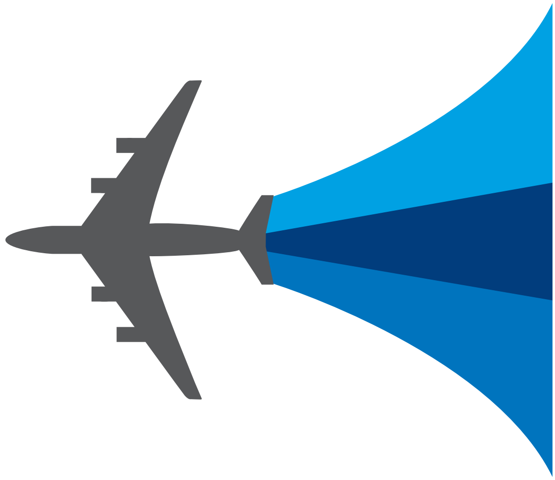

PART II

NEEDS AND TECHNOLOGICAL CAPABILITIES

4 DESIRED PRODUCTS, TECHNOLOGIES OR PROCESSES

Augusto Barbosa Cortez [et al.]. "Desired products, technologies or processes", p.53-98. In: Luís Augusto Barbosa Cortez (Editor). **Roadmap for sustainable aviation biofuels for Brazil — A Flightpath to Aviation Biofuels in Brazil**, São Paulo: Editora Edgard Blücher, 2014.
http://dx.doi.org/10.5151/BlucherOA-Roadmap-004

4 DESIRED PRODUCTS, TECHNOLOGIES OR PROCESSES

There are many routes to produce jet biofuel because of the several options of feedstock and transformation technologies in store or being developed. The main challenge for jet biofuel is to obtain cost reduction, environmentally sustainable production and improvement of rural development taking into account the combination of the most adequate feedstock and refining technologies rather than for feedstock or processing individually. Logistics also plays an important role because plant production has limitations due to climate, soil type, etc, and not all crops can be produced everywhere. In addition, plant material is usually bulky. Therefore, where the feedstock is produced, and all the costs associated with transportation of raw and intermediate materials, and of the jet fuel itself may determine the economical viability of the whole process.

4.1 Feedstock

4.1.1 Biomass production

High agricultural prices combined with strong policies for the adoption of biofuels have transformed the availability of feedstocks for biofuels in a global challenge, especially because the opportunity costs of agricultural-based feedstocks have been increasing. On the other hand, the portfolio feedstock options is vast: oil-bearing crops, sugar/starch crops, cane bagasse, algae, agricultural residues, forestry residues, cooking oil, municipal solid waste, flue gas and tallow. Due to the increasing interest in producing biofuels, these options are being studied by different organizations, with different refining processes and in several regions.

Some of the options, such as sugarcane, soybean, palm, sunflower and tallow, are already being used for producing bioethanol or biodiesel in Brazil. The exception in this group in Brazil is probably cassava.

Other feedstocks, such as camelina and jatropha, are in the early stages of introduction as agricultural crops in Brazil and still require agronomic research. Residues from agricultural production and forestry, and co-products such as sugarcane bagasse, are available but their use depend more on the development of new or cost-effective refining technologies. Flue gas, municipal solid waste, cooking oil and sewage are alternatives being developed only in other countries, but some of these have great potential in Brazil, considering the high population and large cities that abound in this country.

Because Brazil has very favorable conditions for agricultural production (land and water availability, rain feed agriculture, millions of hectare of pasture land available, good climate in most regions, and long tradition in agriculture), the production of biofuels from residues is less developed than in other countries in which the agricultural sectors have more constraints to expand. On the other hand, exactly because the Brazilian agriculture sector still has room to expand, issues such as food versus fuel and indirect land use change has less importance than in other countries, although they must be taken into account in the sustainability debate. Issues such as the compliance with labor and environmental regulations are strongly raised by NGOs and the civil society. However, the feedstock options examined in this report also include plant residues, wastes, by-products and non-food crops that can eventually be grown in marginal lands, which minimizes competition with food production. Despite the particular situation of Brazil regarding that issue, the food x fuel and indirect land use change debate is strong in some international arenas. The European Unit has a proposal for revision of the Renewable Energy Directive (RED) which, among other things, places a 5% cap on the amount of food crop-derived biofuels used to meet the EU's goal of reducing transport energy usage by 10% by 2020 (EC, 2011).

This section of the report summarizes the discussions on feedstocks for biofuels from the 2nd Sustainable Aviation Biofuels for Brazil Project Workshop. The workshop was organized in two parts; in the first, invited specialists made presentations focused on broad range of feedstocks and in the second part a group discussion covered the strategic potential, the technical risks, and the commercial risks associated to the feedstocks. The following feedstocks were addressed through individual presentations or in the group discussions: sugarcane, sweet sorghum, cassava, elephant grass, soybean, palm, jatropha, camelina, photosynthetic algae, sunflower, rapeseed, peanut, other Brazilian palm trees, other oils, forestry wood residues, cane bagasse, industrial forestry residues (pulp, sawdust, bark), agricultural residues (straw, grasses, etc.), flue gas, municipal solid waste (MSW), used cooking oil (UCO), tallow and sewage.

With respect to the current situation of the feedstocks in Brazil, four topics are relevant: basic indicators (yields and availability), costs and prices, GHG emissions and savings and economic competitiveness against jet biofuel prices.

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. This remarkable combination places Brazil, from a feedstock supply perspective, in a good position, if policies are 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 24**). 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, 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.

Brazil has very good conditions to supply high amounts of feedstocks for biofuels. In addition of having plenty of area for agriculture expansion, the output of Brazilian agriculture is increasing steadily at a rate much higher than that of the cropped area (**Figure 25**). For instance, grain yields increased by 169% from 1992 to 2012 whereas the cultivated area expanded only by 49%. This was done with the incorporation of modern agriculture technologies such as the use of fertilizers to overcome problems of the low soil fertility of most soils: fertilizer consumption increased from 9.28 million tonnes to 29.54 million tonnes (+218%) (MAPA, 2012; CONAB, 2012, 2013).

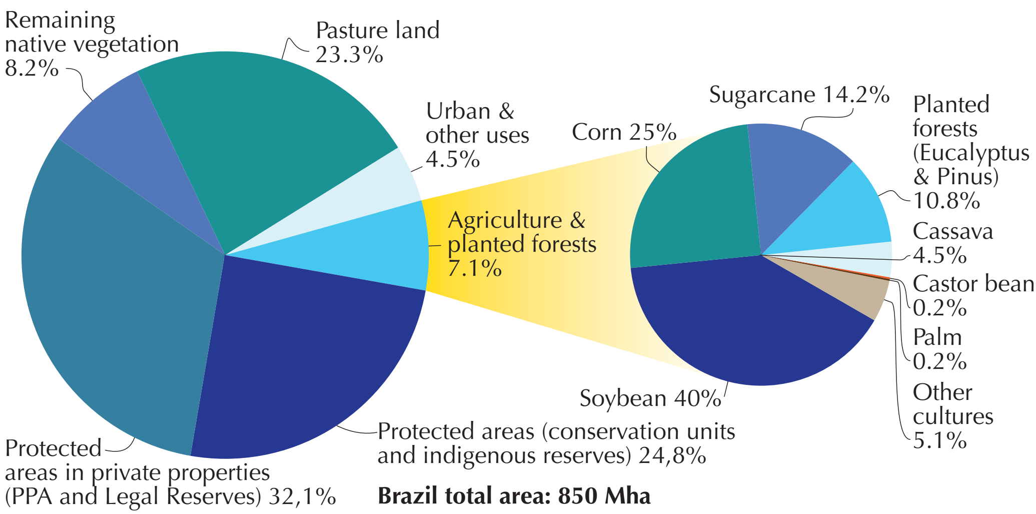

Figure 24 Land Use and planted area with some biofuel feedstock in Brazil and potential for expansion.

Notes:

1) The data on Conservation Units exclude the areas called Environmental Protection Areas (APAs); 2) The Permanent Protection Areas (PPA) 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 and other remaining natural vegetation areas; 4) The protected areas in private properties were estimated based on the new Forest Code, approved in 2012.

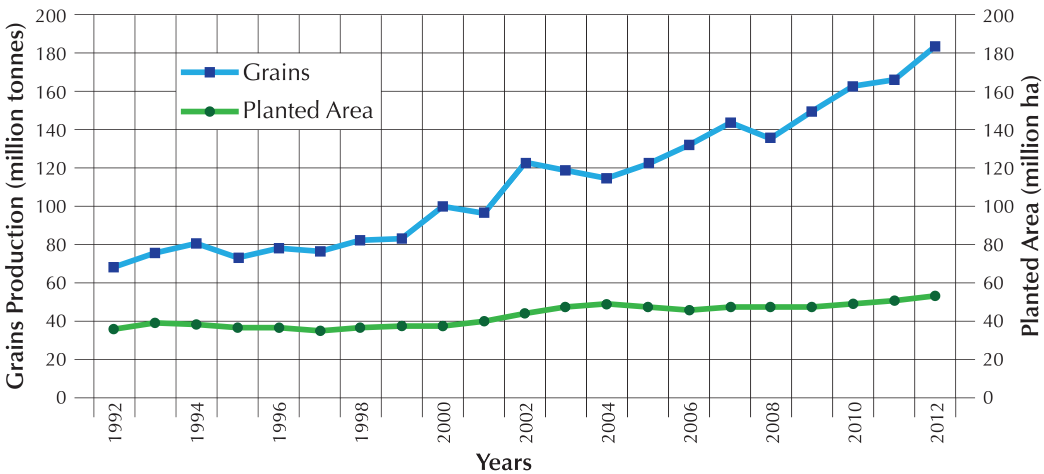

Figure 25 Evolution of grain production and planted area in Brazil in the past 20 years. Source: CONAB, 2013.

Table 6 summarizes the basic indicators for different feedstocks, and comparing feedstocks. The first criterion is the availability of the feedstock in Brazil (production and planted area). Crops such as sweet sorghum, camelina, jatropha and elephant grass have negligible planted area in Brazil. Peanut, castor bean, sunflower seed and even palm are still small in Brazil. In terms of energy yield per hectare, the second criterion, the situation of each feedstock is more associated to natural potential than specific conditions of producing in Brazil. Energy yield was calculated for the main feedstock of the crop (for example, soy oil) and total energy yield, including co and by-products (soy oil and meal).

The third criterion is economics. Producer price and production cost give an idea of the cost of energy content of the feedstocks. Given that the focus is on the feedstocks and not on the final biofuel product, prices and costs for the biofuels are not included in the table. Energy balance and GHG emissions and savings are items associated to the sustainability of the biofuels produced from the feedstocks. Differently from the other items, they are not necessarily specific to the production conditions in Brazil and they are the only item focusing the final biofuel product and not the feedstock. Several of them were collected in literature review. As any life cycle analysis, they were based on several assumptions that might not be the same for all biofuel types.

In order to understand the table, it is also necessary to read the sources and assumptions used to prepare.

The highest energy yields per area are obtained with C-4 grasses such as sugarcane and elephant grass, and trees such as eucalyptus and pinus. Paulownia was also taken into account along the roadmap studies but there is little data available. Although trees of the Paulownia genus (*Paulownia* spp) have interesting characteristics such as fast growth and are adapted to several environments, they are not extensively cultivated in Brazil and their actual potential as jet fuel feedstock remains to be proven. However, eucalyptus is a well established crop in Brazil, where it is grown successfully in many regions. Currently Brazil has 6.5 Mha of planted eucalyptus and pinus - 75% eucalyptus and 25% pinus (ABRAF, 2012), an area almost equivalent to that of sugarcane. Other planted trees, including Acacias (*A. mearnsiie*), rubber tree (*Hevea brasiliensis*), parica (*Schizolobium amazonicum*), Teca (*Tectona grandis*), Araucária (*A. angustifolia*), Populus (*P. spp*), are grown in Brazil in smaller scale, but, still a large area, totaling 0.49 Mha (ABRAF, 2012) and may be suitable options.

Another comparative advantage of planted trees in Brazil is the high yields obtained (**Figure 26**). Research efforts have allowed a favorable yield evolution: from 2005 to 2011 eucalyptus yields increased from 36.7 to 40.1 m^3/ha.year. Average yields of pinus and teca were 35.9 and 14.7 m^3/ha.year in 2011 (ABRAF, 2012). Yields in top farms can be much higher. With an average harvesting cycle of 7 years, 1 ha of eucalyptus can yield around 280 m^3 of round wood. Around 20 m^3 of forest residues are also produced (see Logistics), which must also be considered as potential feedstock for bioenergy production because wood may have other better paid options.

The potential for sustainable wood annual production in Brazil in 2011 was 255 Mm^3 (196 Mm^3 of eucalyptus and 59 Mm^3 of pinus). About 36% of the wood produced went to cellulose and paper production, 26% was for lumber & processed wood. Vegetable coal for the steel industry consumed about 10% and firewood and other used another 26% (ABRAF, 2012). Therefore, part of the wood is already used for energy production. There is plenty of room for planted forest expansion in Brazil and the planted area is growing relatively fast: in 2005 5.29 Mha were planted with eucalyptus and pines; in 2011 the area was 6.52 Mha, an increase of almost 23% in 6 years (ABRAF, 2012).

Table 6 Basic Indicators of Agricultural-Based Feedstocks.

Feedstock	Planted Area	Production	Yield			Producter Price	Production cost		Energy/ balance	GHG	
			Physical	Energy content GJ/ha/year						Emission	Saving
	1,000 ha	1,000 tons	tons/ha//year	Main Feedstock	Feedstock + co-product	R$/ton	R$/ha	R$/ton	MJ/MJexp	gCO_2eq/MJ	% reduction
Sugarcane	8,521	595,127	84	145.2	448.3	65	4,811	60	8.3	24	71%
Soybeans	24,088	74,942	3.1	22.2	60.0	1,ev017	1,567	475	4.5	50-58	40%-31%
Corn	15,018	71,490	4.8	92.7	119.2	367	1,446	289	NA	37-43	56%-49%
Cassava	2,673	24,314	38	169.6	262.9	185	4,281	122	2.7	45	46%
Sorghum (sweet)	NA	NA	30	31.8	31.8	NA	NA	NA	NA	NA	NA
Peanut	99	314	4.2	70.9	89.6	1,286	3,676	865	NA	NA	NA
Castor bean	119	26	1.5	31.5	31.5	1,320	1,574	1,049	NA	NA	NA
Sunflower seed	78	122	2.2	39.6	62.7	917	1,049	477	NA	35-41	58%-51%
Camelina	NA	NA	1.5	22.5	56.3	NA	NA	NA	4.0	25	70%
Palm	109	1,301	22	180.0	243.3	250	4,229	218	8.7	32-37	62%-56%
Jatropha	NA	NA	4.5	57.4	107.9	601	1,889	420	5.5	18-38	79%-55%
Elephant grass	NA	NA	25	–	297.7	NA	NA	NA	7.7	15	82%
Eucalyptus (m^3)	4,874	117,628	40	–	321.1	52	1,149	28	NA	17-22	80%-74%
Pinus (m^3)	1,642	49,,811	37	–	287.4	NA	NA	NA	NA	NA	NA

Notes:

- Heating Value (MJ/liter, MJ/kg). Ethanol: 21.2, 26.9; Biodiesel: 33.0, 37.5.
- Heating Value (MJ/kg): Soy meal: 15.4; Corn DDGS: 18.4; Cane bagasse (wet): 8.9; Jatropha cake: 17; Eucalyptus (wood): 12.98; Eucalyptus (bark): 8.78; Elephant grass (dry matter): 15.9; Cane trash (wet, dry): 13.5, 19.2;
- Data for Eucalyptus: density: 0.6 kg/m^3; wood/celulosis: 4 m^3/ton; bark: 7 ton/ha; rotation: 7 years.
- Data for Pinus: rotation: 15 years
- Content data (kg/ ton of bean). Soybean: Oil (190), Meal/Cake (790); Peanut: Oil (450), Meal/Cake (290); Castor bean: Oil (550); Sunflower: Oil (480), Meal/Cake (280); Camelina: Oil (400), Meal/Cake (600); Jatropha: Oil (340), Meal/Cake (660).
- Data for Palm (kg/ton FFB): Oil (220), Palmist oil (25), Cake (220).
- Productions. Sugarcane: Ethanol (81.5 liters/ton), Bagasse (280 kg/ton), Straw/trash (140 kg dry matter/ton and 164.7 kg/ton); Sorghum (sweet): Ethanol (50 liters/ton); Corn: Ethanol (2.77 gallons/bushel), DDGS (17 pounds/bushel); Cassava: Ethanol (210.5 liters/ton of root), Plant (25 ton/ha and 176 liters/ton).
- GHG, Saving (% reduction): fossil fuel comparator 83.8 gCO_2eq/MJ;
- NA: not available.

