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ENVISIONING A "ZERO CLIMATE IMPACT" INTERNATIONAL AVIATION PATHWAY TOWARDS 2050: HOW GOVERNMENTS AND THE AVIATION INDUSTRY CAN STEP-UP AMIDST THE CLIMATE EMERGENCY FOR A SUSTAINABLE AVIATION FUTURE

(Presented by the International Coalition for Sustainable Aviation (ICSA))

EXECUTIVE SUMMARY	
This Information Paper sets out ICSA's vision for a "zero climate impact" international aviation pathway towards 2050.	
Strategic Objectives:	This working paper relates to Strategic Objective – Environmental Protection
Financial implications:	Does not require additional funds
References:	• A40-WP/58, *Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection - Climate Change* • A40-WP/277, *Setting a Long-Term Climate Change Goal for International Aviation*

1. OVERVIEW

1.1 The International Coalition for Sustainable Aviation's (ICSA's) vision for a "zero climate impact" international aviation pathway towards 2050 is set out in Appendix A.

1.2 ICSA's call to action:

1.2.1 As a matter of urgency, governments and the aviation industry must adjust their short-term actions and develop a long-term decarbonization vision for the aviation sector to align with the Paris Agreement objective of limiting the increase in global temperatures to 1.5 C above pre-industrial levels.

1.2.2 ICSA believes that the current target of so-called "carbon neutral growth" at 2020 levels that covers international aviation's net CO_2 emissions growth should be broadened to cover aviation's non-CO_2 climate effects, extended to cover all international aviation emissions (not only growth), and ratcheted downward to form a 1.5C pathway.

1.2.3 To specifically set international aviation's well-to-wake emissions on a 1.5C pathway, ICSA recommends governments follow a set of five Enhanced Climate Mitigation Targets and Levers for International Aviation. First, governments should set targets that have:

a) Well-to-wake greenhouse gas (GHG) emissions[1] not exceeding 2020 levels in 2035; and

b) Well-to-wake GHG emissions reduced at least 50% from 2005 levels by 2050.

1.2.4 Second, to meet these emissions goals, governments must set policies and measures that activate Core Mitigation Levers for Aviation and bring about the following:

a) Fleetwide fuel efficiency improvements of 2.5% p.a. from 2020 to 2050.

b) Use of certified[2] sustainable alternative fuels that deliver substantial emissions reductions[3] on a life-cycle basis should start as soon as possible, displacing conventional fossil fuels; care must be taken to ensure that the reductions provided by these fuels are not double-claimed.

c) Demand management, to the extent that fuel efficiency and sustainable alternative fuel are not delivering the necessary emissions reductions towards meeting the 2035 and 2050 targets.

1.2.5 Governments must examine how to incentivize additional climate mitigation related to aviation now, so that aviation contributes a reasonable share to achieving the Paris Agreement's temperature goals and gets on a pathway to "zero climate impact" by 2050. This additional mitigation should not only be taken at an international level through ICAO, but also by national and subnational governments.

1.2.6 Climate mitigation efforts—both government policies and voluntary actions by aviation industry actors—that lead the aviation sector to a truly sustainable future must deliver more efficient operations, new aircraft with lower fuel burn, cleaner fuels, and manage unsustainable levels of demand for aviation through transport modal shifts and greater use of communications technologies like videoconferencing. Without maximizing the mitigation from these interventions, the aviation sector will not be doing its share towards a global 1.5C mitigation pathway.

1.2.7 ICSA believes that measures to address aviation's non- CO_2 climate impacts must be incorporated into government policy plans for the aviation sector. The scientific community is closer to developing new methods that would make this possible.

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[1] Measured on a CO_2-equivalent basis taking into account the full set of upstream (well-to-tank) GHG emissions plus CO_2 emissions from aircraft engines (tank-to-wake).

[2] An example of a best-in-class sustainability certification standard for advance aviation fuels is the Roundtable for Sustainable Biomaterials (RSB). The current sustainability themes and associated criteria agreed currently in ICAO are not sufficient.

[3] The Roundtable for Sustainable Biomaterials (RSB) only certifies fuels that deliver at least 50% lower life-cycle emissions (60% for biofuel produced in a new installation). To achieve the level of ambition needed to meet the 2035 and 2050 emissions benchmarks recommended by ICSA, alternative fuels should be delivering at least an average of 80% lower life-cycle emissions.

1.2.8 The aviation industry should also incorporate ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation into its own internal climate change strategy and advocate for policy measures that are consistent with them.

