UNIVERSIDADE FEDERAL DO PARANÁ
MBA EM GESTÃO ESTRATÉGICA DE ENERGIAS RENOVÁVEIS
E BIOCOMBUSTÍVEIS

LARYSSA ALVES BORBA

Current overview of aviation biokerosene

Curitiba
2020

LARYSSA ALVES BORBA

Current overview of aviation biokerosene

Artigo apresentado como requisito parcial à conclusão do curso de MBA em Gestão Estratégica de Energias Renováveis e Biocombustíveis, Setor de Ciências Agrárias, Universidade Federal do Paraná.

Orientador: Prof. M.Sc. Marcelo Langer

Curitiba

2020

Panorama atual do bioquerosene de aviação

Laryssa Alves Borba

Resumo

A busca por alternativas para substituir os combustíveis fósseis no setor energético tem crescido exponencialmente nos últimos anos. Os biocombustíveis são uma alternativa de grande interesse em muitos setores, como é o caso da aviação que é responsável pela emissão de 2% de todo o CO_2 emitido mundialmente. A mistura do bioquerosene de aviação ao querosene de aviação (QAV) fóssil é permitida, desde que atenda as regras internacionais e os parâmetros estabelecidos pela Agência Nacional de Petróleo, Gás Natural e Biocombustíveis (ANP). O bioquerosene de aviação enfrenta barreiras técnicas quando comparado aos biocombustíveis utilizados no setor de transporte terrestre, devido aos requisitos de padrão de qualidade dos órgãos reguladores. Apesar disso o panorama do uso do bioquerosene é promissor e é essencial conhecer o panorama do seu uso no Brasil e estudar quais as perspectivas para seus usos no futuro.
Assim, o presente trabalho teve como objetivo apresentar o panorama atual do bioquerosene de aviação no Brasil e as perspectivas futuras para utilização em transportes aéreos no país. Para avaliar a emissão proveniente do biocombustível, foram criados cenários a partir dos dados da aviação brasileira e constatou-se que a substituição do querosene pelo bioquerosene resulta em redução de mais de 70% na emissão de CO_2. Apesar de o bioquerosene de aviação estar ganhando destaque ainda é necessário investir em pesquisa e tecnologia para viabilizar seu uso.

Palavras-Chave: biocombustíveis, transporte aéreo, emissão de GEE, bioquerosene

Current overview of aviation biokerosene

Abstract

The search for alternatives to replace fossil fuels in the energy sector has grown exponentially in recent years. Biofuels are an alternative of great interest in many sectors, such as aviation, which is responsible for the emission of 2% of all CO_2 emitted worldwide. The mixture of aviation biokerosene and fossil aviation kerosene (QAV) is permitted, if it meets the international rules and the parameters established by the National Agency of Petroleum, Natural Gas and Biofuels (ANP). Aviation biokerosene faces technical barriers when compared to biofuels used in the land transport sector, due to the quality standards requirements of regulatory agencies. Despite this, the outlook for the use of biokerosene is promising and it is essential to know the panorama for its use in Brazil and to study the prospects for its uses in the future. Thus, the present work aimed to present the current panorama of aviation biokerosene in Brazil and the future perspectives for use in air transport in the country. To assess the emission from biofuel, scenarios were created using data from Brazilian aviation and it was found that the substitution of kerosene by biokerosene results in a reduction of more than 70% in CO_2 emissions. Although aviation biokerosene is gaining prominence, it is still necessary to invest in research and technology to enable its use.

Keywords: Biofuels, air transport, GHG emission, biokerosene

1 INTRODUCTION

The climate changes and the contribution of the energy sector to it has been gaining prominence in the last years and the decrease of the greenhouse gases (GHG) emission is a discussion present in the energy sector. Countries around the world reunite to discuss proposals to limit the present GHG emissions and find solutions to avoid or to reduce emissions in the future. Thus, the search for energy alternative sources increased exponentially and the countries invest in new sources and technology to obtain clean energy.

Even if the global warming is a current concern, the fossil fuels are more viable, the technology applied to this kind of sources are efficient and it is well defunded. The search for new technologies to make the use of alternative energies more accessible is indispensable, as well as the investments in new enterprises. The interested in renewable energies generated a growth in the number of solar energy and wind energy ventures in Brazil and increased the investments in biofuels.

The growth of the energy demand in the different sectors shows the necessity of the renewable energies. One solution to reducing transport emissions is to move, gradually from fossil fuels to biofuels. The transition from fossil fuels to biofuels is already a reality in the transport sector, and it is the best option to decrease the emissions.

Greenhouse gas emissions from commercial aviation are rapidly increasing; hence, this industry needs to be aware of the necessity of changes to reduce the carbon footprints among fliers. The aviation is responsible for 2.4% of global CO2 emissions from fossil fuel use and a 32% increase over the past five years. (ICCT, 2019). By 2045, compared with an anticipated increase of 3.3 times growth in international air traffic and the fuel consumption is projected to increase by 2.2 to 3.1 times compared to 2015 (ICAO, 2019).

The aviation industry has made great efforts to lower aviation-related emissions, such as the use of alternative fuels, improved airplane designs, new aircraft concepts, and fuel saving operational procedures (Boeing, 2017). The International Air Transport Association (2013) with initiatives to decrease the emission from the aviation industry to 50% of the 2005 levels in 2050 established a guideline.

The lack of technological alternatives with less environmental impacts is one of the main motives to search for other types of solution to decarbonize the air sector; one of the solutions is the use of compensation mechanisms or commerce of emissions and the replacement of part of the fossil fuel for biofuel. The sustainable fuels are a promisor option, once that besides the advantage of reducing the GHG emission, they use the same infrastructure of distribution of fuel and the same motors that are use nowadays (ROITMAN, 2018).

This work aim to analyze the current overview of the biokerosene in the aviation industry.

2 MATERIALS AND METHODS

This study applies a methodology to assess the situation of the aviation biokerosene in the national and international aviation by analyzing the insertion of the biofuel in the aviation industry, identifying potential for biojet production and the development of the biokerosene. For this purpose, it is necessary to characterize the fuel and biofuels, analyze the aviation sector growth and fuel consumption and the environmental impact that concerns aviation. This study, took into account some potential scenarios for the use of biokerosene in aviation, where a prospection was made to simulate how much CO_2 would be emitted for a blend of biokerosene and kerosene 50/50 and biokerosene 100% in the Brazilian flights for 2017.

2.1 AVIATION KEROSENE CHARACTERIZATION

Aviation gas turbines are powered by liquid petroleum fuels, obtained by the refining process and known as jet fuel or aviation kerosene. The petroleum refining process separates many compounds present in the crude petroleum through the atmospheric and vacuum fractional distillation process (DE CARVALHO, 2017).

The aviation kerosene needs to be appropriate to the internationals standards specified to the fuel Jet A-1, described by Aviation Fuel Quality Requirements for Jointly Operated Systems (AFQRJOS). Considering the necessity of adequacy to the international standards, the JET-A1 do not present big variations in your composition and physic characteristics around the world (TERAMOTO, 2015).