Sources and assumptions:

FEEDSTOCK	PLANTED AREA	PRODUCTION	YIELD		
			PHYSICAL	ENERGY CONTENT	
	unit.	unit.	unit.	Main Feedstock	Feedstock + co-product
Sugarcane	Source: CONAB (2012)		Data for: cane stalk, optimized yield (South-Centre Region)	Data for: recoverable sugar (TRS)	Data for: TRS, bagasse and trash (50% collection)
Soybeans	Source: IBGE (2013)		Data for: bean	Data for: soy oil	Data for: soy oil an meal
Corn	Source IBGE (2013) Data for: 1^{st} and 2^{nd} crops		Data for: grain	Data for: grain USDA	Data for: grain and DDGS USDA
Cassava	Source: IBGE (2013)		Data for: roots (optimized yield)	Data for: roots	Data for: roots and plant
Sorghum (sweet)	Currently there is not commercial production in Brazil		Source: CERES (estimated)	Data: fermentable sugar	Data: fermentable sugar
Peanut	Source IBGE (2013)		Data for: optimized yield	Data for: peanut oil	Data for: peanut oil and meal
Castor bean				Data for: castor oil	
Sunflower seed				Data for: sunflowers oil	Data for: sunflowers oil and meal
Camelina	Currently there is not commercial production in Brazil			Data for: camelina oil	Data for: camelina oil and meal
Palm	Source: IBGE (2013) Production data for: fresh fruit bunches (FFB)			Data for: palm oil	Data for: palm oil, palm kernel oil and ampty bunches
Jatropha	Currently there is not commercial production in Brazil			Data for: jatropha oil	Data for: jatropha oil and cake
Elephant grass			Source: Embrapa Agrobiologia Data in: ton of dry matter (leaves and sterns)	Currently it is not applied	Data for: whole plant
Eucalyptus	Source: ABRAF (2012) Production data in: m^3		Source: ABRAF (2012) Data in: m^3/ha/year (mean annual increment)		Data for: whole tree, including bark
Pinus					Data for: whole tree, not including bark

PRODUCER PRICE	PRODUCTION COST		ENERGY BALANCE	GHG	
				EMISSION	SAVING
unit.	unit.	unit.	unit.	unit.	unit.
Data for: Consecana (2013)	Source: Agrianual (2012) Data for: São Paulo State		Source: Nassar and Cantarella (2012b)	Source: EU (2009) Data for: ethanol from sugarcane	
Source: Agrianual (2012)	Source: Agrianual (2012) Data for: Parana State, GMO		Source: Nassar and Cantarella (2012b)	Source: EU (2009) Data for: biodiesel from soybean	
	Source: Agrianual (2012) Data for: 2nd crop		Not available	Source: EU (2009) Data for: ethanol from corn	
Source: Agrianual (2012)			Source: Nassar and Cantarella (2012b)	Source: Nguyen et al. (2007) Data for: ethanol from cassava	
Not available	Not available	Not available	Not available	Not available	
Source: Agrianual (2012)			Not available	Not available	
Source: Agrianual (2012)			Not available	Not available	
Source: Agrianual (2012)			Not available	Source: EU (2009) Data for: biodiesel from sunflower seed	
Not available	Not available	Not available	Source: Nassar and Cantarella (2012b)	Source: SWAFEA (2011) Data for: biodiesel from camelina	
Source: Agrianual (2012) Data in: R$/t FFB	Source: Agrianual (2012) Data for: average of 20 years		Source: Nassar and Cantarella (2012b)	Source EU (2009) Data for: biodiesel from palm fruit	
Source: Agrianual (2012)	Source: Agrianual (2012) Data for: average of 15 years		Source: Nassar and Cantarella (2012b)	Source: SWAFEA (2011) Data for: biodiesel from jatropha	
Not available	Not available	Not available	Source: Nassar and Cantarella (2012b)	Source: SWAFEA (2011) Data for: switchgrass	
Source: Agrianual (2012) Data: not included harvest and handlling	Source: Agrianual (2012) Data for: average of 14 years and not included harvest and handlling		Source: Nassar and Cantarella (2012b)	Source: EU (2009) Data for: biodiesel from wood waste	
Not available	Not available	Not available	Not available	Not available	

Planted forests may be grown in hilly terrain, not suitable for row crops, and, many times considered as marginal land. Forests have a long harvesting season and their products may be stored for long time. Importantly, forests may increase carbon storage in the soil thus representing a further mitigation of CO_2 emission, in addition to the replacement of fossil fuel by the biofuel produced.

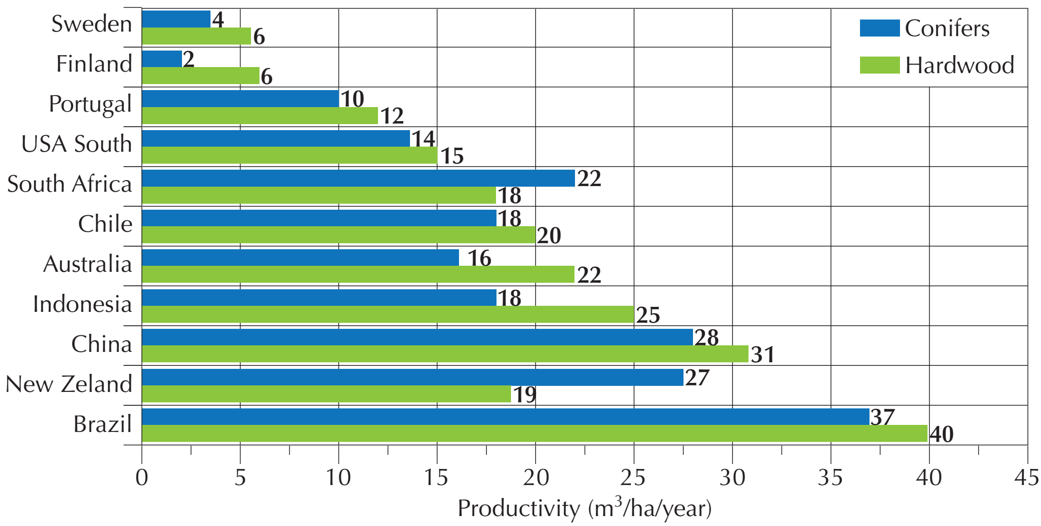

Figure 26 Yields of planted forests in several countries. Source: ABRAF, 2012.

Sugarcane is in a very favorable position both in terms of energy yield and GHGs emissions. Sugarcane is grown in more than 9 Mha in Brazil, where it has being used as a feedstock for biofuel for many decades and has an important production and research infrastructure (CANTARELLA et al., 2012). Elephant grass (*Pennisetum purpureum* Schum) as well as other tropical grasses are cultivated as grazing plants but there are also varieties that are suitable as a biofuel feedstock (MORAIS et al., 2009). Elephant grass also has good numbers as to the reduction of GHGs emission.

Yields of both biomass and energy of oil crops are somewhat lower than those of grasses and wood, but they are also suitable feedstocks for jet biofuel. Brazil has already a mandate to produce biodiesel (5% maximum blended to the diesel) and presently this fuel is derived from renewable sources (85% vegetal oils and 15% animal fats). Most of the biodiesel in Brazil is made with soybean because this crop is extensively cultivated, has high yields and competitive prices (although government subsidies are in place). When the biodiesel program started in Brazil castor bean was one of the target crops because it could be cultivated by small farmers of poor regions but production costs, scale and logistics were not favorable. This is a limitation that may apply to other oil crops but, notwithstanding, many oil producing species are potential feedstock for jet fuel.

The competitiveness of the different feedstocks against jet fuel prices in Brazil is presented in **Figure 27a**. The opportunity costs on are expressed in US$/GJ. Energy yields and prices for the feedstocks were the same as in **Table 6**. The first graph presents the opportunity costs departing from the agricultural product, while in the second the departing product is the main final product of the feedstock, including the biofuel in specific cases (ethanol from sugarcane, for example).

Intuitively, the difference between the opportunity cost of the final product and the agricultural product is the value added of the industrialization, including processing costs. The assumptions are presented below the figure. The intention of this figure is to show that the opportunity costs of feedstocks are high in comparison with aviation kerosene prices in Brazil.

The opportunity costs of feedstocks changes with time due to price fluctuations. Data from 2012 indicate that all feedstocks considered, excluding soy bean, have lower cost per unit of energy than aviation kerosene (**Figure 27a**). However, when the comparison is done taking into account the final products, only bagasse and wood have lower cost per unit of energy than aviation kerosene. Palm oil, anhydrous ethanol and soybean oil have prices slightly higher but, eventually can also be competitive, whereas the use of sugar and cassava for production of aviation kerosene will hardly be justifiable due to the more favorable price if directed to the sugar and cassava flour market. The need for a special tax treatment for jet biofuels in order for the aviation industry to decrease carbon emission and have more sustainable fuels was a conclusion reported in the Sustainable Aviation Fuels Northwest (SAFN, 2011). **Figure 27b** indicates that a special treatment is also necessary to allow the development of the jet biofuel production in Brazil.

The definition of policies make sense environmentally because biofuels have a potential to reduce GHG emissions, which is one key objective pursued by the aviation industry. That price comparison shows that reducing production cost is also a central objective to allow biofuels to become more competitive. It should be also considered that prices of petroleum-derived fuels are likely to increase in the future.

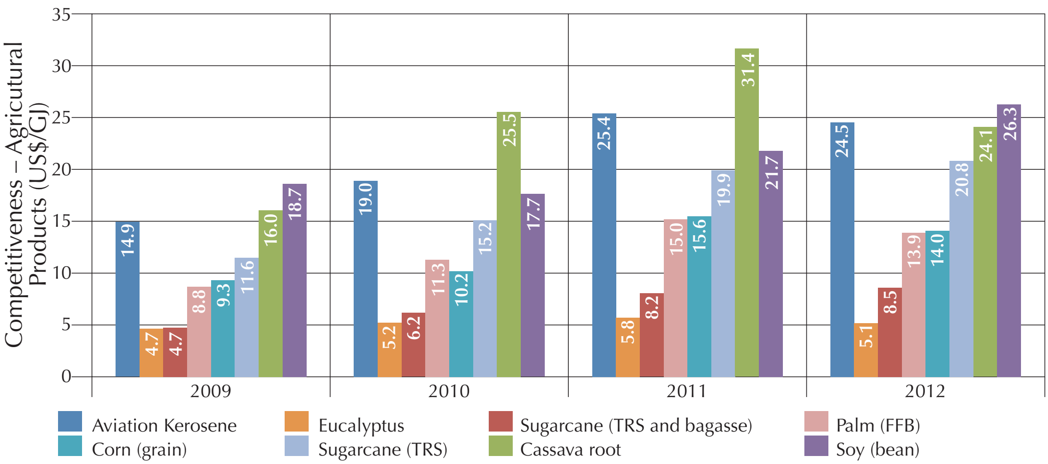

Figure 27a Feedstocks and Jet Fuels: Competitiveness (US$/GJ) – Agricultural products and Final products.

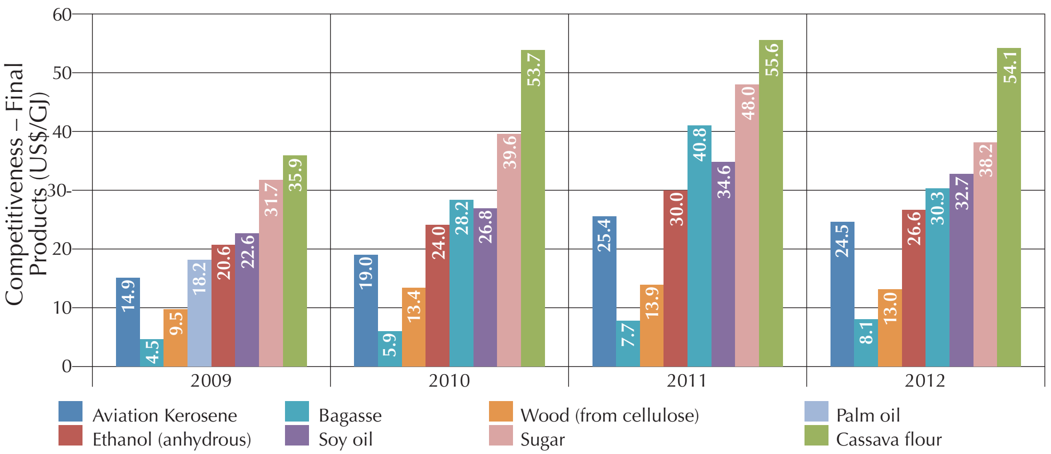

Figure 27b Feedstocks and Jet Fuels: Competitiveness (US$/GJ) – Agricultural products and Final products.

Parameters:

- Biodiesel: 37.5 MJ/kg; Ethanol: 21.2 MJ/liter; TRS Ethanol: 1.77 kg/liter; TRS sugar: 1.04 kg/kg; Eucaliptus wood/pulp: 4 m^3/ton; Eucaliptus density: 0.6 kg/m^3; Eucaliptus:12.98 MJ/kg (30% humidity); Cassava (root): 210.5 liter ethanol/ton; Cassava flour: 300 kg/ton of cassava root; Bagasse (only electricity sugar): 296.4 kWh/ton bagasse; Bagasse (total energy): 1240 kWh/ton bagasse; Sugarcane: 81.5 liters ethanol/ton; Sugarcane: 64.6 kg ethanol/ton; Sugarcane: 280 kg bagasse/ton; Jet fuel: 34.4 MJ/liter; Soy: 190 kg oil/ton; Soy: 790 kg meal/ton; Soy meal: 15.4 MJ/kg; Corn: 412.8 liters ethanol/ton; Corn DDGS: 303.2 kg DDGS/ton; Soy: 190 kg biodiesel/ton; Soy: 19291 MJ/kg; Bagasse: 8.9 MJ/kg (50% humidity); Sugarcane: 4225.4 MJ/ton; Corn DDGS: 18.4 MJ/kg; Corn: 14318 MJ/ton; Palm (FFB): 220 kg oil/ton FFB, 25 kg palmiste oil/ton FFB, 220 kg cake/ton FFB, 9,188 MJ/kg.

4.1.1.1 Feedstock groups

In this study, the feedstocks were separated into four groups according to the nature of the compounds used for transformation: sucrose/starch (sugarcane, sweet sorghum, cassava and algae), oil-bearing feedsocks (soybean, palm, castor beans, jatropha, camelina, sunflower, rapeseed, peanut, other native palm trees and photosynthetic algae), cellulosic (grasses, forestry wood residues, forestry industrial residues, cane bagasse, agricultural residues) and wastes (flue gas, MSW, used cooking oil, tallow and sewage).

Table 7 brings a summary of the main technological areas, technologies or process which requires R&D efforts, as pointed out in the presentations of the feedstock experts.

Sources, Bases and Prices: Agricultural products & Final products:

AGRICULTURAL	Unit	Source	Base	2009	2010	2011	2012
Sugarcane	R$/ton	Consecana/UNICA	delivered at mill	39.9	46.4	57.7	70.3
Cassava	R$/ton	IEA/São Paulo State	farm gate	142.4	200.6	234.9	210.5
Soy	R$/ton	DERAL/Parana State	farm gate	720.3	599.2	701.4	990.2
Corn	R$/ton	DERAL/Parana State	farm gate	267.0	256.7	373.5	392.0
Eucalyptus	R$/$m^3$	IEA/SP, including harvest and handling	delivered at mill	72.4	71.9	75.4	78.1
Palm (FFB)	R$/ton	Agrianual/FNP	delivered at mill	161.0	183.0	230.0	250.0

FINAL	Unit	Source	Base	2009	2010	2011	2012
Palm Oil	US$/ton	CME Group	world price	682.8	900.8	1,125.4	999.3
Soy oil	US$/ton	CME Group/CBOT	world price	848.7	1,004.6	1,299.3	1,226.3
Sugar	US$ cents/ pound	CME GROUP/NYMEX	world price	394.7	492.9	598.5	475.8
Ethanol (anhydrous, sugarcane)	R$/liter	ESALQ/CEPEA	ex-factory price	0.9	1.1	1.4	1.3
Cellulose	US$/ton	SECEX/MDIC	export price	385.8	541.1	563.1	527.0
Wood (from cellulose)	US$/$m^3$		derivated from cellulose	96.5	135.3	140.8	131.7
Cassava flour	R$/ton	IEA/São Paulo State	whole sale price	1,066.4	1,406.5	1,385.2	1,571.3
Electricity	R$/MWh	Empresa de Pesquisa Energetica	auction price	134.0	138.5	145.0	144.0
Bagasse (total energy)	R$/ton		derivated from electricity	166.2	171.7	179.8	178.6
Bagasse (only electricity surplus)	R$/ton		derivated from electricity	39.7	41.1	43.0	42.7
Bagasse	R$/ton		Same price of sugar	39.9	46.4	57.7	70.3
Aviation Kerosene	R$/liter	ANP/Federal Government		1.0	1.1	1.5	1.7

Exchange rate	R$/US$		2.00	1.76	1.67	1.95	

Table 7 Main limitations and areas for which research and technological development are needed to increase feedstock feasibility for jet biofuel production.