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APPENDIX A

ENVISIONING A "ZERO CLIMATE IMPACT" INTERNATIONAL AVIATION PATHWAY TOWARDS 2050: HOW GOVERNMENTS AND THE AVIATION INDUSTRY CAN STEP-UP AMIDST THE CLIMATE EMERGENCY FOR A SUSTAINABLE AVIATION FUTURE

INTRODUCTION

Civil aviation accounted for 2.4% of fossil CO_2 emissions in 2018[4], and up to 5% of total global warming impact when including warming from non-CO_2 effects of combusting fuels in the upper atmosphere.[5] International aviation alone was responsible for 543 million tonnes (Mt) of CO_2 emissions in 2018,[6] more than the Indonesian economy and about 1.5% of the global total. By comparison, international aviation and domestic aviation together represent 918 Mt of CO_2, or equivalent to the combined fossil fuel emissions of Germany (6th largest country emitter) and the Netherlands (36th largest country emitter).[7]

Countries in the UN's International Civil Aviation Organization (ICAO) have agreed to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a market-based measure that sets a target of net CO_2 emissions of international aviation at the average of 2019-2020 levels for the years 2021-2035. CORSIA requires individual aeroplane operators to compensate for their calculated share of emissions above their 2020 baselines using eligible emissions units[8] and sustainable alternative fuels with demonstrably lower life-cycle emissions. While CORSIA is anticipated to address up to 2.5 Gt of CO_2 emissions between 2021-2035[9], this is not enough to ensure that this rapidly growing industry decarbonizes at levels and timeframes required to meet the 1.5C temperature goal of the Paris Agreement. Other policies such as ICAO's 2016 CO_2 standard are also not sufficient. **As a result, ICSA urges governments and the aviation industry to adopt the Enhanced Climate Mitigation Targets and Levers for International Aviation, detailed below, and enhance action now with aspirations of achieving "zero climate impact" by 2050.**

GOVERNMENTS' OPPORTUNITY TO COMMIT INTERNATIONAL AVIATION TO A 1.5C ALIGNED PATHWAY

The International Coalition for Sustainable Aviation (ICSA) believes that industry and government policymakers must commit to a pathway for the industry that includes near- and long-term goals and reflects an ambitious contribution to the overall effort necessary to achieve the 1.5C temperature goal.

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4 Graver, B.; Zhang, K.; Rutherford, D. (2019). CO2 Emissions from Global Aviation. International Council on Clean Transportation WP2019-16. Retrieved from www.theicct.org/publications/co2-emissions-commercial-aviation-2018

5 Lee et al. (2009). Aviation and global climate change in the 21st century. Atmos. Environ., 43 (2009) pages 3520-3537. Retrievable from https://www.sciencedirect.com/science/article/pii/S1352231009003574

6 Muntean, M., Guizzardi, D., Schaaf, E., Crippa, M., Solazzo, E., Olivier, J.G.J., Vignati, E. Fossil CO2 emissions of all world countries - 2018 Report, EUR 29433 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97240-9, doi:10.2760/30158, JRC113738.

7 Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., LoVullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E.: Fossil CO2 and GHG emissions of all world countries, Publications Office of the European Union, Luxembourg, 2019.

8 CORSIA Eligible Emissions Units have not be designated yet. Fourteen programmes are currently being screened by the Technical Advisory Body. See https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

9 See EDF. Cumulative Emission Reductions to be Achieved Depending on Participation in ICAO's MBM. Retrievable from https://www.edf.org/climate/icaos-market-based-measure; and see IATA (2019). Fact sheet: CORSIA. Retrievable from https://www.iata.org/policy/environment/Documents/corsia-factsheet.pdf.

Despite successive Assembly resolutions calling on the Council to continue exploring the feasibility of a long-term goal (Assembly Resolutions, 37-19, 38-18 and 39-2), ICAO is yet to bring forward a proposal. Now nine years later, the draft *Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change* presented in A40-WP/58, repeats the same long-term goal language.

Some technical analysis did take place in ICAO in between 2016 and 2019 conducted by the Committee for Aviation Environmental Protection (CAEP) Secretariat and the CAEP Impacts and Science Group. As detailed further in ICSA's working paper *Setting a Long-term Goal for International Aviation* (A40-WP/277) ICSA supports CAEP's initial "bottom-up" analysis; however, this must be accompanied by "top-down" approach whereby analysts seek to understand the emissions reductions required by the international aviation sector, so that it plays an equitable role in contributing to the Paris Agreement's temperature goals.

ICSA believes that "Envisioning a 'Zero Climate Impact' International Aviation Pathway towards 2050"—and most notably the Enhanced Climate Mitigation Targets and Levers for International Aviation within the document—can be an input to the CAEP process, so that the ICAO may adopts a long-term goal proposal by no later than the 41st Assembly.

