Overview of Alternative Jet Fuels in 2014*

** This paper is an update of the text that was originally published in the IATA 2014 Report on Alternative Fuels as a contribution from ICAO Secretariat.*

1 Introduction

In 2009, the International Civil Aviation Organization (ICAO) organized the Conference on Aviation and Alternative Fuels, during which ICAO Member States endorsed the use of sustainable alternative fuels for aviation as an important means of reducing aviation emissions. This turning point, where consideration of alternative fuels became global, further led to the inclusion of recommendations in the Resolution on Aviation and Climate Change, Resolution A37-19, adopted by the 37th ICAO Assembly, for States to consider policies and measures to support and accelerate, as appropriate, the development and deployment of such fuels as part of the basket of measures to reduce aviation's impact on climate.

Also in 2009, ASTM International approved the Fischer-Tropsch process as the first process for producing alternative jet fuel, crowning the effort undertaken to introduce "drop-in" alternative fuels in aviation[1], with the support of the United States' Commercial Aviation Alternative Fuels Initiative (CAAFI) and the US Air Force.

Following these milestones, initiatives multiplied worldwide to promote, support or initiate the development, deployment or use of sustainable alternative fuels in aviation. The approval of HEFA fuels (made through hydroprocessing of vegetable oils and animal fats) by ASTM in September 2011 triggered the take-off of the first commercial flights using alternative fuels and, by June 2012, more than 1500 had already been flown by 17 airlines.

In the 2013 edition of this IATA report, ICAO reported on the ongoing developments and challenges on the road to large-scale deployment of alternative fuels in aviation. This contribution to the 2014 report constitutes an updated overview of the major achievements and progress made in 2014.

2 Technology developments

The outstanding technological achievement for 2014 is certainly the approval in June by ASTM of the third pathway to produce alternative jet fuels. This new pathway is referred to as "Synthetic Iso-paraffin from Fermeted Hydroprocessed Sugar (SIP), and was formerly known as Direct-Sugar-to-Hydrocarbon. It is a proprietary process developed by Amyris and Total, which uses advanced fermentation to convert sugars into a hydrocarbon molecule, the farnesene, that can be upgraded into a jet fuel component through hydroprocessing. A paraffin is then obtained, as for HEFA and Fischer-Tropsch, with the peculiarity that it consists of one carbon chain-length only (C-15) when kerosene's paraffins include chain-lengths from 9 to 16 carbon atoms. As a consequence, the blending ratio with fossil Jet-A1 is currently limited to 10 per cent. In the future, it is expected that engineered yeasts will be developed that produce additional carbon chain-lengths and allow for an increase in the blending ratio. The farnesene molecule is already produced at initial commercial scale in the Amyris plant of Brotas in Brazil, which can deliver 40 kt of fuel per year. Currently, the plant uses sugar cane as a feedstock, but the process can be applied to other

[1] A drop-in fuel is a substitute for conventional jet fuel, which is fully compatible, mixable and interchangeable with conventional jet fuel. Such an alternative fuel does not require any adaptation of the aircraft and or infrastructure, and does not imply any restriction on the domain of use of the aircraft.

feedstock, in particular cellulosic sugars from woody biomass and agricultural or forest residues.

The approval of additional pathways is still ongoing. These include Alcohol-to-Jet, pyrolysis and catalytic cracking (Hydroprocessed Depolymerized Cellulosic Jet), catalytic hydrothermolysis and catalytic conversion of sugars[2].

In 2014, Boeing also proposed to examine the possibility to use green diesel at a low blending ratio to produce aviation drop-in fuel. Unlike conventional biodiesel, which is an oxygenated compound and is unsuitable for use in aircraft, green diesel is produced from vegetable oils and animal fats via the same method as HEFA bio-jet fuel. Green diesel is chemically similar to HEFA, but the aviation fuel requires additional hydroprocessing to achieve the lower freezing point required for use in aircraft. This additional processing induces increased cost and a lower product yield, which is a disincentive for producers to make bio-jet fuel. In an initial step, blending a low ratio of green diesel, in order to comply with the jet fuel freezing point, could be a way to introduce some volume of biofuel in aviation at a lower cost.

From a longer term perspective, and with a view to the emergence of innovative technologies, it is worth noting that in 2014 the first ever "solar" jet fuel was produced, made from CO_2, water and solar energy, under the European SOLAR-JET project. The technology is currently at lab-scale, but could open the way to large-scale sustainable production of alternative fuels.

