumption and analyze, for that special situation, the effects of producing feedstock for biofuel on local agriculture and its sustainability for the next generations. The following issues should be fulfilled for the substitution to be valid:

- a. evaluate the present economic benefits of the specific site and compare it to the benefits that would be obtained if the new feedstock (even if only for energy) was to be grown there. Consider the prices for one or two decades ahead bearing in mind the maximum feedstock price compatible with an energy price of biofuel equal to the price of conventional fuel. Eventual land valorization and food price increases resultant directly from the implementation should not be considered as benefit. The results should be favorable to feedstock for biofuel production;

- b. evaluate the social and environmental impacts in the region, including small properties and familiar agriculture, and compare the sustainability indicators with the ones for the actual occupation. The results should be favorable to feedstock for biofuel production.

Also, it is important to be emphasized that industrial wastes and municipal solid wastes do represent a great potential in Brazil and therefore should be seriously considered for biofuels production.

#### Which are the identified pathways?

Considering pathway as a combination between a given feedstock and a refining technology, 13 pathways were identified in the *Sustainable Aviation Biofuels for Brazil Project*.

Of course, there are many combinations of feedstock and process likely to be feasible alternatives for aviation biofuel production in the medium-long term.

Given that not a single solution could be selected, the *Sustainable Aviation Biofuels for Brazil Project* has recommended the most promising and sustainable alternatives for implementing more R&D efforts.

Promising short-term possibilities include the use of sugarcane sucrose and ethanol, since they can benefit from low sugarcane production costs and good sustainability indicators in Brazil. However, in the medium to long term, it appears that fiber cellulosic feedstocks such as wood-derived products and sugarcane trash and bagasse will have better competitive possibilities due to their high sustainability values. Several other feedstocks may have medium and longer term potential for cost effective production.

#### Which are the impacts? What about sustainability issues?

The basic reasons for the increasing global interest in aviation biofuels are: to reduce volatile fossil energy costs, to improve energy security and to mitigate GHG emissions. Although they are correlated, those reasons are constrained by the need to encourage jet biofuels that are, in a full context, sustainable and able to follow a continuous improvement path in the direction of the sustainability.

The most critical jet biofuel features are the potential to mitigate GHG emissions and to be produced at competitive costs. Alternatives that supply low costs and high emissions or low emissions and high costs are not, strictly speaking, considered sustainable solutions, even though some positive externalities could justify their acceptance.

Another important finding of the *Sustainable Aviation Biofuels for Brazil Project* was the difficulty in accessing reliable data on Life Cycle Analysis (LCA) and production costs for the different analyzed pathways under Brazilian conditions. Further R&D is considered essential to overcome the identified gaps, see **Table 2** in page 50.

In the Brazilian context of abundant opportunities to increase the productivity of existing agricultural lands, biofuel production can be accelerated without endangering food security

if the relevant policies are implemented, as we have validated in the Sustainability Indicators section of this report.

The real issue is how to improve the sustainability of agriculture in general, which requires economic resources to promote the farmer's necessary cultural change. This aspect can be somewhat improved when agriculture is upgraded by economic resources transferred from urban areas, for instance to pay for feedstock for biofuels.

As presented in the sustainability workshop, the social and environmental issues should not be treated statically. Similarly to the necessary learning curve for the production cost, environmental and social performance should be improved over the long run to build-up a sustainable biofuel industry. Not only sustainability is a dynamic process, but its criteria are also dependent on national and regional contexts. Because countries have different environmental and social requirements, although it is positive that sustainability criteria are defined globally, they always will require national interpretations.

Because aviation is largely an international business, it is very important to utilize sustainability criteria that are agreed upon internationally, such as those of the RSB and Bonsucro.

To fill social and environmental gaps Brazilian institutions must identify practical ways to use the opportunity of growing energy feedstocks to push sustainability culture into the whole of Brazilian agriculture. Also, it is recognized that research initiatives are fundamental to improve performance to sustainability indicators by developing appropriate technologies, both to lower feedstock production costs and reduce unwanted impacts.

#### Which R&D efforts are necessary?

R&D is an essential element to render a possible and sustainable given pathway. Brazil has dedicated substantial R&D efforts that allowed sugarcane and eucalyptus to be competitive crops for biofuels. Therefore much more is needed for other crops and pathways.

Among the production pathways, the Hydro-processed Esters and Fatty Acids (HEFA) and Synthetic Paraffinic Kerosene by Fischer-Tropsch (SPK FT) processes already have received ASTM approvals for use as aviation fuels. Alternatives based on sugar/lignocellulosic feedstock, as Alcohols to Jet Fuel (ATJ) and some advanced biobased processes (Synthetic Kerosene from Metabolic Process), all still in pilot phase, also present good potential. A properly designed R&D program in aviation biofuel is necessary to screen the several pathways for feedstock and processes, which should be evaluated mainly for prospective economic competitiveness, LCA and other environmental and social impacts.