The JET-A1 is a petroleum derivation obtained for direct distillation with a temperature range between 150 and 300ºC (PETROBRÁS, 2014). Aviation kerosene is a multi-component fuel, which was developed from lamp oil. It is consisted typically of hydrocarbons with 9-16 carbon atoms, and composed by groups of paraffin, naphtenes or cyclo-paraffin and aromatics, with olefins being present in small amounts.

The composition of paraffinic compounds is variable according to the type of oil processed in refineries (CARVALHO, 2017), but the average volumetric percentage of each hydrocarbon is: paraffin (alkanes) 33-61%, Naphthenic (cycloacanes) 33-45%, Aromatic 12-25%, Olefin (alkenes) 0,5-5%. (TERAMOTO, 2015). For these petroleum derivative present accurate characteristics to the energy generation for gas turbine, several physical-chemical criteria are required during its production that includes from fluidity (flow), stability (storage) to proper combustion for these engines (PETROBRÁS, 2014).

There are two type of aviation kerosene produced and commercialized in Brazil, one that is used in the civil aviation known as JET-A1 and other one for military use known as JET-A5. The basic difference between these two types of fuel is the biggest restriction related to the presence of light compounds to guarantee the security on the handling and stocking of the product in boats (PETROBRÁS, 2014).

2.2 AVIATION BIOKEROSENE CHARACTERIZATION

The biofuels are obtained by the transesterification of fatty acids there are in vegetal oil and they can be obtain from a diversity of oilseed species (CANTARELLA et al., 2015). To synthesis of aviation fuels, several types of feedstocks can be used, however, these sources derivate from food crops as corn and soybean, that are also used as food for humans and animals, what can generates a competition for sources. There is a necessity to study what is the better culture and technology to produce biokerosene.

Between the oilseeds crops, the soybeans, even with a low yield of oil, must be the most viable option of source to the production of biokerosene in a short term (CANTARELLA et al., 2015). However, soybeans are already the main source to produce biodiesel, so, besides the competition with food chains, another concern about the soybean crops is the competition with other types of biofuels. In this case, a good alternative is the utilization of non-food crops like jatropha, camelina and halophytes, which can be grown on marginal land (DE CARVALHO, 2017).

The most important requirement of the aviation biofuels is to be drop-in[1], completely miscible and compatibly with the conventional fuel, avoiding adaptations in the plane, on the motor or in the fuel supply infrastructure and to abstain the plane utility restriction. Depending of the productive process, the biofuel can be considerate drop-in only until a determinate blend level, since in larger quantities, the mentioned requirements are unreached (ROITMAN, 2018). These conditions make the biokerosene production more challenging, especially considering the high requirements for the quality standard (RIBEIRO; RIBEIRO, 2019).

The biokerosene can be produce from several feedstocks and applying different processes. The Commercial Aviation Alternative Fuels Initiative (2017) divulgated five approved productions routers of the following drop-in alternative jet fuels certified for commercial use. The approved routes are described below as CAAFI (2017):

2.2.1 Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)

- Year of Certification: 2009
- Blend Level: Up to a 50%
- Feedstock(s): Biomass such as municipal solid waste (MSW), agricultural and forest wastes, wood and energy crops and non-renewable feedstocks such as coal and natural gas
- Process/Product Description: The Fischer-Tropsch (FT) Synthesis Process is a catalyzed chemical reaction in which synthesis gas, a mixture of carbon monoxide and hydrogen, is converted into liquid hydrocarbons of various forms via the use of a reactor with cobalt or iron catalyst. The feedstock is gasified at high temperatures (1200 to 1600 degrees Celsius) into carbon monoxide and hydrogen primarily (synthesis gas or syngas), and is then converted to long carbon chain waxes through the FT Synthesis Process. The wax is then cracked and isomerized to produce drop-in liquid fuels essentially identical to the paraffins in petroleum-based jet fuel, but does not include aromatic compounds.

2.2.2 Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)

[1] Alternative fuel able to replace the equivalent fossil fuel, without the necessity of adapting the engine (EPE, 2018).

- Year of Certification: 2011
- Blend Level: up to a 50% blend
- Feedstock(s): Plant and animal fats, oils and greases (FOGs)
- Process/Product Description: Natural oils are converted from lipids to hydrocarbons by treating the oil with hydrogen to remove oxygen and other less desirable molecules. The hydrocarbons are cracked and isomerized, creating a synthetic jet fuel blending component.

2.2.3 Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (HFS-SIP)

- Year of Certification: 2014
- Blend Level: Up to a 10%
- Feedstock(s): Sugars
- Process/Product Description: The process uses modified yeasts to ferment sugars into a hydrocarbon molecule. This produces a C15 hydrocarbon molecule called farnesene, which after hydroprocessing to farnesane, can be used as a blendstock in jet fuel.

2.2.4 Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (FT-SPK/A)

- Year of Certification: 2015
- Blend Level: Up to 50%
- Feedstock(s): Biomass such as MSW, agricultural and forest wastes, wood and energy crops and non-renewable feedstocks such as coal and natural gas
- Process/Product Description: Uses the FT Synthesis Process plus the alkylation of light aromatics (primarily benzene) to create a hydrocarbon blend that includes aromatic compounds that are required to ensure elastomer seal swell in aircraft components to prevent fuel leaks. FT-SPK/A introduces the migration toward fuels that offer a full spectrum of molecules found in petroleum-based jet fuel, rather than just paraffins.

2.2.5 Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK)

- Year of Certification: 2016
- Blend Level: Up to 50%
- Feedstock(s): Starches, sugars, cellulosic biomass

- Process/Product Description: Dehydration of isobutanol or ethanol followed by oligomerization and hydrogenation to yield a hydrocarbon jet fuel.

In Brazil, the ANP Resolution 63:2014 establishes the specifications for the Alternatives Aviation Kerosene and the Aviation Kerosene B-X (JET B-X). This resolution covers three types of biofuel: the paraffinic kerosene synthetize by Fischer-Tropsch (FT), the paraffinic kerosene synthetize by fatty acids and hydroprocessed esters (HEFA) and isoparaffin synthetize (SIP). The use of biofuels is volunteer, but has to obey the ANP regulation and approved routes are in different stages of technological development (ROITMAN, 2018).

2.3 GROWTH IN AVIATION AND THE CONSUME OF AVIATION KEROSENE

The sustainable rise of aviation is essential for future economic growth and development, trade and commerce, cultural exchange and understanding among peoples and nations (ICAO, 2019). The International Air Transport Association (2019) prevised that the number of routes served by aviation in the world would increase to over 58,000 in 2019, up from 52,000 in 2014. According to the International Civil Aviation Organization (2019) by 2045, the expected growth in the international air traffic [expressed in revenue tonne kilometres (RTK[2])] is 3.3 times of 2015.

The freight aviation grew of 3.4% in 2018, but the passenger demand growth is expected to be more robust than for cargo. The passenger demand is measured in Revenue Passenger Kilometers (RPK[3]) and was forecast to grow 5% in 2019, a smaller growth than 2018, when this type of aviation grew 7.4% (IATA, 2019). Taking into account the number of passengers, nearly 4.4 billion passenger were carried by the world´s airlines in 2018 (ATAG, 2018) and the total passenger numbers were expected to rise to 4.6 billion in 2019 (IATA, 2019).