3 Commercial production and use of sustainable alternative fuels

The impressive number of commercial flights that were operated by airlines in the months following the approval of HEFA fuel in September 2011 should not mask the nascent character of the alternative jet fuel industry. More generally, advanced biofuels (including for example cellulosic ethanol for road transportation) are still at an early phase of development, with the first-of-their-kind plants beginning operation. Thus, commercial availability of the fuels is still limited and, in the case of aviation alternative fuels, to date, there has been no routine production of alternative jet fuel. All the commercial flights thus far were operated with especially produced batches of fuel[3].

However, circumstances are changing. Over the last two years, there have been signals that the regular commercial production of biojet fuel can be expected in the near future. In 2013, United Airlines announced a purchase agreement with AltAir for HEFA fuel to be produced in the Bakersfield refinery that AltAir is retrofitting. The plant should start production at the beginning of 2015, with a nominal production capacity of 90 kt/y of renewable diesel and jet fuel. In September 2014, the US Department of Defense awarded USD 210 million for the construction of three biorefineries that will produce military drop-in fuels. One of the recipients, Fulcrum Bioenergy, also obtained a loan guarantee from the US Department of Agriculture and entered a long term supply agreement with Cathay Pacific that made a strategic equity investment in the company. The fuel will be produced from municipal solid waste at a plant located in Nevada, which Fuclrum BioEnergy will begin construction on by the end 2014. It is anticipated that this plant will produce 30 kt of drop-in fuel from 2016, annually. A second recipient, Red Rock Biofuels, also signed an agreement with Southwest Airlines for the supply of about 10 kt of fuel per year, which will be produced from forest residues through gasification and Fischer-Tropsch synthesis. In the United Kingdom, Solena, which has concluded a partnership and purchase agreement with British Airways, has now confirmed the location of their waste-to-liquid plant, the initial production of which is expected in 2017 with 50 kt of jet fuel per year.

[2] Reader is invited to refer to 2013 report or ICAO page on alternative fuels for further details.

[3] For example, Neste Oil, that today have the largest production capacity of hydroprocessed oils with about 2 Mt/y, direct all their production toward diesel fuel, upgrading to jet fuel being only done on demand.

As mentioned, the existing Amyris/Total production plant in Brotas, Brazil, has a production capability of 40 kt/y of farnesene that can be upgraded into the newly approved SIP fuel. Moreover, Indonesia is pursuing a regulatory target to include 2% of biofuels in jet fuel by 2016 and has formed a working group to set up the production, with an agreement with the Minister of Agriculture for the supply of the feedstock.

These announcements should not hide the general difficulties of emerging alternative fuels companies to scale up their process and reach commercial production. In November 2014, Kior, a company developing a catalytic cracking process and which had present in ASTM for the approval of a process to make jet fuel, went bankrupt and abandoned its production project. Gevo, a major actor in the approval of alcohol-to-jet, reported repeated financial difficulties in 2014. In the short term, a number of companies, such as Solazyme or Virent, tend to focus on chemical markets which are less demanding in term of production quantities and offer higher margins than the fuel market.

In spite of these difficulties, 2014 confirmed airlines' interest for alternative fuels. If 2013 saw only a few commercial flights using alternative fuels, over 200 flights were operated in 2014. The Brazilian company GOL was very active in this field. GOL are working with the Brazilian Biojet Fuel Platform to achieve their target of blending 1% of biofuels in their jet fuel by 2016. GOL has achieved 200 flights with a 4% biofuel mixture during the FIFA World Cup, using 92,000 L of HEFA supplied by UOP. GOL also committed to use the newly approved SIP from Amyris/Total and achieved the first commercial flight with this fuel in September 2014. KLM continued to pursue their efforts to deploy biofuel with a new series of 20 weekly intercontinental flights from Amsterdam to Aruba, using a 20% blend of biofuels made from used cooking oil. In October 2014, AirFrance initiated a one-year series of weekly flights between Toulouse and Paris, using a 10% blend of Amyris/Total fuel. Lastly, SAS and Norwegian operated in November 2014 their first commercial flight using biofuel.

