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WORKING PAPER

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CONFERENCE ON AVIATION AND ALTERNATIVE FUELS

Mexico City, Mexico, 11 to 13 October 2017

Agenda Item 4: Defining the ICAO vision on aviation alternative fuels and future objectives

TRENDS AND SCENARIOS ON ALTERNATIVE FUELS

(Presented by the ICAO Secretariat)

SUMMARY

This paper presents the environmental trends endorsed at the 39th Session of the ICAO Assembly, including further details on the role of sustainable aviation fuels (SAFs), in order to support the discussion on the ICAO Vision on Aviation Alternative Fuels.

Action by the conference is in paragraph 4.

1. INTRODUCTION

1.1 Assembly Resolution A38-17 requested the ICAO Council to assess regularly the present and future impact of aircraft engine emissions. As a response, updated environmental trends were presented at the 39th Session of the Assembly[1], and were endorsed by the ICAO Assembly as the basis for decision-making on environmental matters.

1.2 The trends include the possible contribution of the four elements of the basket of measures to address CO_2 emissions towards the objective of a carbon-neutral growth for international aviation from 2020. These four elements are: technology improvements, air traffic management (ATM) and infrastructure use improvements, sustainable aviation fuels (SAFs), and a global market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The specific SAF deployment scenarios were evaluated by the ICAO Committee on Aviation Environmental Protection (CAEP). Both the environmental trends and SAFs scenarios are fully documented in ICAO Doc 10069, *Report of the Tenth Meeting of the Committee on Aviation Environmental Protection*. The amount of SAF and the associated greenhouse gas (GHG) emissions reductions were allocated proportionally between international and domestic use based on the respective projected fuel demand. This paper summarizes the SAF scenarios evaluated for global SAF production capacity, with a focus on international aviation.

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[1] https://www.icao.int/Meetings/a39/Documents/WP/wp_055_en.pdf

2. TRENDS AND SCENARIOS ON FUEL BURN AND CO_2 EMISSIONS FROM INTERNATIONAL AVIATION

2.1 Figure 1 provides the trends on conventional aviation fuel (CAF) consumption from international aviation up to 2050, and the associated CO_2 emissions, including specific scenarios with the contribution of the basket of measures elements.

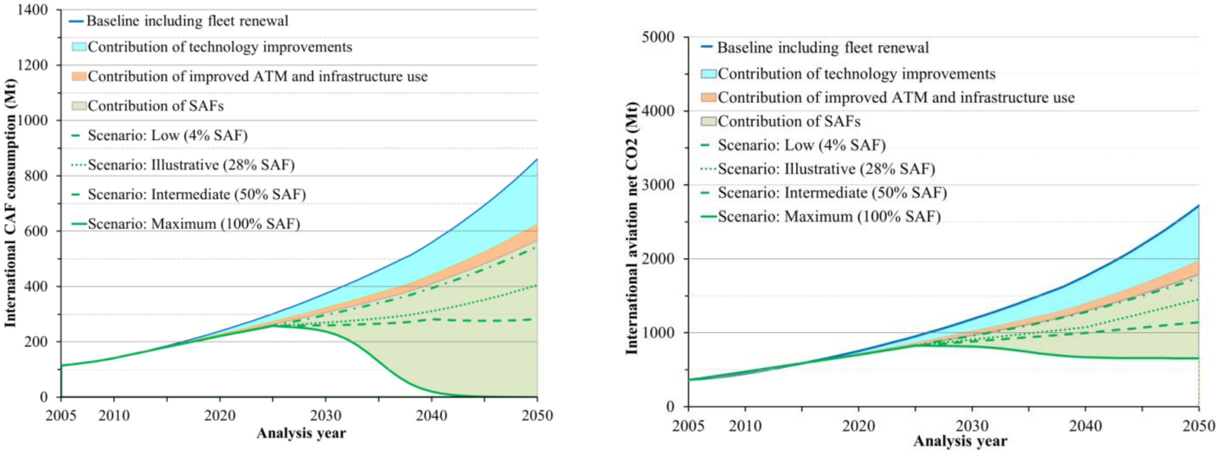

Figure 1. Expected fuel consumption and aircraft CO_2 emissions from international aviation, reflecting aircraft technology, ATM and infrastructure use improvements, and possible substitution with SAFs from 2005 to 2050.

