Green Flight

Study encourages biokerosene production for civil aviation

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PUBLISHED IN JULY 2013

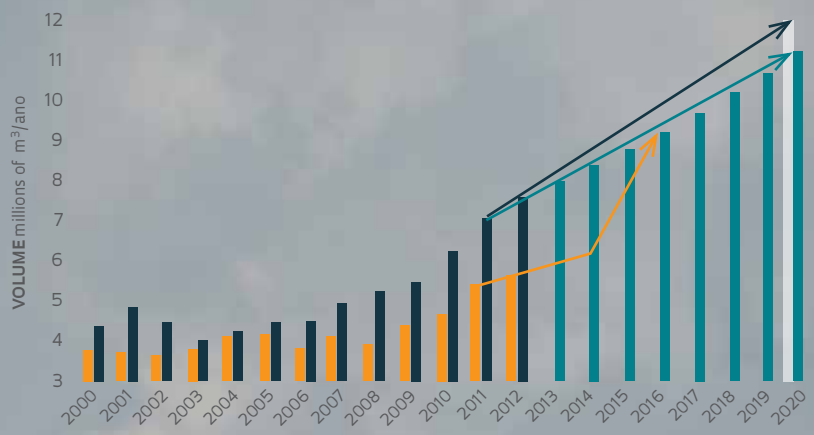
By the year 2050, commercial aviation is expected to reduce its emissions of carbon dioxide (CO_2) by 50% compared to the amount emitted by aircraft engines in 2005. To accomplish this, institutions and companies in a number of countries are conducting a great deal of research and development to produce a non-petroleum-based kerosene from renewable sources, one that will release fewer harmful gases into the atmosphere. Biokerosene, as it is being called, is likely to once again make Brazil a major world center for the development and production of a biofuel, as it was with ethanol and biodiesel. This trend is highlighted in the study "Flightpath to Aviation Biofuels in Brazil: Action Plan" presented in early June in São Paulo, which was sponsored by two of the three largest aircraft manufacturers in the world, Boeing and Embraer, with FAPESP funding, and was coordinated by the University of Campinas (Unicamp) Interdisciplinary Center for Energy Planning (NIPE). Thirty-three other partners, including national and international companies, universities and research institutes, also participated in the study, which was developed in eight workshops that occurred over the course of a year.

The study presents several technological methods that begin with raw materials, such as traditional sugarcane, algae, animal fats, vegetable oils, lignocellulosic material, starches and urban waste, and use different conversion and refining technologies to obtain biokerosene. At this stage, the study concludes that there are still many significant gaps that need to be closed with regard to technology and cost. Technical difficulties will require the participation of all those involved, air-

Embraer fleet: the company has partnered with Boeing to find alternatives to petroleum-based kerosene

Consumption and future projection

Commercial aviation in Brazil is expected to grow 5% a year on average between now and 2020



- Kerosene production in Brazil
- Kerosene consumption in Brazil
- Projected production in Brazil
- Projected consumption of the National Fuel and Lubricant Distributors Union (Sindicom)
- Projected consumption of the Energy Research Company (EPE)

SOURCE ANP 2012

Brazilian refineries produce 75% of the kerosene consumed by aviation in Brazil

62,000 international flights take off from Brazil each year. There are 1,000,000 domestic flights

On average worldwide, fuel represents 34% of airline operating costs

EMBRAER

craft manufacturers and aviation companies, developers and suppliers of fuel, in addition to the world's certifying bodies. Another factor to be taken into consideration is the logistics of biofuel production and distribution to the 108 domestic airports where large aircraft operate, representing 1 million scheduled flights in Brazilian airspace alone, and the need to service the 62,000 international flights that depart each year from Brazil and are bound for 58 airports in 35 countries. These outgoing flights use 60% of the kerosene consumed by aviation in -Brazil.

