Summary of fuels-related information from the ICAO Long-term Aspirational goal (LTAG) Analyses

Introduction

Extensive technical analyses supported the ICAO decision on a Long-term Aspirational goal for international aviation. These analyses are contained in various documents that are available on the ICAO public website (LTAG report and its Appendixes, LTAG data to States spreadsheet, ICAO Environmental Report 2022).

This document summarizes the main fuel-related information contained in these analyses, directing to additional references that provide further details. The fuel-related information from the LTAG report is divided into 8 topics below:

(5 pages)

Summary of fuels-related information from the ICAO LTAG Analysis

1. LTAG Fuels classification

Three main classes of fuels were considered on the LTAG analysis:

1) LTAG Sustainable Aviation Fuels (LTAG-SAF), which comprise:
    a. **biomass-based fuels** (vegetable oil crops, lignocellulosic energy crops, starchy energy crops, sugary energy crops)
    b. waste-based fuels
        i. solid wastes - crop residues, Municipal Solid Waste, Forestry Residues.
        ii. liquid wastes - Waste and by-product Fats Oils and Greases (FOGs).
        iii. gaseous wastes - waste CO2 from: ethanol production, ammonia production, iron and steel production, and cement production.
    c. **atmospheric CO2**-based fuels.
2) LTAG Lower Carbon Aviation Fuels (LTAG-LCAF) - **petroleum-based fuels** that achieve a well-to-wake carbon intensity of <80.1 gCO2e/MJ with the use of greenhouse gas (GHG) mitigation technologies and best practices
3) Non-drop-in fuels, comprising **cryogenic Hydrogen (LH2), Electricity and Liquefied gas aviation fuels (ASKT)**.

References for further details –
LTAG Report – Appendix M5, page 9-12 – general description of the classifications
LTAG Report, Attachment A to Appendix M5 and Attachment B to Appendix M5– details on LTAG-SAF (biomass, solid waste, and liquid waste).

2. LTAG Fuel Scenarios

Three deployment scenarios that reflect levels of emissions reductions representative of varying levels of readiness and attainability, as detailed in the table below.

	MDG/FESG Baseline	LTAG-TG Scenarios		
	Integrated Scenario 0 (IS0)	Integrated Scenario 1 (IS1)	Integrated Scenario 2 (IS2)	Integrated Scenario 3 (IS3)
General Description	Projection of current technologies available in base year (through fleet renewal). No additional improvements from tech, ops and fuels. No systemic change – e.g. infrastructure changes to accommodate growth only.	**Low / nominal** Current (c. 2021) expectation of future available tech, ops efficiencies, fuel availability, costs. Includes expected policy enablers for technology, ops and fuels. **Low systemic change** – no ***substantial*** infrastructure changes.	**Increased / further** Approx mid-point. Faster rollout of future tech, increased ops efficiencies and higher fuel availability. Assumes increased policy enablers for technology, ops and fuels. **Increased systemic change** – limited infrastructure changes.	**Aggressive / speculative** Maximum possible effort: tech rollout, ops efficiencies, fuel availability, costs. Assumes max policy enablers for tech, ops and fuels. **High, internationally aligned systemic change** e.g. significant and broad change to airport and energy infrastructure.
Fuels (F)	No emissions reductions from low-carbon fuels (e.g. SAF).	**Low GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)**	**Mid GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)**	**High GHG reduction from Fuels (LTAG-SAF, LTAG-LCAF and non-drop-in fuels)**
		ASTM Intl develop methods to approve use of alternative jet fuels at blend levels above 50%.	ASTM Intl develop methods to approve use of 100% Synthesized Jet Fuel in existing aircraft and engines without any modification. This enables use of 100% SAF in all existing and new aircraft.	
		Ground transportation and aviation have level playing field with respect to alternative fuel use.	Electrification of ground transportation leads to increased availability of SAF as ground transport uses more electricity and less renewable fuels.	Economy-wide deep decarbonisation. Extensive electrification of ground transportation and widespread availability of renewable energy.
		Low incentives for LTAG-SAF/LTAG-LCAF production.	Increased incentives lead to reduced LTAG-SAF/LTAG-LCAF fuel cost for users.	Large incentives lead to widespread use of low GHG fuels for aviation.
		Technology evolution **enables use of waste (CO/CO_2) gases for LTAG-SAF, feedstock from a variety of settings** (e.g., oilseed cover crops), and **use of blue/green hydrogen** for LTAG-SAF/LTAG-LCAF production.	Technology evolution **enables widespread use of waste gases for LTAG-SAF, increased feedstock availability**, and **widespread use of blue/green hydrogen for LTAG-SAF/LTAG-LCAF** production. **Carbon Capture Utilization and Storage (CCUS) is in use.**	Technology evolution **enables widespread use of atmospheric CO2 for LTAG-SAF, further increases in feedstock availability, widespread use of CCUS**, and sufficient H2 exists to **enable use of cryogenic H2 use in aircraft**.
				Infrastructure developed to enable **use of non-drop-in fuels at airports** around globe