PRODUCTS	RELEVANT TECHNOLOGICAL AREAS, TECHNOLOGIES OR PROCESSES
Soybean	• Improve crop management • Genetic improvement - Improve drought tolerance - Increase oil content - Decrease the use of agrochemicals for pest and disease control • Decrease harvest and storage losses, and transportation costs, through better logistics and more efficient machines • Improve GHG performance
Palm	• Strengthen breeding program • Improve or develop varieties with resistance to Bud Rot • Develop high efficiency cloning system • Increase seed production • Reduce production cost • R&D and strengthening of the production chain
Camelina	• Introduction of a new crop to local growers • Adapt camelina variety to local conditions • Definition of the optimized camelina planting protocol • Determine camelina sustainability, including LCA analysis • Agricultural machinery, crushing facilities availability, logistics and transportation
Jatropha	• R&D and strengthening of the production chain • Definition of a production system • Broaden genetic diversity (plant breeding), • Develop suitable cultivars; solve problems of uneven fruit ripening, toxicity of the biomass residuals • Reduce production cost • Develop mechanical harvest: machines, as well as adapt the plants for it
Sugarcane	• Decrease cost of harvesting and transportation • Improve planting practices (decrease seed use, improve yields etc) • Competition for other energy sectors (electricity, ethanol from 2nd generation, others) • Increase investment in plant breeding: varieties for new frontiers of cultivation; drought tolerance 1. Transgenic varieties • Adoption of precision agriculture to increase overall efficiency (increase yields, increase plant longevity, improve GHG and energy balances) • Improve nitrogen fixation • Improve recycling of nutrients
Sweet sorghum	• Plant breeding for increased yield and development of hybrids with different photoperiod response • Plant breeding for extended harvest period. • Deployment of transgenic sorghum, regulatory issues • Minimum/reduced tillage planting to protect soil and provide better crop development • Industrial processing of sugar and starch (grain)

Table 7 Main limitations and areas for which research and technological development are needed to increase feedstock feasibility for jet biofuel production (continued).

PRODUCTS	Relevant technological areas, technologies or processes
Cassava	• Increase general investment in the crop (few scientists working on this crop) • Development of new varieties for the production of energy and greater exploration of the interaction genotype environment • Development of more efficient production systems based on crop rotation and consortium • Rationalization of fertilization • Development of machines for harvesting • Improve industrial development for processing feedstock for biofuel production Uncertainties related to efficiency and supply of enzymes
Eucalyptus	• Improve plant breeding, especially to meet needs of new planting frontiers and drought tolerance • Adapt plants and crop management to future climatic and economic uncertainties • Improve harvesting and transportation systems, specially for forest residues
Grasses	• Breeding and selection of genotypes of high biomass yield for each edaphoclimatic condition • Improve the biological fixation of nitrogen (BNF) characteristics in new hybrids and varieties • Optimize the use of nutrients, specially N and K • Improve cutting, collection, and drying of large quantities of biomass • Develop better strategies for stocking and processing large quantities of plant biomass
Plant residues	• Decrease cost of collection and transportation • Develop strategies for minimizing the effect of organic matter and nutrient removal from the field
Solid waste	• High feedstock volume required for large scale production • Transition from compost or anaerobic digestion to biofuel plant • Biogenic municipal solid waste (MSW) collection costs must be competitive with current costs • Environmental legislation constraints: air permit; solid waste permit
Flue gas	• Scaling up the technology • Feedstocks used are point sourced, available in high volumes with low intrinsic value and are non food • Increase efficiency through integrated systems • Expanding range of usable gas streams
Algae (sugar)	• Scaling up the technology • Need to widen the variety of inputs to feed to algae (sugar, starch and cellulosic ethanol) • Need of LCA analysis

It is clear that each feedstock has specific problems and challenges and the specialists may have used different approaches to select priorities. Although some technologies were quoted in several cases, such as plant breeding, current knowledge on feedstocks is very different. In addition, specific challenges are related to characteristics such as production cycle (annual crops vs. perennial crops), use as food, or the waste nature of the feedstock. Their challenges, therefore, must be considered individually.

In general, for all cultivated crops, continuous genetic improvement through plant breeding is an important tool to increase yield, adapt plants to different regions or environments, improve plant resistance or tolerance to pests and diseases, improve plant quality for processing for biofuel production, increase drought tolerance, nutrient use efficiency, and many other useful traits. Crops such as soybean, sugarcane, and eucalyptus have already a solid research base in Brazil so that the knowledge baseline is high; therefore, R&D results can come relatively fast but gains will not be significant in the short term. Modern molecular biology tools and transgenics may be important for these crops (**Table 7**).

Other crops with some tradition in Brazil are in an intermediate level of technological development, but may have substantial gaps concerning their use as biofuel feedstock, including cost and competitiveness: peanuts, sunflower, castor bean, cassava. Sorghum is a relatively known crop in Brazil but its use as a source of sugar is of little significance so far; therefore, the research effort in this case is relatively high. The infrastructure and critical mass of research in Brazil is good for these crops, so progress is expected.

Palm has specific needs because of its high water and temperature requirements (**Table 7**); it is suitable, with present technology, only to the Northern Brazil forest areas. An agroecological zoning for palm plants in the already cleared lands of the Amazon was recently proposed (EMBRAPA, 2010), highlighting the environmental, economic and social benefits that this crop can bring to the region. The research infrastructure is relatively small and need expansion.

Other crops that could be used as jet biofuel have a small research base in Brazil. These are the cases of jatropha and camelina.

Jatropha curcas is a perennial crop whose seeds contain large amounts of oil that can have many uses, including the production of biofuel. Jatropha has been inadequately promoted as an oil crop capable of reaching high seed yields in low fertility soils, with very little fertilizer needs, tolerant to drought, diseases and pests, and suitable to be grown in marginal areas – promotion that seems rather premature since Jatropha still has several hurdles to be overcome through R&D. Its cultivation has been stimulated in many places in order to produce oil for biofuels and other uses. In 2008 an estimated 900 thousand hectares of jatropha was cultivated worldwide, most of it in Asia (KANT; WU, 2011). However, reports of crop failure to meet the initial expectancy are common. Probably, the most critical case of failure was in India (OPENSHAW, 2000; KANT; WU, 2011; KUMAR et al., 2012), where the Government promoted the cultivation of jatropha by smallholders to meet most of the needs of an audacious program to reach a 30% blending of biodiesel by 2020 (KANT; WU, 2011). Most farmers have discontinued cropping after some time (AXELSSON et al., 2011). Unfavorable results were also reported in other countries in Asia and Africa (KANT; WU, 2011; MUBONDERI, 2012). The same happened in Brazil. For instance, about 1200 ha of jatropha was planted in 2007 at Ribas do Rio Pardo, MS, but most of the plants were removed after sometime, although experimental efforts still continue (CANTARELLA, 2013b).

Even the authors of critical reports on jatropha failures usually agree that this crop has potential as a source of vegetal oil. However, several limitations must be overcome. There is a need of improved varieties (for high yields, pest and disease tolerance, adapted to different regions, uniform flowering and production to allow mechanical harvest), development or adaptation of harvesting machines, and use of co-products (**Table 7**). Berenchtein et al. (2010) reported that jatropha meal detoxified during oil extraction could be used as animal feed, thus increasing the value of the whole crop.

The challenges of turning jatropha into a viable alternative for biofuel production are being addressed by several public and private institutions. For instance Seeds Genomics Biofuels (SGB), an energy company headquartered in San Diego, CA, is using modern biotechnology tools to develop and speed up the production of new hybrids from a wide collection of germplasm (12 thousand genotypes) and testing them in several countries and regions within countries, including Brazil. SGB is also perfecting agronomic practices to obtain high yields, based on the use of fertilizers and agrochemicals and not in the "miracle-plant" concept that characterized the early attempts to promote jatropha (CANTARELLA, 2013b). Several institutions in Brazil (Embrapa and the Agronomic Institute of Campinas) and in the world are also making efforts to improve jatropha. SGB and Embrapa are planning to work together to advance jatropha research. However, much work remains to be done with this crop.

Camelina is a crop that has no tradition in Brazil so far, but, its use as feedstock for jet biofuel will benefit from the investments and developments of the other oil crops. It has lower yields than jatropha but has a short cycle and both its oil and meal can have other uses. It can be grown as a second crop in the same season, similarly to peanut, sunflower, and other plants, which can minimize the completition with food production. Camelina's opportunity cost and relatively low GHGs and energy balances may hinder its use as a feedstock for jet biofuel (**Table 7**). Camelina lacks the critical mass and research infrastructure of other crops already grown in Brazil so its adoption as a cultivated crop may take longer. However, camelina may take advantage of the research expertise in other countries to make up for the knowledge gap under Brazilian conditions. For instance, The Camelina Co, based in the USA, is developing agronomic technology and camelina varieties in partnership with research institutions in North America. Camelina is presently cultivated in 20 thousand ha in the dry lands of Northern USA in rotation with cereals. Sizeable areas are also grown in Canada (MOSER, 2010). Camelina España is promoting this crop in the dry lands of Spain, where it expects to reach 15 thousand ha in 2013-2014 (CANTARELLA, 2013a). In both North America and Spain camelina is considered a non-food crop, although its oil is rich in omega-3 fatty acids, an interesting trait for the food industry. In Brazil, BIOECA is testing camelina as a second crop in succession with the summer crops, taking advantage of this crop's drought tolerance. Much work remains to be done in order to select varieties and adapt agronomic technologies but camelina may become an option of oil crop for the second season, depending on oil yields and price. Similarly to jatropha, an adequate supply chain needs to be established.

Many tropical grasses can be used to produce bioenergy but most of the studies with these plants have been done for pasture or animal feed production. Despite the high yield potential, limitations for their use as biofuel include the high fertilizer requirements to produce optimum yields, the costs of collection, transportation and storage, and the GHGs and energy balances (**Table 7**). Morais et al. (2009) have identified varieties of elephant grass that are suitable for bioenergy production.

Algae are also potential producers of jet biofuel, both as source of oil through photosynthesis or transformation of sugars, starch or other compounds directly into biofuels. Despite the huge potential for oil production per unit area of photosynthetic algae, the cost and operational problems seem to be too high at present. Other limitations for jet fuel production from algae were discussed at the SAFN (2011). The photosynthetic algae option is acknowledged but it was not included in the present report because of the enormous R&D needed. Technologies for transformation of sugars, starch, ethanol etc into biofuel exist but need scaling up. In this case, the feedstock is the raw material to feed the algae (i.e. sugar), and it was treated with their respective source (**Table 7**).

Wastes and residues are very convenient feedstock for jet biofuel because the benefits are two-fold: they do not compete with food production for land or other resources and their use avoids or decreases the cost and impact of their disposal into the environment. Wastes and residues are also widely available and in many cases are point sourced so there is no requirement to develop dedicated feedstock production infrastructure.

There are plenty of options of plant residues in Brazil because of its large agricultural production, including those of grain and perennial crops. Probably the plant residues available in the largest amounts are those of sugarcane, especially bagasse, but also harvest residues, composed of leaves and tops (ROSSETTO et al., 2010; MAGALHÃES et al., 2012). Bagasse, which is generated from the crushing of sugarcane for sugar or ethanol production at a rate of 250 kg (50% moist) per tonne of sugarcane processed (MAGALHÃES et al., 2012), has the advantage of being available at the mill, meaning that the cost of collection and transportation is generally allocated to sugar or ethanol costs. However, bagasse is already used to produce vapor power and electricity to run the mill and surpluses may be sold as bagasse or energy to the grid. Today, almost 6% of the electricity in Brazil comes from plants burning sugarcane bagasse, hence, it has already a market value. However, only 30% of the sugar and ethanol mills sell electricity, indicating that if current furnace efficiency is increased, there may be a surplus of bagasse for other uses. If second or third generation biofuel (or specially jet biofuel) can compete pricewise with other uses for bagasse, there is already a huge amount of feedstock.

Crop residues that have to be collected from the field are also abundant, especially for sugarcane. The amounts of leaves and tops that remain in the field after sugarcane harvest vary from 8 to 20 t/ha of dry matter. Modern grain crops usually have a harvest index around 40 to 50% (40 to 50% of the dry matter is grain); therefore, large amounts of plant material are left behind the grain harvest (CLAY et al., 2012). Two important aspects of crop residues that need studies and technological developments are the cost of collection plus transport and the definition of how much residue to leave on the soil (**Table 7**). Operations of field collection and transport are significant components of overall feedstock cost because plant residues have low density and low unit price (MAGALHÃES et al., 2012). In addition, not all plant residues should be harvested for fuel production because soil organic matter reposition is essential for long term soil quality preservation as well as nutrient recycling, usually a site-specific problem (CANTARELLA et al., 2012; CANTARELLA; ROSSETO, 2010; CLAY et al., 2012).

Forest residues are also options of feedstock (see Logistics, ahead) because of the high volumes of plant material left after round wood is harvested. The limitations of cost of collection and definition of how much organic material to leave on the soil also apply here.

Urban wastes are plentiful because cities are the destination of most of the agricultural products including food, paper and packing, and other raw materials. This is an advantage because these wastes may be available at or near the site of processing and use of the bioenergy. Wastes may have negative price because their producers usually pay for their disposal and the cost of landfills are increasingly high almost everywhere. However, wastes are heterogeneous material, the cost of separation and processing are normally high and there may be environmental legislation constraints that must be addressed (**Table 7**).

4.1.1.2 Sustainability issues

The 4th Workshop – "Sustainability" – aimed to enhance the discussion on aspects of sustainability of biofuels for aviation, related to environmental, social, economic, and institutional aspects.

The main topics presented and discussed in the 4th Workshop were: energy balance; greenhouse gases emissions; productivity; agricultural and environmental best practices: fertilizer consumption, consumption of pesticides, soil loss, water use; biodiversity; energy self-sufficiency; social, economic, institutional environment aspects: legislation, and regulations.

It is important to assess central sustainability aspects related to the production and adoption of jet biofuels, such as GHG reduction potential and the capacity of supply chains to comply with sustainability standards and national social and environmental laws, as well as the economic aspects related to this.

In the 4th Workshop the gaps of supply chains to meet the sustainability requirements were identified and discussed, as well as the impacts of the compliance of the sustainability requirements on financial, technical and commercial risks.

The theme of sustainability is growing in importance in recent years, especially in a scenario with the need for reduction of greenhouse gases emissions, the food versus fuel debate, and the increasing need to meet environmental and social standards.

The plausible feedstock identified in previous workshops (namely sucrose, oils, cellulosic, and waste) were analyzed according to the most known sustainability criteria. The analysis included, although was not limited to, the evaluation of some parameters (when data is available): (i) Potential of CO_2 net reduction per ha; (ii) Land use change (LUC and ILUC); (iii) GHG emissions; (iv) Food security; (iv) Water Use; (vi) Technical skills of rural workers in feedstock value chain; (vii) Mean income per rural worker; (vii) Labor intensity; (viii) Mechanization of planting and harvesting; (ix) Use of agrochemicals; (x) Pollution.

The principles stated in RSB (2010) illustrate the main requirements related to biofuel production when analyzing sustainability aspects (**Table 8**), and were used in the groups discussion with the stockholders in the Workshop. In order to select a set of parameters in the three sustainability pillars (economic, social and environmental), the principle and criteria of three sustainability standards, not coincidentally the ones most used for biofuels, were used as reference. They were Bonsucro, RSB and ISCC and the selection was based in ICONE (2012).

There is a demand in Brazil and worldwide by agricultural practices that are both economically and socially sustainable, which has motivated efforts and investments of producers. Due to this, private sustainability standards and certification schemes have become developed by initiatives such as Bonsucro, the Roundtable on Sustainable Biomaterials (RSB), the Roundtable on Responsible Soy (RTRS), and the Roundtable on Sustainable Palm Oil (RSPO), became common in the market over the past years, as a way of improving and demonstrating the sustainability of the production chain.

The aviation industry will most likely require a sustainability certification for the production of jet biofuels, including feedstocks production, in order to the guarantee that such fuels are produced in compliance with environmental and social requirements determined through a multi-stakeholder process.