**Technological gaps and actions** – improve agricultural productivity of identified feedstocks and research to find new ones; improve energy efficiency of processing technologies and develop new processes; study the best location and incentivize the construction of demonstration and first commercial plants for the main identified routes for jet biofuel production; extend the installed competence for testing and certification of jet biofuel throughout the country.



### Which infrastructure actions are needed in Brazil to allow adequate logistics of feedstocks and biofuels?

Brazil has important bottlenecks in logistics and needs, both for feedstock and biofuel transportation, to overcome the barriers and help making a competitive biofuel. Although they require attention, blending logistics and specs regulation issues seem to be properly outlined by ANP's revision of Resolution 37/2009 and, due to the "drop-in" concept, do not represent insurmountable obstacles to aviation biofuels. However, explicit investments will be necessary in storage and blending facilities.

Jet fuel consumption is specially concentrated in the country's southeast, but generally in cities not far from the seashore. On the other hand, there is abundant agricultural inexpensive land available in the interior of the country, far from the consumption centers (distances larger than 1,000-2,000 km). Therefore, improvement of feedstock and jet biofuel logistics is a significant need for economic competitiveness of the various pathways for production of jet biofuel. The diversity of available feedstock and specific consumption sites in different regions of the country can impel the materialization of niche solutions taking advantage of long distance and high logistics cost, depending on installed competence for testing and certification of aviation fuels.

**Economical gaps and actions** – develop logistic studies for investment on railways and waterways taking into account feedstocks for biofuels in general and jet fuel specifically; make sure that the cost advantage of Brazilian agriculture products in international markets is reflected in aviation biofuels production similarly to other biofuels; take actions to ensure that the cost difference of aviation biofuel to conventional fuel in Brazil is smaller than in other countries, in a way that the possible exportation of jet biofuel through international flights can enable the competitiveness of the aviation biofuels industry established in the country.

### Is Brazil ready to build the new biofuels for aviation industry?

After decades of regular use of ethanol and mandatory biodiesel blends since 2005, with the active participation of government, Brazil offers a real experience on how to introduce a biofuel in the market. However, despite the previous experiences with production and use of biofuels in Brazil, there are important and relevant institutional issues when the construction of the new biofuels for aviation industry is considered.

Under this scenario, the *Sustainable Aviation Biofuels for Brazil Project* has identified the main institutional issues relevant to aviation biofuels development in the Brazilian context:

- a. the development of the aviation biofuel production in Brazil, associated or not with the current biofuel industry, is able to open a new and innovative chain of sustainable bioenergy, with a growing global demand. Thus, it should be considered strategic and evaluated not only from the immediate point of view, but taking into account its potential to foster economic, environmental and social benefits;
- b. institutional conditions are decisive for promoting aviation biofuels, especially with regards to incentives and financing mechanisms, imposing well designed and coordinated public policies. Government actions in this direction are observed in Brazil, but more is needed,

especially in terms of energy policy, to define the role expected for this renewable fuel in the future and for this new industry;

- c. aligned with the principles of “drop-in” and adopting a worldwide specification, implemented with regular balloting with stakeholders, ANP is providing solid backing to aviation biofuel development and implementation in Brazil, in cooperation with the civil aviation agencies, ANAC and SAC;
- d. it seems relatively premature to recommend targets for mandatory blending of aviation biofuels in Brazil, but studies in this direction are advisable and should be done in order to assess the alternatives, evaluating their implications, costs and benefits;
- e. there are several financing mechanisms that can be directed to promoting aviation biofuels R&D activities and demonstration projects;
- f. biofuels production and use involve necessarily several ministries and interests (Agriculture, Energy, Environment, Science, Technology and Innovation, Defense, etc.) and aviation biofuels of course include another group of agencies and issues. Thus, all stakeholders and decision makers should be included in the discussion and evaluation of alternatives and aims. Since R&D is the prevalent activity at this point, it is recommended that, at least in the pathways screening stage, the leading role must be kept by science and technology agencies at federal and state levels, in an active collaboration with all stakeholders to set practical parameters and identify needs that drive R&D towards effective implementation.

#### What are the main policies and actions required to implement a new jet biofuels industry in Brazil?

Public policies are essential to develop agro-industrial technology for aviation biofuels, as well as to implement financial and regulatory measures able to support aviation biofuels production and use. In this context, how to share the costs and benefits of aviation biofuel adoption should be analyzed and discussed.

