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ENVIRONMENT

INNOVATION FOR A GREEN TRANSITION



2022 Environmental Report



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Message from the President of the International Civil Aviation Organization (ICAO) Council

Despite COVID-19 presenting unprecedented challenges to the implementation of the Strategic Objectives of the International Civil Aviation Organization (ICAO), the Organization has remained steadfast to its remit of environmental protection. It continues to lead the international aviation sector towards recovery, resilience, and sustainable growth.

This 2022 Environmental Report is testament to ICAO's ongoing and thriving efforts in environmental protection to face the current challenges of our times. It would not have been made possible without the dedicated work of the ICAO Committee on Aviation Environmental Protection (CAEP) and its working groups, the active engagement of ICAO Council, from ICAO's 193 ICAO Member States, continuous support from the ICAO Secretariat, as well as ICAO's strong partnership with various industry stakeholders, many of which have deployed breakthrough innovations towards mitigating aviation CO₂ emissions, in noise as well as in local air quality.

Much progress has been made in the 2019-2022 Triennium, with ICAO continuing to develop recommendations, guidance, policies and Standards in relation to environmental protection. Highlights would include the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) sustainability criteria for sustainable aviation fuels (SAF). The annual ICAO Stocktaking events have also become mainstays in the aviation sector calendar, and the ICAO Global Coalition for Sustainable Aviation comprising various stakeholders, provides a valuable network accelerating innovative aviation solutions.



2022 is a crucial year for ICAO. As preparations for the 41st Session of the ICAO Assembly intensify, the international aviation sector is on the cusp of delivering yet another milestone – an ambitious long-term aspirational goal for international aviation (LTAG). There are high expectations for consensus amongst ICAO Member States on an LTAG, and to facilitate implementation of the various innovations available – aircraft technologies, operations, and fuels, and means of monitoring the sector's progress.

A key step taken to facilitate sustainable aviation transition is the new ICAO Assistance, Capacity Building and Training for Sustainable Aviation Fuels (ACT-SAF) launched in June 2022. It will provide opportunities for all ICAO Member States to develop their full potential in SAF development and deployment, in line with ICAO's *No Country Left Behind initiative*. A decision on an ambitious LTAG will trigger further opportunities for similar programmes for additional aspects, (aircraft technologies and operations), contributing to aviation emissions to be established.

In addition, the upcoming periodic review on the ICAO CORSIA will also ensure that its robust implementation continues to support the sector's sustainability, further cementing its role as a global market-based measure in mitigating international aviation emissions.

ICAO's efforts and progress in the area of environmental protection, in collaboration with ICAO Member States and industry stakeholders, is crucial in ensuring the Organization's continued relevance and impact in addressing global climate change issues through international aviation.

Let us all unite in our efforts to build a better aviation environment for future generations.

Mr. Salvatore Sciacchitano

President of the ICAO Council

Message from the Secretary General of the International Civil Aviation Organization (ICAO)

The Triennium in Review: Aviation at the Crossroads

This triennium was both outstanding and challenging for the International Civil Aviation Organization (ICAO) and the worldwide aviation sector. An ambitious environmental agenda in ICAO strongly linked to 14 of the 17 United Nations Sustainable Development Goals (SDGs) has been substantially advanced over the last three years under the Air Transport Bureau's Environment Branch. These United Nations SDGs adopted under the ambitious and transformative Agenda 2030 for Sustainable Development, are our common roadmap toward a sustainable future for the aviation sector.

The latest 2021 Climate Report from the International Panel for Climate Change (IPCC), revealed that climate change is growing at an alarming rate, demanding more action inside and outside the aviation sector. As highlighted by the United Nations Secretary General, the recent IPCC Climate Report is a 'Code Red for Humanity', stressing the 'irrefutable' evidence of human influence. Under the mandate given by its 193 Member States, ICAO undertook bold actions to address the climate change.

Since the last session of the ICAO Assembly, held in October 2019, one of the major endeavors was to complete a report on the feasibility of a global Long-Term Aspirational Goal (LTAG) for CO₂ emissions reduction in international aviation. This report is, to date, the most comprehensive,



inclusive and transparent report on this matter. Almost 300 experts from all over the world, United Nations bodies, environmental NGOs, aviation and energy industry representatives, to mention some, were part of the report's development. It was approved by consensus and made publicly available free of charge to ensure that all States and stakeholders could consider its findings as the basis of further consideration on the feasibility of an LTAG.

In line with the ICAO "No Country Left Behind" initiative, ICAO has also successfully conducted regional LTAG Global Aviation Dialogues (GLADs) to keep its 193 States well-informed for the subsequent discussions at the High-Level Meeting on LTAG, and at the 41st Session of the ICAO

Assembly in September of 2022, when a decision on an LTAG is expected.