2.2 Figure 1 shows that international aviation consumed approximately 142 million metric tons (Mt) of CAF in 2010. By 2050, CAF consumption is estimated to reach 860 Mt, considering only the demand for air travel and natural fleet renewal. Including the potential contribution of technology and ATM and infrastructure use improvements, this estimated fuel consumption in 2050 might decrease to 570 Mt, which would represent a 71% share of the expected global, i.e. international plus domestic, aviation fuel burn. The following analysis is based on this expected international aviation fuel demand of 570 Mt in 2050.

2.3 Significant uncertainties exist in predicting the contribution of SAFs in the long term. Therefore, CAEP evaluated 120 SAF deployment scenarios for 2050. The global availability of resources, economic conditions, financial investments, and policy decisions required to reach the assessed levels of global SAF production and associated CO_2 emissions reductions are calculated for each scenario.

2.4 Based on the scenarios evaluated by CAEP, it is possible that up to 100% of international aviation's CAF demand could be met using SAFs in 2050. This possibility is illustrated by the "Maximum" scenario shown in Figure 1. However, complete replacement of CAF with SAF would require approximately 170 new biorefineries to be built annually from 2020 to 2050, at an approximate cost of $15B-$60B/year if growth occurred linearly. If investment and growth began slowly and ramped up over time, over 500 new biorefineries would have to be constructed every year in the late 2040s, and almost 1000 new biorefineries would be required in 2050, requiring capital investments of $1B-$3B/year in 2025 and $80B-$340B/year in 2050.

2.5 As a comparison, recent-year global biofuel production increased by about 70 biorefineries per year, brought about by production or consumption incentives being put in place in different world-regions. However, the development of biorefineries and the associated cost only address a single aspect of the SAF supply chain. Similar significant development of the feedstock production and transportation logistics aspects of the supply chain would be required. It is not clear from the CAEP analysis which of these aspects might limit the adoption of SAFs to 2050.

2.6 Also as a comparison, reported global upstream investment in Oil and Gas among companies representing ~39% of non-OPEC production averaged over $600 billion per year from 2010 to -2013[2]. Although this number represents investments in the complete Oil and Gas supply chain for all industry sectors, and not only the construction of refineries for aviation fuel production, it shows that the required capital estimated for the construction of biorefineries in the SAF deployment scenarios is well within the range of current investments of the energy industry.

2.7 The "Low" substitution scenario achieving 4% of international aviation's CAF demand would require a SAF production of about 20 Mt/year in 2050. In addition to the Maximum and Low scenario, Figures 1 presents an "Illustrative" scenario evaluated by CAEP, where 28% of international aviation's CAF consumption are replaced by SAF. Further, an "Intermediate" scenario with 50% substitution is provided for information. These scenarios assume improvements in fuel production efficiencies and high availability of bioenergy feedstocks, production of which is significantly incentivized by favourable markets or policy mechanisms.

2.8 The estimated CO_2 emissions shown in Figure 1 for the SAF replacement scenarios consider life cycle assessment (LCA) emission factor specific to the SAF types that contribute to fuel volumes in each CAEP scenario. Life cycle emissions from direct land use change are also taken into account.