Presenting simultaneously favorable conditions to foster biofuels production, a large experience with automotive biofuels and an active aviation industry, Brazil is exceptionally well posed to put forward a program of aviation biofuels, with clear targets, clear supporting mechanisms and participation of all stakeholders. It is important to recommend policies to support the deployment of new technologies pathways from, for example, spin-off companies. We lack such policies in Brazil nowadays.

Long-term biofuels policies, which integrate fuels for all motorized transportation modes and recognize the particular need of aviation for sustainable fuel alternatives, will have to be established to make aviation biofuel economically viable due to the extra cost of producing a “drop-in” fuel.

#### Institutional gaps and actions

- a. prepare the Brazilian set of regulations relative to aviation fuels to accept biofuels according to ASTM approval;

- b. establish the “drop-in” sites as far as possible downstream in the distribution chain without compromising fuel quality and technical certification requirements of aviation sector<sup>4</sup>;
- c. establish legal mechanisms to ensure that incentives for aviation biofuels are only available where demonstrated to fully implement national laws and regulations, especially environmental and social safeguards, natural forest and other habitat protections, land use zoning and worker protections;
- d. observe closely and anticipate regulatory actions by ICAO in such a way to take advantage of international regulations to promote a jet biofuel industry in Brazil;
- e. establish a governmental long-term program for integrated use of biofuels in all transportation modes in the country, to neutralize the cost difference of producing a “drop-in” fuel versus a product for biofuel-adapted engines as is the case for road transportation.

**Table 2** presents a preliminary list of limiting factors and policy recommendations for Aviation Biofuels development, to answer those questions taking into account the particular Brazilian context. This table is a preliminary summary, since a deeper reflection and discussion on these perspectives, involving stakeholders, will address these needs in a more complete way. However, other relevant and more specific recommendations have been addressed and detailed in all *Sustainable Aviation Biofuels for Brazil Project* workshops.

In conclusion, the substitution of fossil fuels for aviation represents a very important opportunity for sustainable biofuels and Brazil has a great comparative position in this area to become a global player. There are important challenges to be overcome to create the basis for this new emerging industry and Brazil cannot afford not to participate.

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<sup>4</sup> To benefit from the logistics of feedstock produced close to remote airports it will be necessary to develop additional personnel and laboratory competences to comply with aviation safety requirements.

Issue	Limiting factors		
	Current	Future	Relevance / Priority
<b>Feedstock</b>	<ul style="list-style-type: none"> <li>Limited information about species with potential for bioenergy</li> <li>Limited information on land zoning for bioenergy</li> <li>High costs for producers to comply with environmental and social regulations</li> </ul>	<ul style="list-style-type: none"> <li>Risk of constraints in natural resources supply (water, chemicals, etc.) for efficient biomass production</li> <li>Risks of expanding biofuels production with high impacts on land use change</li> </ul>	Medium/High
<b>Refining</b>	<ul style="list-style-type: none"> <li>Lack of information about process feasibility, high technology risk.</li> </ul>	<ul style="list-style-type: none"> <li>Technology risk associated to development of innovative process</li> </ul>	High
<b>Logistics</b>	<ul style="list-style-type: none"> <li>Infrastructure constraints.</li> </ul>		High
<b>Sustainability</b>	<ul style="list-style-type: none"> <li>Need for successful enforcement of social and environment laws.</li> </ul>	<ul style="list-style-type: none"> <li>Protect workers, and avoid potential loss of Brazil's major natural resources.</li> </ul>	High
	<ul style="list-style-type: none"> <li>Need for monitoring of performance of aviation biofuels to international social and environment standards.</li> </ul>	<ul style="list-style-type: none"> <li>Avoid difficulties to Brazil's aviation biofuels production.</li> </ul>	High
<b>General</b>	<ul style="list-style-type: none"> <li>Lack of co-ordination among governmental agencies and stakeholder in fostering aviation biofuels;</li> <li>Lack of information about aviation biofuels among decision makers and public.</li> </ul>	<ul style="list-style-type: none"> <li>Heterogeneity and lack of clarity in the sustainability evaluation of biofuels.</li> </ul>	High