CHARTING A COURSE TO 1.5C: ENHANCED CLIMATE MITIGATION TARGETS AND LEVERS FOR INTERNATIONAL AVIATION AND ZERO CLIMATE IMPACT FOR AVIATION

This document outlines (1) the level of overall ambition needed for 1.5C aligned long-term climate mitigation, (2) details ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation, (3) provides greater detail on how the Core Mitigation Levers might be activated, (4) looks at the challenge of non-CO2 effects from aviation, and (5) conceptually explores how to reach "zero climate impact" by 2050.

- ICSA believes that the current target of so-called "carbon neutral growth" at 2020 levels that covers international aviation's net CO_2 emissions growth should be broadened to cover aviation's non-CO_2 climate effects, extended to cover all international aviation emissions (not only growth), and ratcheted downward to form a 1.5C pathway.

- To specifically set international aviation's well-to-wake emissions on a 1.5C pathway, ICSA recommends governments follow a set of five Enhanced Climate Mitigation Targets and Levers for International Aviation. First, governments should set targets that have:
    1. Well-to-wake greenhouse gas (GHG) emissions[10] not exceeding 2020 levels in 2035; and
    2. Well-to-wake GHG emissions reduced at least 50% from 2005 levels by 2050.

- Second, to meet these emissions goals, governments must set policies and measures that activate Core Mitigation Levers for Aviation and bring about the following:
    3. Fleetwide fuel efficiency improvements of 2.5% p.a. from 2020 to 2050.
    4. Use of certified[11] sustainable alternative fuels that deliver substantial emissions reductions[12] on a life-cycle basis should start as soon as possible, displacing conventional

[10] Measured on a CO_2-equivalent basis taking into account the full set of upstream (well-to-tank) GHG emissions plus CO_2 emissions from aircraft engines (tank-to-wake).

[11] An example of a best-in-class sustainability certification standard for advance aviation fuels is the Roundtable for Sustainable Biomaterials (RSB). The current sustainability themes and associated criteria agreed currently in ICAO are not sufficient.

fossil fuels; care must be taken to ensure that the reductions provided by these fuels are not double-claimed.

5. Demand management, to the extent that fuel efficiency and sustainable alternative fuel are not delivering the necessary emissions reductions towards meeting the 2035 and 2050 targets.

Governments must examine how to incentivize additional climate mitigation related to aviation now, so that aviation contributes a reasonable share to achieving the Paris Agreement's temperature goals and gets on a pathway to "zero climate impact" by 2050. This additional mitigation should not only be taken at an international level through ICAO, but also by national and subnational governments.