Despite the most serious and disruptive global health crisis in several generations, the COVID19 pandemic, aviation has the opportunity to build back better towards a sustainable decarbonized future. ICAO recognizes that innovation is key to achieving this goal, and the ICAO stocktaking process and complementary innovation focused seminars held in 2020 and 2021, unlocked and showcased many revolutionary and innovative solutions being developed inside and outside the sector. These solutions have the potential to transform our industry in a way and at a pace never seen before. ICAO and Member States were also very inspired by the various initiatives and commitments to a net zero aviation future even prior to the Organization's consideration of an LTAG.

To make this green transition a reality, the aviation community will need broader and deeper international cooperation in various areas, such as supportive policies, investments, certification, and multi-stakeholder partnerships. Green finance access by aviation will be key. In parallel with intense outreach and capacity-building, ICAO is ready to assist States in the preparation of national action plans on CO₂ emissions reduction in light of the future decisions to be made on LTAG and beyond.

As ICAO strives to exceed the expectations set by its Member States in addressing global concerns on environmental protection, its commitment to develop timely, robust and effective measures to reduce the impact of international civil aviation on the environment, from noise, local air quality, and climate change has never been so strong. The world remains connected by aviation, and to reach our mutual goals, ICAO calls for further cooperation between the States and all stakeholders worldwide to ensure that we remain connected and increase sustainable air transport in the years to come.

Juan Carlos Salazar

Secretary General, ICAO

Message from the Director of the Air Transport Bureau of the International Civil Aviation Organization (ICAO)

Addressing Aviation Environmental Challenges

The International Civil Aviation Organization's (ICAO) Air Transport Bureau (ATB) supports the implementation of the Strategic Objectives of ICAO, and in particular, security and facilitation, the economic development of air transport, and environmental protection. ICAO's environmental protection goal is to minimize the adverse environmental effects of global civil aviation activities. This objective fosters ICAO's leadership in all aviation-related environmental activities and is consistent with the ICAO and United Nations (UN) system environmental protection policies and practices.

ICAO Member States have already agreed on two global aspirational goals for international aviation: 2% annual fuel efficiency improvement through to 2050, and carbon neutral growth from 2020 onwards. To achieve these global aspirational goals and promote the sustainable growth of international aviation, ICAO is pursuing a basket of measures including aircraft technology, operational improvements, sustainable aviation fuels, and market-based measures (CORSIA) and ensuring that all the necessary legal and operation framework and all necessary information for



its implementation is up to date and available to our 193 Member States,

In addition, the Environmental Programme also assists States directly in the implementation of measures through robust assistance programmes, and cooperates directly with UN and international bodies in the field.

The COVID-19 pandemic has profoundly affected the operations of air carriers, airports and air navigation service providers (ANSPs). After the outbreak of COVID-19 in early 2020, it has become a key priority for ICAO

to provide the necessary support to Member States in the restart, recovery and long-term resilience of the civil aviation sector. While improving air transportation remains the organization's top priority, the crisis has opened up new opportunities to meet the organization's objective of building an even more sustainable aviation sector. Aviation today is at a turning point, with all stakeholders acting now to set the path to ensure a green recovery. ICAO is leading and facilitating the actions to implement systemic changes through innovative and novel solutions.

Since the 40th Session of the Assembly in 2019, ICAO has been working on the feasibility of a Long Term Aspirational Goal (LTAG). The ICAO Committee on Aviation Environmental Protection (CAEP) has carried out a comprehensive technical analysis through a cooperative, inclusive and transparent process. This work identified a set of LTAG scenarios by evaluating existing, foreseen, and innovative in-sector measures in technology, fuels and operations, and their enablers, including information on probable cost.

Despite the negative effects of the COVID-19 pandemic, CORSIA implementation is on pace, thanks to the assistance provided to States through the ICAO Assistance, Capacity-building, and Training for CORSIA (ACT-CORSIA) initiative. It is still the sole global market-based measure for international aviation CO₂ emissions, implying that CO₂ emissions from aviation are only accounted once. CORSIA is critical to reaching the sector's ambitious goals in addressing its impact on the global climate.

ICAO is working steadily to address the environmental aspects associated with international civil aviation by incorporating innovation effectively and practically into the exploration of pathways to decarbonize the aviation sector and address climate change. ICAO recognizes its leadership position in environmental protection, particularly at this unique time of green transition, and change to a new normal, through collaboration with 193 Member States and other aviation stakeholders willing to embrace a sustainable aviation future. We remain ready for the challenge.

Mohammed Khalifa Rahma

Director, Air Transport Bureau, ICAO

Message from the Deputy Director Air Transport Bureau responsible for the Environment Programme at the International Civil Aviation Organization (ICAO)¹

Green Transition of Aviation

I am proud to introduce this fifth edition of the ICAO Environmental Report. We have now covered fifteen years of evolution of the aviation sector action to address its impacts on the environment, and the least we can say is that substantial progress was achieved in the reduction of noise and emissions affecting local air quality and global climate.