2.9 Based on these assumptions, if enough SAFs could be produced in 2050 to completely replace CAFs (Maximum scenario) net CO_2 emissions could be reduced by about 63%. Achieving this level of emissions reduction would require the realization of the highest assumed increases in agricultural productivity, highest availability of land for feedstock cultivation, highest residue removal rates, highest conversion efficiency improvements, largest reductions in the GHG emissions of utilities, as well as a strong market or policy emphasis on bioenergy in general, and SAFs in particular. This implies that a large share of the globally available bioenergy resource would be devoted to producing aviation fuel, as opposed to other uses.

3. SCALING UP PRODUCTION TO 2050

3.1 CAEP did not specify a function for connecting the 2020 and 2050 SAF production estimates. However, the growth of a new industry, such as that for SAFs, often follows an "S-shaped" trajectory. It is not clear when investment, and therefore, growth of production capacity of the industry, will ramp up. Ramp up to SAF production in 2050 is anticipated to be somewhere between linear and exponential growth i.e., the lower end of the S-curve with the upper end of the S-curve occurring at some later date, e.g., around 2100. Therefore, the values provided in the Appendix for 2040 and 2050 for the SAF scenarios should be considered illustrative only.

3.2 For the short-term 2025 values, all scenarios are presented with a 5 Mt/year production of SAF for international aviation. As a reference, current off-take agreements sum up to about 0.9 Mt/year (see CAAF/2-WP/10). Further, the policy requirements in the CAEP analysis did not take into account possible disruptive policies similar to the recently announced decisions by Norway, India, France[3], and U.K.[4] aiming to end the sale of gasoline and diesel cars by 2040 or earlier. This kind of policy could direct

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[2] https://www.eia.gov/todayinenergy/detail.php?id=16011

[3] https://www.nytimes.com/2017/07/06/business/energy-environment/france-cars-ban-gas-diesel.html

[4] https://www.nytimes.com/2017/07/26/world/europe/uk-diesel-petrol-emissions.html

large quantities of HEFA-diesel ("green diesel") designated for road transport toward aviation, provided the expected ASTM certification. The current global capacity of HEFA-diesel facilities reaches about 4.3 bln liters (3.45 Mt/year)[5].

3.3 In the trends assessment, the calculations of number of biorefineries and capital investment needed assumes that this growth occurs through building new, so-called "greenfield", developments. However, as outlined in CAAF/2-WP/08 utilizing "brownfield" facilities, i.e. existing infrastructure that is un- or under-used might allow for considerably lower capital requirements. Furthermore, as ground transport electrifies, demands for petroleum-derived ground transport fuels will decrease and existing petroleum refining capacity will become available to be re-tooled to process bio-derived input. Such co-processing or refinery integration of future underutilized refining capacity may provide an opportunity to scale-up SAF production with much lower capital investment requirements. However, there could also be challenges presented if the existing petroleum refineries are located far from the SAF feedstock production.

3.4 It is also highlighted that the analysis only considered technologies that are proven at the lab or pilot scale, and may be close to commercial development. However, the introduction of a disruptive fuel production technology could also dramatically increase the potential for SAFs to reduce aviation CO_2 emissions. For example, it is possible that an entirely new technology such as Power-to-Liquids (PtL) could emerge that would increase the potential for SAF to reduce aviation CO_2 emissions.

3.5 With these caveats in mind, possible facilitation requirements for four SAF deployment scenarios are presented in the Appendix, as well as some assumptions used, in order to provide some information to the Conference on possible investment, technology, and policy initiatives to achieve the described scenarios for SAF deployment.

4. ACTION BY THE CAAF/2

4.1 The CAAF/2 is invited to:

a) consider the information on possible investment, technology, and policy initiatives to achieve the four described scenarios for SAF deployment when agreeing to the ICAO Vision on alternative fuels;

b) agree that the 5 Mt/year production of SAF for international aviation is a reasonable assumption for the 2025 short-term deployment of SAF; and

c) consider the four deployment scenarios for mid- and long term (2040 and 2050) when agreeing to the ICAO Vision on Aviation and Alternative Fuels.