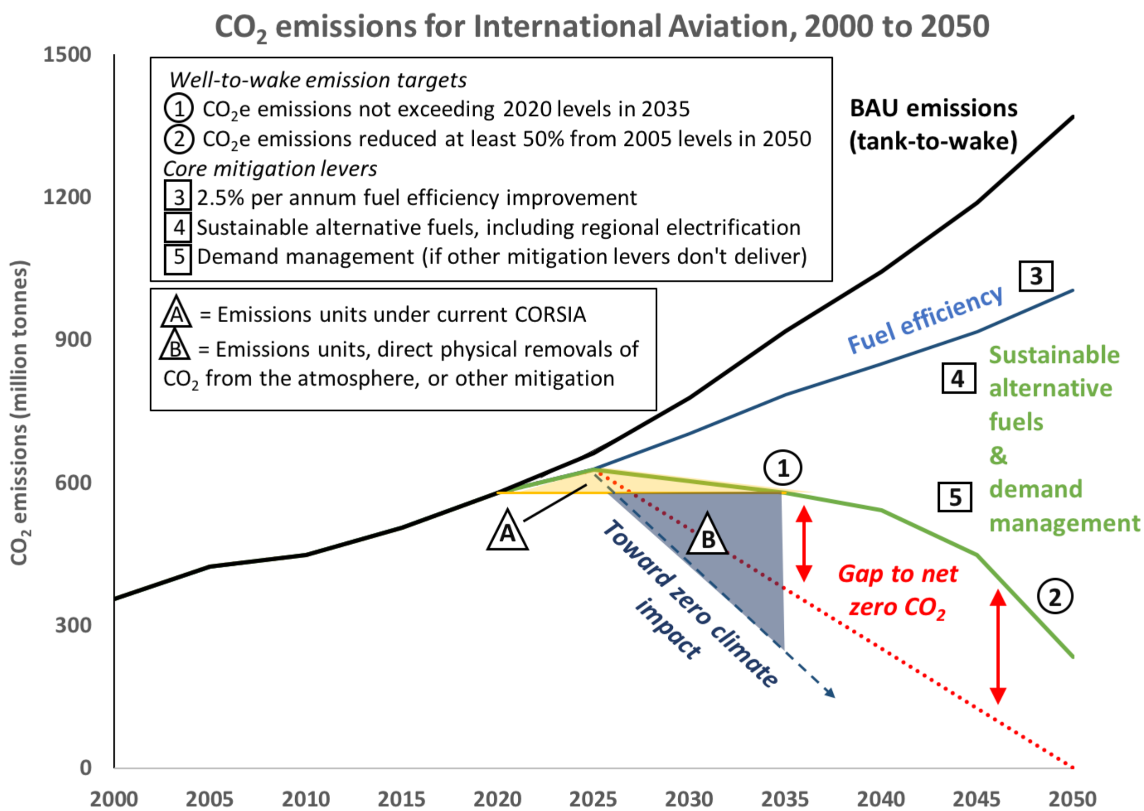

Figure 1. Visualizing ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation and a notional path toward "zero climate impact" aviation. The schematic displays ICSA's Enhanced Climate Mitigation Targets (1-2) and Levers (3-5). (A) represents emissions units that would be claimed under CORSIA if all international aviation emissions were covered, which they are not. Sustainable alternative fuels can also count towards CORSIA obligations, but we've chosen to split sustainable alternative fuels from emissions units. (B) represents additional action out to 2035, which could be continued to reach "zero climate impact" aviation.

[12] The Roundtable for Sustainable Biomaterials (RSB) only certifies fuels that deliver at least 50% lower life-cycle emissions (60% for biofuel produced in a new installation). To achieve the level of ambition needed to meet the 2035 and 2050 emissions benchmarks recommended by ICSA, alternative fuels should be delivering at least an average of 80% lower life-cycle emissions.

Figure 1 displays ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation and a notional path toward "zero climate impact" aviation on a CO_2 basis.[13] The Business as Usual line (black) represents tank-to-wake CO_2 emissions from international aviation assuming a 2.9% annual increase 2015 to 2050, in the range of the ICAO Environmental Goals Trends Assessment summarized in A40-WP/54. Projected emissions under the 2.5% p.a. fuel efficiency pathway (blue line, #3), represent an additional 1% annual acceleration of fuel efficiency improvement over the BAU trend shown in black. Modeling of other Core Mitigation Levers for Aviation– including low carbon advanced biofuels and power-to-liquid (PtL) applications, electrification of regional flights, and demand management as needed—underlying goals 2 and 3 are under refinement and will be expanded upon in future ICSA work. ICSA does not support the ICAO Council's decision to credit "low carbon aviation fuels" under that ICAO CORSIA, because it undermines efforts to transition towards sustainable alternative fuels; therefore, the potential for lifecycle emissions reductions from these fuels is not modelled. Accelerated mitigation is assumed to start in 2025 for the core mitigation levers of sustainable alternative fuels and potentially demand management (green), gap to net zero (red), and toward zero climate impact lines (purple arrow).

Box 1: How is *"zero climate impact"* aviation defined?

In light of the IPCC's Special Report on 1.5C, most industries are pursuing net zero emissions by 2050, which it defines as: "Net zero emissions are achieved when anthropogenic emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over a specified period".[14] The Business Ambition for 1.5C campaign is encouraging businesses to voluntarily align with 1.5C climate mitigation pathways by committing to set a 1.5C Science-Based Target and/or commit to net-zero emissions by no later than 2050. Net zero emissions for most companies is the equivalent of having no net impact on planetary warming (i.e. "zero climate impact").

However, non-CO_2 climate forcers emitting by aircraft in the upper atmosphere are not entirely emission, hence the term "zero climate impact" aviation.

MITIGATION STRATEGIES TO ACHIEVE THE ENHANCED CLIMATE MITIGATION TARGETS AND LEVERS FOR INTERNATIONAL AVIATION

To achieve the global goal of limiting climate change to 1.5C the IPCC has highlighted that it is necessary to achieve net zero emissions globally by 2050. For aviation, ICSA believes that the industry first must focus on maximizing climate mitigation opportunities within aeroplane operators' "well-to-wake" boundaries—referred to earlier as Core Mitigation Levers for Aviation. They include (1) fuel efficiency measures related to operational improvements and cleaner aircraft technology; (3) responsibly managing demand for aviation; and (4) sustainable alternative fuels (which we break up into power to liquids and biofuels and other advanced fuels). Modelling done within ICSA shows that even if airlines maximize

[13] As noted above, the recommended goals themselves are defined on a CO_2e basis for all upstream (well-to-tank) GHG emissions plus CO_2 emissions from aircraft engines (tank-to-wake).