Table 8 Principles that should be followed for biofuel production according to Goldemberg (2011).

1	**Legality**	Biofuel operations shall follow all applicable laws and regulations.
2	**Planning, Monitoring and Continuous Improvement**	- Sustainable biofuel operations shall be planned, implemented, and continuously improved through an open, transparent, and consultative impact assessment and management process and an economic viability analysis; - Biofuel operations shall undertake an impact assessment process to assess impacts and risks and ensure sustainability through the development of effective and efficient implementation, mitigation, monitoring and evaluation plans; - Free, Prior & Informed Consent (FPIC) shall form the basis for the process to be followed during all stakeholder consultation, which shall be gender sensitive and result in consensus-driven negotiated agreements.
3	**Greenhouse Gas Emissions**	Biofuels shall contribute to climate change mitigation by significantly reducing lifecycle GHG emissions as compared to fossil fuels.
4	**Human and Labor Rights**	Biofuel operations shall not violate human rights or labor rights, and shall promote decent work and the well-being of workers.
5	**Rural and Social Development**	In regions of poverty, biofuel operations shall contribute to the social and economic development of local, rural and indigenous people and communities.
6	**Local Food Security**	Biofuel operations shall ensure the human right to adequate food and improve food security in food insecure regions.
7	**Conservation**	Biofuel operations shall avoid negative impacts on biodiversity, ecosystems, and conservation values.
8	**Soil**	Biofuel operations shall implement practices that seek to reverse soil degradation and/or maintain soil health.
9	**Water**	Biofuel operations shall maintain or enhance the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.
10	**Air**	Air pollution from biofuel operations shall be minimized along the supply chain.
11	**Use of Technology, Inputs, and Management of Waste**	The use of technologies in biofuel operations shall seek to maximize production efficiency and social and environmental performance, and minimize the risk of damages to the environment and people.
12	**Land Rights**	Biofuel operations shall respect land rights and land use rights.

These sustainability certifications are focused especially on GHG emissions reductions, other environmental impacts (such as water and biodiversity), and minimization of socio-economic impacts. These standards address similar sustainability issues, and a comparison among them can be found in the WWF, IUCN and NRDC reports (WWF, 2013; IUCN, 2013; NRDC, 2014). They all require compliance with the currently available national law 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).

Broadly, most criteria are related to indirect impacts, such as food security, Indirect Land Use Change (ILUC) and biodiversity. These additional criteria are associated to complex issues that are still being extensively discussed. There are no widely accepted methodologies to address them, which complicates even more their inclusion into the standards, which ends up being done in a very conservative manner.

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. While they may generate benefits for producers and processors, they may also generate additional costs and hurdles. It is fundamental to understand the differences between the standards and the gaps to compliance when considering the context and opportunities for jet biofuel production in Brazil.

To define the Sustainability requirements to be analyzed during the 4th Workshop a recent report released by ICONE (2012) on sustainability private standards was taken into account. ICONE carried out a benchmark study to assess the main differences between three standards for certification of biofuels (Bonsucro, RSB, and ISCC) and to identify the main gaps for compliance with these standards in Brazil. Although the study was focused on a jet biofuel produced from sugarcane, many of the issues identified are common to the whole agricultural sector, among them compliance with the Brazilian laws, especially those on environment, labor and worker health and safety. There are other gaps that go beyond the law, especially those related to the interpretation and implementation of certain criteria, such as Human Capital Value Added (HCVA), ILUC and food security.

4.1.2 Feedstock logistics

Logistics of feedstocks plays a very important role in biofuels sustainability since it greatly affects costs and CO_2 emissions. In order to discuss in more detail the logistics to produce biofuels for aviation in Brazil three feedstocks were selected due to their present importance in Brazilian agriculture: soybean, sugarcane, and wood.

Each of these three feedstocks present different characteristics that make them unique as far as logistics is concerned. Particularly bulk density, harvest seasonality and storage capacity are critical factors affecting plant supply. Therefore, logistics may greatly affect jet biofuel manufacturing plant size and the entire economics of biofuels. **Table 9** presents a brief comparison considering soybean, sugarcane, and wood.

Table 9 Feedstock characteristics affecting logistics for biofuels production.

ITEM	FEEDSTOCK		
	SOYBEAN	SUGARCANE	WOOD (EUCALYPTUS AND PINE)
Feedstock characteristic	Grains	Stalks and leaves	Logs, charcoal, firewood, forest residues
Present feedstock logistics	Transport harvested grains to oil extraction plants (up to thousands km)	Transport harvested cane stalks and leaves to the mill (up to 50 km; avg 40 km)	Transport harvested wood to the mill (avg 88 km)
Relative importance of feedstock cost and logistics in final biofuels cost	High (~90% of biodiesel)	High (~60-70% of ethanol)	Low (~30% of synthetic FT biofuels)
Average Yield	2-3.5 tons of grains/ha.year	60-100 tons of cane stalks/ha.year	45 tons of wood/ha.year
Feedstock bulk density	High (~450-500 kg/m^3)	Low (~200 kg/m^3)	Medium-High (~400 kg/m^3)
Feedstock Moisture Content	Low (~12% d.b.)	High (~70% d.b.)	Medium (~40-50% d.b.)
Harvest Season	Jan - May	April-November in Central South Brazil	All year, except rainy days
Need to be processed after harvest	No immediate need, if dried	Needs to be processed with 24-48h after harvest	No immediate need, if dried
Storability	Very high	Difficult. An alternative is Sucrose concentration and fiber densification	High. L logs are very easily stored, residues can be compressed
Importance in Brazilian Food Market (Domestic and Exports)	High	High	None
Importance in Brazilian Energy Matrix	Low (only biodiesel ~1%)	High (~20%)	High (~10%)
Total annual production	70 million tons	650 million tons	254 million m^3

These three crops (soybean, sugarcane, and wood) are cultivated in Brazil in large scale. Typically a Brazilian farm for these crops can reach several thousand hectares but can also be a small to medium size farm. The main reason for using large scale production systems are the gains associated with scale, such as cost reduction, possible with centralized management.

Soybean

Soybean is the most important grain produced in Brazil followed by corn. In 2013-2014 around 90 million tons are expected to be harvested. Although soybean cannot be considered an energy crop, around 80% of biodiesel produced in Brazil (around 2.5 billion liters) used soybean as feedstock. The present prices paid for biodiesel – including subsidies – in Brazil to guarantee B5 turn the use of soybean for biofuels economically viable. However, this scenario doesn't seem to be sustainable for B10 because, under current diesel prices, subsidies would be costly.

Soybean started to be cultivated in Brazil in the early seventies in the Southern states of Rio Grande do Sul and Paraná. Later, this crop spread from north to west to São Paulo, Minas Gerais, Mato Grosso do Sul, Mato Grosso, Goiás, Rondônia and Bahia. The **Figure 28** presents the main soybean producing areas in Brazil highlighting the agroindustrial plants.

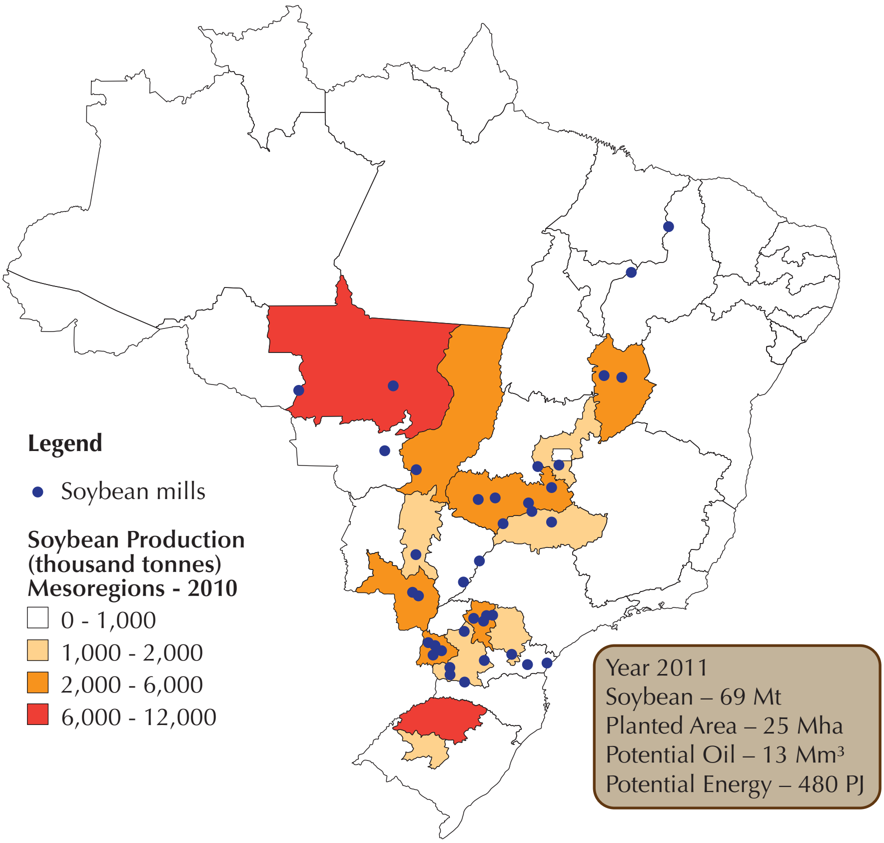

Figure 28 Map of production areas and location of mills of soybean in Brazil. Source: ESALQ-LOG apud Nunes, 2012.

Soybean grains are transported from the agricultural fields basically to two destinations: agroindustrial plants, where the grains are crushed, and harbors from where the grains are exported. Since soybean presents a relatively high bulk density and is easily stored it can be transported to long distances by trucks, trains and ships.

In Brazil there are basically the following corridors for soybean transportation:

1. The south involving soybean grains produced in the southern states of Rio Grande do Sul and Paraná and Central West states of Mato Grosso do Sul, Mato Grosso, Minas Gerais and Goiás. The soybeans grains are transported by truck to Paranaguá harbor located in the Paraná state and then exported mostly to Europe and China. Other harbors used are those of Paranaguá, in Paraná and Santos, in São Paulo
2. The North corridor involving basically Mato Grosso state. The soybean grains are transported by truck to Itacoatiara, AM, and Santarém, PA harbors. Large ships can access these harbors and go directly to Europe and China.
3. The so called "new agricultural frontier", also in the North of the country, specifically West Bahia and the states of Maranhão, Piaui and Tocantins, which is transported by trucks through the Bahia port of Aratu or through the Itaqui port in Maranhão. For this last corridor, the North-South Railway has also been used.

The Brazilian transportation infrastructure, composed by roads, railroads and waterways are considered a major obstacle for efficient and low cost soybean grain long distance hauling. **Figure 29** shows the existing road and waterway system in Brazil. The Brazilian federal government has plans to invest in the railway system to facilitate cargo transportation. **Figure 29c** indicates the possibilities in this area

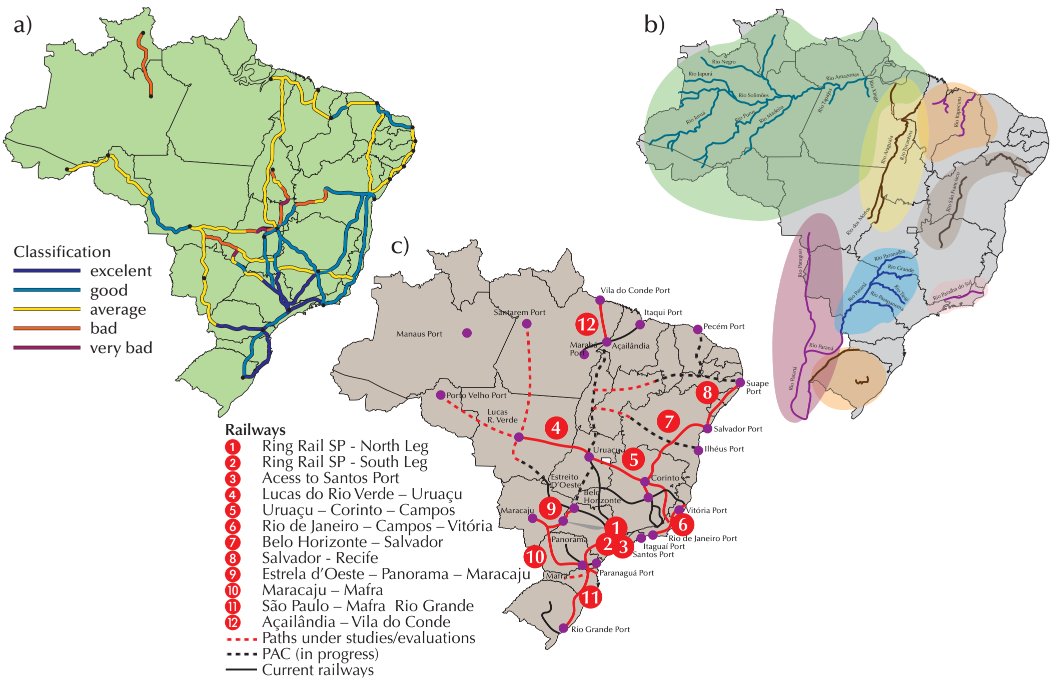

Figure 29 (a) Roads usually considered for the transportation of soybean in Brazil and their state of conservation. Source: CNT apud Nunes, 2012. (b) Main watersheds and rivers used for the transportation of commodities in Brazil. Source: ESALQ-LOG apud Nunes, 2012. (c) Railroad system in Brazil: existing grid and planned. Source: Brasil nos Trilhos apud Nunes, 2012.

Since soybean is cultivated in many regions in Brazil, the infrastructure as well as the limitations described for soybeans also apply to other similar feedstocks that can be used for jet biofuel production.

Sugarcane

Sugarcane is produced in Brazil basically in two areas: Northeast coast (RN, PB, PE, SE, AL states) responding for ~10% of production and Central-South (SP, PR, MS, MT, GO, MG and RJ) responding for ~90% of production. **Figure 30** presents (a) the current sugarcane producing areas in Central-South Brazil and (b) potential sugarcane producing areas in Brazil.

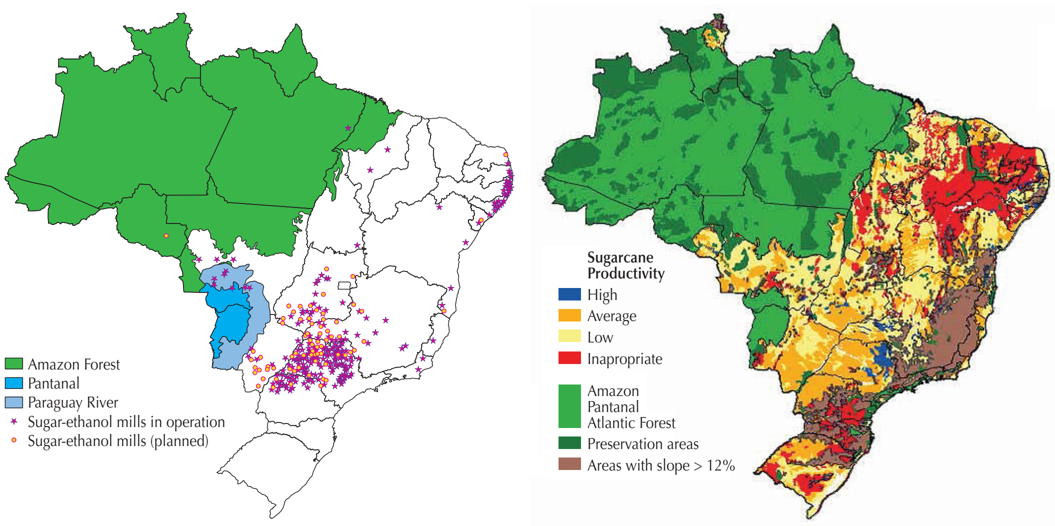

Figure 30 (a) the present sugarcane producing areas in Central-South Brazil. Source: EMBRAPA, 2009. (b) potential sugarcane producing areas with expected yields in Brazil. Source: CGEE, 2009.

The possible sugarcane feedstocks are: sugarcane stalks, sugarcane bagasse, tops and leaves, and ethanol. Important characteristics for sugarcane-derived feedstocks are shown in **Table 10**.

Table 10 Sugarcane feedstocks characteristics affecting logistics for biofuels production.