The evolution of the ICAO Environmental Report itself was also remarkable as it became a benchmark publication widely recognized as a trusted and reliable source reference for innumerable publications and academic work and the basis for the objective information required for discussions and decisions of the ICAO Assembly sessions on aviation environmental sustainability.

This issue of the report, by all accounts, is a special one as despite the COVID-19 pandemic crisis, and resultant air traffic disruption worldwide, the last triennium has been the stage for one of the most rapid evolutions on environmental



sustainability for the sector. This unprecedented pace was also clearly reflected by progress of the International Civil Aviation Organization (ICAO) in its environmental activities, with exceptional support of its 193 Member States, the aviation industry, and other partners. The triennium was also the stage for many important developments

¹ The Environment programme at the International Civil Aviation Organization (ICAO) encompasses the areas of aircraft noise, local air quality And Climate change mitigation and adaptation as well as cleaner energy sources.

and milestones such as the Sixth IPCC report, the IPCC Adaptation report, the Glasgow Climate Pact and many net zero commitments from States, sectors, and industry, including the aviation sector, and Stockholm +50 that influenced the shape of aviation's green recovery.

In the ICAO Environmental Report 2022, a full spectrum of the achievements addressing aviation noise, local air quality, and climate change impacts are covered but particular emphasis was given to innovation, revolutionary technologies and new approaches, ideas, methods, and systems that have arisen from the "building back better" of international aviation.

One of the main achievements highlighted in this 2022 Report is the Long-term Aspirational Goal (LTAG) Report with wide range of information regarding the work underpinning the feasibility study of a long-term aspirational goal (LTAG) for international aviation. Following the ICAO Assembly's request to the ICAO Council to investigate the feasibility of LTAG for international aviation, the Committee on Aviation Environmental Protection (CAEP) conducted a comprehensive technical analysis through a collaborative, inclusive and transparent process. The twelfth meeting of the CAEP (CAEP/12) held in February 2022, unanimously approved a technical report addressing the feasibility of a series of LTAG scenarios, emphasizing the potential for significant CO₂ reductions through in-sector measures including innovative technologies, operations, and fuels.

With appreciation to the establishment of a consensus scientific understanding on climate change, and the findings of the LTAG report, all ICAO Member States now have a solid base for understanding and decision making on long-term sustainability goal options for international aviation. These options are to be defined at the LTAG High-Level Meeting, and toward the 41st Session of the ICAO Assembly to be held in Fall 2022.

As a matter of course, the LTAG work has innovations at its core, and to support this challenging endeavour, ICAO has organized a continuous Stocktaking process to support and showcase novel solutions, technologies and partnerships to energize the green transition of the aviation sector.

Commencing and delivering from March 2021 to August 2021, ICAO organized a series of ICAO pre-Stocktaking monthly webinars dedicated to battery technology, use of hydrogen, synthetic fuels, eVTOL and urban air mobility, infrastructure development for supplying clean energy for air travel, and a 2021 ICAO Stocktaking preview. Pre-Stocktaking events paved the way to the 2021 ICAO Stocktaking held 31 August – 3 September 2021. It represented unique opportunities for unlocking and showcasing solutions and provided tools toward decarbonized future for the aviation sector.

During the 2021 ICAO Stocktaking event, States, industry leaders, researchers and innovators shared their ambitious plans, solutions, and policies for decarbonizing international aviation, including measures from technology, operations, and fuels. The event concluded with a policy day, featuring high-level interventions to discuss the link between the post-pandemic green recovery and the future of sustainable aviation.

During the 2021 ICAO Stocktaking event, ICAO announced an open call and support for the establishment of a youth umbrella group, which would allow the global youth to engage with ICAO and provide views on aviation sustainable future. The Global Youth Engagement – Facilitation Session which took place on 28 October 2021, furthered the call for worldwide youth, to form an independent Youth Umbrella Group for Sustainable Aviation. ICAO facilitated the initial stages of forming this independent group, and encourages universities, young entrepreneurs, students, and environmental activists throughout the world to participate.

During the COVID19 pandemic, ICAO has also explored the opportunities for the aviation sector to assist in a green recovery to "build back better". The ICAO Aviation Green Recovery (AGR) Seminar held 23-24 November 2021, offered a holistic view of the potential opportunities for aviation to take concrete measures to address environmental issues. It stressed the need for climate action by aviation, displaying inspiring solutions for aviation's deep decarbonization and green recovery. It also discussed how aviation could support others in addressing CO₂ emissions in combating climate change, as well as policies and measures that need to be in place within and outside aviation to support a decarbonization path for aviation.