[14] IPCC, 2018: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press

climate mitigation efforts using the Core Mitigation Levers for Aviation, their uptake is likely to be slow even if incentivized by well-designed, enabling government policies, and in 2050 some aeroplane operator emissions and (especially) non-CO_2 effects will likely remain.

CORE MITIGATION LEVERS FOR AVIATION

Fuel efficiency

One key lever to put aviation on a 1.5C pathway is to accelerate fleetwide fuel efficiency improvements beyond ICAO's current goal of 2% per year, aspirational from 2020. Globally, fleetwide fuel efficiency improvements for airlines averaged 2.3% per annum over the decade ending in 2017.[15] ICSA believes that a 2.5% per annum fleetwide fuel efficiency goal for aviation is achievable and necessary for aviation to contribute fairly to international efforts to protect the global climate. Since fuel costs already account for 23% of the global airline industry's operating expenses,[16] this goal would need to be supported by policies which would include, but not be limited to, R&D funding, incentives, and technology-forcing standards to promote uptake of new, more fuel-efficient airframes, engines, and operational practices.

Aircraft technology

Fuel efficiency improvements can be divided into two components: new technologies to reduce fuel burn from new aircraft, and operational efficiency improvements for the in-service fleet. Research suggests that the fuel consumption of new airframes can be reduced cost-effectively by approximately 25% by 2024 and 40% by 2034 compared to 2016 aircraft or an annual improvement of 2.2%.[17] Additional improvements are possible thereafter by a shift to advanced airframes (strut-based wing, "double bubble", blended wing body etc.) and through hybrid and full electric propulsion. Schafer et al. (2016) identified technologies that could be used to reduce the lifecycle CO_2emissions per passenger kilometer by 2% per year through mid-century.

"Clean sheet" airframes will be needed to achieve greater jumps in efficiency than the derivative designs common today. New aircraft should be built of advanced materials (e.g., composites, light-advanced alloys), improved control surfaces (e.g., wingtip devices) and improved engines. Accelerating the adoption of these technologies will require policies promoting fuel efficiency, including stronger emissions performance standards for new and in-service aircraft, incentives for fleet turnover, and funding for research to reduce the cost of bringing new technologies to market.[18]

Operational improvements

Assessment of airline fuel efficiency[19] have concluded that operational variables such as passenger load factor, seating density, and belly freight load carriage explain 60 to 75% of the fuel efficiency variation across international carriers in a given year. Operational improvements such as maximizing load factors, traffic and descent optimization, weight management, and measures to reduce ground-level fuel burn can reduce aircraft fuel burn and CO2 emissions. Better flight routing can lower radiative forcing from non-CO_2 effects in the upper atmosphere. Adjusting flight paths to avoid climate-sensitive areas in the atmosphere is likely to lead to increased fuel burn (and the associated fuel costs), so regulators will need to

[15] ATAG (2019). Fact Sheet 3: Tracking Aviation Efficiency. Retrieved from https://aviationbenefits.org/downloads/fact-sheet-3-tracking-aviation-efficiency/

[16] IATA (2019). Fuel Fact Sheet. Retrieved from: https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-fuel.pdf

[17] Tecolote Research, 2015.

[18] Kharina, A.; Rutherford, D., Zeinali, M. (2016).

[19] Graver & Rutherford (2018a and 2018b)

strike the right balance between fuel burn and climate-related routing to maximize overall mitigation benefits across non-CO_2 effects and CO_2 emissions.

Consistent with the CAEP/11 Environmental Trends Assessment highlighted in A40-WP/54[20], this work assumes a 0.39% annual improvement in fuel efficiency due to improvements in operational practices. Added to the fuel efficiency potential for new aircraft highlighted above, this supports an annual fleetwide rate of fuel efficiency improvement of 2.5%.

Responsibly managing demand for aviation

IATA projects a 3.5% compound annual growth rate in global aviation resulting in 8.2 billion passengers in 2032, almost double today's levels[21]. Highest growth is anticipated in Asia, and between Asia and Europe. However, air travelers, particularly within in Europe where some regional air travel can realistically be replaced by rail, are increasingly recognizing that flying less is the most direct way to reduce their individual climate footprint. Large-scale shifts from air to other less carbon-intensive means (e.g., rail powered by renewable electricity) could, in principle, reduce all climate impacts associated with aviation fuel burn, including not only CO_2, but also non-CO_2 gases and particles that are responsible for significant warming effects when emitted into the upper atmosphere.