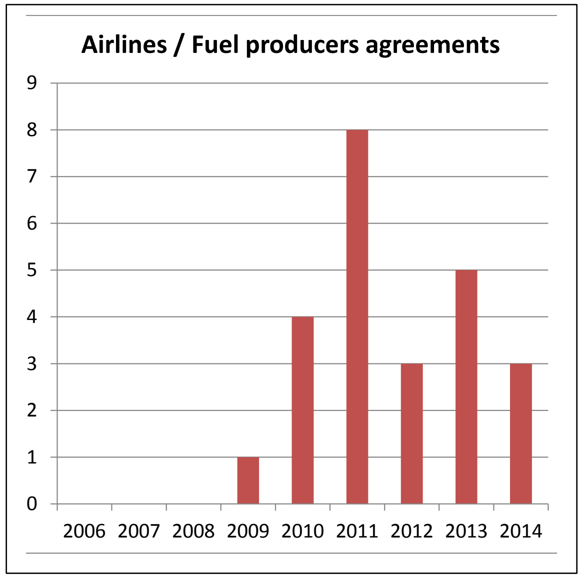

Figure 1: Airlines/Fuel Producers agreements since 2009

4 Initiative for the development and deployment of alternative fuels

A number of collaborations from airlines and fuel producers to initiate the deployment of alternative fuels in aviation have already been mentioned. Since 2009, a total of 21 agreements between airlines and fuel producers have been recorded (Figure 1) in the Global Framework on Aviation Alternative Fuels (GFAAF), the ICAO database dedicated to alternative jet fuels[4]. These include fuel supply agreements (e.g. United Airlines with AltAir), cooperation for technology development (the most recent example being Lufthansa with Gevo for testing of alcohol-to-Jet) or for the establishment of a production chain (e.g. British Airways with Solena), and even equity investment of airlines in fuel companies (Cathay Pacific with Fulcrum BioEnergy).

As noted in the previous edition of this report, a remarkable tendency, besides this cooperation between airlines and fuel producers, is the emergence and multiplication of stakeholders' initiatives and cooperation agreements worldwide. By the end of 2014, 15 new multi-stakeholder

[4] http://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

initiatives and projects had been announced for 2014 (Figure 2). These initiatives have a wide range of purposes, including networking and coordination of national stakeholders for the development of alternative jet fuels, international cooperation, research and development, assessment of potential for production or setting-up production value-chains.

Of particular note for 2014:

– the creation of a stakeholders action group in Japan aiming at developing a roadmap to establish an alternative jet fuel supply chain in Japan by 2020, with the target of having commercial flights using biofuels for the Tokyo Olympic games; and
– the BIOjet Abu Dhabi initiative pursuing the setting of a supply chain in the United Arab Emirates;
– the initiative of Avinor to provide a unique airport incentive at Oslo airport for airlines uploading the biofuel that will be supplied by SkyNRG Nordic, a partnership between SkyNRG and Statoil Fuel & Retail Aviation.