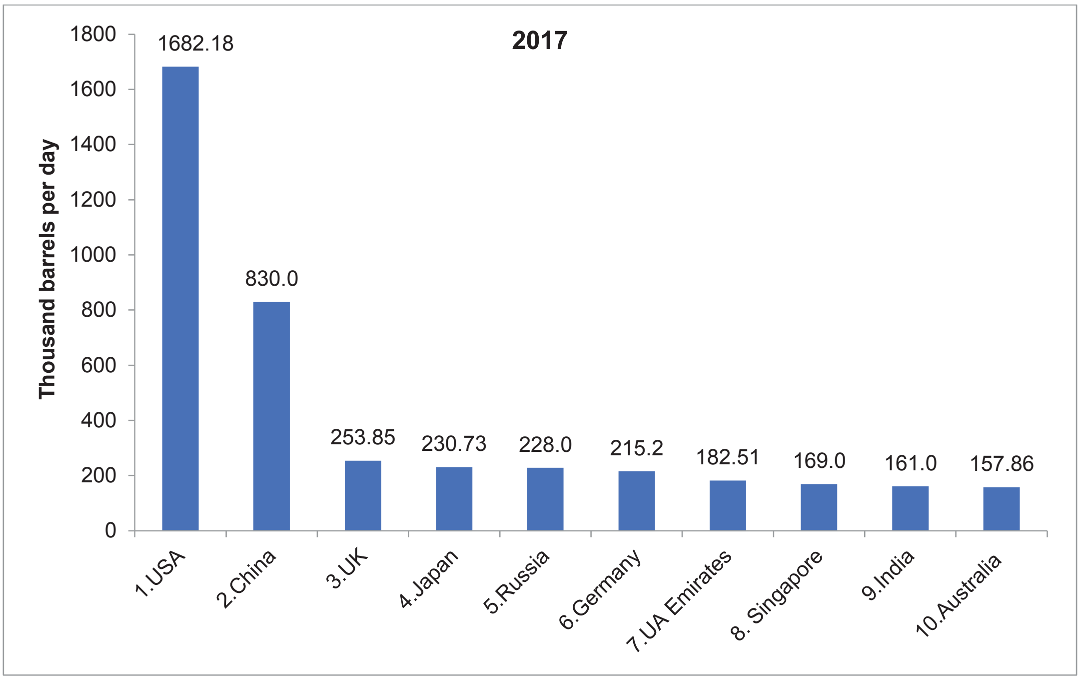
---

[2] It represents the demand for passenger air transport. For the calculation of the index, in each paid flight stage is multiply the number of paid passengers carried by the number of kilometers flown (1 passenger-kilometer is the same as 1 passenger who flew 1 kilometer) (ANAC, 2015).

[3] It represents, in general, the demand for air transportation of passengers. For the calculation of the index, at each paid flight stage, the number of paid passengers transported is multiplied by the number of kilometers flown (1 passenger-kilometer is the same as 1 passenger who flew 1 kilometer). (ANAC, 2015).

International aviation consumed approximately 160 megatons (Mt) of fuel in 2015 (ICAO, 2019), where the average of jet fuel[4] consumption was 32.25 thousand barrels[5] per day (THE GLOBAL ECONOMY, 2015). In 2017, the countries that led the aviation fuel consumption ranking were: United States, China, United Kingdom, Japan, Russia, Germany, United Arab Emirates, Singapore, India and Australia as showed in the Graphic 1 (IEA, 2019; THE GLOBAL ECONOMY, 2017). Brazil was occupying the 17th position in the world ranking in 2017 with the consumption of 115.36 thousand barrels per day of aviation fuel (THE GLOBAL ECONOMY, 2017).

Graphic 1: Fuel consumption of the top ten consumer countries in 2017



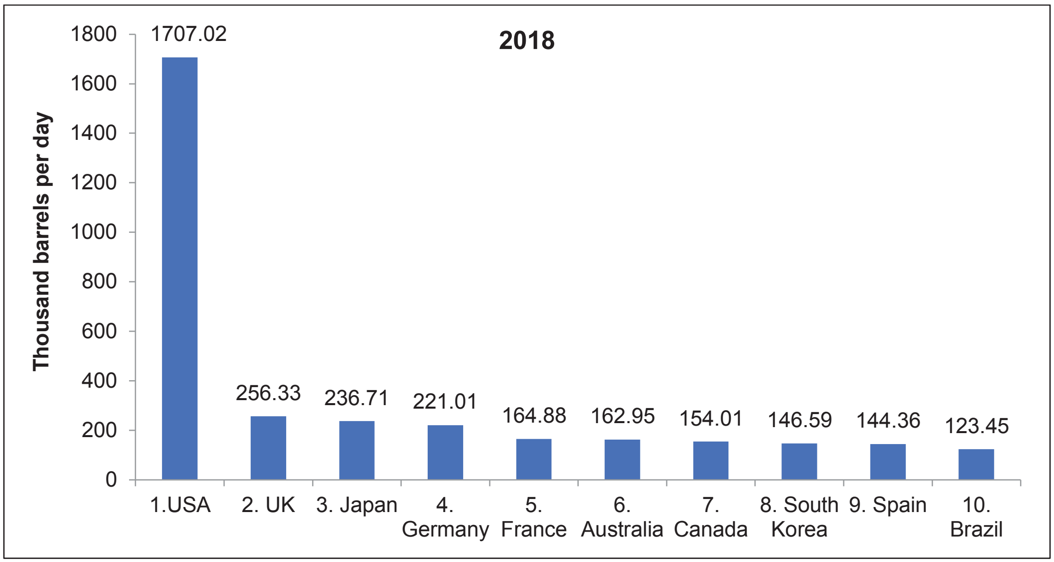
Source: IEA (2019); The Global Economy (2017)

In the 2018, the scenario changed and Brazil became part of the top 10 world consumers of aviation fuel as presented in the Graphic 2, where the bigger consumers were United States, United Kingdom, Japan, Germany, France, Australia, Canada, South Korea, Spain and Brazil (THE GLOBAL ECONOMY, 2018). Brazil is the 10th in the ranking of fuel consumption, showing the importance of country in the world scenario.

---

[4] Jet fuel is a refined petroleum product used in jet aircraft engines and it includes kerosene-type jet fuel and naphtha-type jet fuel (THE GLOBAL ECONOMY, 2017).
[5] One barrel corresponds to 159 liters (IEA, 2019b)

Graphic 2: Fuel consumption of the top ten consumer countries in 2018



Source: The Global Economy (2018)

In the scenario of Brazilian air sector, the domestic market prevailed in comparison to the international market (Brazilian and foreign airlines that operate internationally). In 2012, the passenger transport in the domestic market was five times higher than in the international market and the domestic traffic was characterized by a strong growth from 2000 to 2012 (10.4% per year and 228% accrued), while the international traffic increased 6.9% per year and 122% accrued in the same time period (ANAC, 2012). In 2012, Brazil performed 1,126,000 flights (ANAC, 2012b) and consumed an average of 5,852,898,190 kg of aviation kerosene (ANAC, 2012). In 2015 the volume of passengers was 117 million, 96 million in the domestic market and 21 million in the international operations (ANAC, 2015), with a total of 1,083,000 flights performed in this year (ANAC, 2015b) and a consumption of 6,476,497,751 kg of aviation kerosene (ANAC, 2015). Therewith, the consumption of fuel increased from 2012 to 2015 IN 10.7%, even with the wane of the number of flights in 3.8%, evidencing even more the growth in the consumption of aviation kerosene in Brazil.