While individual preferences are shifting, the right incentives must be in place to support alternative low-carbon transportation and communications technologies that can reduce the need to fly. Various regulatory measures such as taxes on fuel and/or frequent fliers, carbon pricing, and mandates to use lower carbon fuels could increase ticket prices and thereby reduce demand. Unrestricted growth is not compatible with responsible emissions targets, and the extent to which aviation must be limited in its growth directly depends on its ability to significantly reduce emissions in line with the 1.5C temperature goal.

Sustainable alternative fuels

The displacement of conventional aviation fuel with sustainable alternative fuels with an average of 80% fewer lifecycle emissions is critical to achieve the emissions reductions modelled in Figure 1. Below attention is put on power-to-liquid fuels, biofuels and other advanced fuels (which includes "waste-to-jet" fuel pathways, hydrogen and electricity). ICSA does not support the ICAO Council's decision to credit "low carbon aviation fuels" under the ICAO CORSIA, because it undermines efforts to transition towards sustainable alternative fuels.

Power-to-Liquid (PtL) fuels

Power-to-Liquid (PtL) fuels can be a substitute for conventional aviation fuel and is made by combining hydrogen and CO_2 to form synthetic hydrocarbons. When the hydrogen is produced with renewable electricity and the CO_2 is obtained via direct air capture technology that is also powered by renewable energy, PtL's net well-to-wake lifecycle CO_2 emissions could approach zero, provided that there are no indirect effects (e.g., that renewable electricity is diverted from other uses, and fossil electricity is increased to make up the shortfall). If these conditions are met, PtL could have mitigation advantages comparable to high-quality biofuels and could potentially reduce demand for land and water resources.[22] Non-CO_2 effects from aviation burning PtL will remain, though possibly to a lesser extent as combustion of synthetic

[20] ICAO (2019).

[21] IATA. (2018, October 24). IATA Forecast Predicts 8.2 billion Air Travelers in 2037. Retrieved from https://www.iata.org/pressroom/pr/Pages/2018-10-24-02.aspx

[22] ICSA. (2019). Summary of the 2019 Aviation Decarbonization Forum. Retrieved from https://www.icsa-aviation.org/wp-content/uploads/2019/04/Summary_of_the_2019_Aviation_Decarbonization_Forum.pdf

hydrocarbons may release fewer particulates.[23,24] Given its potential for near-zero lifecycle emissions, a comparatively low ecological footprint, and the potential for large scale sustainable production, ICSA supports the adoption of PtL when the conditions for doing so responsibly, as described below, are realized.

Power-to-Liquid fuels are currently only being produced on a pilot industrial scale. High costs and competition for clean, renewable electricity remain obstacles to its responsible adoption as an alternative aviation fuel, even as the cost of producing non-fossil-based hydrogen is decreasing due to lower renewable electricity costs.[25] Moreover, the question remains as to whether PtL production is the most appropriate use of renewable electricity so long as supply is constrained. Because using electricity resources in other sectors like ground transportation for electric vehicles is more efficient and therefore delivers greater carbon cutting benefits, commercial PtL production for aviation should be prioritized for areas where, and timeframes when, indirect effects are smaller (e.g., when the energy transition to renewables has progressed significantly further such that using renewables to produce PtL raises very little risk of indirectly spurring increases in fossil energy generation). While some estimates indicate the cost of capturing carbon dioxide from the air to be on the order of $550/ton, new developments indicate that direct air capture could be done for as little as $94-$232/ton, which has the potential to reduce the costs of PtL.[26] Support for research and development and other policy incentives to drive investment and deployment will be needed to overcome barriers to PtL at scale.

Biofuels and other advanced fuels

ICSA supports the uptake of biofuels that (1) deliver substantial emissions reductions on a life-cycle basis relative to conventional aviation fuel, while accounting for indirect land use change, and (2) are certified against robust environmental, social and economic sustainability criteria to ensure that their production, processing and consumption is sustainable. Biofuels can be produced in ways that makes their lifecycle emissions profiles worse or only minimally better than fossil fuels. However, sustainable advanced biofuels are possible today. As a result, the biofuels emissions scenario in Figure 1 assumes an average lifecycle emissions reduction improvement 80% compared to a fossil fuel baseline. Lifecycle emissions should account for both direct and indirect emissions, such as those from land use. Biofuels that have high lifecycle emissions, lead to the conversion of ecologically important systems, or otherwise do not meet robust sustainability criteria are not acceptable.