To investigate broader opportunities for the aviation sector to address climate change, ICAO organized the ICAO Flying Forest Fire Fighting (I4F) Dialogue on 22 November 2021. This Dialogue presented and demonstrated best practices, initiatives and encouraged the strengthening of international cooperation for aerial firefighting action.

The Dialogue also highlighted the importance of the role of ICAO and identified the need for an informal multi-stakeholder working group to increase awareness and gain support for forest fire fighting efforts. This included: the need for additional outreach, certification, awareness and innovations on firefighting forecasting, mitigation and prevention, and the coordination on facilitating new international aviation regulations and harmonization across Member States.

While aiming to make in-sector CO₂ emissions reductions, I am also very pleased to say that CORSIA implementation is on track. The Carbon Offsetting and Reduction Scheme (CORSIA), as the only global market-based measure for international aviation, ensures that CO₂ emissions from aviation are accounted for just once. CORSIA is crucial to the ambitions of the aviation sector in dealing with its impact on the global climate. This implementation was enabled by the ACT-CORSIA capacity building initiative and is another great example of ICAO Member States cooperating to implement global and robust ICAO policies.

Another important step towards a decarbonized aviation sector, ICAO organized the ICAO Global Coalition for Sustainable Aviation. This Coalition was designed to serve as a forum for those stakeholders who aim at facilitating the development of new ideas, and to accelerate the implementation of innovative solutions that will further reduce greenhouse gas emissions at source, both on the ground or in the sky.

The main objective of this Coalition is to promote a sustainable international civil aviation by close collaboration among the proposed global coalition partners – Member States, aviation industry and other stakeholders, toward the sustainable future for aviation system.

During the 2021 United Nations Climate Change Conference, held 31 October – 12 November 2021 in Glasgow, Scotland,

United Kingdom, ICAO also launched the first edition of “Innovation Driving Sustainable Aviation” which provided an overview of the innovations presented during the 2021 ICAO Stocktaking, and updates from the Global Coalition Partners. This Global Coalition Partners remains open and is welcoming new partners to join.

It is worth noting that all this progress was achieved under the unusual working mode “virtually”, the so-called new normality. Instead of face-to-face meetings, we have made a transition to multiple online events and meetings, where the top-level experts from all around the world could contribute to the mutual efforts. To support the new mode of work, we have also prepared additional tools, taking advantage from the online paradigm.

As a part of the ICAO Global Coalition for Sustainable Aviation, we developed the ICAO tracker tools of aviation CO₂ emissions reduction initiatives to monitor the latest innovations from aviation stakeholders. These interactive tracker tools regularly provide a wealth of information on measures to reduce the environmental footprint of aviation, including details on the most ambitious actions being taken by stakeholders. The tracker tools are organized to capture initiatives on four main streams namely Technology, Operations, Sustainable Aviation Fuels (SAF), and Net-Zero Initiatives.

The technology tracker tool captures all the latest initiatives from all stakeholders, containing initiatives on electrification, hydrogen, Urban Air Mobility/Advanced Air Mobility (UAM/AAM) and all aircraft technologies. The operations tracker tool on operations gathers all the most recent initiatives from all stakeholders, containing initiatives on green infrastructure, and operations in the air and on the ground.

The Sustainable Aviation Fuels tracker tool captures all fuel related announcements and data such as airports that distribute SAF, policies on SAF, SAF offtake agreements, certified conversion processes, and the commercial flights that used SAF.

During this triennium, the ICAO State Action Plan (SAP) initiative celebrated its 10th anniversary. SAP has become one of the most successful assistance and capacity building programs in the Organization since it was launched at

the 37th Session of the ICAO Assembly in October 2010. ICAO initiated the second phase of the ICAO Project-Capacity Building for Carbon dioxide (CO₂), Mitigation from International Aviation-Development of ICAO SAPs with an implementation period from 2020 to 2023. In the second phase of the project, ICAO will also assist 10 African countries in developing their State Action Plans.

State Action Plans will continue to increase its relevance by allowing States to demonstrate their latest green innovations and longer-term low-carbon strategies in a more robust, quantitative, and forward-looking manner. The State Action Plans will also act as “dynamic communication tools” via which countries may present their coordinated aviation and climate change plans and promote green finance in the context of achieving a global long-term aspirational goal. The continued success of the ICAO State Action Plans initiative requires the participation and cooperation of both States and other stakeholders in delivering and refining quantified and qualified inputs.

In my role as the Secretary of CAEP, I would like to welcome new CAEP Members and Observers, who have joined the Committee during the last three years. These

additions in CAEP membership have improved geographical representation and added to the global significance and relevance of its recommendations. It is a great pleasure to see the increased interest and expert participation from more States and Regions worldwide.

