ICAO SHORT-TERM PROJECTIONS ON SAF PRODUCTION

SUMMARY

This document outlines the work conducted on SAF production projections out to the year 2030. Section 2 discusses the methodology. Section 3 shows and discusses the results.

1. INTRODUCTION

1.1 During its CAEP/12 cycle (2019-2022), the ICAO CAEP developed SAF production scenarios in the short-term (out to 2025), and in the long term (2035 and 2050), in support of the assessment on the feasibility of a long-term aspirational goal for international aviation (LTAG). These short-term scenarios have been updated and extended to 2030, in support of the upcoming Conference on Aviation Alternative Fuels (CAAF/3).

1.2 This document outlines the approach taken to develop these short-term SAF production scenarios, and the results.

1.3 All figures and tables are shown in the Appendix of this WP.

2. METHOD

2.1 The analysis considered a set of four production scenarios (low, moderate, high, and high+). These scenarios differ with regard to the type of companies included, the maturity of the production plans, product slate assumptions, and assumptions with regard to the success rate of announced production plans. The different scenarios are representative of more optimistic or pessimistic developments of the SAF market in the short-term.

2.2 The short-term projections rely on the ICAO Fuels Task Group (FTG) short-term projections database. The database was initially developed during the CAEP/10 cycle (2016-2019) and has been maintained and updated since then. The database includes data and references from publicly-available production announcements from companies planning to produce alternative fuels by 2030. In late 2022 to early 2023, a comprehensive update of the database was conducted in which the existing entries were checked for relevance and accuracy, and changed or removed, where needed and in which additional entries were added. Moreover, all entries were given a maturity definition based on the criteria explained further below. The short-term database only tallies the potential production of sustainable aviation fuels (SAF), not lower carbon aviation fuels (LCAF).

2.3 Four production scenarios have been defined (low, moderate, high, and high+) that differ with regard to the type of companies included, the maturity of the production plans, product slate assumptions, and assumptions with regard to the success rate of announced production plans. Table 1 shows the scenario definitions in detail, and Table 2 outlines the maturity definitions employed.

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2.4 While not explicitly modelled, the gradient of parameters chosen in the scenarios with regard to success rates and product slate assumptions is reflective of different levels of policy-support for SAF deployment out to the year 2030 (Table 3).

2.4.1 In the "low" scenario, only companies that have a dedicated SAF production target (code 1) and that are either already producing at commercial scale (maturity A) or have a commercial plant for an ASTM approved process under construction (maturity B) are included. A relatively low success rate of 25% (maturity A) and 10% (maturity B) is assumed, and product slates that contain relatively low amounts of jet fuel. This can be interpreted as a scenario without any SAF policy support.

2.4.2 For the "moderate" and "high scenarios", companies without specific SAF production targets and lower level of maturity are included at sequentially higher success rates and with higher jet fuel production slate share assumptions. The "moderate" scenario, assumes success rates of 50% (maturity A), 25% (maturity B), and 10% (maturity C) and in the high scenario, success rate assumptions of 75% (maturity A) and 50% (maturity B), and 25% (maturity C) are used. With regard to the type of facilities considered, both scenarios include facilities with a specific quantified SAF production target (code 1), facilities whose operators have announced that they plan to produce SAF but do not mention SAF production targets (code 2), as well as facilities that use a technology that can be used for SAF production, but whose operators have not announced that they will actually produce SAF (code 3). However, as mentioned above, in the high scenario, a higher success rate of these different facilities is assumed than in the moderate scenario. Overall, these assumptions are meant to imply that the moderate scenario is in line with a policy landscape in which SAF is receiving some policy support, but not at a level equivalent to the support received for road transportation biofuels, whereas the high scenario can be interpreted as a scenario where there is at least a level playing field between road transportation biofuel and SAF incentives.