Today, biofuels are used commonly in the road transport sectors, but in aviation biofuel use accounts for only 0.002% of all aviation fuel and is 2.5 to 5 times more expensive on average than conventional aviation fuel. Policy efforts need to, first, set robust, comprehensive sustainability standards for biofuels and address the constraints related to securing feedstock supplies based on those standards. Various forms of government incentives can promote production capacity and help secure the availability of high-quality sustainable feedstocks.[27] Strong carbon pricing policies would further incentivize the use of fuels with lower lifecycle emissions. Investment subsidies could aim to address the upfront costs required to establish biorefineries and sustainable biofuel feedstocks. Governments must fund additional research and

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[23] CE Delft (May 2017). Towards Addressing Aviations Non-CO2 Climate Impacts. Retrieved from https://www.cedelft.eu/en/publications/1961/towards-addressing-aviations-non-co2-climate-impacts

[24] Bock, L. and Burkhardt, U. (2019). Contrail cirrus radiative forcing for future air traffic, Atmos. Chem. Phys., 19, 8163–8174, https://doi.org/10.5194/acp-19-8163-2019

[25] Gleck, G. and Reichelstein, S. (2019). Economics of converting renewable power to hydrogen, Nature Energy, 4, 216-222, https://www.nature.com/articles/s41560-019-0326-1

[26] Keith, D., Holmes, G., St. Angelo, D., Heidel, K., A Process for Capturing CO_2 from the Atmosphere, Joule, Volume 2, Issue 10, 17 October 2018, Pages 2179, https://doi.org/10.1016/j.joule.2018.09.017

[27] ICCT (January 2019). Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities. Retrieved from https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf

development and deploy the necessary incentives to improve the cost-effectiveness of converting biomass into aviation fuel at scale.

While the above constraints must be addressed, decarbonization in other sectors is necessary as well to enable biofuel uptake from aviation. Ground transportation biofuels represent direct competition for feedstock sourcing and refinery capacity. In today's market, biofuels might be more efficiently used in the ground transportation sector to maximize GHG mitigation potential, but ideally ground transport and aviation should not be competing for fuel if governments are setting aggressive policies to electrify ground transport in addition to providing incentives to increase advanced aviation feedstock supplies. Policies that support the electrification of ground transport would contribute toward freeing up feedstock resources for aviation.

Electric, hybrid, or hydrogen-powered aircraft are emerging as viable options and will themselves require additional research and development funding if they are ever to be commercialized at levels that contribute to a sustainable future for the aviation industry.[28] Producing electric power and hydrogen using renewable energy is critical to capture the maximum emissions reduction benefits from flying aircraft powered by these fuels.

NON-CO_2 EFFECTS

While the effect of aviation-related contrail cirrus cloud formation is still uncertain,[29] calculations indicate that, overall, aviation contributes about 5% of manmade global warming. About 50-60% of this warming is due to CO_2 and roughly the other half due to non-CO_2 climate forcers.[30] Policies like the ICAO CORSIA and emissions estimation tools like the ICAO Carbon Emissions Calculator[31] focus on CO_2 released by aircraft engines in flight, and do not quantify aviation's other climate impacts. While estimates of the climate impact of non-CO2 can be calculated using the Radiative Forcing Index (RFI), there is no scientific consensus on the most appropriate metric to use as a multiplier. ICSA believe that non-CO_2 effects must be incorporated eventually into aviation policy plans, such as the ICAO CORSIA. This time could be coming soon as new methods are maturing that will help policy makers and others account for non-CO_2 effects on a flight-by-flight basis and converting these into a CO_2 equivalent.

While there are ways that non-CO_2 effects can be reduced, there are significant challenges. Mitigation measures for non-CO_2 effects include lowering cruise altitudes, restricting access to "climate-sensitive" airspace, or otherwise optimizing flight trajectory.[32] Optimizing these actions (e.g., model-informed flight routes) to minimize the overall climate warming impact of the flight would benefit from funding for additional research.[33] Aeroplane operators using PtL fuels could potentially reduce their non-CO_2 effects as well. A 50% PtL fuel blend is estimated to reduce contrail formation (a key non-CO_2 forcer) by around 20%.[34]

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[28] ICSA (2019). Summary of the 2019 Aviation Decarbonization Forum. Retrieved from https://www.icsa-aviation.org/wp-content/uploads/2019/04/Summary_of_the_2019_Aviation_Decarbonization_Forum.pdf

[29] Grewe (2019) Addressing non-CO2 effects of aviation. Retrieved from https://www.icsa-aviation.org/wp-content/uploads/2019/02/Grewe-nonCO2.pdf

[30] Eurocontrol, EASA & EEA. (2019). European Aviation Environmental Report. Retrieved from https://www.easa.europa.eu/eaer/

[31] ICAO. Carbon Emissions Calculator FAQ. Retrievable from https://www.icao.int/environmental-protection/CarbonOffset/Pages/FAQCarbonCalculator.aspx

[32] Linke, F. (2017). The implications of intermediate stop operations on aviation emissions and climate. Met. Zeitsch., 26 (2017), pages 697-709. Retrievable from https://www.schweizerbart.de/content/papers/download/87337

[33] CE Delft (May 2017). Towards Addressing Aviations Non-CO2 Climate Impacts. Retrieved from https://www.cedelft.eu/en/publications/1961/towards-addressing-aviations-non-co2-climate-impacts

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Unless aviation can miraculously shift all planes to electric propulsion (which is highly unlikely) or some other unanticipated, major step-change in technology comes, aviation will always be a contributor to global warming due to the challenge of mitigating non-CO_2 effects. As a result, reaching "zero climate impact" aviation will require aeroplane operators to counterbalance these warming effects with mitigation opportunities outside their boundaries.