To prove itself an acceptable addition to the aviation industry, biokerosene must meet certain rigorous criteria. It must have the same technical specifications as the currently used fuel to be considered a drop-in fuel (one that can be mixed with conventional jet fuel) that ensures a ready supply for current engines and those that are still under development. "The consensus is that in the coming decades there will not be huge technological changes in commercial aviation fuel, such as the incorporation of solar energy, or fuel cells that run on hydrogen or lithium batteries, for example. Such equipment takes up too much space and is heavy, which requires a greater expenditure of fuel," says Professor Luís Augusto Cortez, vice president of international relations at Unicamp and the study's coordinator. "There is no way to reduce emissions just by improving engine efficiency, and so we are encouraging the search for new biofuels," says Mauro Kern, Embraer's executive vice president of engineering and technology. In June, the company announced its new line of jets, the E2, which will begin flying in 2018 with a lower fuel expenditure and fewer emissions.

Among the most advanced technologies under development in Brazil and cited when the study was announced are the biokerosenes from Amyris and Solazyme, two California-based bioenergy

Current comparison

Fuel used today still has advantages in terms of price and distribution logistics, which is worldwide

KEROSENE	BIOKEROSENE
Nonrenewable	Renewable
Produced with oil	Produced primarily with sugarcane and vegetable oils
More polluting	Less polluting
Unique production process	Several technological production methods
Well-established production and distribution worldwide	No industrial-scale production, only experimental
Market price	Price still high

PHOTOS 1 BOEING 2 EMBRAER

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1 Boeing 747 engines: biokerosene for international flights

2 E2 Design: new Embraer jet engines will be more economical

companies. Both companies are part of the group of partners that conducted the FAPESP-coordinated study. The first, founded by University of California at Berkeley researchers, has been in Brazil since 2007. Since December 2012, the company has been producing farnesene, which is a liquid made from sugarcane juice that uses genetically modified *Saccharomyces cerevisiae* yeast strains, in the city of Brotas, São Paulo State. Such transformed microorganisms act in the fermentation process to produce farnesene instead of ethanol. Using specific refining processes, it is possible to manufacture biokerosene from this product for the chemical industry and even diesel, which was the first goal of the company in Brazil (*see* Pesquisa FAPESP *Nº 153*) and has been used experimentally by some bus fleets in the cities of São Paulo and Rio de Janeiro.

"With a minimum hydrogenation process, farnesene becomes farnesane, which is nothing more than biokerosene," says Joel Velasco, senior vice president of Amyris. "Our patents and technology are mainly in the yeast strains developed by Amyris, but farnesane is not a transgenic product," says Velasco. "Until now, farnesene was produced on a relatively small scale, which obviously led to higher costs than traditional kerosene. However, these costs are already coming down as we increase the scale of production," says Velasco. Founded in 2003, Amyris received an investment in the form of a partial purchase of shares by Total, the fifth largest oil and gas company in the world, which is based in France and is currently the largest distributor of aviation fuel in Europe. "Once we are operating on an industrial scale, we expect to be a more competitive alternative among the renewable aviation kerosenes," says Velasco.

To be a supplier of biokerosene, companies developing this biofuel must receive approval from the American Society for Testing and Materials (ASTM). As part of this process, test flights were performed using a maximum of 50% biofuel mixed with an equal portion of traditional fuel. This occurred on June 20, when Amyris, along with Total, supplied biokerosene to an Airbus 321 for the Paris Air Show. "The fuel was produced from Brazilian sugarcane," says Velasco. Earlier, in June 2012, the company had supplied biokerosene for a flight in Rio de Janeiro for the Rio +20 Conference. In this case, the aircraft was an Azul Linhas Aéreas E195 jet that had been manufactured by Embraer. In June of this year, the National Petroleum Agency (ANP) published the Brazilian specifications for aviation biokerosene, aligned with international procedures, which enables commercial flights to use biofuel in Brazil.