2.4.3 The "high+" scenario is derived from the scenario definition for the "high" scenario. The difference between high and high+ scenarios lies in assumptions for the share of SAF in the total product slate of facilities. The high+ scenario assumes that SAF is produced at relatively high shares ("High facility jet fuel ratio") for all conversion methods, implying a change in the economics of these facilities by means of policy-support for SAF that makes the production of SAF economically superior compared to the production of road transportation biofuels. This is in contrast to the high scenario which assumes a status-quo product slate for existing facilities or facilities with an announced SAF production target (called 'actual' facility jet fuel ratio in the scenario definitions) and a low facility jet fuel ratio for code 3 (e.g. renewable diesel) facilities. As such, the high+ scenario is indicative of a possible policy policy-landscape in which SAF production is prioritized over road transportation biofuel production.

2.5 A forecasting approach was used to estimate the potential SAF production for years 2028, 2029, and 2030 due to the scarcity of additional announcements for those years. Table 4 below provides an overview on the model types and their suitability as a function of the developmental stage of a technology/market under consideration. Market diffusion models estimate the degree of entry of a new product or technology into the market over time assuming it as an evolutionary process of replacement of an old technology covering the same needs. This type of model has been widely used in the literature before for forecasting future energy market developments (see Table 5). This market diffusion approach was used to project volumes from 2028 to 2030 (more specifically, the Sharif Kabir 2 model described in Table 6).

3. RESULTS

3.1 The updated database includes 108 distinct facilities, out of which 25 with a maturity level of A, 19 with a level of B, and 27 with a maturity level of C. 34 facilities received a maturity level of D and were, therefore, not used in the analysis.

3.2 It is noted that the database contains relatively few additional entries for plants starting operation in the year 2028 and beyond compared to previous years. More precisely, while for a production start in 2027 there have been 9 additional production facilities announced by early 2023, for the year 2028 and 2029 the number of additional facilities is just one, each. However, this does not necessarily mean that production growth will flatten off in the later years of this decade. The relatively small growth in volumes in the scenario results is rather, we believe, a consequence of the fact that given permit and construction times, companies that want to produce in 2028 (or beyond) may not necessarily have disclosed their plans to do so by early 2023, especially for relative mature technologies such as HEFA.

3.3 Table 7 shows the updated results for the four scenarios per year out to 2030 using the short-term production database without any adjustments made for the low number of additional announcements for later years of the decade.

3.4. When analyzing the results by region of production, it is found that across all scenarios more than 58% percent of fuel is produced in North America, with estimated production shares in Europe and Asia ranging from 16% to 27% (Europe) and 2% to 4% (Asia), respectively (see Figure 1).

3.5. Table 8 indicates the contribution that facilities with different degree of SAF-focus have on the SAF volumes in each scenario. The results from in this table shows that significant volume shares come from facilities that currently plan to produce SAF.

3.6 Moving on to the results that include the SAF diffusion modeling from 2028 to 2030, Table 9 shows the projected SAF volumes out to 2030 from the Sharif-Kabir 2 diffusion model, by scenario, in kt. For the four scenarios (low, moderate, high, and high+ scenario), SAF volumes in the year 2030 range from 3kt in the low scenario, to 17kt in the high+ scenario.

3.7 The results were compared with the LTAG Integrated scenario definitions. IS1 represents some incentives for SAF/LCAF production to level the playing field with ground transportation fuels and most closely aligns with the "Moderate scenario". The IS2 scenario provides increased policy enablers for technology evolution to enable more widespread use of waste gases for SAF production as well as electrification of ground vehicles, which further increases SAF/LCAF availability for aviation. This scenario is modeled using the "High" scenario. Finally, IS3 represents economy-wide deep decarbonization and large incentives for low GHG fuels for aviation. This final scenario was captured by the "High+" scenario under the current modeling work. Table 10 maps the SAF volumes from the short-term projections to the LTAG scenarios.