FEEDSTOCK CHARACTERISTICS	SUGARCANE STALK	SUGARCANE BAGASSE	SUGARCANE LEAVES
Plant part	Stalk, either whole stick from burned cane or billets from green cane harvesting	Wet bagasse from crushing cane stalks	Dry and green leaves from green cane harvesting
Present feedstock logistics	Transport harvested cane stalks to the mill (up to 50 km; avg 30 km)	Produced at the mill, no transportation required if conversion technology is located at the mill	It can be transported to the mill mixed with stalks or baled (up to 50 km; avg 30 km)
Relative importance of feedstock logistics in final biofuels cost	High (~20-50 % of ethanol)	Tend to be high because bagasse tends to be priced as cane. But bagasse is available at the mill	Tend to be high because leaves tend to be priced as cane. Low density material. If collected separately from stems, extra logistics costs apply
Average Yield	60-100 tons of cane stalks/ha.year	20-25 tons of wet bagasse/ha.year	20-25 tons of green leaves/ha.year
Feedstock bulk density	Low (~200 kg/m^3)	Low (~200 kg/m^3)	Low (~200 kg/m^3)
Feedstock Moisture Content	High (~70% d.b.)	High (~50% d.b.)	High (~50% d.b.)
Harvest Season	April-November in Central South Brazil	April-November in Central South Brazil	April-November in Central South Brazil
Need to be processed after harvest	Needs to be processed with 24-48h after harvest	No need to be processed immediately	No need to be processed immediately
Storability	Difficult. Eventually sucrose can be concentrated and fiber can be densified	Can be stored as is (bagasse is normally stored) or densified as bales or pellets	Can be stored as is or densified as bales or pellets
Importance in Brazilian Food (Domestic and Exports)	High	No use for food	No use for food
Importance in Brazilian Energy Matrix	High (ethanol accounts for ~10%)	High (bagasse accounts for ~10%)	Limited use for energy at present
Total annual production	650 million tons of stalks (sucrose + bagasse + water)	250 million tons of wet bagasse	250 million tons of wet leaves

For a better understanding of how sugarcane is produced in Brazil a typical sugarcane mill may be taken as an example (CGEE, 2012):

1. Production capacity: 2 million tons/year (operating 200 days/year);
2. Harvest 25,000 ha/year; Needs to reform (plant): 4,000 ha/year;
3. Annual production: 160 million liters ethanol, 500,000 t bagasse; 1.5 billion liters of vinasse; 70 million tons of filter cake; 250 thousand tons of straw;
4. Transportation system by truck (traylers or semi traylers):
   (a) By "*rodotrem*[5]" (60 tons of payload): mill receives avg 7 rodotrens/h;
   (b) By "*treminhão*[6]" (45 tons of payload): mill receives avg 9 rodotrens/h.

Using a harvester with a 600 tons/day (25 tons/h), 16 harvesters and other 30 tractors and 60 infield wagons are needed. Considering average transportation distance around 40 km, 28 transportation units ("*rodotrens*") are needed for the typical sugarcane mill.

Three field operations – cutting, loading, and transporting, represent in average, 34 to 39% of the sugarcane cost in Brazil (**Table 11**). Therefore it becomes essential to optimize on-farm logistics as well.

Table 11 Sugarcane Production Cost in Brazil (Central South Region, Harvest 2011/2012) (PECEGE, 2012).

	Cutting-Loading-Transportation Cost (CLT)		Mechanization Cost (MC)			Production Cost (PC)
	R$/t	% PC	R$/t	% CLT	% PC	R$/t
Producers (traditional)	23.92	33.9%	17.32	72.4%	24.5%	70.63
Producers (expansion)	20.46	36.3%	19.04	93.1%	33.8%	56.29
Mills (traditional)	23.56	33.6%	15.03	63.8%	21.5%	70.06
Mills (expansion)	23.56	38.9%	15.38	65.3%	25.4%	60.52

Notes:
- Machines and equipment depreciations are included in Mechanization Cost.
- CLT: included Mechanization Cost, Manpower and Inputs.
- Mechanization cost: Costs of Cutting, Loading and Transportation of sugarcane (only machines and fuel).

Sugarcane in Brazil yields sugar and ethanol. Both can be used as feedstock for the production of biofuels for aviation. The present location of existing plants (black dots) and planned units (yellow dots) are shown in **Figure 31**. From these plants both products are typically transported by trucks to sugar refining centers (some sugarcane mills also refine sugar) or fuel terminals, or exported, depending on the case. Ethanol pipelines will so be

5 *Rodotrem*: combination of a semi trailer-truck and a large semi-trailer.
6 *Treminhão*: combination of a single trailer-truck and two semi-trailers.

available. A 215-km ethanol pipeline linking Ribeirão Preto, in the main producing region, to Paulinia, the largest petroleum refining and distribution hub in Brazil, is about to be inaugurated (O ESTADO DE S. PAULO, 2013). An addition, another 136 km stretch of this pipeline, from Ribeirão Preto to Uberaba will probably be ready early in 2014 that will allow the transport of ethanol from areas of the new sugarcane frontier.

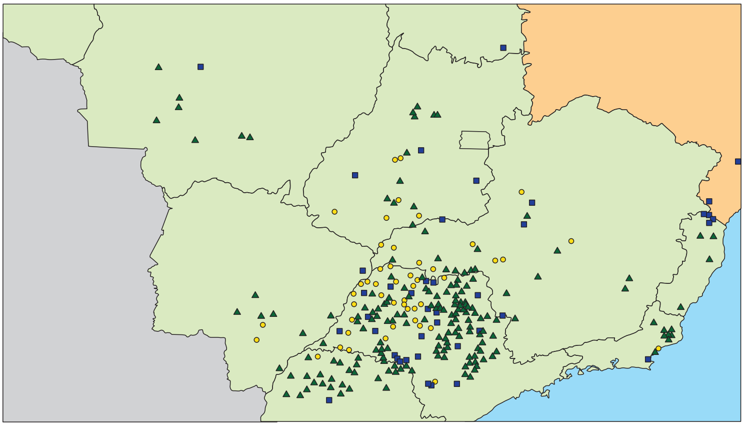

Figure 31 Present location of sugar-ethanol mills. Source: CGEE, 2009.

CGEE (2009) discussed the possibilities of Brazil to produce enough sugarcane ethanol to substitute 10% of 2025 consumption of gasoline worldwide. The necessary amount is around 205.5 billion liters of ethanol. Seventeen areas were selected in Brazil and the logistics associated with ethanol transportation were considered. **Figure 32** illustrates the necessary transportation schemes. The CGEE (2009) report is a fine example of the potential of sugarcane to supply large quantities of biofuel not only for the Brazilian market, but also for export.

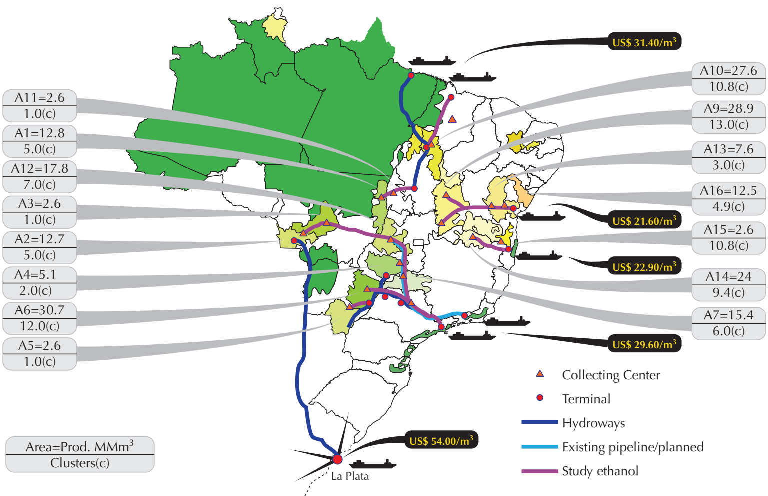

Figure 32 Possible ethanol transportation routes for Brazil to supply ethanol to replace 10% of the world gasoline consumption by 2025. Source: CGEE, 2009.

Wood

The present situation of forests in Brazil indicate that public forests are mainly in the Amazon region or scattered small portions over the whole territory and the forest plantations more concentrated in the State of Minas Gerais and São Paulo, as shown in **Figure 33**. Natural forests are not suitable feedstock for jet biofuel because of the restriction due to sustainability questions.

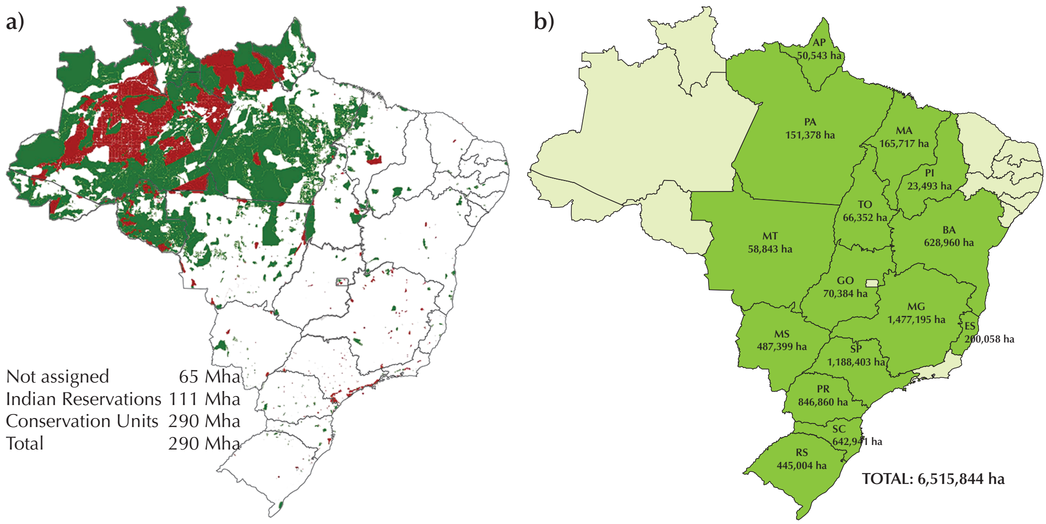

Figure 33 (a) Public Forests in Brazil. Source: SFR apud Rodriguez. (b) Forest Plantations in Brazil. Source: ABRAF apud Rodriguez, 2012.

Forest plantations all together covered nearly 6.5 million ha in 2011 (ABRAF, 2012), coincidentally approximately the same as sugarcane area with a very good potential to grow since its productivity in Brazil is higher than observed in other regions (see **Figure 33** and **Table 12**). According to ABRAF (2012) total wood production in 2012 in Brazil was estimated in 255 million m^3 (77% eucalyptus and 23% pines).

Table 12 Planted forest productivity in selected countries (NAHUZ, 2012).

COUNTRY	SPECIES	GROWTH RATES (m^3/ha/year)	ROTATION (year)
Brazil	Eucalyptus	35 – 50	6
	Pine	20 – 35	12 – 20
Chile	Eucalyptus	25 – 30	8 – 12
	Pine	20 – 30	25 – 30
Argentina	Eucalyptus	15 – 30	10 – 14
	Pine	20 – 25	20 – 25

Table 12 Planted forest productivity in selected countries (NAHUZ, 2012).

COUNTRY	SPECIES	GROWTH RATES (m^3/ha/year)	ROTATION (year)
Uruguay	Eucalyptus	20 – 35	8 – 12
	Pine	20 – 25	20 – 25
Venezuela	Pine	8 – 20	15 – 20
China	Eucalyptus	9 – 18	5 – 10
	Fir	10 – 14	18 – 20
Indonesia	Acacia	20 – 25	6 – 7
Thailand	Eucalyptus	12 – 25	6 – 7
Malaysia	Acacia	15 – 25	7 – 9
Australia	Eucalyptus	15 – 25	10 – 12
	Pine	15 – 25	25 – 35
New Zealand	Pine	15 – 30	25 – 35
Spain	Eucalyptus	10 – 21	8 – 20
	Pine	4 – 15	25 – 40
Portugal	Eucalyptus	10 – 18	8 – 10
UK	Spruce	12 – 14	40 – 60
Ireland	Spruce	15 – 18	40 – 45
South Africa	Eucalyptus	20 – 22	6 – 10

One hectare of eucalyptus, managed to produce 45 m^3/ha.year over 7 years rotations using mechanized harvesting for pulp wood (harvesters/feller bunchers) or (chainsaw/forwarders) and debarking on site, is expected to provide, according to an estimate of total forest products of 1 ha of eucalyptus was made by Nahuz (2012), based on Foelkel (2007), using the following conditions: Eucalyptus sp.; productivity of 45m^3/ha.year; cutting cycle – 7 years; using mechanized harvesting for pulping (harvesters/feller bunchers) or (chainsaw/forwarders); debarking on site. Total harvested volume: an average of 315 m^3/ha. The resulting residues are: (thick branches (> 2 cm): 3.05 m^3/ha; tops (diameter < 7 cm): 8.70 m^3/ha; thin trees (left standing): 4.70 m^3/ha; logs (leftover): 1.6 m^3/ha; bark: 3.9 m^3/ha; stump (7.5 cm): 0.63 m^3/ha; total residues: amounting to 21.96 m^3/ha (7%) and a net volume for pulp of: 293.04 m^3/ha (93%).

Logistics (transportation) plays an important role in wood overall costs. Data of **Table 13** indicated that Harvesting & Transport combined with Road represented more than 25% of the investment in 2011 by the sector.

Table 13 Participation & prospective investment on wood production (2011 & 2012-2016) (ABRAF, 2012).

ITEM	PARTICIPATION 2011		PROSPECTIVE 2012-2016	
	million R$	(%)	million R$	(%)
Planting	1,041	35.9	3,442	43.7
Harvesting & Transport	629	21.7	2,038	25.9
Land	589	20.3	343	4.4
Industry	4	13.8	976	12.4
Roads	116	4.0	469	5.9
R&D	35	1.2	409	5.2
Other	9	3.1	202	2.6
Total	2,900	100.0	7,879	100.0

Wood harvesting is an expensive logistics element in wood overall costs. The technology employed depends on the distance:

Figure 34 presents the distribution of forest plantations and industrial wood consumers in Brazil.

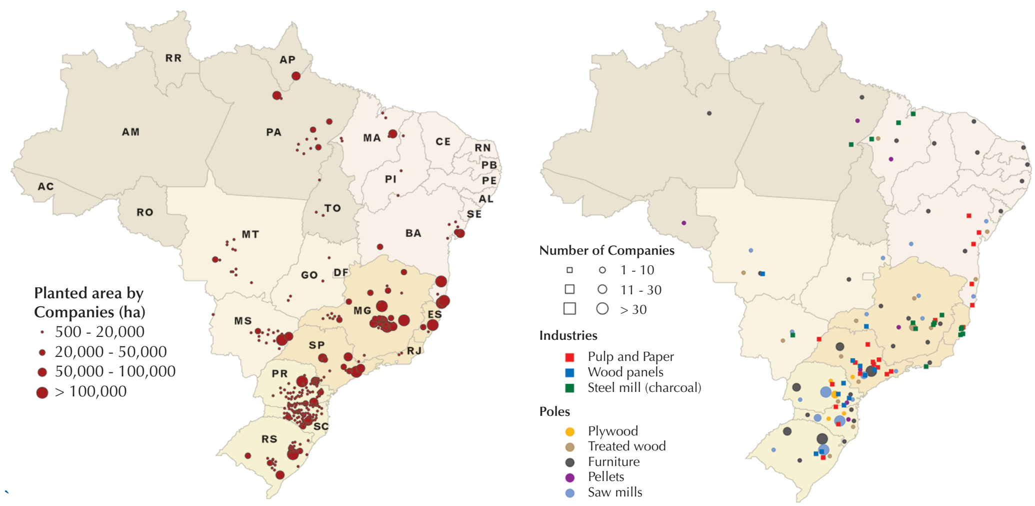

Figure 34 (a) Distribution and size of forest plantations. (b) Distribution of industrial wood consumers. Source: ABRAF apud Rodriguez, 2012.

According to BRACELPA (2009) the average distance from the forest to the factory is about 88 km. Transportation represents 30-60% of the harvest+transportation costs, basically transported by truck (96% of total). However wood can also be transported by train or ships in Brazil, although the existing infrastructure is limited.

For urban residues, the cost of separation of useful material will comprise the highest component of overall cost because the residues are already close to industry or places with infrastructure to process the feedstock into jet fuel.

4.2 Refining Technologies

Aviation kerosene, from fossil source has been used on commercial aviation for over 50 years. It is a well-known product (jet A/A1 turbine fuel), meets international specifications (Joint Operated System, ASTM, DefStan, Military Standards, etc.) and is a complex combination of hydrocarbons between C8 and C16 and additives, separated by fractional distillation followed by treatments that warranty the product final qualities. Aviation kerosene is going to be used on commercial aviation for many years, since it satisfies the fleet and existing infrastructure technical requirements (BLAKEY et al., 2010). The composition and properties of a desirable jet biofuel should be similar to petroleum jet fuel. **The term "drop-in fuel" is used to describe an alternative fuel, that is indistinguishable from conventional fuel, with no changes of aircraft, engine or supply infrastructure required, according to IATA**. The international requirements issued by ASTM D4054 (Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives), D1655 (Specification for Aviation Turbine Fuels), D7566 (Aviation Turbine Fuel Containing Synthesized Hydrocarbons), and UK-MoD Defense Standard 91-91, make sure that the fuels properties are fully assured, in order to ensure the proper performance of the aviation fleet.