**Table 2:** Limiting factors and policy recommendations for Aviation Biofuels development

Policy recommendations		
Immediate/ Short Term	Medium Term (2020)	Long Term (2050)
<ul style="list-style-type: none"> <li>Promote the development of human resources</li> <li>Promote LCA studies on crops with bioenergy potential</li> <li>To evaluate gaps and mechanisms to allow producers to become regularized</li> </ul>	<ul style="list-style-type: none"> <li>Promote advanced agronomic studies on bioenergy cultures</li> <li>Develop assessment on residues availability and collection</li> <li>Promote above trend yields increase</li> </ul>	<ul style="list-style-type: none"> <li>Promote studies on innovative sources of biomass for bioenergy</li> </ul>
<ul style="list-style-type: none"> <li>Promote the development of human resources;</li> <li>Support (financing) for pilot and demonstration plants.</li> </ul>	<ul style="list-style-type: none"> <li>Support (financing/regulatory) aviation biofuel demonstration programs and commercial use.</li> </ul>	
<ul style="list-style-type: none"> <li>Evaluate needs of regions with potential for biofuel production.</li> </ul>	<ul style="list-style-type: none"> <li>Promote logistics improvements;</li> <li>Assess new productive schemes, reducing transport of bulky biomass.</li> </ul>	
<ul style="list-style-type: none"> <li>Establish legal mechanisms to ensure that incentives for aviation biofuels are only available where national laws and regulations, especially natural forest and other habitat protections, land use zoning and worker protections, are demonstrated to be fully implemented.</li> </ul>		
<ul style="list-style-type: none"> <li>Consolidate the sustainability certification process.</li> </ul>		
<ul style="list-style-type: none"> <li>Research and incentives only to feedstocks systems which increase overall productivity of energy and food/feed/fiber on same land.</li> </ul>		
<ul style="list-style-type: none"> <li>Launch an aviation biofuel program, with a clear agenda of strategic actions;</li> <li>Promote information campaign on potential, benefits and implications of aviation biofuels.</li> </ul>	<ul style="list-style-type: none"> <li>Assess and issue regularly indicators of the aviation biofuels program;</li> <li>Consolidate the sustainability certification process.</li> </ul>	

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## Glossary

<b>A</b>	
ABRABA	Brazilian Alliance for Aviation Biofuels
ACA	ACA Associates. The new name for Airline Capital Associates, Inc. Company working on consulting and financial advisory, specialize in the commercial aviation industry, which includes manufacturers, airlines, airports, after-market support companies, and ground service companies
AIAB	Aerospace Industries Association of Brazil. National trade association that represents the Brazilian aerospace industries
Amyris	Integrated renewable products company providing sustainable alternatives to a broad range of petroleum-sourced products
ANAC	National Civil Aviation Agency
Andritz	Company working on supplying of plants and services for the hydropower, pulp and paper, metals, and other specialized industries
ANFAVEA	Brazilian Automotive Industry Association
ANP	Brazilian National Agency of Petroleum, Natural Gas and Biofuels.
APTA	Agência Paulista de Tecnologia dos Agronegócios São Paulo State Government
APTTA	Associação Portuguesa de Transporte e Tráfego Aéreo
ASTM	American Society for Testing and Materials
AZUL	Brazilian air transport company
<b>B</b>	
Bioeca	Company devoted to producing sustainable non-food feedstock for advanced biofuels (mainly aviation bio-kerosene), introducing camelina ( <i>Camelina sativa</i> ) crop and cultivation in Brazil
Byogy Renewables	Company working on producing advanced biofuels, namely jet fuel and gasoline from any source of bio ethanol
BNDES	Brazilian Development Bank
Boeing	The Boeing Company, a global aerospace and defense company that manufactures commercial jetliners and defense, space and security systems
<b>C</b>	
CAAFI	Commercial Aviation Alternative Fuels Initiative
CEPID	Research, Innovation and Dissemination Centers (FAPESP Research Program)
CSIRO	Commonwealth Scientific and Industrial Research Organization
<b>D</b>	
DCTA	Department of Aerospace Science and Technology
<b>E</b>	
Embraer	Brazilian private company working on aircraft manufacturer and systems for defense and security segments
EMBRAPA	Brazilian Agricultural Research Corporation
EMBRAPA BIOENERGY	Brazilian Agricultural Research Corporation – Bioenergy Center
EPE	Brazilian Enterprise for Energy Research
EPFL	École Polytechnique Fédérale de Lausanne
EPUSP	Polytechnic School of University of São Paulo
Ergostech	Brazilian company working on renewable energy solutions
ESALQ	Luiz de Queiroz College of Agriculture from USP
ESALQ-LOG	Group of Research and Extension in Agroindustrial Logistics from ESALQ