Since 2005 it was possible to observe the expressive growth on consume of aviation kerosene (JET-A1) in the domestic and international revenues in Brazil, where the domestic had a rise of 78% while the international increased 55% until 2015. Between 2013 and 2015, the proportion of fuel consumption was approximately 60% for domestic flights and 40% for international flights. The Table 1 shows the consumption data for fuel from 2013 to 2015 for domestic operations and total international operations.

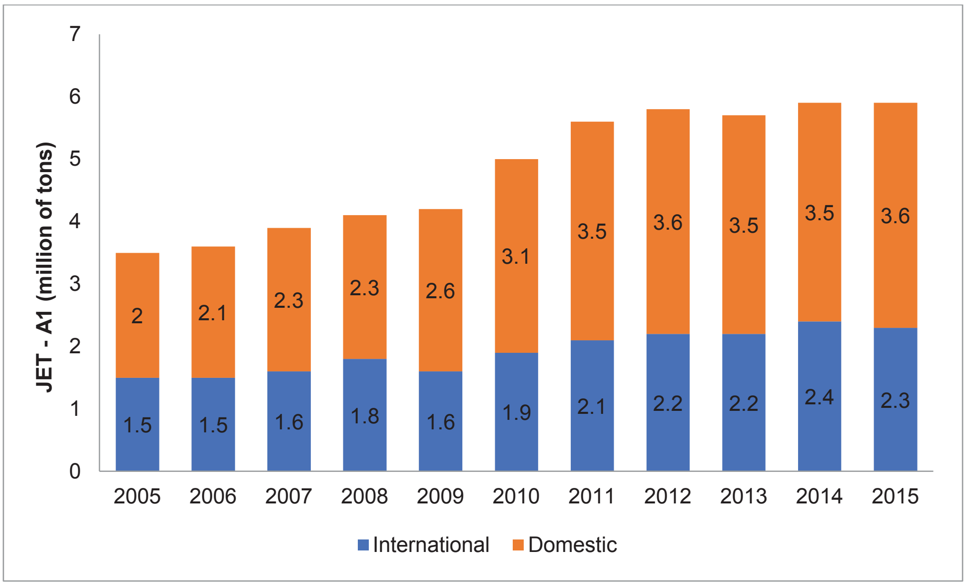
TABLE 1: FUEL CONSUMPTION OF DOMESTIC AND INTERNATIONAL OPERATIONS IN KG

Years	Domestic Operations	International Operations
2013	3,508,980,991	2,740,229,354
2014	3,540,949,758	2,886,323,380
2015	3,578,031,940	2,898,465,811

SOURCE: ANAC (2015)

Considering the domestic and international operations, the average consume of fuel grew 4.2% per year from 2005 to 2015 as demonstrated in Graphic 3 (ANAC, 2015). With the rise of flight number and of fuel consumptions, to understand associated environmental implications in terms of emissions is crucial (ICAO, 2019).

Graphic 3: Fuel consumption of domestic and international operations in Brazil -2005-2015



Source: ANAC (2015)

2.4 GUIDELINES TO MITIGATE AVIATION EMISSIONS

The International Air Transport Association 69th Annual General Meeting, in 2013, overwhelmingly endorsed a Resolution on “Implementation of the Aviation

Carbon-Neutral Growth (CNG2020) Strategy", establishing principles to carbon-neutral growth until 2020.

Some initiatives were determined by the aviation industry, considering the scenario of climate changes and the United Nations Climate Change Conference in Copenhagen in 2009 (COP15). The aviation industry announced its commitment to a global approach to mitigating aviation GHG emissions, setting the following objectives: improvement in fuel efficiency of 1.5% per year from 2009 to 2020, carbon-neutral growth at 2020 and reduction in CO_2 emissions to 50% of 2005 levels by 2050 (BOEING, 2017).

IATA (2013) created a Roadmap to point where the aviation industry needs to invest and develop to reach the carbon-neutral growth. Boeing (2017) pointed in your report about the aviation initiatives the areas that need development, according to the Group on International Aviation and Climate Change (GIACC):

- Investment in new technologies like the purchase of new aircraft, retrofitting and upgrade improvements on existing aircraft, new designs in aircraft/engines, fuel efficiency standards and alternative fuels.
- Development of efficient operations such as minimizing weight, improving load factors, reducing speed, optimizing maintenance schedules, and tailoring aircraft selection to use on particular routes or services.
- Investment on effective infrastructure aiming more efficient air traffic management planning, ground operations, terminal operations (departure and arrivals), en-route operations, airspace design and usage.
- Positive economic measures, including voluntary carbon offsetting, emissions trading schemes, emissions charges and positive economic incentives.
- Regulatory enforcements on carbon emissions reduction and other initiatives such as enhanced weather forecasting, transparent carbon reporting and education/training programs.

In 2012, the Brazilian National Agency of Civil Aviation published the “Brazil’s Action Plan on the reduction of Greenhouse Gas Emissions from aviation” aiming to portray the sector’s evolution and the GHG emissions which followed this evolution. The inventory of emissions is preceded by an analysis of the economic data and evolution of the national air fleet, presenting the evolution of fuel consumption and associated emissions, showing an improvement of the Brazilian air sector energy efficiency, verified over the period under analysis. This Plan also aims to present the actions already in course and ones intended to be implemented for the improvement of the civil aviation fuel efficiency (ANAC, 2012). A second edition of this Plan was published base on the year of 2015, updating the data in the last report (ANAC, 2015).

To achieve the mitigation of aviation emissions, transiting from conventional fuel to biofuel generates also socio-economic advantages in addition to the environmental benefits, then; the biokerosene life cycle needs to be take into consideration.