References for further details –
LTAG Report – Appendix M5, Section 3-Methods (page 14)
ICAO Environment Report 2022, LTAG Assessment from a Fuels Perspective

3. Prioritization methodology

In some of the scenarios, the combined projected technical production potential for LTAG-SAF and LTAG-LCAF exceeded the total expected aviation fuel demand. Prioritization of fuel categories was developed with the following criteria:

Scenario	**Prioritization criteria**
F1	low cost GHG reduction - fuels prioritized by minimum selling price (MSP)
F2	cost effective GHG reduction – fuels prioritized by marginal abatement cost ($/kg CO_2 reduced)
F3	Maximization of GHG reductions - fuels prioritized by lowest LCA values

References for further details **-** LTAG Report – Appendix M5, Section 4.1 – Integrated Scenario Development (page 47)

4. Results - Volume Projections

Three traffic forecasts (LOW/MID/HIGH) were integrated with the technology and operational improvements for each of the Fuel Scenarios (F1/F2/F3) that were modelled. Fuel volumes for each of these scenarios were then evaluated.

1) Based on the Fuel Scenarios results for the MID traffic forecast
    a. Under F1, in 2050, conventional jet fuel supplies two-thirds of total international jet fuel demand with LTAG-LCAF and LTAG-SAF supplying roughly one-third of international jet fuel demand
    b. Under F2, in 2050, LTAG-LCAF and LTAG-SAF supply 100% of international jet fuel demand with roughly two-thirds from LTAG-SAF and one-third from LTAG-LCAF
    c. Under F3, in 2070, non-drop-in demand grows to roughly one-third of all international jet fuel demand

References for further details –

LTAG Report – Appendix M5,

Executive Summary (pages 5-6),

Section 4 – Results – Volume projections (pages 47-58)

Data spreadsheet – LTAG data to States (sheets marked in green).

LTAG Report Attachment A to Appendix M5 – Details on SAF based on biomass and solid/liquid-waste: Projected production volumes (Table 3); Feedstock projections (Figure 7).

Updated short-term projections – After the LTAG report was published, updated SAF projections were developed by CAEP with the use of more recent information.

5. Results - GHG emissions savings

The LTAG report includes Emissions Reduction Factors (ERF) that represent the reduction in GHG emissions achievable from Fuels . The ERFs for F1, F2 and F3 for the MID traffic forecast are as follows.

Year	**F1**	**F2**	**F3**
2035	5%	20%	37%
2050	20%	56%	81%
2070	28%	66%	88%

References for further details –

Summary of fuels-related information from the ICAO LTAG Analysis

LTAG Report – Appendix M5, Section 5 – Results – GHG emission savings (Page 59-62),

LTAG Report Attachment A to Appendix M5 – details on Lifecycle GHG emissions from SAF based on biomass and solid/liquid-waste (Tables 2, 4, 5,6 ,and 9).