Petrochemical refining processing has evolved during the last 100 years in hundreds of refineries over the world. The worldwide consumption by aviation is approximately 200 million tons of kerosene per year. European consumption in 2010 was 53 million tons from petrochemical conversion processes, which is extremely complex but very efficient on such a massive scale. Aviation is one of the fastest growing transport sectors, and up to 2050, worldwide aviation is expected to grow by 4.5% annually (GOODWIN; LYONS, 2010).

Sustainable jet fuels are produced from various feedstocks by a combination of different operations of 1) pretreatments, 2) conversion and 3) technological process to obtain the jet fuel.

The approach which is going to be used in this text is that some pretreatments are not going to be detailed separately from the most important conversion technologies associated to refining processes developed so far to lead to renewable fuels. Combinations of those will be needed to lead to the best technologies to produce renewable drop-in jet biofuel. It is important to realize that each process used to transform different types of biomass to jet fuel containing synthesized hydrocarbons has specific efficiency and yield. Thus, combining different operations will result in different conversion ratios and yields. Therefore, in order to compare different processes, for a given biomass to a desired product, the yield, productivity, selectivity and properties of each operation should be taken into account.

The desirable product of this project is a jet biofuel. However, this fuel must be price competitive and a "drop-in" jet fuel.

General Analysis of Components

Diverse other biofuels have applied to be certified as jet fuel (CHARLES et al., 2007), although this will depend on the advances of the technologies by the producing industries. They are produced from renewable biomass, by a combination of different operations:

1. pretreatments of the biomass (steam explosion, hydrolysis of lignocellulose, pyrolysis, etc);
2. conversion (fermentation to alcohols, farnesene, lipids and other building blocks), gasification, fast pyrolysis or solvent liquefaction, direct conversion of sugars to fuels by catalyzed reactions) and;
3. technological processes to obtain the jet fuel, as Fischer-Tropsch synthesis, HEFA processing, upgrading by catalytic hydrogenation, alcohol oligomerization, etc.

Most of the new technologies, such as fermentation of sugars to alcohols of different chain lengths, catalytic conversion of alcohols to hydrocarbon fuels, biological production of lipids, alcohols, organic acids or other building blocks by fermentation by microalgae, bacteria, and yeasts, further transformed in jet fuels, are technically feasible and are still being scaled up and validated (DIAS, 2011).

Biomass as source for biofuels

Among the several feedstocks already mentioned, which included wastes and industrial residues not necessarily from recent bio-origin, biomass deserves special considerations.

In order to partially replace petrol fuels by biofuels, our focus should be also on reducing overall cost by converting biomass into refinery ready materials that use today's infrastructure and distribution channels. This partial replacement seem to offer high potential in Brazil, due to the local abundance of large national areas originated from degraded pasture or not-in-use land (LUQUE et al., 2012; LEITE et al., 2009).

Abundant biomass is considered a low to medium concentration energy source, easily obtained via photosynthesis.

The main constituents of biomass are polysaccharides (hemicellulose, cellulose, starch, etc.), monosaccharides, lignin, oils and fats and proteins, which offer potential energy applications. They may be derived from anything from forest-harvested material to significantly diverse products (quantitatively and qualitatively), depending on the species/techniques used. They can also be originated from plant harvesting or wood processing, achieving a high local concentration index and considerably heterogeneous products, or even from cultures of short and medium rotation with a potential for energy use. Often they are originated from urban municipal wastes, as also from animal, vegetable and industrial and forest residues. Lipids have different chemical formulas, as triacyl glycerides, esters, fats and oils, and other hydrophobic (low polar) compounds (CASTOR et al., 2003).

The feedstock is a critical element in the production of a biofuel for aviation. (KOIZUMI, 2013). It needs to be rich energy dense molecules, as sugars, starch, fat, oil or lignocellulose, obtained directly or indirectly by cultivating crops, from wastes, residues or microbial biomass (microalgae, yeasts, etc.). Therefore, a large number of feedstocks can be used in the production of biofuels for aviation. However, important requirements such as capacity to improve yields, low direct and indirect emissions, high efficiency in land use and positive social and economic impacts also need to be fulfilled (JENKINS et al., 2013).

4.3 Logistics

4.3.1 Actual jet fuel distribution logistics and infrastructure

The jet fuel logistics everywhere was constructed for supplying the fossil fuel to the airports. Therefore, any alternative fuel has to make the best possible use of the available infrastructure to become more competitive. **Figure 35** locates the Brazilian Refineries, pinpointing the ones that produce jet fuel by the amount produced during the year of 2011. The main source of data for this whole section is ANP – National Agency for Petroleum, Natural Gas and Biofuels (see "Anuário Estatístico 2012" at ANP website). The refining capacity concentration in the Southeast region surpasses 80%. It is worth recalling that Brazil has imported 25% of the jet fuel consumption in 2011, fact that allows the substitution of internal distribution by long distance cabotage, by jet fuel importation. The main ports for this matter are São Sebastião in São Paulo State, Suape in Pernambuco and São Luiz in Maranhão, as indicated in the figure. REVAP, the refinery at São José dos Campos, is the largest jet fuel producer in the country, and its entire production is completely used in supplying the "fuel farm" at Guarulhos International Airport (IATA code: GRU).

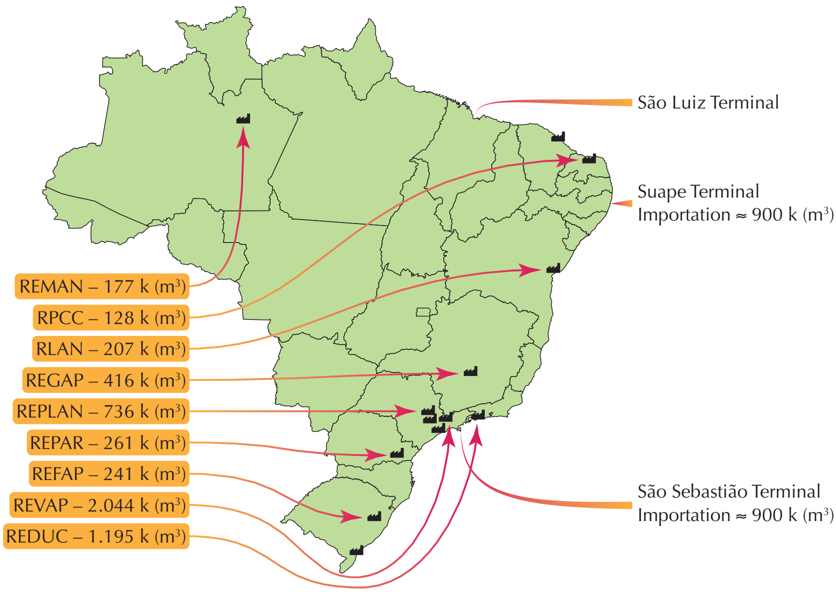

Figure 35 Oil Refineries and Jet Fuel Supply for the Year of 2011.

Figure 36 displays the location of the 149 airports that have to receive jet fuel regularly in the country. It is important to remark that circa one third of them, mainly in the Amazon region, can only be reached by air or by waterways commonly not navigable all year around. This fact can complicate the jet fuel distribution logistics in those areas, where it is not unusual for the jet fuel to be stored for more than six months. Although the jet fuel consumption under those conditions is estimated here to be less than 3% of the total, it cannot be ignored when one are thinking of implementing the use of renewable drop-in jet fuel. Another aspect worthwhile to pinpoint is that only the airports of Guarulhos and Galeão (IATA code: GIG) are supplied by pipelines, while the remaining are supplied by tank trucks or, eventually by barges.

Figure 36 Location of Airports Supplied by Jet Fuel Regularly. Source: Sindicom apud Schumman, 2012.

Figure 37, presented by SINDICOM in 6th workshop, gives an overall picture of jet fuel logistics in Brazil.

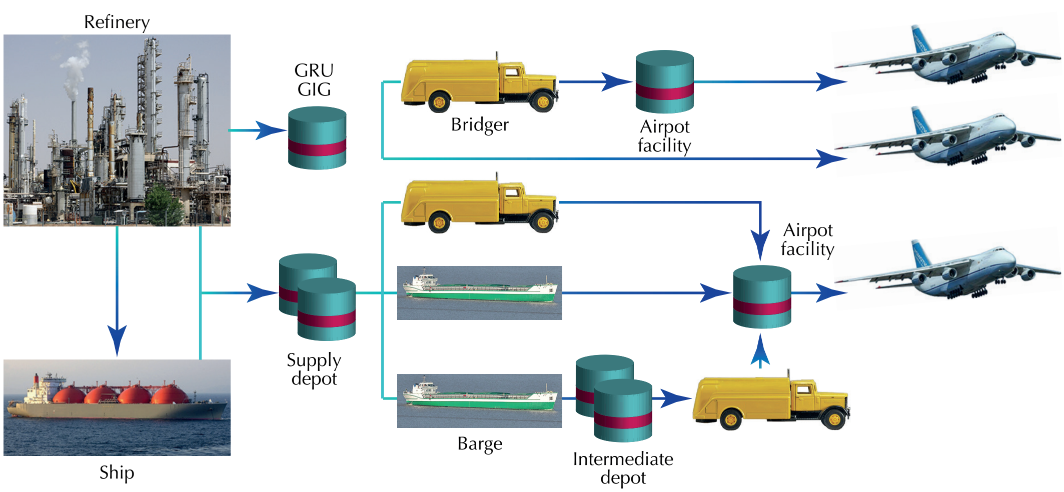

Figure 37 General View of Jet Fuel Distribution Logistics in Brazil. Source: adapted from Sindicom apud Schumman, 2012.

Figure 38 presents the municipal areas were the main airports in terms of demand for jet fuel are located, together with an estimation of their daily consumption. The metropolitan regions of São Paulo and Rio de Janeiro, followed by Brasilia, are the most important.

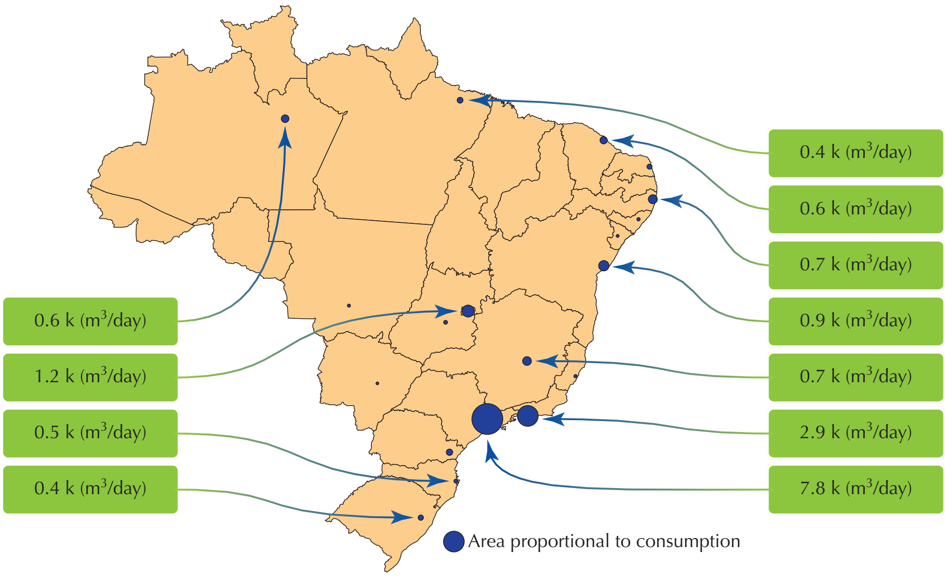

Figure 38 Main Consumption Sites.

The States of São Paulo and Rio de Janeiro consumed 4 million m^3 in 2011, corresponding to 56% of the country's consumption, of which 45% was due only to Guarulhos and Galeão international airports. Each region of the country has its particular distribution logistics by tank trucks or barges as detailed by SINDICOM during 6th workshop and the whole supply is provided by Petrobras.

Figure 39 presents schematically the supply logistics for the largest consumer, Guarulhos International Airport. It is worthwhile to observe that the supply of Congonhas Airport is made by tank trucks loaded in the same Guarulhos Fuel Farm that supplies the International Airport. Similarly, although not indicated in the figure, several small airports in Sao Paulo State are supplied by tank trucks loaded in the same Fuel Farm.

According to Petrobras presentation at the same workshop, the supply situation of each regional Brazilian jet fuel market can be described by:

1. **North Region** (comprising mainly REMAN Refinery and Belém Terminal): area is under-stocked; an increase in production is difficult; the source to complement demand is the use of ships to bring jet fuel from other regions;
2. **Northeast Region** (comprising mainly the terminals in São Luiz, Fortaleza and Suape and the refineries RELAM and RPCC): area is under-stocked, except for Rio Grande do Norte due to RPCC production; both refineries have capacity to increase production; the source of complementary volume is the use of ships bringing imported jet fuel to Suape and São Luiz Terminals; part of the imported volume is used to supply other markets;

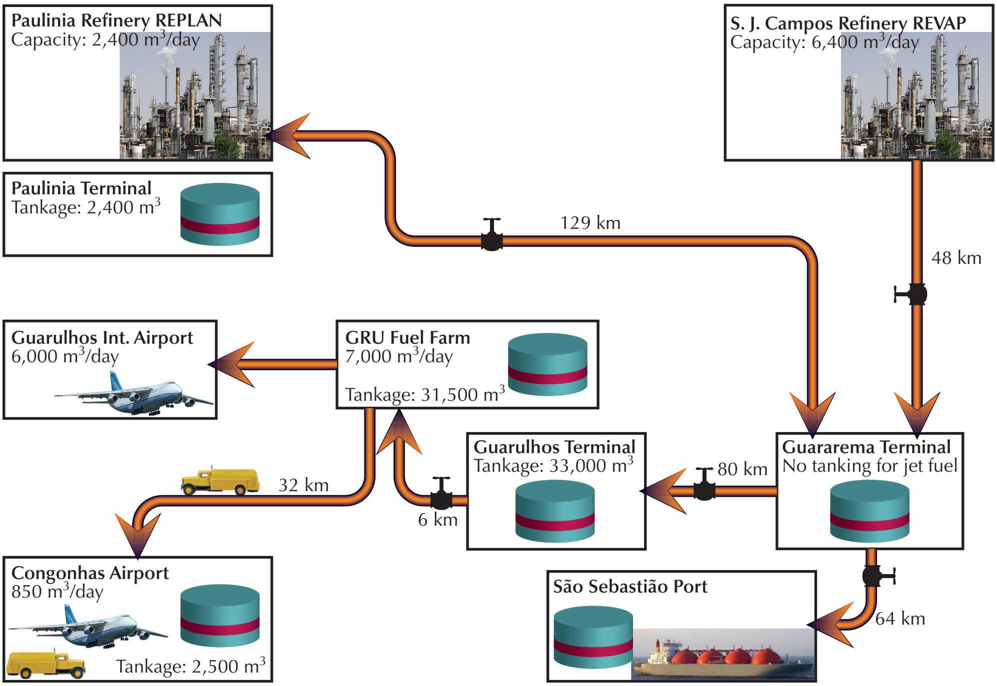

Figure 39 Pipeline Infrastructure for Supplying Guarulhos and Congonhas Airports. Source: Sindicom apud Schumman, 2012.

3. **Southeast/Midwest Region** (comprising REVAP, REDUC, REPLAN and REGAP refineries and São Sebastião Terminal): REGAP (Minas Gerais) is balanced while São Paulo System and REDUC (Rio de Janeiro) are under-stocked; there are few possibilities of production increase on these areas; the source of complementary volume is the use of ships arriving at São Sebastião Terminal, which accounts for 50% of all the imported jet fuel by the country; part of the imported volume is used to supply other markets;

4. **South Region** (comprising REPAR and REFAP refineries): both systems are balanced and it is possible to increase their productions.

Summarizing the jet fuel logistics in Brazil, one can say that the country has a single producer and importer, Petrobras, four authorized distributors, 13 supply sites (9 refineries and 5 water terminals and 173 authorized resellers. The consumption is extremely concentrated mainly in the Southeast Region of the country and almost each large airport has as a nearby supplier that is a refinery or a maritime terminal. The exception here is the Brasilia International Airport, which is supplied from REGAP by tank trucks through a distance of 700 km. On the other hand, the country has many small airports in remote regions, mainly in the North Region, that can be reached only by air or waterways during part of the year, forcing the jet fuel to be stored for longer than normal periods.