To conclude, I have to emphasize that this green transition that we are evidencing in aviation was only possible and can only be sustained if the level of cooperation from all States and partners within and outside the aviation sector continues to be at the same unprecedented level, we experienced during these last three years. We are grateful for their cooperation and enthusiasm and look forward to continuing our partnership and cooperation.

As we look back, this triennium was very rich on challenges and achievements, and we are delighted to share with you this progress and the incredible foundations for the sustainable journey of the aviation sector that were forged. I hope you enjoy reading this 2022 Environmental Report.

Jane Hupe

Deputy Director, Environment, ICAO

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CHAPTER ONE

Aviation & Environmental Outlook

Building back better: a crucial opportunity for green recovery for aviation

By ICAO Secretariat

Over the past three years since the publication of the 2019 ICAO Environment Report, the aviation sector has faced one of the most critical challenges in its history; the novel coronavirus (COVID-19) pandemic. The world passenger traffic experienced an unprecedented decline in history, with an overall reduction of over 2.7 billion passengers (-60%) and an approximate USD 372 billion loss of gross passenger operating revenues of airlines in 2020 alone, compared to 2019 levels¹. With the virus evolving into new variants and spreading with varying speed and impact around the world, the industry and the world is far from a full recovery and a return to the new normal.

In the midst of all, what has emerged along with travel restrictions and new public health measures was the sharp realization of the new opportunity to transform the economy into a greener and sustainable future. The United Nations Secretary-General, Mr. António Guterres, termed the pandemic as an unprecedented “wake-up call” to turn the recovery into a real opportunity to do things right for the future. A number of governments and world leaders followed suit and called for green recovery to build back better including several business leaders. Promises of green recovery dominated public debates across much of the world’s leading economies.

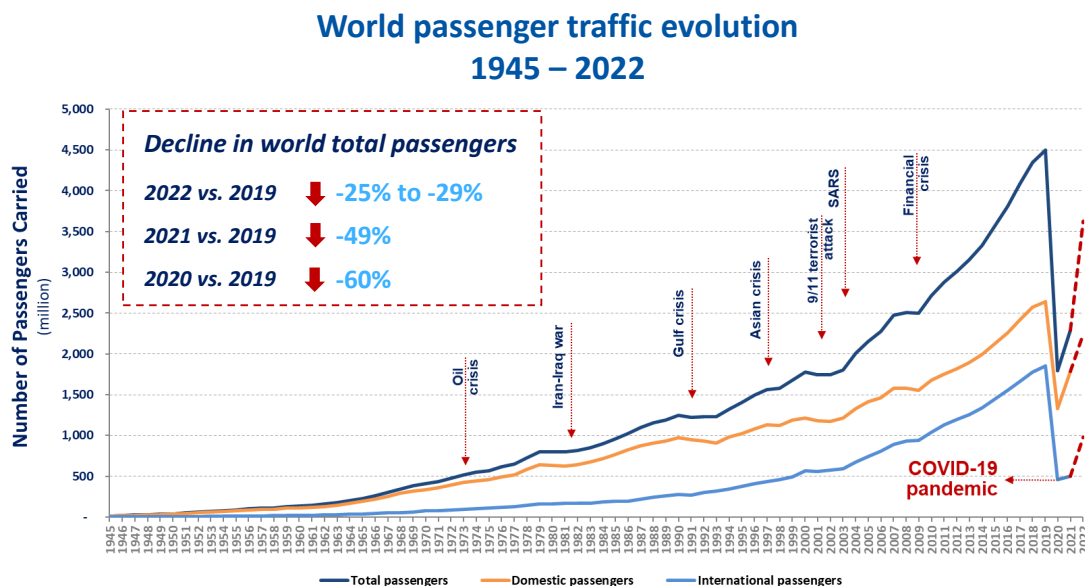


FIGURE 1: World passenger traffic evolution, 1945–2022

¹ Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis (5 May 2022), Economic Development, Air Transport Bureau, ICAO
² Ibid.