ENHANCING ACTION AND AIMING TOWARDS "ZERO CLIMATE IMPACT" AVIATION

To stay within a 1.5C climate trajectory, all sectors need to enhance their action now. Even if airlines achieve ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation outlined above and if aviation is allocated double the amount of the remaining carbon global budget than what they proportionally consume today, there is still a substantial climate mitigation gap for international aviation to fill. Once international aviation's non-CO_2 effects are included (which is not visually represented in Figure 1), this climate mitigation gap gets even larger.

ICSA recommends that governments begin implementing policies (in ICAO and at other levels of government) to unlock even greater climate mitigation for the aviation industry. Starting ambitious climate action now avoids locking in additional emissions growth, which will make achieving a net zero target, and the interim reductions towards that target, more difficult. Without waiting for coordinated international action, states have within their competencies the ability to adopt a range of policies and measures which can facilitate such action. A variety of policy tools could be debated within countries including the pricing of aviation emissions (through taxation or market-based measures), moratoriums on airport expansion, mandates for sustainable fuels (if paired with strong sustainability safeguards), and including all aviation emissions (international and domestic) in nationally determined contributions. Countries with high per capita emissions should move first with such measures.

How governments and the aviation industry are to fill this sizable mitigation gap is speculative. ICSA has modelled the near-maximum known mitigation potential that the Core Mitigation Levers for Aviation could deliver (see Figure 1). That being said, governments could decide to manage demand further, and additional breakthrough propulsion technologies or airframe designs could theoretically materialize to fill some of this gap. Similarly, if sustainable alternative fuels used in international aviation have an average of 100% less lifecycle emissions than conventional fuels, this would be additional mitigation.

Much of the projected mitigation potential lies outside of international aviation's well-to-wake emissions. At a global level, staying below 1.5C implies that some physical carbon dioxide removal (CDR) from the atmosphere will be needed. These "removals" could come from the enhancement of forest stocks—for example, through restoration of ecological functioning of degraded forest landscapes, which comprise peatlands, mangroves, coastal wetlands/ecosystems or low-productive land. Another technique to remove carbon from the atmosphere could be to enhance soil carbon by sequestering it in agricultural soils, which also enhances soil health and productivity. Some nature-based sequestration approaches, however, could have negative social and environmental impacts such as afforestation at scale on non-degraded land. Other synthetic carbon dioxide removal technologies may have a role too, but these have their own uncertainties and/or potential drawbacks. Direct air carbon capture and storage (DACCS), for example, is expensive and energy intensive but has large potential and fewer and less severe land-competition impacts. However, the synergies between this technology as a means to capture and sequester carbon versus capturing it and using it to produce PtL fuels should not be overlooked.

These physical removals of carbon from the atmosphere, whether nature-based or technology-based, could theoretically be funded directly by a government or private sector actor like an airline, or they could be financed in other ways.

TANGIBLE NEXT STEPS FOR GOVERNMENTS AND THE AVIATION INDUSTRY

ICSA calls on governments to:

- Adopt, strive and advocate for setting targets in line with ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation.
- Formally commit, at the 40th ICAO Assembly, to a process and timetable for the analysis and development of a proposal for a long-term goal, to be presented for adoption as soon as possible at an extraordinary meeting of the Assembly, but certainly no later than the scheduled date for the 41st Assembly in 2022. Delaying this decision beyond the 41st Assembly would be unacceptable to civil society organizations, and would fail to send the necessary signals to the industry on the scale of improvement required to guide the development of sustainable alternative fuels, and new technologies. This would be a missed opportunity.

ICSA calls on the aviation industry to:

- Update the ATAG climate change mitigation strategy to incorporate ICSA's Enhanced Climate Mitigation Targets and Levers for International Aviation.
- Advocate for policy measures that are consistent with a reasonable share of climate mitigation for aviation of the global economy's transition to a 1.5C future without detracting from other sectors' decarbonization efforts.
- Without delay, adopt measures at a national and regional level, which would rein in the runaway emissions growth from the sector.

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