3.8 These projected SAF volumes will displace conventional, petroleum-derived jet fuel. In order to calculate the replacement rate of conventional jet fuel through SAF, projections for future-year total jet fuel consumption are required. The replacement analysis conducted here, therefore, relies on the LTAG fuel burn forecasts for the medium traffic scenario for IS1, IS2 and IS3 as published in the "ICAO LTAG Data to support state analysis". For the three LTAG scenarios (IS1, IS2, and IS3), replacement ratios in the year 2030 range from 2.54% in the IS1 scenario, to 5.01% in the IS3 scenario (see Table 11).

APPENDIX A:

TABLES, FIGURES AND REFERENCES

Table 1: Definitions of short-term scenarios

Scenario	Code	Maturity	Facility Jet Fuel Ratio	Overall Success Rate for A Maturity	Overall Success Rate for B Maturity	Overall Success Rate for C Maturity
Low	1	A, B	Actual or low %	25%	10%	0%
Moderate	1-2	A, B, C	Actual or low %	50%	25%	10%
High	1-3	A, B, C	Actual or high% for codes 1-2, Actual or low% for code 3	75%	50%	25%
High+	1-3	A, B, C	High%	75%	50%	25%

Note: Code 1: Company has SAF production plans, Code 2: SAF production mentioned but no specific plans & process relevant to SAF, Code 3: process relevant to SAF, but no SAF production plans mentioned, Maturity: See Table 2 below.

Table 2: Maturity definitions

Maturity level		**Criteria**	**Guidelines**
A (VERY HIGH)		Company is already producing and selling renewable fuel that has ASTM approval	
B (HIGH)	or	Company has a plant under construction	Physical construction has started
		+ Company has already run a demo or pilot	Demo or pilot depends on the technology maturity (e.g. for HEFA a newcomer can build a plant)
			A demo should have been done by one of the partners
		+ Credibility of the partnership (e.g. financial backing)	
	and	Fuel is already certified for use by aviation	
C (moderate)		The company has not yet started to produce but has financial partners, off-take agreement and/or some government support for technology scale up to commercial demo	
	and	The fuel readiness level is greater or equal to 6	FRL >=6 is equivalent to saying under evaluation for approval
	and	Company has made some kind of communication and/or public information can be found on on-going activities over the last 12-18 months.	
D (low)		All other situations	

Table 3: Policy-mapping of scenarios

Scenario	**Implicit SAF Policy landscape**
Low	No policy support for SAF
Moderate	Some level of policy support for SAF, but lower than for road transportation biofuels
High	Level-playing field between SAF and road transportation biofuels
High+	SAF-emphasis in policies

Table 4: Suitability of different prediction models for novel technologies, by developmental stage (Packey, 1993), ‘x’ denotes that a prediction model is suited in this developmental stage

Prediction model	**Description**	**Developmental stage**			
		Conceptualization	**Introduction**	**Increased acceptance**	**Mature**
Subjective estimation	This method can be as simple as the sole entrepreneur’s intuitive decision to market a product or as complex as a formal decision-making process such as the Delphi method.	x			
Historical analogy	Comparison of an existing product’s trend to a new product or technology assuming that their market penetration paths are the same.	x	x		
Market survey	Information from decision makers regarding their preferences, planned behavior can be used to define future businesses plans.	x	x		
Cost models	Estimation of the market penetration of a product based on cost-related aspects.		x	x	
Diffusion models	Estimation of the degree of entry of a new product or technology into the market assuming it as an evolutionary process of replacement of an old technology covering the same needs.		x	x	x
Time-series models	Derivation of a technology’s future development from its historical trend.			x	x
Econometrics	Use of historical data to estimate a functional relationship between the market penetration of a product and a set of independent variables (production costs, nominal income, gross domestic product, etc.).			x	x

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Table 5: Examples of studies that use diffusion models to forecast energy markets