6. Analysis of Fuel readiness and Attainability

The analysis of fuel readiness and attainability considered the following criteria:

		LTAG-SAF	LTAG-LCAF	**non-drop-in** fuels (LH2)
Readiness criteria	R.1 Current status of the fuel conversion technology	X	X	X
	R.2 current status in the ASTM approval process	X	X	
	R.3 availability of systems to produce low carbon energy carriers (incl. feedstock availability)	X		X
	R.3 Standards/regulations to govern safety/handling etc.			X
Attainability criteria:	A.1: Capital investment requirements	X	X	X
	A.2: Cost competitiveness.	X	X	X
	A.3: Land area requirements	X	X	X
	A.4: Water requirements	X	X	X
	A.5: Soil requirements	X	X	X
	A.6: Biodiversity assessment,	X	X	X
	A.7: Infrastructure for fuel transportation	X	X	

References for further details –
LTAG Report – Appendix M5, *Section 6 - Results – Readiness And Attainability* (pages 63-78).

7. Costs and investments associated with fuels scenarios

The LTAG Costs and investments analysis included the following cost elements:

- Research and Development (R&D),
- Total capital investment (TCI),
- Total feedstock costs,
- Total infrastructure cost,
- Minimum Selling Price (MSP) of fuels vs. conventional jet fuel:

The table below summarizes the results of the investments for fuel suppliers and airlines associated with the fuels scenarios. For airports, fuel-related costs and investments are only relevant in IS3 ($125 billion related to fuel infrastructure for hydrogen). No fuel-related costs were identified for States, OEMs, and ANSPs.

	Costs and Investments for fuels suppliers (billion USD)			Costs and Investments for airlines (billion USD)		
	IS1	**IS2**	**IS3**	**IS1**	**IS2**	**IS3**
SAF biomass-based fuels	480	1,200	950	300	1,200	1,600
SAF from gaseous waste	710	1,000	1,700	770	1,400	1,800
SAF from atmospheric CO2	-	-	460	-	-	600
LCAF	50	105	60	50	105	60
hydrogen	-	-	55	-	-	10
total	**1,300**	**2,300**	**3,200**	**1,120**	**2,705**	**4,070**

It should be noted that some investments from fuel suppliers are passed on to operators as part of Minimum Selling Price, therefore costs are not meant to be added towards a total cumulative cost.

References for further details –
LTAG Report, Section 4.4 - Cost and Investments Associated with Integrated Scenarios. See the interactive dashboard with the overall cost results.
LTAG Report – Appendix M1, Attachment C - Cost (Investment) Estimations: Fuels (Page M1-83) - includes details on all assessed fuel cost elements
LTAG Report Attachment A to Appendix M5 – Details on SAF based on biomass and solid/liquid-waste: Figure 2: Annual capital investment required per scenario, Figure 3: Historical annual investment into renewable energy, Figure 4: Minimum Selling Price Estimates

8. Costs in context

After the LTAG report was published, additional analysis was published by ICAO to place costs associated with LTAG Integrated Scenarios in context.

Baseline fuel cost - The LTAG baseline scenario assumed a unit cost of conventional jet fuel of 0.60 $/L. Since the LTAG-TG report was published, jet fuel price has increased to about 1 $/L in May 2022.

Incremental fuel cost in context of operating costs - Under IS3, incremental costs of Fuels may represent 7% of total operating costs by the international aviation in 2030, and 24% in 2050.

Incremental fuel cost per flight/seat -Under IS3, incremental cost from Fuels may represent an additional $3300 in 2030 for an average flight of about 2700 km, and $10.000 in 2050. In a per seat context, this represents about $3 to $15 per seat equivalent.

Incremental fuel cost per passengers Under IS3, the fuel costs could represent ≈ $14 to an average ticket price in 2030, and ≈ $38 in 2050, in the context of an average fare of ≈$140–$160 (in $2020).

References for further details –
ICAO Environmental Report 2022, *Placing Costs Associated with LTAG Integrated Scenarios in Context*,

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