The Solazyme process transforms the sugarcane juice into high-added-value oil by means of microalgae

More than 1,500 commercial and military flights have used mixtures of renewable and fossil kerosene. The Solazyme product is also worth testing in aircraft, not only for certification purposes but also for verification and analysis by aircraft manufacturers. The first

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commercial flight using biokerosene that was produced by the company occurred in 2011 on a United Airlines Boeing 737-800 between the cities of Houston and Chicago, a distance of 1,700 km. According to data from Solazyme, the flight released 10-12 fewer metric tons of CO_2 than it typically does into the atmosphere. This quantity is equivalent to the amount released by the average passenger automobile using gasoline and driven 48,000 kilometers in the United States. The company, founded in 2003 and present in Brazil since 2011, produces bio-jet fuels from sugar-fed microalgae. After "fattening up" in fermenters, the microalgae produce oil internally. The oil is extracted by crushing; after a refining process similar to that used by the petrochemical industry, the oil is fractionated into various types of biofuels and products for the chemical industry. "We crack the oil produced by the algae. This is followed by the hydrogenation and isomerization phase, which results in, among other products, a biokerosene that meets the specifications for aviation," relates Rogério Manso, Solazyme's global sales director. "To develop our process, we selected microalgae specimens from nature that are more likely to produce oil. Then, by traditional means of selection, we induced mutations; finally through genetic engineering, we made the final selection for our microalgae strains," says Manso.

Solazyme, in Brazil, has partnered with Bunge, a producer of vegetable oils for the biodiesel and food markets, which has sugarcane production plants. Thus, Solazyme Bunge Renewable Products is building a production facility next to a plant in the town of Orindiúva, in São Paulo State. Production of the essential oil is based on a process whereby the sugar found in sugarcane juice is fermented by means of microalgae, the nature of which the company will not disclose. "Our process transforms the sugarcane juice into an oil with high added value," says Walfredo Linhares, manager of Solazyme in Brazil. He says the company now has partnerships with Volkswagen and a supply contract with the US Navy, which no longer wants to rely exclusively on petroleum derivatives. Production in Brazil should begin in late 2013, and Solazyme Bunge has an investment of R$246 million from the Brazilian Development Bank (BNDES). Biokerosene manufacturing in Brazil still depends on an arrangement with another company that specializes in refining or even building its own unit. Both Solazyme

PHOTOS 1 AMYRIS **2** SOLAZYME

1 Amyris Plant in Brotas (SP)

2 Growing Solazyme's microalgae

"There is a global demand by airlines for a fuel that emits less CO_2," says Luiz Nogueira

and Amyris can adapt their own technologies to other types of sugar, such as beets in Europe, or the starch from corn in the United States and also bagasse from sugarcane.

Another renewable biokerosene manufacturing technology, from the Unicamp School of Chemical Engineering (FEQ), developed under the coordination of Professor Rubens Maciel Filho, is at the laboratory scale and is ready to move to a pilot production line (*see* Pesquisa FAPESP *Nº 164*). "We have reached the maximum production we can make in a laboratory environment; we are now working to raise funds to expand production and do an economic evaluation of our biokerosene and a parallel study of sustainability," says Maciel Filho, who is also one of the coordinators of the FAPESP Bioenergy Research Program (Bioen). "A trade agreement is being negotiated," he states, without revealing the name of the company. This process uses various fats and oils, depending upon local availability, which means that raw material logistics can have a significant impact on production costs. "Biofuel is made from vegetable oils, ethanol, and a specific catalyst, which initiates a reaction without the need for genetically modified organisms," Filho says.

These examples of renewable biokerosene production processes that are under development in Brazil show that Brazil is seeking to carve out a leading position for itself in the world of biofuels. "The country has significant advantages and is in a different place than it was with ethanol and biodiesel, whose acceptance by companies resulted from government incentives. Now is different. There is a global demand by airlines for a fuel that emits less CO_2," relates Professor Luiz Horta Nogueira of the Federal University of Itajubá (Unifei), Minas Gerais State, a study participant. Still, the path to success is a long way off-even allowing biokerosene trucks to enter airports to service the aircrafts can be an obstacle. The chance for success also depends on having to prove how much less CO_2 and other pollutants each biofuel releases in comparison to oil. "We still have difficulty establishing and analyzing the life cycle of biokerosene emissions. Reliable data do not exist, as was apparent from our study," says Cortez. ■

Project

Technological roadmap for sustainable biofuels for aviation - Opportunities for Brazil (No. 2012/50009); **Grant Mechanism** Partnership Program for Technological Innovation (PITE); **Coordinator** Luís Augusto Cortez / Unicamp; **Investment** R$565,550.00 (FAPESP).