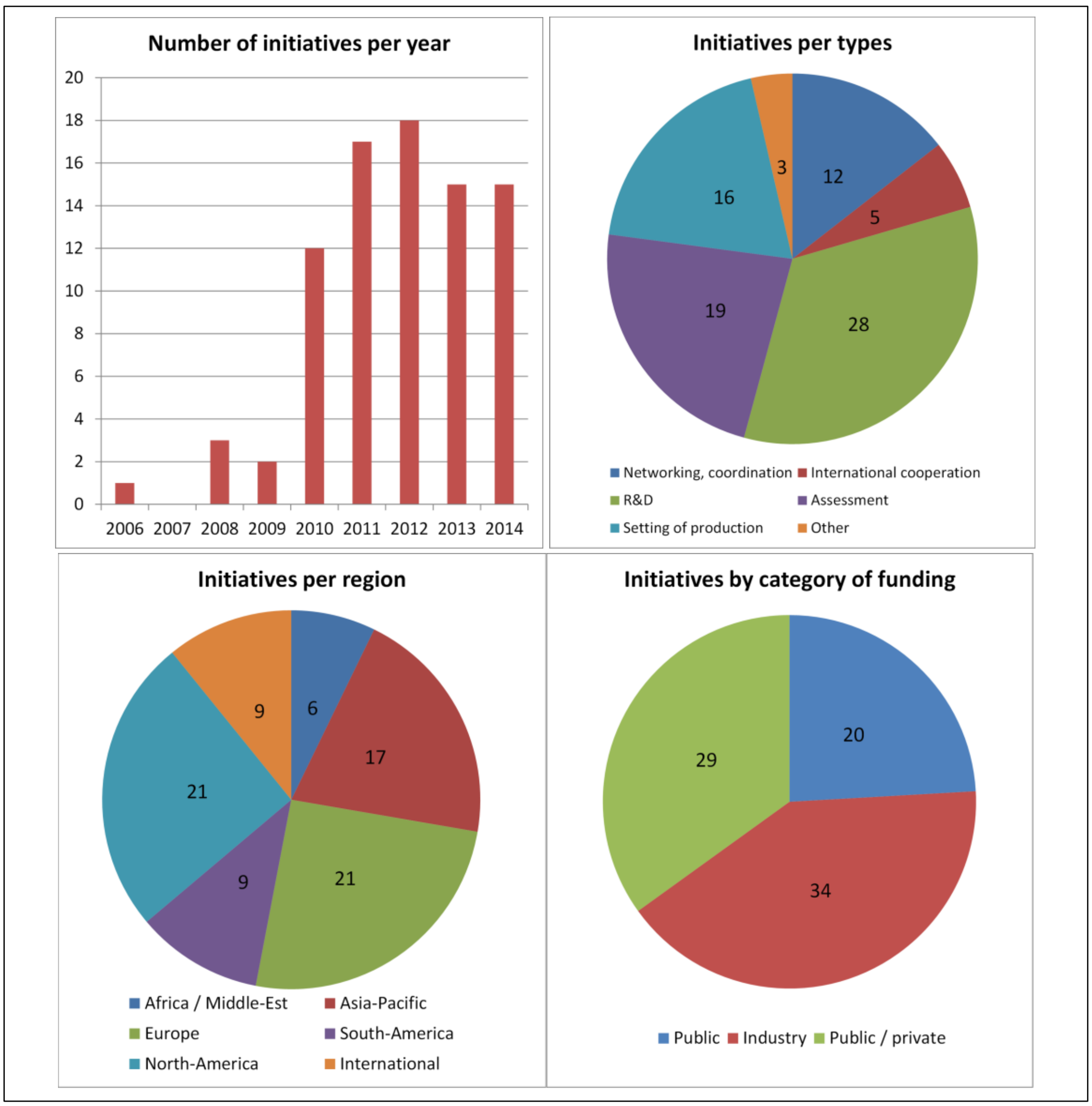

Figure 2: multi-stakeholders initiatives announcements (Synthesis of GFAAF database as per October 2014)