Reference	Remarks
Harris et al., (2018)	Study forecasts the production and consumption of primary energy in the United States to 2040 based on historical data from 1949 to 2015.
Morrison et al., (2016) & Morrison et al., (2014)	These studies forecast future volumes of “leapfrog” biofuels out to 2030.
Davidsson et al., (2014)	Study forecasts the cumulative installed capacity of wind power to 2050.
Daim et al., (2012)	Study forecasts the share of different sources of renewable energy in the US energy production.
Höök et al., (2011)	Study evaluates different diffusion models to forecast the production/consumption of energy considering historical data.
Chen et al., (2011)	Study forecasts the development of the hydrogen energy and fuel cell technologies.
Changliang and Zhanfeng, (2009)	Study forecasts the installed capacity of wind power in China to 2030.
Siemek et al., (2003)	Study estimates the natural-gas consumption in Poland.
Ang and Ng, (1992)	Study reviews the use of different diffusion models in energy studies from 1969 to 1988.

Table 6: Potential diffusion models to forecast the pattern of the market penetration of SAF production

Model	**Description**	**Functional form**	**Variables**[b]
Models dependent on a exogenous asymptote[a]			
Logistic	Genuine S-shaped curve, symmetric, and with a point of inflection at $0.5S$	$y(t) = \frac{S}{1 + a \cdot b^{(-c \cdot t)}}$	• $y(t)$, demand for SAF by year t • S, exogenous asymptote • a, b, c, constants
Gompertz	Simple mathematical function that depicts an asymmetric S-shaped curve.	$y(t) = S \cdot e^{-a \cdot e^{-b \cdot t}}$	
Blackman	This model assumes that the environment of the diffusion is unchanged.	$y(t) = S \cdot \left[\frac{e^{a+b \cdot t}}{1 + e^{a+b \cdot t}}\right]$	
Sharif-Kabir	Known as a flexible technology replacement model that involves the delay of the adoption compared to optimistic approaches.	$ln\left(\frac{y}{S - y}\right) + \frac{a \cdot S}{S - y} = b + c \cdot t$	
Model with an endogenous asymptote			
Logistic model 2	Variation of the original logistic model to include the initial demand for SAF.	$y(t) = \frac{a \cdot y_0}{b \cdot y_0 + (a - b \cdot y_0) \cdot e^{-a \cdot t}}$	• $y(t)$, demand for SAF by year t • y_0, initial demand for SAF • a, b, c, constants • S^*, endogenous asymptote
Gompertz 2	Variation of the Gompertz model to include the initial demand for SAF.	$y(t) = e^{\frac{e^{-b \cdot t} \cdot [b \cdot ln(y_0) - a] + a}{b}}$	
Sharif-Kabir 2	Variation of the Sharif-Kabir model but treating S^* as an unknown parameter.	$ln\left(\frac{y}{S^* - y}\right) + \frac{a \cdot S^*}{S^* - y} = b + c \cdot t$	

Notes: [a] Models in this table can be classified as: (1) models dependent on an exogenous asymptote, and (2) models with an endogenous asymptote. [b] Parameters are estimated by means of curve fitting.

Table 7: Annual global (domestic and international) SAF production by scenario (2022-2030), without adjustments made for low announcements in 2028, 2029, 2030

Year	**Low**	**Moderate**	**High**	**High+**
2022	273	273	273	273
2023	468	820	1,507	2,474
2024	664	1,367	1,728	3,050
2025	859	1,914	4,321	5,712
2026	940	2,160	5,071	6,920
2027	955	2,539	6,019	7,868
2028*	959	2,544	6,027	7,876
2029*	995	2,548	6,035	7,876
2030*	1,073	2,777	6,381	8,231

Note: * Years 2028 – 2030 data from short-term analysis as shown here will not be used in final results as they potentially underestimate SAF volumes in that year. Instead, data generated through the market diffusion approach will be used. For the low scenario, raw values for the years 2023 and 2024 were lower than actual market production in 2022. Instead of these raw values, a linear growth from 2022 to 2025 was assumed.