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[5] IRENA (2017), *Biofuels for aviation: Technology brief*, International Renewable Energy Agency, Abu Dhabi.

APPENDIX

POSSIBLE FACILITATION CONDITIONS FOR FOUR SAF DEPLOYMENT SCENARIOS

Assumptions:

- average production facility size of 5000 barrels per day (bpd) with a 50% SAF output share and 365 production days per year; and
- annual capital investment lower bound of $175 million U.S. Dollars per facility, corresponding to a petroleum refinery[6], and an upper bound of $700 million U.S. Dollars per facility based on techno-economic studies of biorefineries in literature.

Analysis year	Key indicators on 4% SAF replacement (Scenario: Low)				Potential facilitation conditions			
	International aviation CAF consumption (Mt/year)	International aviation SAF availability (Mt/year)	Substitution of CAF	CO$_2$ reduction from SAF use	Total number of biorefineries	Cumulative CapEx investment in biorefineries (in billion 2015 USD)	Technology requirements	Policy requirements
2025	270	5	2.0%	0.9%	45	$5 to $15		
2040	400	11	2.8%	1.3%	100	$10 to $35		
2050	570	20	4.0%	2.0%	200	$20 to $70		

Analysis year	Key indicators on 28% SAF replacement (Scenario: Illustrative)				Potential facilitation conditions			
	International aviation CAF consumption (Mt/year)	International aviation SAF availability (Mt/year)	Substitution of CAF	CO$_2$ reduction from SAF use	Total number of biorefineries	Cumulative CapEx investment in biorefineries (in billion 2015 USD)	Technology requirements	Policy requirements
2025	270	5	2.0%	0.9%	45	$5 to $15	- Improvements in fuel production efficiencies	- Bioenergy production incentivized by policies
2040	400	89	22%	15%	800	$70 to $280		- Bioenergy resource allocation to all end-usages in proportion to share in final energy demands
2050	570	160	28%	19%	1400	$100 to $500		

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[6] Gary, J.H., Handwerk, G.E. & Kaiser, M.J. 2007. *Petroleum Refining: Technology and Economics*, 5th edn. (Taylor & Francis, Basel, Switzerland).

Analysis year	**Key indicators on 50% SAF replacement (Scenario: Intermediate)**				**Potential facilitation conditions**			
	International aviation CAF consumption (Mt/year)	**International aviation SAF availability (Mt/year)**	**Substitution of CAF**	**CO_2 reduction from SAF use**	**Total number of biorefineries**	**Cumulative CapEx investment in biorefineries (in billion 2015 USD)**	**Technology requirements**	**Policy requirements**
2025	270	5	2.0%	0.9%	45	$5 to $15	- Improvements in fuel production efficiencies	- Bioenergy production strongly incentivized by policies
2040	400	128	32%	12%	1100	$100 to $400	- Increased agricultural yields and arable land availability	- Bioenergy resource allocation to all end-uses in proportion to share of final energy demands
2050	570	285	50%	33%	2400	$200 to $850	- Significant agricultural and forestry residue removal	

Analysis year	**Key indicators on 100% SAF replacement (Scenario: Maximum)**				**Potential facilitation conditions**			
	International aviation CAF consumption (Mt/year)	**International aviation SAF availability (Mt/year)**	**Substitution of CAF**	**CO_2 reduction from SAF use**	**Total number of biorefineries**	**Cumulative CapEx investment in biorefineries (in billion 2015 USD)**	**Technology requirements**	**Policy requirements**
2025	270	5	2.0%	0.9%	45	$5 to $15	- Highest agricultural yield growth rates and highest land availability	- Bioenergy production strongly incentivized by policies
2040	400	342	86%	49%	2900	$250 to $1000	- Highest agricultural and forestry residue removal rates	- Alternative jet fuel production prioritized over all other uses of bioenergy
2050	570	>570	100%	63%	5200	$450 to $1800	- Improvements in fuel production efficiencies	

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