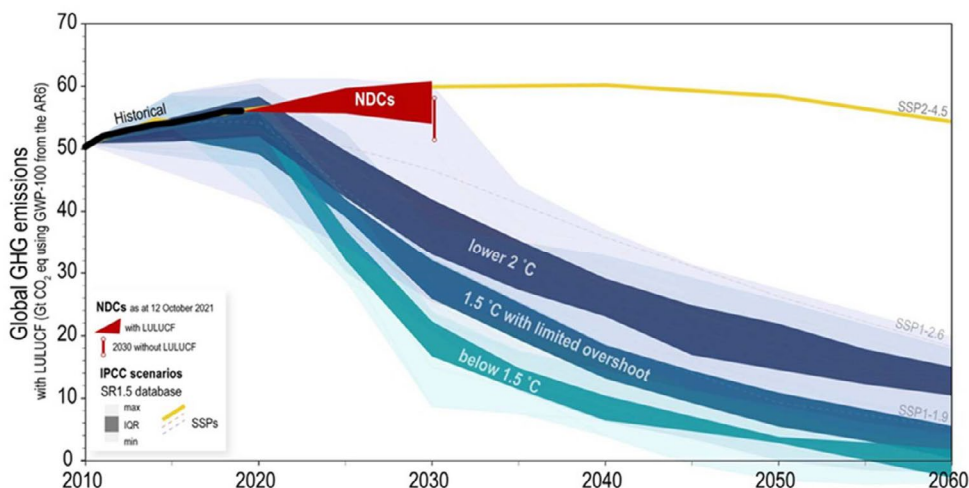


FIGURE 2: Comparison of global emissions under scenarios assessed in the IPCC Special Report on Global Warming of 1.5 °C with total global emissions according to nationally determined contributions, NDC Synthesis Report, UNFCCC Secretariat⁶

“This is a moment of truth for people and planet alike. COVID and climate have brought us to a threshold. We cannot go back to the old normal of inequality, injustice, and heedless dominion over the Earth. Instead, we must step towards a safer, more sustainable, and equitable path. The door is open; the solutions are there. Now is the time to transform humankind’s relationship with the natural world – and with each other. And we must do so together. Solidarity is humanity. Solidarity is survival.
—Mr. António Guterres, United Nations Secretary-General³”

Indeed, the Sixth Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC)⁴ as well as the synthesis report on Nationally Determined Contributions (NDC) by the UNFCCC Secretariat⁵ highlighted the current lack of global commitment contained in the latest Nationally Determined Contributions (NDCs). Limiting the temperature increase in line with the goals of the Paris Agreement is likely unattainable unless an immediate and significant increase in the level of emissions reduction is achieved to reach net zero in the near future.

According to OECD Green Recovery Database⁷, out of the USD 3,300 billion that has been allocated to recovery measures by the world’s government, a close to one-third is allocated to recovery measures with direct positive environmental impact. A bulk of such measures with positive environmental impact represents grants or loans with clear environmental implications, with some with tax reductions or subsidies and regulatory changes, including toward the transport and energy sector.

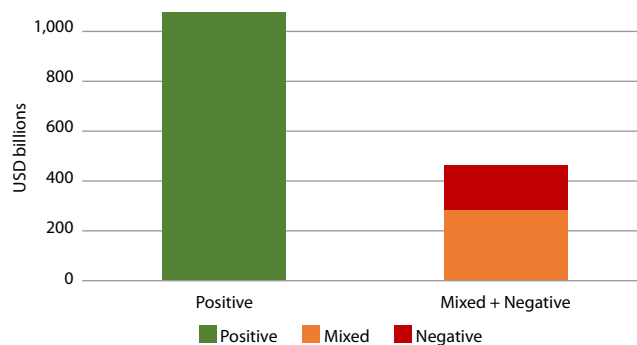


FIGURE 3: Total recovery funding allocated by environmental categorization, OECD Green Recovery Database⁹

³ UN Secretary-General’s speech on the state of the planet <https://www.un.org/en/climatechange/un-secretary-general-speaks-state-planet>

⁴ Third part of the Sixth Assessment Report, Climate Change 2022: Mitigation of Climate Change, the Working Group III contribution.

⁵ Revised synthesis report on the nationally determined contributions under the Paris Agreement, UNFCCC secretariat https://unfccc.int/sites/default/files/resource/cma2021_08r01_E.pdf

⁶ Ibid.

⁷ <https://www.oecd.org/coronavirus/en/themes/green-recovery>

Private sector investors' and financial stakeholders' interests in considering environmental, social and governance (ESG) criteria when making investment decisions have been even more prominent than that of the governments. According to Gartner⁸, over 85% of investors considered ESG factors in making their investment decisions in 2020, with 91% of banks monitoring ESG factors and over 90% of insurers.

Aviation sector is one of the most hard-to-abate sectors thereby playing a vital role in fighting the challenges of climate change and achieving the 1.5°C and 2°C temperature goals of the Paris Agreement. Support and investment from governments and the financial sector, in addition to those within the sector, are crucial in raising the emissions reduction ambition on a global scale. Innovations in aircraft technology including advanced aircraft configuration and energy systems require substantial investments from governments and aircraft manufacturers. Investments in airports and air navigation service providers are needed to bring about improvements in operations. Scaling the production of sustainable aviation fuels and other energy sources requires substantial investment and financial support from both fuel suppliers and governments on top of what would be needed for associated infrastructural changes. This is particularly important, considering that the drop-in fuels have the largest potential to reduce the overall emission from international aviation by 2050, according to the recent ICAO Report on the feasibility of a Long-Term Aspirational Goal (LTAG) for international civil aviation CO₂ emission reductions (*refer to the LTAG article in Chapter 4 of this report and to the LTAG Special Supplement*).