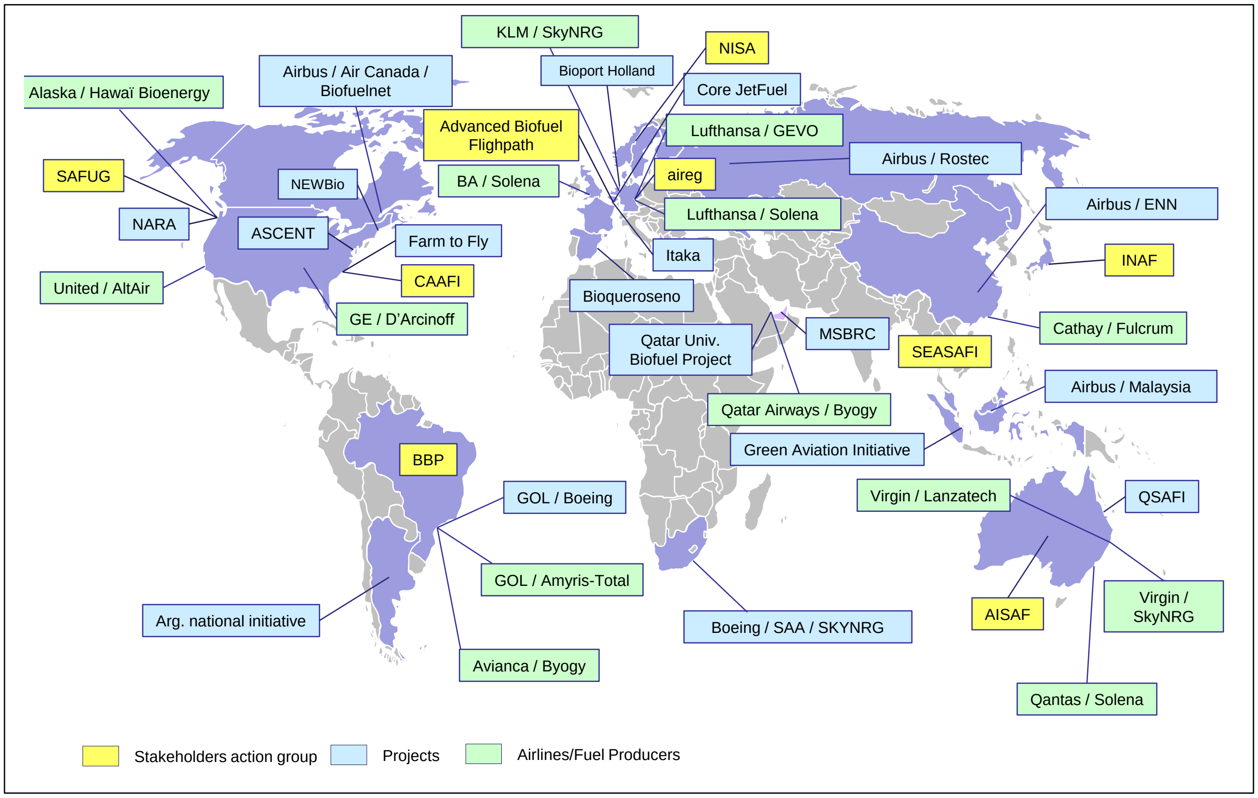

Figure 3: mapping of worldwide initiatives
(based on announcements recorded in GAAF - *Non meant to be exhaustive – mainly initiatives since 2013)*

Major aircraft manufacturers continue to be active in developing regional cooperation and initiatives. A MoU was signed between Airbus and Malaysian stakeholders for the creation of a centre of excellence that will assess the promising pathways for the production of alternative jet fuels in Malaysia. In the context of their cooperation announced in 2013, Boeing and South African Airways have launched their first projects to explore the potential of tobacco as an energy crop and to develop pilot programmes with small holders to produce crops for energy. In addition, Boeing is sponsoring, with the Commercial Aircraft Corporation of China (Comac), a pilot plant to produce jet fuel from gutter oils in China. Boeing also announced the creation of a joint research center with Embraer, which will carry out and coordinate biofuel research with a focus on gaps in the supply chain for sustainable aviation biofuels in Brazil. Boeing also announced the creation of a joint research center with Embraer, which will carry out and coordinate biofuel research with a focus on gaps in the supply chain for sustainable aviation in Brazil.

5 The challenges

In 2014, the price gap with conventional jet fuels remains the first hurdle to commercial deployment of alternative jet fuels. Although fuel costs should decrease with the scale-up of production, in the short term, sustainable alternative fuels are not expected to arrive at par with fossil Jet-A1. Today, airlines are not in the position to deal with the associated premium. In addition, apart from a few exceptions, there are generally no policy in place to support the deployment of such fuels in aviation while incentive and mandates are in place for road transportation. Recent developments in biofuels policy, both in the USA and Europe, where established targets for biofuel penetration were reconsidered, have also reinforced the demand for stable and long term-oriented supporting policies.

An additional challenge is to complete the development of the technologies, which are not all yet mature, and to bring them to market. The experience with the general development of advanced biofuels shows that the demonstration step and the scale-up from the laboratory or demonstration facility to the commercial plant are usually big challenges for start-up companies which often experience critical financial situation during these phases.

In the longer term, pursuing research to increase efficiency and decrease costs for both conversion processes and feedstock is key to bridging the price gap with fossil fuels. Work on feedstock is also key to making sufficient volumes of sustainable feedstock available for long term, large-scale deployment. This includes increasing yields and developing innovative feedstock, such as algae.

Ensuring sustainable deployment is also a core challenge for the aviation industry. This includes not only achieving life cycle GHG emissions reductions, but also compliance with the environmental, societal and economic pillars of sustainability as recognized by ICAO Resolution A38-18 on Aviation and Climate Change. In that domain, it is notable that a number of actors are in the process or have already achieved environmental certification, as is the case for Amyris, LanzaTech or SkyNRG with the RSB[5] standard. However, as pointed out by ICAO SUSTAF experts group in 2013, not all the impacts of deploying alternative fuels can be measured at the individual production-chain level and there is a need for States' policy and monitoring to address sustainability at a more global level, including in decision-making. Due to the global nature of international aviation, sustainability is certainly a topic for which increased harmonization and collaboration between countries would yield benefit to facilitate the deployment of alternative fuels.

A significant challenge today regarding sustainability is the assessment of the indirect impacts of a large scale deployment of alternative fuels. Indirect land use change[6] (ILUC) and impacts on food security have raised a number of discussions over the past year. The assessment and management of these impacts is currently not fully mature and require additional methodological work and increased cooperation.