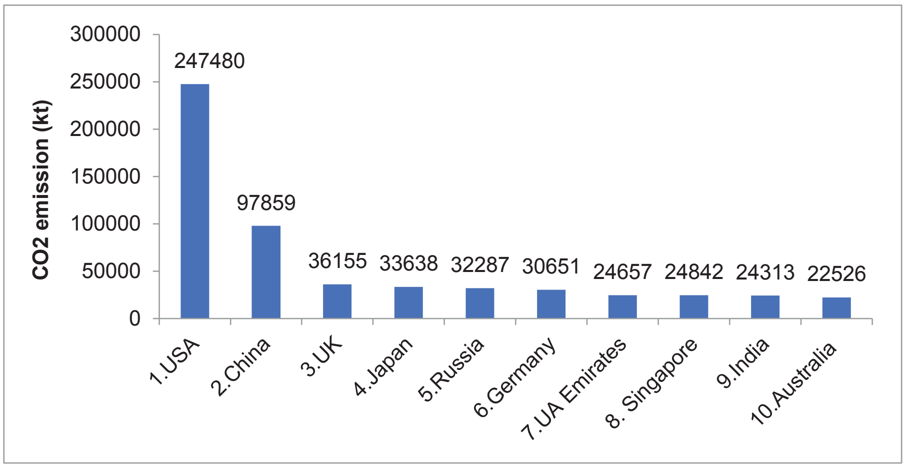
2.5 EMISSIONS OF THE AVIATION SECTOR

The GHG emissions during operation are associated with fuel combustion in aircraft. Major emissions are CO_2 and water vapor, as well as methane (CH_4) and N_2O, contributing with global climate changes (DE CARVALHO, 2017), which CO_2, comprises about 70% of the exhaust, and water vapor comprises about 30%. Less than 1% of the exhaust is composed by pollutants like nitrogen oxides (NO_x), oxides of sulfur (SO_x), carbon monoxide (CO), partially combusted or unburned hydrocarbons (HC), particulate matter (PM), and other trace compounds (BOEING, 2017).

In the 2017, the ten biggest consumers of fuel in the world were responsible for the emission of 574,409 ktCO_2, where United States leaded the emissions being responsible for approximately 43% of the total as presented in the Graphic 4 (IEA, 2019b).

From 2018, nearly 39 million flights were analyzed, and passenger aircraft flew 38 million of these. Total CO_2 emissions from all commercial operations, including passenger movement, belly freight, and dedicated freight, totaled 918 million metric tons (MMT) in 2018 (ICCT, 2019). In the case of Brazil, the emissions of CO_2 in 2015 were 18.8 million of tons (ANAC, 2015).

Graphic 4: CO_2 emission of the ten most fuel consumer countries in 2017



Source: IEA (2019b)

According to ANAC (2015), from 2005 to 2015, the volume of emissions from Brazilian domestic aviation raised 5.9% annually and the emission intensity in 2015 was 12 kg CO_2e per 100RPK. In the international operations, the flights originate from Brazil, the volume of emission for the same period grew 3.0% annually and the emission intensity in 2015 was 5.8 kg CO_2e per 100RPK.

Biofuels derived sources such as algae, jatropha, or waste by-products have been shown to reduce the carbon footprint of aviation fuel by up to 80% over their full lifecycle (ATAG, 2018).

2.6 CO_2 EMISSION ESTIMATION

The air companies have been using engines more efficient to decrease the fuel consumption and consequently to reduce CO_2 emissions. Therefore, along with a sustained improvement in energy efficiency, Sustainable Aviation Fuels (SAF) such as aviation biofuels are the key to reduce aviation's carbon emissions. In 2008, the first flight using blended biofuel happened and since then, more than 150,000 flights have used biofuels (IEA, 2019c).

Some Brazilian companies have taken actions to reduce the use of fossil fuels and in this way, decrease the emissions. Some measures like the management of young fleet, with new technology and the participation the Biofuel and Renewable Energy Program that is related to the Intergovernmental Panel on Climate Change (IPCC) and aim to reduce the impacts of CO_2 emissions (ANAC, 2015).

To better understand carbon emissions associated with aviation kerosene and aviation biokerosene, the creation of scenarios that estimates the CO_2 emission according to the use of biofuel is important. In this sense, using the data about the number of flights performed in Brazil in 2017, as well as the number of passengers and freights transported (ANAC, 2017), the volume of fuel consumption for the country in the same year and the emission factor for aviation kerosene (IPCC, 2006) and biokerosene (IEA, 2019b), it is possible to estimate CO_2 emission for the use of a blend 50% biokerosene and 50% kerosene, and for 100% biokerosene. To calculate the emissions it is used the simplest (Tier[6] 1) methodology to estimate CO_2 emissions from fuel combustion based on the 2006 GLs. The computation follows the concept of conservation of carbon, from the fuel combusted into CO_2. Generally, the Tier 1 estimation of CO_2 emissions from fuel combustion for a given fuel can be summarized as showed in the Table 2 (IEA, 2019b).

The amount of CO_2 emission was calculated for the total number flights in 2017 and after the total for the total weight transported in 2017, considering passengers, freight and luggage to obtain how much kilograms of CO_2 was emitted for each kilograms transported for the aviation industry.

TABLE 2: EQUATIONS USED TO COMPARED THE CO_2 EMISSIONS IN THE SCENARIOS

Variable	Equation
CO_2 emission	$\text{Fuel consumption X Emission factor}^7$
CO_2 emission/ kg transported	$\frac{\text{Total emission}}{\text{Total weight transported}}$

SOURCE: IEA (2019b); ANAC (2017)

3 RESULTS

3.1 CO_2 EMISSION OF BRAZIL

According with IEA (2019b) in 2017 the Brazilian CO_2 emission for the aviation industry was $16{,}475.10^6$ kg CO_2e and the consumption of jet kerosene was 5,503

[6] A *Tier* represents a level of methodological complexity. Usually three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 the most demanding in terms of complexity and data requirements (IPCC, 2019).
[7] Aviation kerosene = 71.50 (kg/GJ) (IPCC, 2006).
Aviation biokerosene = 19.50 (kg/GJ) (IEA, 2019).

ktoe[8]. In the same year Brazil performed 940 thousand of flights carrying a total of 9684.4 $.10^6$ kg (including freights, passengers and luggage) (ANAC, 2017). This means that every kilogram transported for the aviation industry in 2017, resulted in 1.7 kg of CO_2e emission to the atmosphere.

The jet kerosene calorific value is 42.8 MJ/kg (PETROBRÁS, 2014) and to be considered suitable as an aviation fuel, the jet biokerosene must have at least the same calorific value as kerosene (SANTOS, 2015; SILVA, 2019). Therefore, for the biokerosene to replace the kerosene in aviation the quantity of biokerosene required is equivalent. However, SAF and JET-1 have different emission factors, resulting in less emission due the use of the biokerosene.

Considering a scenario where is used a blend of 50%/50% of kerosene and biokerosene and a scenario using 100% of SAF. Calculating the emission using the Tier 1 and the fuel consumption of Brazilian air industry in 2017, they are presented in the Table 3.

TABLE 3: SCENARIOS OF THE CO_2 EMISSION FOR KEROSENE, BIOKEROSENE AND BLEND

Scenario	**Fuel**	**Total CO_2e emission (kg)**	**CO_2e per kg transported (kg)**
1	Jet kerosene	$16,475.10^6$	1.7012
2	Blend 50%/50%	$10,483.10^6$	1.0825
3	Jet biokerosene	$4,493.10^6$	0.4639

SOURCE: OWN ELABORATION

The replacement of the jet kerosene for jet biokerosene shows a decreased in the CO_2 emission related to the fuel consumption of the current planes. So considering the created scenarios and the data about flights in Brazil in 2017, with the blend 50/50 the CO_2 emission would be 1.08 kg of CO_2e kg every ton transported for one kilometer the aviation industry, and using only biokerosene as fuel, the emission would decline to 0.46 kg of CO_2e per kg transported.