In view of the above, the ICAO Secretariat organized the Aviation Green Recovery Seminar in 2020 to provide a holistic view of the potential opportunities for aviation to take concrete measures to reduce its emissions footprint as the sector sought to build back better. The seminar not only highlighted ongoing works by ICAO and the aviation community vis-a-vis green recovery and sustainability but also provided a forum for representatives of ICAO member states to discuss how the green aviation future could be shaped.

During the seminar, several heads- and high-level officials of United Nations agencies, governments, industry, and academia participated and shared their thoughts on the critical importance of urgent climate action on aviation, policies, and measures that need to be in place within and outside aviation to support its decarbonization path. The seminar also showcased how innovative aviation solutions help shape the future within the sector as well as outside the sector to cope with the environmental and humanitarian crises worldwide.¹⁰

The journey to green recovery for aviation has just begun. The support for aviation green recovery plans should scale further in the face of other pressures and competing priorities. The ICAO LTAG report has shed light on the scale of investment needed to ensure much-needed innovation and scaling are achieved in the coming future. As the Secretary-General of the United Nations has said, the door is open and the solutions are there, and now is the time for solidarity to transform for a greener future.

ICAO Aviation Green Recovery Seminar

TIME TO BUILD BACK BETTER

Virtual event | 23 - 24 NOVEMBER 2020

#GreenRecovery

8 <https://www.gartner.com/smarterwithgartner/the-esg-imperative-7-factors-for-finance-leaders-to-consider>

9 OECD Policy Responses to Coronavirus (COVID-19): Assessing environmental impact of measures in the OECD Green Recovery Database, 21 April 2022 <https://www.oecd.org/coronavirus/policy-responses/assessing-environmental-impact-of-measures-in-the-oecd-green-recovery-database-3f7e2670/#section-d1e146>

10 <https://www.icao.int/Meetings/GreenRecoverySeminar/Pages/default.aspx>

ICAO Committee on Aviation Environmental Protection

By Urs Ziegler (Switzerland), Ricardo Antonio Binotto Dupont (Brazil), Tan Kah Han (Singapore)¹

Introduction

The Committee on Aviation Environmental Protection (CAEP)² is a technical committee of the ICAO Council established in 1983. CAEP assists the Council in formulating new policies and adopting new Standards and Recommended Practices (SARPs) related to aircraft noise and emissions, and more generally to aviation environmental assessments. This article provides an overview of the CAEP processes, and describes the work done by the Committee during the CAEP/12 cycle (2019-2022).

CAEP Process

CAEP comprises of 31 ICAO State Members from all regions of the world and 21 Observers. CAEP works under the stewardship of a Chairperson and two Vice-Chairpersons, elected by CAEP from its Members. A CAEP Secretary, who is designated by the President of the ICAO Council, assists the CAEP Chairperson. Being a Committee of the Council, the CAEP holds its deliberations under a confidentiality agreement and results are only made public when approved by the ICAO Council.