<b>F</b>	
FAPESP	São Paulo Research Foundation
FAPEMIG	Minas Gerais State Research Foundation from Minas Gerais State Government
FEAGRI	School of Agricultural Engineering from UNICAMP
FEQ	School of Chemical Engineering from UNICAMP
FIEMG	Federation of Industries of Minas Gerais State
FINEP	Study and Project Finance Agency from MCTI
<b>G</b>	
GE/GRC	General Electric Company – Global Research Center
GHG	Greenhouse Gases
GOL	Brazilian air transport company
<b>H</b>	
HEFA	Hydroprocessing of esters and fatty acids
HDT	Hydrotreating Units
<b>I</b>	
IAC	Agronomic Institute of Campinas from São Paulo State Government
IAE	Institute of Aeronautics and Space from DCTA
IAPAR	Agronomic Institute of Parana from Paraná State Government
IATA	International Air Transport Association
IBGE	Brazilian Institute of Geography and Statistics from Federal Government
ICAO	International Civil Aviation Organization
ICONE	Institute for International Trade Negotiations
IFAD	International Fund for Agricultural Development
ILUC	Indirect Land Use Change
INPE	National Institute for Space Research
IQ	Institute of Chemistry from UNICAMP
ISCC	International Sustainability and Carbon Certification System
ITA	Technological Institute of Aeronautics from DCTA
<b>L</b>	
Lanzatech	American private company working on development and commercialization of proprietary technologies for the production of low-carbon fuels
Life	Life Technologies. LIFE is a global biotechnology company providing complete Synthetic Biology solutions to areas such as Biofuels, Agricultural Biotechnology, Bio-based Chemicals, Industrial Enzymes, Biocontrols, Life Science Research, Pharma, Vaccines and Antibodies
LCA	Life Cycle Analysis
LCFS	Low-Carbon Fuel Standard
LUC	Land Use Change
<b>M</b>	
Mount Rundle	Mount Rundle Financial. Company working on investment advisory service, with an emphasis on Brazil and Latin America
<b>N</b>	
Neste Oil	Finnish oil refining and marketing company producing mainly transportation fuels and other refined petroleum products
NIPE	Interdisciplinary Center of Energy Planning from UNICAMP
NGO	Non Governmental Organization
NWF	National Wildlife Federation. Non-profit organization working on protecting wildlife and saving habitats
<b>O</b>	
Oleoplan	Company working on producing vegetable oils, mainly soybean oil

<b>P</b>	
PETROBRAS	Brazilian oil company
P&G	Procter & Gamble
<b>R</b>	
RED	Renewable Energy Directive. The RED was implemented by the European Commission Directorate General for Energy and sets mandates for the use of renewable energy in the European Union
RFS2	Renewable Fuel Standard. The RFS program was created under the Energy Policy Act (EPA) of 2005 and developed in collaboration with refiners, renewable fuel producers, and many other stakeholders, and established the first renewable fuel volume mandate in the United States. In 2007 the program was expanded, and today RFS2 lays the foundation for achieving significant reductions of greenhouse gas emissions from the use of renewable fuels, for reducing imported petroleum, and encouraging the development and expansion of the United States renewable fuels sector
RSB	Roundtable on Sustainable Biomaterials. An international multi-stakeholder initiative that brings together farmers, companies, non-governmental organizations, experts, governments, and inter-governmental agencies concerned with ensuring the sustainability of biofuels production and processing
<b>S</b>	
SAC	Secretary of Civil Aviation from ANAC
SAFUG	Sustainable Aviation Biofuel User Group
SG Biofuel	An energy crop company developing and delivering high performance bioenergy solutions for the renewable fuel, biomass and chemical markets
SINDICOM	National Association of Fuels and Lubricants Distributor
Solazyme	Industrial biotechnology company using standard fermentation facilities to produce renewable oils and bioproducts using microalgae
SWAFEA	Sustainable Way for Alternative Fuels and Energy for Aviation
<b>T</b>	
TERRABON	American private company working on development and deployment innovative and cost-effective technologies for biomass conversion
<b>U</b>	
UNICA	Sugarcane Industry Association
UNICAMP	State University of Campinas
UNIFEI	Federal University of Itajubá
UOP	A Honeywell Company working on technology development and solutions for the petroleum refining, gas processing, petrochemical production and others manufacturers industries
U.S. EPA	United States Environmental Protection Agency” Agency of the United States federal government which was created for the purpose of protecting human health and the environment. Among others is responsible for developing and implementing regulations to ensure that transportation fuel sold in the United States contains a minimum volume of renewable fuel
USP	University of São Paulo
<b>W</b>	
Weyerhaeuser	Company working on pulp and paper production.
WWF	World Wildlife Found. The leading non-profit organization in wildlife conservation and endangered species
<b>0 - 9</b>	
4 CDM	4 Cantos do Mundo (Brazilian NGO)