3.2 BIOKEROSENE LIFE CYCLE

To verify its real potential to achieve environmental benefits the life-cycle assessments are performed, including all lifetime stages of a product from the extraction of raw material, through processing, manufacturing, distribution

[8] ktoe = thousand tonnes of oil equivalent

(CARVALHO, 2017) and into-plane operations (ATAG, 2011). The biokerosene life cycle start in the feedstock, and there are several types of feedstocks which are potentially amenable to synthesis of aviation biofuel, however, feedstocks, such as corn and soybean are competitive with food production (DINIZ *et al.,* 2018); thus several non-food crops were identified as a potential sustainable feedstock like jatropha, that has oil yield, resilience to drought and pests, and low nutritional requirements (PORTUGAL-PEREIRA *et al*., 2016) and camelina that has a sustainable agricultural system, being well adapted to cultivation in the temperate climate zone and needing fewer inputs than most other crops (SHONNARD *et al.*, 2010). Following the agricultural system to produce the raw material, come the feedstock recovery and transportation (HAN *et al*., 2013).

Several process technologies were described which can be used to convert biomass-based materials into alternative jet fuels nevertheless the vegetal oils transesterification stands out. After this process, the product suffers fractional distillation, resulting in linear and cyclic hydrocarbons with composition similar to the conventional fuel (MORAES, 2018). These latter technologies were noted to be dependent upon the type of feedstock, and some have already reached commercial demonstration scale, whereas others are still in the research and development stage (DINIZ *et al.,* 2018) Two bio-based aviation fuels production pathways are Fisher–Tropsch jet (FTJ) and pyrolysis jet fuel from cellulosic biomass and hydroprocessed renewable jet (HRJ) fuel, which is also known as hydroprocessed esters and fatty acids (or HEFA) from oil crops, algae, and waste oil (HAN *et al*., 2013).

The life cycle also takes to account the logistic of the biofuel transportation, distribution and fuel consumption during aircraft operation (HAN *et al*., 2013). Nowadays the supply of fuel to the commercial aviation industry is also on a relatively smaller scale and less complex than for other forms of transport (ATAG, 2011). Though, according to Roitman (2018), the biokerosene distribution can be done using the current infrastructure used for distributing the conventional fuel and considering. The storage of the product has also shown some challenges, as the difference in densities between the biofuel and the fossil fuel have to be taken into account (ATAG, 2011).

3.3 ENVOIRAMENTAL AND SOCIO-ECONOMIC BENEFITS

The biokerosene production generates environmental and socio-economic benefits. life-cycle The second generation feedstocks or non-food feedstocks guarantee food security; use minimal land area; require relatively low water and energy resources; minimize impacts on biodiversity; and also provide socioeconomic value to local communities where biomass is grown (DINIZ *et al*., 2018).

To overcome the financial barriers, the collaborations across the various stakeholder groups involved in all aspects of aviation biofuel production and use is required. These groups can generate many benefits such as bring together airlines, airports, aircraft and engine manufacturers; academic institutions; fuel refining companies; agricultural companies and farmers groups and local, regional and national governances (ATAG, 2011), resulting in local and regional development, jobs and income generating and technology development (ROITMAN, 2018).

In addition to the environmental advantages caused by the mitigation of CO_2 emission due the combustion of biokerosene in the engines and the sulfur dioxide emissions avoided due that biofuels are sulfur-free (MORAES, 2018), the life-cycle of biofuel production can reduce the emissions up to 80% (ATAG, 2018). The fostering of a sustainable aviation biofuel industry will provide a double benefit – building green industry and making the vital tourist and business connections economically and environmentally viable (ATAG, 2011).

3.4 BIOKEROSENE PANORAMA

Alternative fuels, particularly sustainable biofuels, have been identified as excellent candidates for helping achieve the industry targets for carbon-neutral growth (ATAG, 2018). The long-term commitments to halve CO_2 emissions from the sector will rely on the introduction of radical new technology and an energy transition to fossil free sustainable aviation fuels (ATAG, 2019b). Regarding sustainable aviation fuels, up to 2.6% of fuel consumption could potentially consist of sustainable aviation fuels by 2025 (ICAO, 2019).

The drop-in sustainable aviation fuels are the most promising near-term options. These fuels use the same fuel distribution infrastructure and aircraft engines already in use, with the advantage of reduced GHG emissions. By November 2017, five conversion processes to produce sustainable aviation fuels had been certified and over 100,000 commercial flights had been completed using these fuels (ICAO, 2017).

The first biojet fuel to achieve commercial production was fuel produced by the HEFA pathway, in up to a 50% blend with traditional jet fuel (ICAO, 2017). Alternatively jet fuel components such as FT-SKA that are high in aromatics compounds may be a route to 100% alternative jet fuel blends. Sasol (South Africa refinery) developed FT-SKA using coal and employs the technology to blend its fully synthetic jet fuel. FT-SKA has been successfully evaluated under ASTM D4054 (EIA, 2015).

The technical barriers for the use of biokerosene have been overcome, but even being technically viable, the price is not competitive yet in comparison of the fossil fuel. Notwithstanding, the petroleum prices with the collection of emission credits are incentives to projections reducing the cost of aviation biofuels, which current are from 2 to 2,5 times the value of the traditional fuel (VELÁZQUEZ, KUBOTANI, VELÁZQUEZ, 2012). In the last decade, the different routes of biokerosene production have been certified to commercial use blended to aviation kerosene up to 50% and commercial partnerships between airlines and biofuels producers were established. However, in Brazil, despite numerous successful test flights, aviation biofuels are not yet widely marketed (ROITMAN, 2018), so FAPESP (2013) developed an action plan to dictate the guidelines to implement the aviation biokerosene in the Brazilian aviation industry.

Worldwide, the first test flights began in 2008 and since the certification for the use of sustainable aviation fuel in 2011until September 2019 the aviation industry reached the mark of 200.000 passenger flights using sustainable aviation fuels. It is in regular use at five global airports today (Bergen, Brisbane, Los Angeles, Oslo and Stockholm), but the centralized nature of aviation fuelling, where less than 5% of all airports handle 90% of international flights, means SAF availability at a small number of airports could cover a large share of demand (IEA, 2019c). Information gathered at the first “ICAO Stocktaking Seminar toward the ICAO 2050 Vision for Sustainable Aviation Fuels (SAF) in April 2019 shows that commercial production of SAF increased from an average of 0.29 million liters per year (2013-2015) to 6.45 million liters per year (2016-2018). Additionally, up to 6.5 Mt (8 billion liters) per year of SAF production capacity may be available by 2032 (ICAO, 2019).

Through deployment of new technology, improvements in operations and infrastructure, the sector is working to improve efficiency and cut CO_2 emissions in the short- and medium-term, but a transition like this cannot happen overnight. There are 11 sustainable aviation fuel production facilities currently in operation, under construction or in the final stages of financing (ATAG, 2019b). Considering also the long-term availability of sustainable aviation fuels, finding that, by 2050, it would be physically possible to meet 100% of international aviation jet fuel demand with sustainable aviation fuels, corresponding to a 63% reduction in emissions. However, this level of fuel production could only be achieved with extremely large capital investments in sustainable aviation fuel production infrastructure, and substantial policy support (ICAO, 2019).