6 Achievements under ICAO

In September 2013, the 38th Session of the ICAO Assembly reaffirmed the role of ICAO to facilitate and support States and stakeholders in their efforts to deploy alternative fuels in aviation, through fostering exchanges, sharing information and promoting further common work under ICAO.

In particular, ICAO maintains and develops the GFAAF, a web platform through which a unique database on aviation alternative fuels developments is made available to the aviation community. This includes up-to-date news and announcements, as well as descriptions of ongoing initiatives, reference documentation and educational material. The GFAAF is a reference for ICAO Member States and for interested stakeholders who want to be informed on alternative fuels development and was proposed as the unifying tool for the aviation community within the SE4ALL[7] initiative of the United Nations.

ICAO was also tasked by the 38th Assembly to provide a global view on the future use of alternative fuels and on the associated changes in life cycle emissions, in order to assess the progress towards achieving ICAO's Member States' aspirational goal to stabilize aviation emissions at their 2020 level. Assessing fuel life cycle emissions is a particular topic for which increased harmonization amongst aviation stakeholders is important in order to acquire a shared understanding of the potential benefit of alternative fuels. Therefore, the Alternative Fuels Task Force (AFTF) was created within the ICAO technical body on environment, the Committee on

[5] Round table for Sustainable Bioenergy.

[6] ILUC is the land-use change induced in a different geographic area by the deployment of energy crops in one locale which leads to the displacement of previously existing crops. It is not directly observable and is recognized to potentially create GHG emissions.

[7] Sustainable Energy for All

Aviation Environmental Protection (CAEP). CAEP is the committee that assists the ICAO Council in formulating policies and adopting new Standards and recommended practices in the field of environment. It undertakes specific studies with groups of technical experts nominated by States and international organizations. The AFTF is tasked to develop a methodology to assess fuels life cycle emissions and will apply it to quantify the emissions associated to a projection of alternative jet fuels production to 2050. The task force gathers 80 representatives from 16 member States and 8 observer organizations. The results will be delivered to the 39th Session of the ICAO Assembly in 2016, and included in ICAO's environmental trends assessment for international civil aviation.

The 38th Assembly also agreed on the development of a global market-based measure (MBM) for international aviation for decision by the 39th Assembly in 2016. The AFTF was requested to make proposals on an approach to assess lifecycle emissions from alternative fuels for use in the monitoring, reporting and verification system of the MBM.

On 23 September 2014, the UN Secretary-General, Mr. Ban Ki-moon, invited Heads of State and Government, along with business, finance, civil society and local leaders to the UN Climate Summit, held in New York. ICAO was invited to participate jointly with the Air Transport Action Group (ATAG) in the Summit as a prime example of a long-standing, successful partnership with the aviation industry to progress shared environmental objectives. The President of the ICAO Council delivered a joint action statement by ICAO and ATAG on the partnership between governments and the aviation industry on actions to reduce aviation CO_2 emissions, including supporting the development of sustainable alternative fuels for aviation.

7 Conclusion

There is a long way before a new industry emerges and reaches a significant market penetration. Aviation has achieved successful steps in bringing sustainable alternative fuels to technical maturity for use in commercial aircraft and numerous flights have demonstrated that the fuels can be safely and regularly used. Stakeholders all over the world are now pushing for the next step, and initiatives continue to multiply in an increasing number of countries, to set up production or assess the feasibility of such production. The first regular commercial production should take off by 2016, though still at a limited scale.

Economics are a prominent barrier to overcome for initial deployment, which needs to be articulated with environmental goals and policies, as, during the preliminary phase, reducing environmental impacts may not be without cost. Long term perspectives and industry time scales should be included in the equation as aviation has limited expectation to move away from liquid fuel in the short to mid-term. Stabilizing aviation GHG emissions in spite of the impressive forecasted growth of air traffic requires developing alternative fuels and associated technologies from now.

The issue is certainly complex, especially from the point of view of the availability of sustainable resources, when considering the production levels required to achieve the aspirational goals. In that sense, progressing together with a better understanding and shared evaluation of the potential for future emissions reduction is a cornerstone to inform decision-making. The work being undertaken by ICAO, and within CAEP by the Alternative Fuel Task Force is a key contribution to this effort, that will also need an increased cooperation with the other stakeholders from the bioenergy sector.