Figure 1: Production by world region (in %) by scenario, year 2030

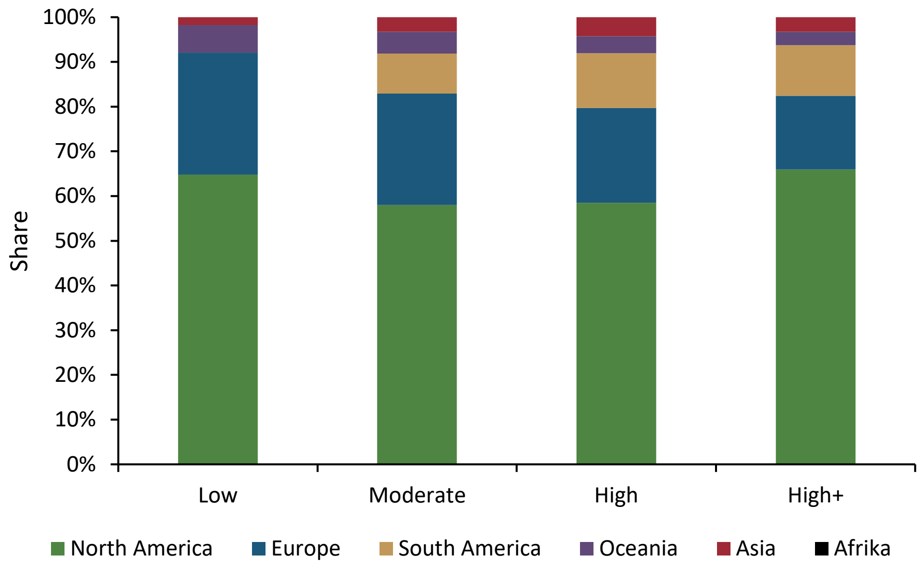

Table 8: Split of SAF volumes by degree of code of facility, in 2030

Code	Low	Moderate	High	High+
1	100%	95%	75%	61%
2	0%	5%	14%	11%
3	0%	0%	11%	28%

Note: Code 1: Company has SAF production plans, Code 2: SAF production mentioned but no specific plans & process relevant to SAF, Code 3: process relevant to SAF, but no SAF production plans mentioned.

Table 9: SAF production volumes in kt (global values), by scenario, 2022-2030, using the market diffusion approach for the years 2028 to 2030

Year	Low	Moderate	High	High+
2022	273	273	273	273
2023	468	820	1,507	2,474
2024	664	1,367	1,728	3,050
2025	859	1,914	4,321	5,712
2026	940	2,160	5,071	6,920
2027	955	2,539	6,019	7,868
2028	965	2,671	6,488	8,468
2029	1,721	4,520	9,454	12,011
2030	3,059	7,608	13,713	16,973

Notes; For the low scenario, raw values for the years 2023 and 2024 were lower than actual market production in 2022. Instead of these raw values, a linear growth from 2022 to 2025 was assumed.

Table 10. SAF production volumes in kt (global values), by LTAG and FTG scenario, 2022-2030

Year	***LTAG scenarios:***	***F1 Scenario***	***F2 scenario***	***F3 scenario***
	FTG scenarios:	**Moderate**	**High**	**High+**
2022		273	273	273
2023		820	1,507	2,474
2024		1,367	1,728	3,050
2025		1,914	4,321	5,712
2026		2,160	5,071	6,920
2027		2,539	6,019	7,868
2028		2,671	6,488	8,468
2029		4,520	9,454	12,011
2030		7,608	13,713	16,973

Table 11: Replacement ratio (global SAF production / global projected jet fuel demand), by scenario, 2022-2030

Year	**F1**	**F2**	**F3**
2022	0.15%	0.13%	0.13%
2023	0.41%	0.59%	0.97%
2024	0.62%	0.59%	1.04%
2025	0.82%	1.43%	1.90%
2026	0.87%	1.64%	2.24%
2027	0.98%	1.89%	2.49%
2028	0.98%	1.98%	2.62%
2029	1.58%	2.81%	3.63%
2030	2.54%	3.98%	5.01%

Notes: Total jet fuel demand for 2022-2030 is taken from the LTAG fuel burn forecast as published in the "ICAO LTAG Data to support state analysis" for the medium traffic growth scenarios.

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