4.3.2 Quality assurance procedures for jet fuel

a. Conventional jet fuel

In order to ensure flight safety, jet fuel is submitted to very strict quality requirements that tag along its whole production and distribution chain up to the airplanes fuel tanks.

These fuel requirements, which are used by the Civil Airworthiness Authorities (ANAC in the Brazilian case) to ensure the safety of aircraft operations, are very similar all over the globe to allow for interoperability, for instance, of international flights. They are based essentially on fuel specifications and quality assurance procedures along the fuel distribution chain.

On the side of the airplanes, airworthiness regulations issued for aircraft and engines require that operating limitations be established for each certificated design based on the specified fuel.

In Brazil, ANP regulates the distribution and re-sale of jet fuel through Resolutions (in Portuguese) Nr. 17/2006 – "Regulates the activities of distribution of aviation fuels" and Nr.18/2006 – "Regulates the activities of re-sale of aviation fuels", and establishes the specifications of jet fuel through Resolution (in Portuguese) Nr. 37/2009, which refers to the Brazilian Standards (in Portuguese) ABNT NBR 15216 "Storage of flammable and combustible liquids – Quality control on storage, transportation and supply of aviation fuels"

In essence the jet fuel specification follows ASTM D1655 – "Standard Specification for Aviation Turbine Fuels" and Defence Standard 91-91(UK) [10].

Quality assurance, similarly, is based on the concepts of "batches" and "traceability". A batch of fuel is defined as a distinct quantity of jet fuel that can be characterized by one set of test results. It is essential that producers ensure batches are homogenous so that test results are representative of the product supplied. In case of petroleum derived jet kerosene, these batches have to be certified at the origin according to ASTM D1655, DS 91-91 or, in Brazil, ANP Resolution Nr. 37/2009.

As presented in the workshop by SINDICOM, **Figure 40**, **Figure 41**, **Figure 42** and **Figure 43** illustrate the main quality control procedures from the refinery, through the distributors and up to the airplane fuel tanks.

b. Alternative jet fuel

Present specification (ASTM D1655 or DS 91-91) evolved as performance specification rather than compositional specification. They rely on accumulated experience and therefore, if the fuel does not originate from conventional sources or specifically approved synthetic processes, it is not enough for the fuel to meet the specification in order to be fit for use as aircraft turbine fuel. One should observe that any significant change on performance in terms of materials compatibility or engine testing would imply in recertification of all existing aircraft. For this reason, any alternative jet fuel has to be shown, not to have the same chemical composition of the petroleum derived jet fuel, but to be fit-for-purpose of being used without difference as a traditional jet fuel.

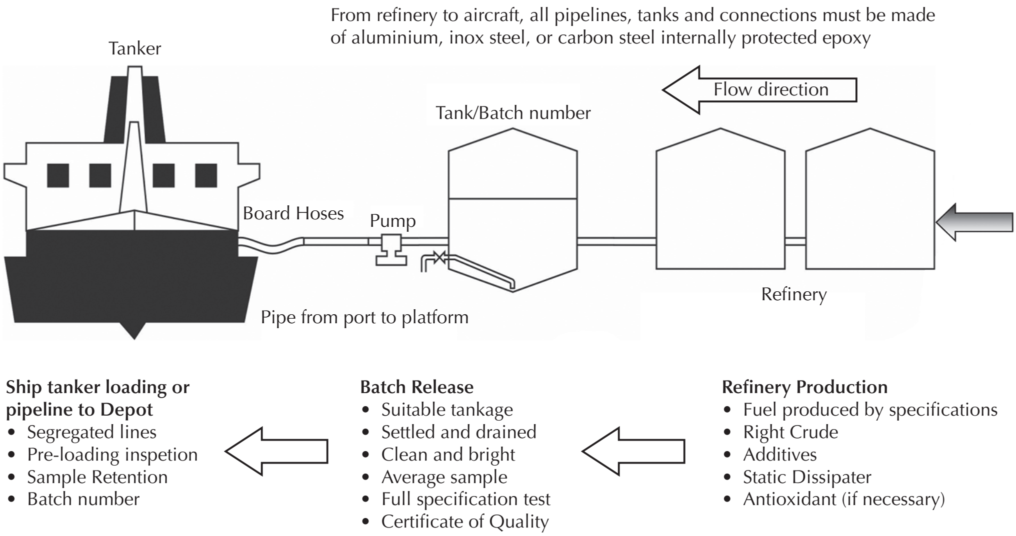

Figure 40 Quality Control Procedures from Refinery to Tanker or Depot. Source: Sindicom apud Schumman, 2012.

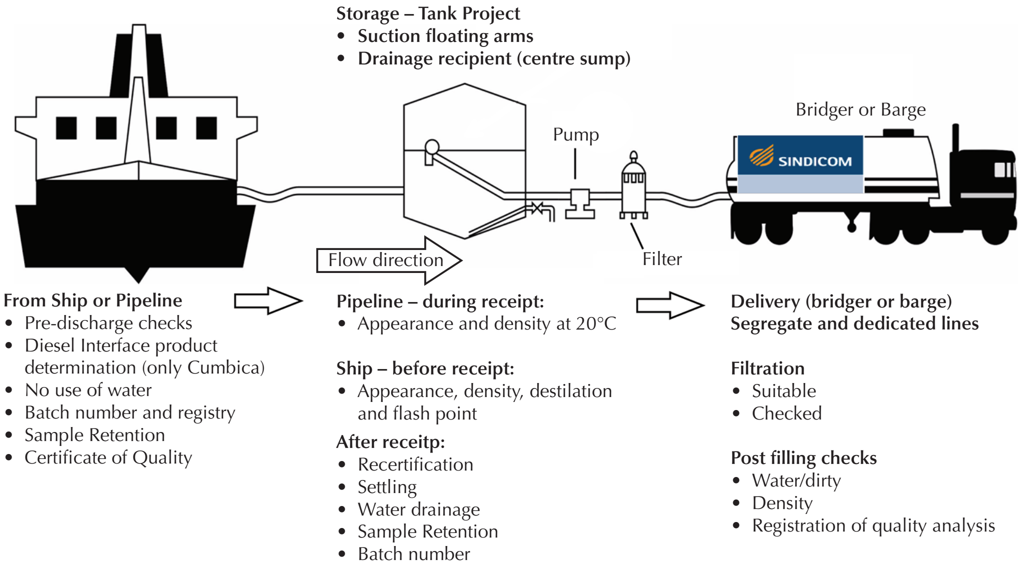

Figure 41 Quality Control Procedures from Tanker or Pipeline to Depot. Source: Sindicom apud Schumman, 2012.

Bridger and Barge discharge:
Certificate of Analysis
Drainage
- Water
- Solids
- Density at 20°C

To release the product to the gantry loading or to the hydrant system is necessary to assure quality control by checking density at 20°C, appearance (water and solids) and measurement of anti-static additive.

Obs.: The product contained in a depot or airport tanks must be recertificated if there is no product receiving in a period of 6 month.

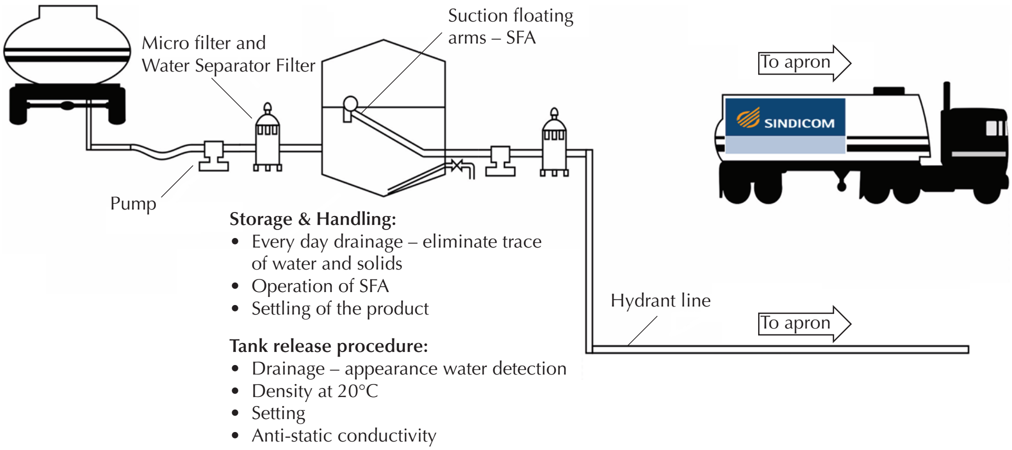

Figure 42 Quality Control Procedures at Airport Facilities. Source: Sindicom apud Schumman, 2012.

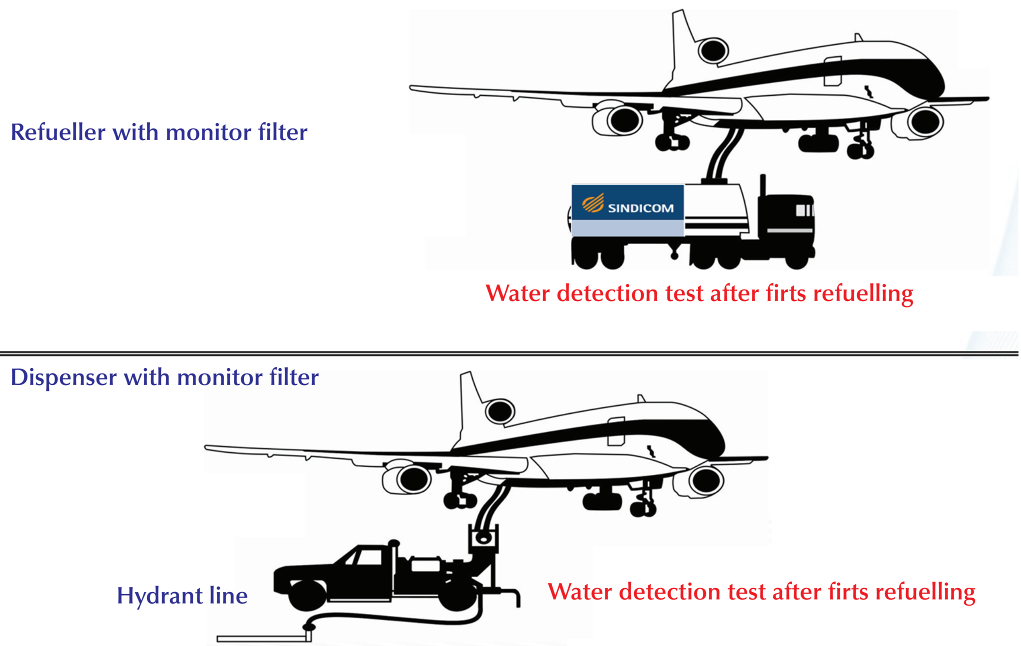

Figure 43 Quality Control Procedures at Apron. Source: Sindicom apud Schumman, 2012.

Besides satisfying the standards above mentioned, the alternative fuels have to meet the terms of ASTM D4054 - "Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives" and ASTM D7566 - "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons".

In this case, the alternative fuel would be a "drop-in" fuel, with features described in ASTM D7566 – as: "*Because the drop-in alternative fuel will be incorporated into the existing jet fuel specifications, there will be no change required to these operating limitations and no associated certification testing. In effect, the alternative fuel seamlessly enters the fuel distribution infrastructure and requires no special treatment or identification, and is co-mingled with conventional jet fuel. From the perspective of the certificated aircraft and engine, conventional fuel and the drop-in alternative fuel provide identical performance and safety*".

The guidelines for qualification and approval of New Aviation Turbine Fuels and Fuel Additives according to ASTM D4054 are presented schematically in **Figure 44**. As one can observe, after a very extensive test program, the results are submitted to an internal review by the OEMs to reach the stage of possible specification change, for instance to include a new annex to ASTM D7566.

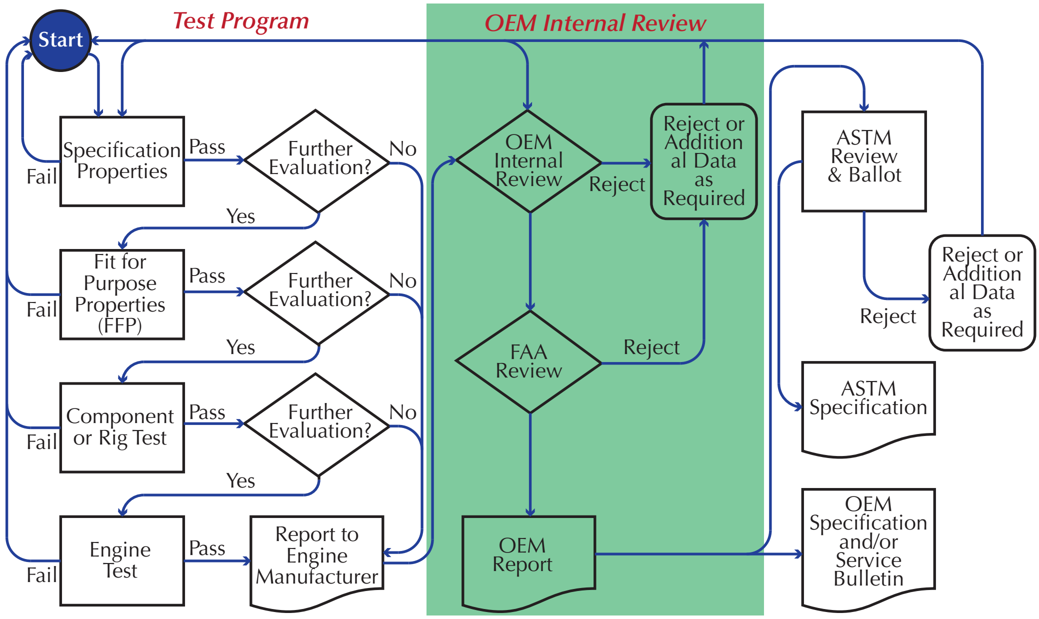

Figure 44 Guideline for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives According to ASTM D4054.

Table 14, reproduced from presentation by George Wilson III, lists the types of testing required for a jet fuel, from a different source than petroleum, to pass the test program.

Table 14 Test Program Requirements for Alternative Fuels for Aviation.

SPECIFICATIONS	FIT FOR PURPOSE	MATERIAL COMPATIBILITY	ENGINE ENDURANCE TEST
Composition	**Chemistry**	**Additive Compatibility**	**Hot Section Corrosion/Erosion**
Acidity	Hydrocarbon Type	FSII	Metallurgy
Aromatics	Aromatics	CI/LI	Coating
Sulfur	**Trace Materials**	SDA	**Component Testing**
Volatility	Organics	AO	Fuel System
Distillation	Inorganics	MDA	Fuel Pump
Flash Point	Metals	**Fuel to Fuel Compatibility**	Fuel Control
Density	**Bulk Property**	**Non Metallic Materials (37)**	Fuel Nozzle
Fluidity	Precision Distillation	Adhesives	Combustor Rig Testing
Freeze Point	VapP vs T	Bladders	Cold Start, SL to 10,000 ft
Viscosity	Deposition Characteristics	Aircraft Coatings	Lean Blowout
Combustion	Lubricity/CI Response	Bulk Tank Coatings	Aerial Restart
Heat of Combustion	Vis vs T	Sealants	TIT Distribution
Smoke Point	Spec Heat vs T	Composite Materials	Combustor Efficiency
Corrosion	Density vs T	Foams	Carboning/Coking
Thermal Stability	Surf Ten vs T	O-rings	Emissions
Contaminates	Bulk Modulus vs T & P	Nitrile	APU Altitude Start
Existent Gum	T Cond vs T	Fluorosilicone	**Engine Test**
MSEP	Water Sol vs T	Fluorocarbon	
Additives	Flash Point	Gaskets	
Conductivity	Freeze Point	Fuel Hose	
	Electrical Properties	Teflon	
	Dielectric vs Density	Nylon	
	Conductivity/SDA Response	Polyethylene	
	Handling and Safety	Kapton	
	Effect on Clay	Potting Compound	
	Filter Separator Efficacy	**Metals/Metal Coatings (31)**	
	Monitor Performance	Al·Cr Anodize	
	Storage Stability	Sulfuric Anodize	
	Peroxides over time	Chromate Conversion	
	Potential Gum	Wrought Aluminun	
	Toxicity	Cast Aluminum	
	LEL & UEL	CuNi	
	AIT	Solder	
	HSIT	Austentic Stainless Steel	
		Non-Aus SS	
		Titanium Alloys	
		IVD Coating	
		Fasteners	
		CPM	
		InCo	
		Nitralloy	
		Monel	
		Waspaloy	
		Lead	
		Brass	
		Wire	

The ASTM standard D7566 covers the manufacture of aviation turbine fuel that consists of conventional and synthetic blending components. Up to this time, the alternative fuels approved by ASTM shall consist of the following blends of components or fuels: conventional blending components or Jet A or Jet A-1 fuel certified to Specification D1655; with up to 50 % by volume of the synthetic blending component defined in Annex A1 or with up to 50% by volume of the synthetic blending component defined in Annex A2[7].