Brazil has a great potential for biokerosene production, since the country has a dynamic agricultural sector with strong productivity growth and a large availability of land due the approximately 55 million degraded hectares from agriculture that can be used for this purpose. The combination of these factors gives to Brazil the opportunity to supply raw material for the biofuel production, expanding the raw material plantation without affect the food production. With policies implementation to develop a biofuel program for aviation, Brazil, can be greatly benefited economically through the export of raw materials and even jet biokerosene itself (RIBEIRO; RIBEIRO, 2019).

4 FINAL CONSIDERATIONS

Aviation biokerosene have a lower rate of CO_2 emission when compared to jet kerosene, evidencing the importance to transit from fossil fuel to biofuel to avoid or reduce the GHG emissions. The SAF has been introduced in the aviation around the world, but the production is still deficient, therefore a significantly faster market development is needed. The aviation industry demonstrates a strong commitment to reduce the emissions; therefore they are committed to sustainable aviation fuel use too.

Brazil has a great potential to production of raw material for biofuel and biokerosene production due the availability of land and the development of agriculture.

The calculation in this article only considerate the emissions related to the consumption of fuel in the engines, to have a better vision of the impact that biokerosene generates in the Greenhouse gas emission it is necessary to consider the biofuel Life Cycle, but the SAF is a promising alternative to JET-1. Although biokerosene has been gaining prominence recently, still there is a necessity to invest in research, technology and development of this biofuel.

5 REFERÊNCIAS

ANAC, Agência Nacional de Aviação Civil, **Brazil's Action Plan on the reduction of Greenhouse Gas Emissions from aviation,** 2012. Available in: <https://www.anac.gov.br/assuntos/dados-e-estatisticas/mercado-de-transporte-aereo/anuario-do-transporte-aereo>. Access: December/2019

ANAC, Agência Nacional de Aviação Civil, **Anuário do transporte aéreo 2012,** 2012b. Available in: < https://www.anac.gov.br/publicacoes/brazil_actionplan.pdf> Access: December/2019

ANAC, Agência Nacional de Aviação Civil, **Plano de ação para a Redução da Emissão dos Gases do Efeito Estufa da Aviação Civil Brasileira**: ano base de 2015, 2015. Available in: <https://www.anac.gov.br/assuntos/paginas-tematicas /meio-ambiente/arquivos/PlanodeAo2015_final.pdf> Access: December/2019

ANAC, Agência Nacional de Aviação Civil, **Anuário do transporte aéreo 2015**, 2015b. Available in: < https://www.anac.gov.br/assuntos/dados-e-estatisticas /mercado-de-transporte-aereo/anuario-do-transporte-aereo> Access: December/2019

ANAC, Agência Nacional de Aviação Civil, **Anuário do transporte aéreo 2017,** 2017. Available in: < https://www.anac.gov.br/assuntos/dados-e-estatisticas/mercado-de-transporte-aereo/anuario-do-transporte-aereo> Access: December/2019

ANAC, Agência Nacional de Aviação Civil, **ANAC vai monitorar e verificar dados de emissões de CO2 de aéreas brasileiras,** 2018. Available in: < https://www.anac.gov.br/noticias/2018/anac-vai-monitorar-e-verificar-dados-de-emissoes-de-co2-de-aereas-brasileiras> Access: December/2019

ANAP, Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, **Resolução ANP Nº 63 DE 05/12/2014** , 2014. Available in: < http://legislacao.anp.gov.br/?path =legislacao-anp/autorizacoes/2014/fevereiro&item=aut-63--2014> Access: December/2019

ATAG, AIR TRANSPORT ACTION GROUP, **Powering the future of flight**: The six easy steps to growing a viable aviation biofuels industry, 2011. Available in: <file:/// C:/Users/usuario/Documents/Universidade%20de%20Trento/TCC%20MBA/power%20of%20the%20future%20%20of%20flights.pdf > Access: July/2020

ATAG, AIR TRANSPORT ACTION GROUP, **Facts & Figures**, 2018. Available in: <https://www.atag.org/facts-figures.html> Access: December/2019

ATAG, AIR TRANSPORT ACTION GROUP, **Over 200,000 commercial flights using low-carbon fuel show an energy transition is possible**, 2019b. Available in: <https://www.atag.org/component/news/?view=pressrelease&id=117> Access: December/2019

CAAFI, Commercial Aviation Alternative Fuels Initiative, **Approved fuels**, 2017. Available in: < http://www.caafi.org/focus_areas/fuel_qualification.html#approved >

CANTARELLA, H. *et al*. Potential feedstock for renewable aviation fuel in Brazil. **Environmental Development**, v. 15, p. 52-63, 2015.

DE CARVALHO, F. M. **Evaluation of the brazilian potential for producing aviation biofuels through consolidated routes**.2017.137f. Dissertação (Mestrado em Planejamento Energético) - Universidade Federal do Rio de Janeiro, Rio de Janeiro, (RJ), 2017. Available in: < http://www.ppe.ufrj.br/index.php/pt/publicacoes/dissertacoes/2017/280-evaluation-of-the-brazilian-potential-for-producing-aviation-biofuels-through-consolidated-routes> Access: November/2019

DINIZ, A. P. M. M. *et al.* Stochastic techno‐economic analysis of the production of aviation biofuel from oilseeds. **Biotechnol Biofuels**, v. 11, n. 161, p.1-15, 2018.

EIA, U.S. Energy Information Administration. **The Flight Paths for Biojet Fuel,** 2015. Available in: < https://www.eia.gov/workingpapers/pdf/flightpaths_biojetffuel.pdf> Access: January/2020

FAPESP, Fundação de Amparo à Pesquisa do Estado de São Paulo. **Plano de voo para biocombustíveis de aviação no Brasil:** Plano de ação, 2013. Available in: <http://www.fapesp.br/publicacoes/plano-de-voo-biocombustiveis-brasil-pt.pdf> Access: December/2019

FREGNANI, J.A.T.G.; ANDRADE, O. **Aviation Initiatives and the Relative Impact of Electric Road Vehicles and Biofuels on CO2 Emissions**, BOEING, 2017. Available in: <https://www.boeing.com/resources/boeingdotcom/features/innovation-quarterly/aug2017/BTJ_CO2emissions_FULL.pdf> Access: November/2019

FREIRE, A. P. **Blendas de bioquerosene e querosene de aviação**: caracterização térmica e espectrométrica. 2014. 49 f. Monografia (Graduação em Engenharia de Energia) - Universidade de Brasília, Brasília (DF), 2014. Available in: < http://bdm.unb.br/handle/10483/9274> Access: December/2019

GRAVER, B.; ZHANG, K.; RUTHERFORD, D. CO_2 emissions from commercial aviation, 2018. **International Council on Clean Transportation (ICCT**), 2019. 13f. Available in: < https://theicct.org/sites/default/files/publications/ICCT_CO2-commercl-aviation-2018_20190918.pdf> Access: November/2019

HAN, J. *et al*. Life-cycle analysis of bio-based aviation fuels. **Bioresource Technology**, v. 150, p. 447-456, 2013. Available in: < https://www.sciencedirect.com/science/article/pii/S0960852413012297?via%3Dihub > Access: July/2020

IATA, International Air Transport Association, **Historic Agreement on Carbon-Neutral Growth,** 2013. Available in: < https://www.iata.org/en/pressroom/pr/2013-06-03-05> Access: December/2019

IATA, International Air Transport Association, **Aircraft Technology Roadmap to 2050**, 2013. Available in: <https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/technology20roadmap20to20205020no20foreword.pdf> Access: December/2019

IATA, International Air Transport Association, **Slowing Demand and Rising Costs Squeeze Airline Profits**, 2019. Available in: < https://www.iata.org/en/pressroom/pr/2019-06-02-01/> Access: December/2019

ICAO, International Civil Aviation Organization, **ICAO Global environmental trends – present and future aircraft noise and emissions,** Assembly-40th sesión, 2019. 8f. Available in: < https://www.icao.int/Meetings/A40/Documents/WP/wp_054_en.pdf> Access: November/2019

IEA, International Energy Agency, **World Energy Balances**, 2019. Available in: < http://wds.iea.org/wds/pdf/WORLDBAL_Documentation.pdf > Access: January/2020

IEA, International Energy Agency, **CO2 emissions from fuel combustion**, 2019b. Available in: < http://wds.iea.org/wds/pdf/Worldco2_Documentation.pdf > Access: January/2020

IEA, International Energy Agency, **Are aviation biofuels ready for take off?**, 2019c. Available in: < https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off> Access: January/2020

IPCC, Intergovernmental Panel on Climate Change, **2006 IPCC guidelines for national Greenhouse Gas Inventories,** 2006. Available in: < https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html> Access: December/2019

IPCC, Intergovernmental Panel on Climate Change, **2019 refinement to the 2006 IPCC guidelines for national Greenhouse Gas Inventories,** 2019. Available in: <https://www.ipcc.ch/site/assets/uploads/2019/05/01_2019rf_OverviewChapter.pdf> Access: December/2019

MORAES, E. S. **Propriedades termodinâmicas: querosene, bioquerosene, Aditivos e mecanismo de detecção de explosivos**. 2018. 121f. Tese (Doutorado em Engenharia de Recursos Naturais da Amazônia) – Universidade Federal do Pará, Belém, 2018. Available in: <

http://repositorio.ufpa.br/jspui/bitstream/2011/10526/1/Tese_PropriedadesTermodinamicasQuerosene.pdf> Access: July/2020

PORTUGAL-PEREIRA, J. *et al.* Life cycle assessment of conventional and optimised Jatropha biodiesel fuels. **Renewable Energy**, v. 86, p. 585-593, 2016. Available in: < https://www.sciencedirect.com/science/article/pii/S0960148115302470?casa_token=ISCI5UCfNdYAAAAA:9Zy5paQUVsphpGhe8wIH57utoDERl26HxoOzm-HRLRiBQ0tBG4f9rgUCQqUty6nyOJGSEWCH > Access: July/2020

PETROBRÁS, **Querosene de aviação**: Informações técnicas, 2014. Available in: < http://sites.petrobras.com.br/minisite/assistenciatecnica/public/downloads/QAV-Informa%C3%A7%C3%B5es-T%C3%A9cnicas-v.1.3-29.pdf> Access: December/2019

RIBEIRO, N. F.; RIBEIRO, E. F. Redução na emissão de dióxido de carbono (CO2) através da implementação de biocombustíveis na aviação comercial brasileira. **Revista Conexão Sinpaer**, v. 10, p. 45-55, 2019.

ROITMAN, T. **Perspectivas e Propostas de Inserção de Bioquerosene de Aviação no Transporte Aéreo de Passageiros no Brasil**. 2018. 158f. Dissertação (Mestrado em Ciências em Planejamento Energético) – Universidade Federal do Rio de Janeiro, Rio de Janeiro (RJ), 2018. Available in: < http://www.ppe.ufrj.br/images/publica%C3%A7%C3%B5es/mestrado/Tamar_Roitman._MESTRADO-2018.pdf> Access: November/2019

SANTOS, I. N. *et al.* Biocombustíveis como fonte alternativa de energia na aviação civil: um estudo bibliométrico. **Anais do IX Simpósio de Engenharia de Produção de Sergipe,** 2017.

SANTOS, F. I. V. **Bioquerosene de aviação**: panorama e perspectiva do biocombustível. Campinas, SP, 2015. Monografia (Graduação em Gestão do Agronegócio), Universidade Estadual de Campinas, Limeira (SP), 2015. Available in: < file:///C:/Users/usuario/Downloads/FELIPEIOAVASSOVIEIRADOSSANTOS%20(2).pdf> Access: December/2019

SILVA, J. Q. **Biodieseis leves derivado dos óleos da macaúba e do palmiste:** propriedades de misturas com o querosene na perspectiva de um combustível alternativo de aviação. 2019. 75f. Dissertação (Mestrado em Ciências em Biocombustíveis) - Universidade Federal de Uberlândia e Universidade Federal dos Vales do Jequitinhonha e Mucuri, Uberlândia (MG), 2019. Available in: < https://repositorio.ufu.br/bitstream/123456789/24768/1/BiodieseisLevesDerivado.pdf > Access: December/2019

SHONNARD, D. R. *et al.* Camelina-derived jet fuel and diesel: Sustainable advanced biofuels. **Sustentable Energy,** 2011. Available in: < https://aiche.onlinelibrary.wiley.com/doi/full/10.1002/ep.10461 > Access: July/2020

TERAMOTO, E. H. **Estudo da efetividade da atenuação natural de compostos BTEX em área contaminada por querosene de aviação**. 2015. 238f. Tese

(Doutorado em Geociências e Meio Ambiente) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista “Júlio de Mesquita Filho”, Rio Claro (SP), 2015. Available in: < file:///C:/Users/usuario/Downloads/000864233%20(1).pdf> Access: November/2019

THE GLOBAL ECONOMY. **Jet fuel consumption, thousand barrels per day, 2015 - Country rankings,** 2015. Available in: < https://www.theglobaleconomy.com/rankings/jet_fuel_consumption/> Access: January/2020

THE GLOBAL ECONOMY. **Jet fuel consumption, thousand barrels per day, 2017 - Country rankings,** 2017. Available in: < https://www.theglobaleconomy.com/rankings/jet_fuel_consumption/> Access:January/2020

THE GLOBAL ECONOMY. **Jet fuel consumption, thousand barrels per day, 2018 - Country rankings,** 2018. Available in: < https://www.theglobaleconomy.com/rankings/jet_fuel_consumption/> Access:January/2020

VELÁZQUEZ, R. S. G.; KUBOTANI, R. T.; VELÁZQUEZ, S.M.S.G. **Novos combustíveis para a aviação: um estudo de caso.** 2012. 93 f. Tese (Doutorado em Engenharia), Universidade Presbiteriana Mackenzie, São Paulo (SP), 2012. Available in: < http://editorarevistas.mackenzie.br/index.php/rmec/article/view/4269 > Access: November/2019