Annex A1 refers to a hydro-processed synthesized paraffinic kerosene wholly derived from synthesis gas via the Fischer-Tropsch process using Iron or Cobalt catalyst (FT- SPK). Subsequent processing of the product shall include hydro-treating, hydro-cracking, or hydro-isomerization and is expected to include, but not be limited to, a combination of other conventional refinery processes such as polymerization, isomerization, and fractionation.

Annex A2 refers to hydro-processed synthesized paraffinic kerosene wholly derived from hydrogenation and deoxygenation of fatty acid esters and free fatty acids (HEFA- SPK). Subsequent processing of the product shall include hydro-cracking, or hydro-isomerization, or isomerization or fractionation, or a combination thereof, and may include other conventional refinery processes.

Figure 45 and **Figure 46**, reproduced from a presentation by Lourdes Maurice from FAA, illustrate the already approved production processes according to ASTM jet fuel specifications and how the biofuel, after shown fit-for-purpose, becomes a drop-in jet fuel.

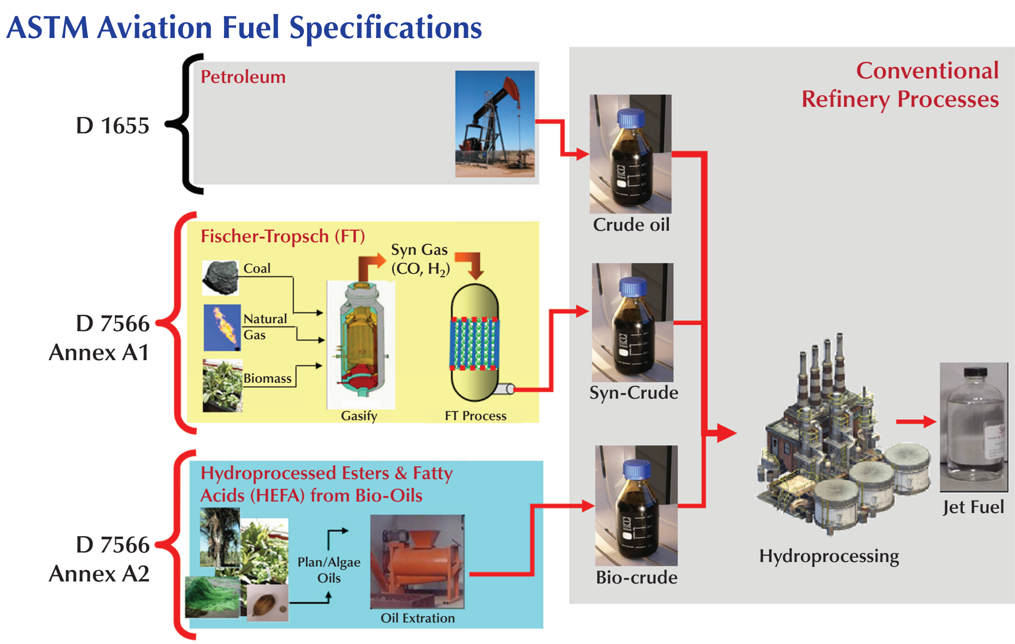

Figure 45 ASTM Approved Routes for Production of Jet Fuel.

7 Annex A3, which was introduced by ASTM in June/2014, refers to Synthesized Iso-Parraffins (SIP) produced from hydroprocessed fermented sugars that will be permitted for blending at up to 10% (vol) with conventional jet fuel. It is the approved denomination of the DSHC (direct sugar to hydrocarbon) route treated in this report as submitted to ASTM.

It is worth to remark that, as depicted in **Figure 46**, after approval by ASTM D7566 (inclusive blended according to the approved annexes) the certified batch is re-identified as satisfying ASTM D1655 and becomes fungible with any approved jet fuel from whichever origin, and can be used as an ASTM D1655 avoiding the whole process of re-certification of aircrafts.

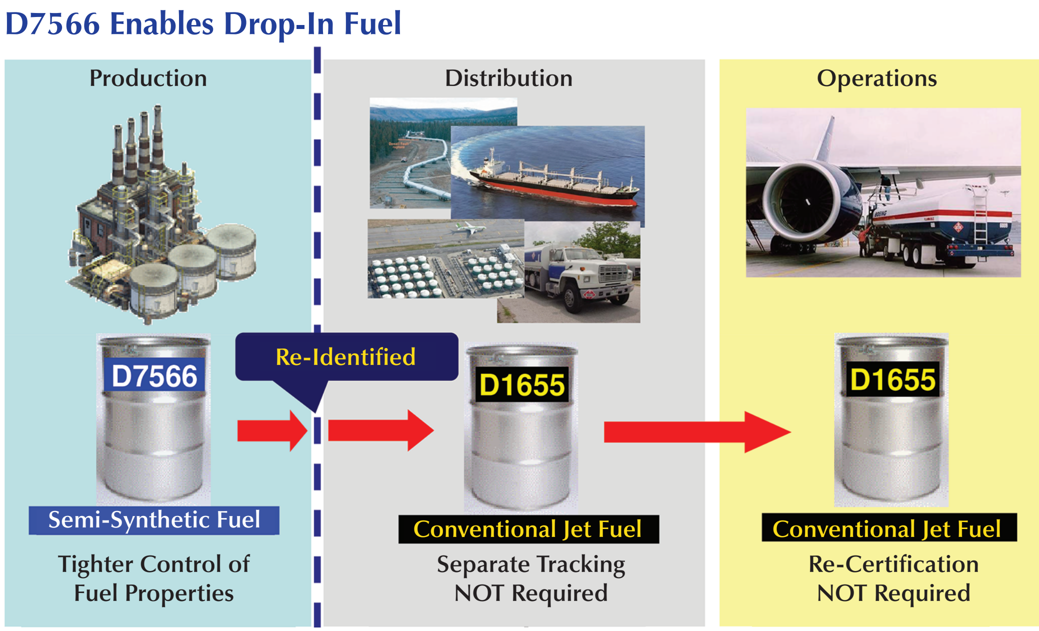

Figure 46 Enabling a Biofuel to Become a Drop-in Jet Fuel.

For commercialization of any new future jet biofuel, other than the ones referred in Annex 1 and 2 and without the airworthiness re-certification of all the aircrafts, it is necessary to have new annexes approved. The ones in preparation by ASTM comprise:

1. Alcohol to Jet (ATJ)
2. Direct Sugars to Hydrocarbons[8] (DSHC)
3. Hydro-treated De-polymerized Cellulosic Jet (pyrolysis) (HDCJ)
4. Catalytic Hydro-thermolysis (CH)
5. Catalytic Conversion of Sugars (CSHC)

Figure 47 and **Figure 48,** reproduced from a recent presentation by Mark RUMIZEN from FAA depict the alternative processes submitted to ASTM.

8 Approved by ASTM in June/2014 as Annex 3 - Synthesized Iso-Parraffins (SIP).

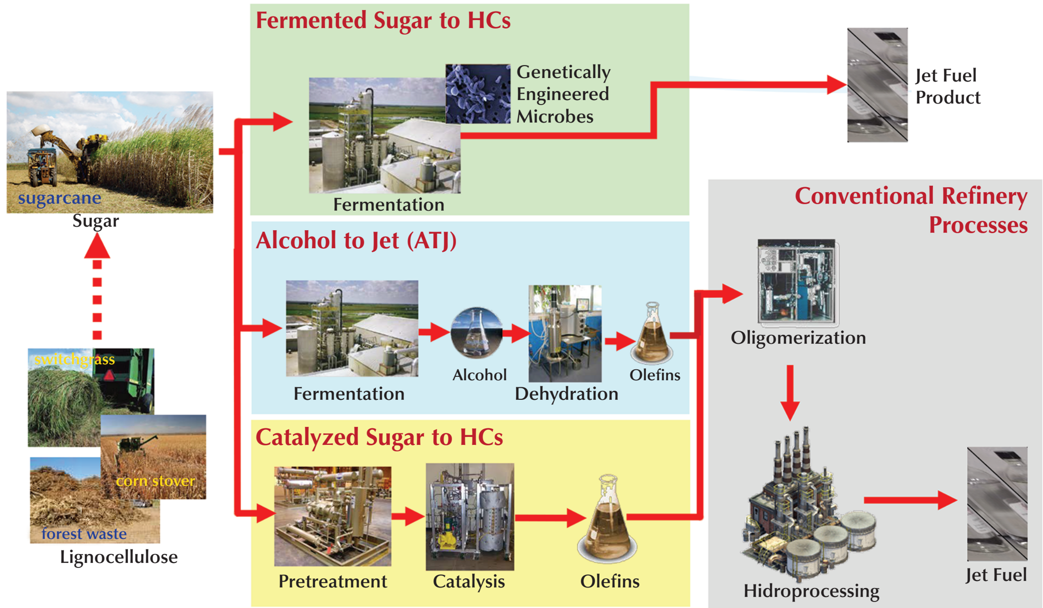

Figure 47 Future Fuels Submitted to ASTM (DSHC, ATJ, CSHC).

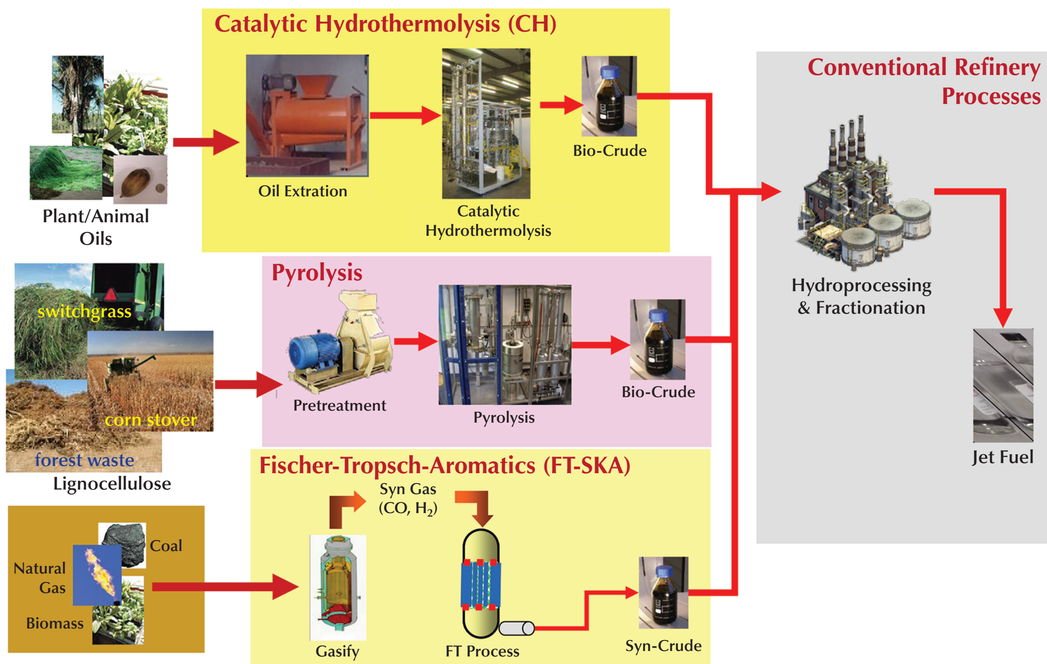

Figure 48 Future Fuels Submitted to ASTM (CH, HDCJ, FT-SKA).

As already mentioned, aviation fuel quality assurance is based on two key concepts: batches and traceability.

The batches that are of the order of ten million liters at refineries have to be homogeneous (density variation smaller than 3 kg/m^3).

At point of manufacture, the producer shall issue a Certificate of Quality to certify that the batch of fuel complies with all of the requirements of ASTM D1655 or D7566 standards as appropriate. The certificate shall cover not only the quantitative limits but also all other requirements set out in the standards.

To certify compliance with the limits, representative samples shall be drawn using appropriate procedures such as those outlined in IP 475 and ASTM D4057.

Documentation shall be provided by the supplier to the purchaser to show that the fuel meets the requirements of these standards and demonstrates traceability to point of manufacture. Upon request, the technical authority or end user shall be provided with the documentation.

Because jet fuel can come into contact with incidental materials during manufacture and distribution, appropriate management of change of the measured values shall be used at manufacturing locations, distribution, and storage facilities to maintain product integrity and detect any contamination, as already presented in **Figure 40** to **Figure 43** for the conventional jet fuel. Exactly the same procedures are to be followed by the drop-in fuel. The only possible differences can occur during the production of the alternative fuels, up to the point where they are blended with conventional jet fuel and certified according to ASTM D7566. The Certificate of Quality issued on this occasion re-identifies the alternative fuel as a jet fuel satisfying ASTM D1655, which is then submitted to the same quality assurance procedures already described.

4.3.3 Requirements for commercialization of alternative jet fuel in Brazil

As already mentioned, the regulatory requirements for jet fuel commercialization in Brazil are set by ANP, particularly by resolution ANP Nr. 37/2009. The Brazilian specification is aligned with the Aviation Fuel Quality Requirements for Jointly Operated Systems (AFQRJOS) that incorporates the requirements of ASTM D1655 and DEF STAN 91-91 and IATA Guidance Material, but not necessarily the last versions. A process for revision of specifications was started in 2012, as presented by ANP at the workshop, of which the objective is to establish the specification for aviation turbine fuel containing synthesized hydrocarbons and the obligations regarding the control of quality to be met by the various economic agents who market the product throughout the Brazilian territory. The specific goals are:

1. specify only the new jet included in ASTM D7566 – Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons;
2. specify the new jet included, using as minimum requirements those of ASTM D7566;
3. define the distribution chain position to make the blend of conventional jet fuel and alternative fuel;
4. define rules for importation of the new jet fuels.

The work group has finished the revision process and, by June 2013, ANP launched the Brazilian Specification and rules for distribution and use of Aviation Biofuels (Resolution ANP Nr. 20/2013).

Certainly, according to the feedstock and process used for obtaining the jet biofuel, and the great number of possible feedstocks in the country, it is quite important to understand the logistics of conventional jet fuel, to choose the best blending point and take advantage of transportation costs of both renewable and fossil fuels.

Another aspect related to commercialization that was tackled in the workshop was the tributary. The presentation by SINDICOM (RODRIGUES FILHO, 2012) has shown that no taxes burden jet biofuel used in international flights, while the fuel used in domestic flights is charged with an average tax among the Brazilian States of approximately 25% of final consumer's price. This percentage includes a Federal tax of 3.2% (PIS/COFINS) over the refinery price plus a State excise tax (ICMS) that can be different among the States, which is a certain percentage of the final price paid by the consumer. **Figure 49** depicts the ICMS variation among the Brazilian States.

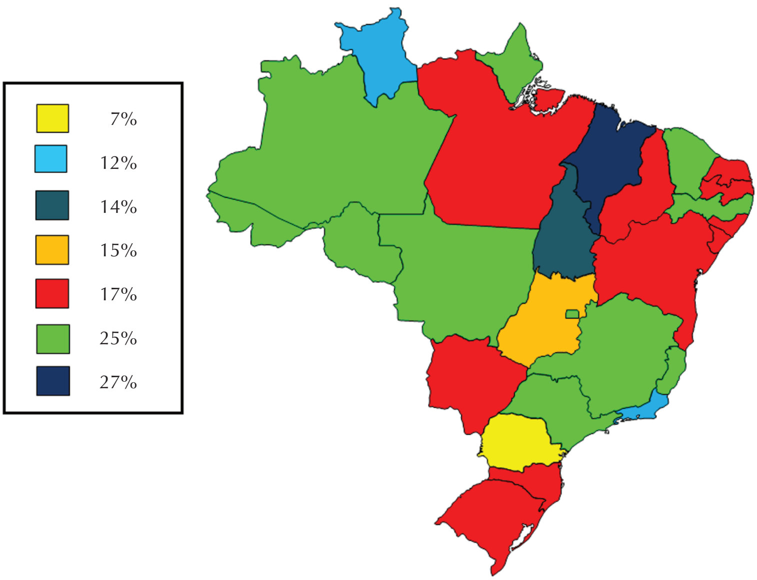

Figure 49 Variation of State Tax (ICMS) Charged on Jet Fuel for Domestic Flight.