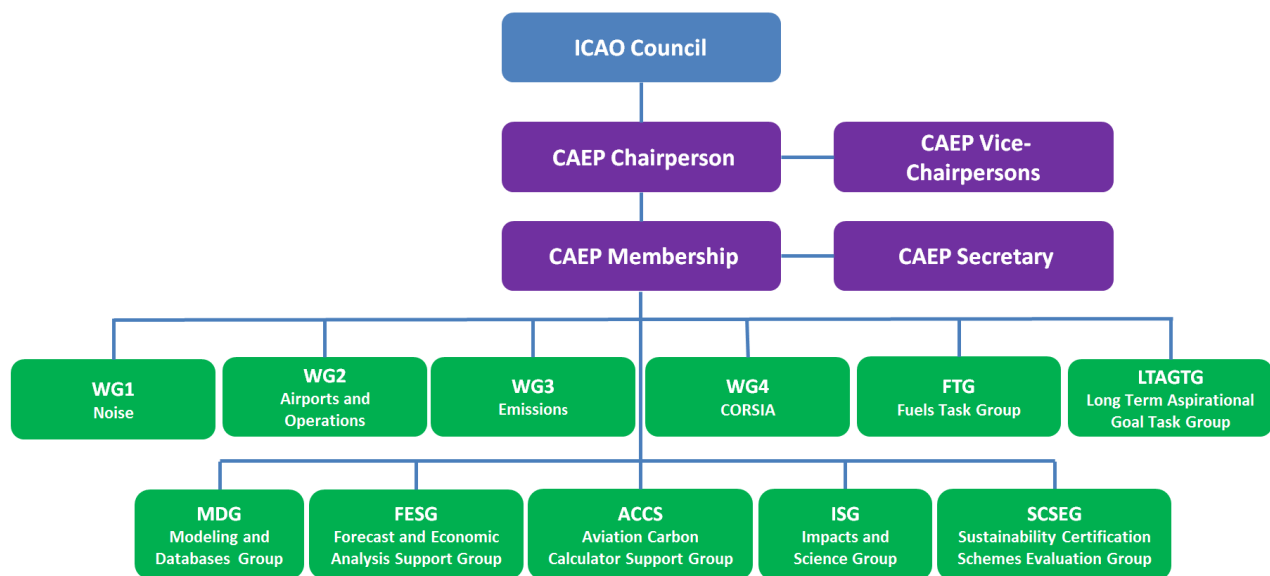


FIGURE 1: CAEP Structure during the 2019-2022 triennium

¹ Urs Ziegler was Chairperson of the ICAO Council's Committee on Aviation Environmental Protection (CAEP) during its twelfth cycle (2019-2022). Ricardo Antonio Binotto Dupont and Tan Kah Han were Vice-Chairpersons.

² <https://www.icao.int/ENVIRONMENTAL-PROTECTION/Pages/CAEP.aspx>

To deliver its work programme, formal meetings of CAEP are normally held once every three years and is complemented by annual Steering Group meetings. As the name implies, the intent of the Steering Group is to steer or provide guidance to the work carry out by Working Groups that are established under CAEP. The Working Groups work on various technical items related to aviation and environment. The scope of CAEP work has been expanding constantly, and eleven Working Groups have been set up to develop the CAEP/12 work programme. Figure 1 presents the current CAEP structure, with details of its Working Groups.

CAEP had to adapt its working arrangements in order to continue progressing its work during the COVID-19 pandemic. For that, various CAEP meetings were held virtually: not only the CAEP/12 meeting itself, which was held from 7 to 17 February 2022, but also the CAEP Steering Group meetings in 2020 and 2021, more than 30 full Working Group meetings, and hundreds of meetings of subgroups.

Operational processes were also reviewed to ensure the effectiveness of CAEP proceedings – some working papers and associated actions were decided following a ‘silent approval procedure’ prior to the meetings. This applied only to items deemed not contentious, identified in coordination between the CAEP working group co-rapporteurs and the CAEP Chairperson. In the absence of objections by a common deadline, the matters addressed under the ‘silent approval procedure’ were considered decided. This facilitated more effective and efficient discussions during actual (virtual/online) CAEP meetings. Ultimately, the experience of online CAEP meetings has allowed meetings to progress more quickly, but not always more easily.

Contributors to CAEP

More than 600 technical experts are involved in CAEP activities. These experts have been nominated by CAEP Members and Observers to provide technical inputs in specific areas of CAEP working groups (e.g. Emissions, Noise, Fuels, CORSIA, etc.). There is close coordination within these working groups to deliver on the work

programmes; for example, the Long-Term Aspirational Goal Task Group (LTAG-TG) worked closely with other working groups (e.g. Forecasting and Economic Analysis Support Group (FESG), Modelling and Databases Group (MDG)) in gathering data from internal and external sources, tapping on mutual expertise in the process. Finally, analysis by the Impacts and Science Group (ISG) has put the results of the LTAG-TG into context of the latest findings in climate science.

Hundreds of meetings have been convened across these Working Groups during the past CAEP cycle, ensuring that CAEP is able to deliver on the work programme assigned by the ICAO Council. We express gratitude for the steadfast commitment and valuable contributions from all the experts, in particular to those who have taken up responsibilities to lead Working Groups and Subgroups focused on specific tasks. This work has significantly advanced ICAO's efforts in aviation environmental protection.

Some key achievements in the CAEP 12 cycle

While making significant progress on issues where global expectations are high, CAEP continued to work on its “fundamentals”. Indeed, aircraft noise and local air quality remain key and limiting factors in airport areas. Operational improvements remain short-term levers accessible to all to reduce emissions, ensuring that in this global journey towards greening the aviation sector.

CAEP continued to contribute to the development of concrete tools to facilitate the implementation of solid action by aviation stakeholders worldwide. For example, on airports and operations, CAEP developed a wide range of materials³, such as the ICAO's Eco-Airport Toolkit e-collection⁴, providing practical and ready-to-use information on a wide range of topics related to airport infrastructure (water management, climate resilience, airport design). CAEP agreed that other technical materials may also be developed into new guidance material to States and aviation stakeholders in the future.

3 “Operational opportunities to reduce aircraft noise”, “Environmental metrics to relevance to the global aviation system”, “Climate change risk assessment, adaptation and resilience”, “Sustainable considerations for airport surface access, as part of the Eco-Airport Toolkit e-collection”, “Investigation on possible indicators for encroachment”

4 <https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx>

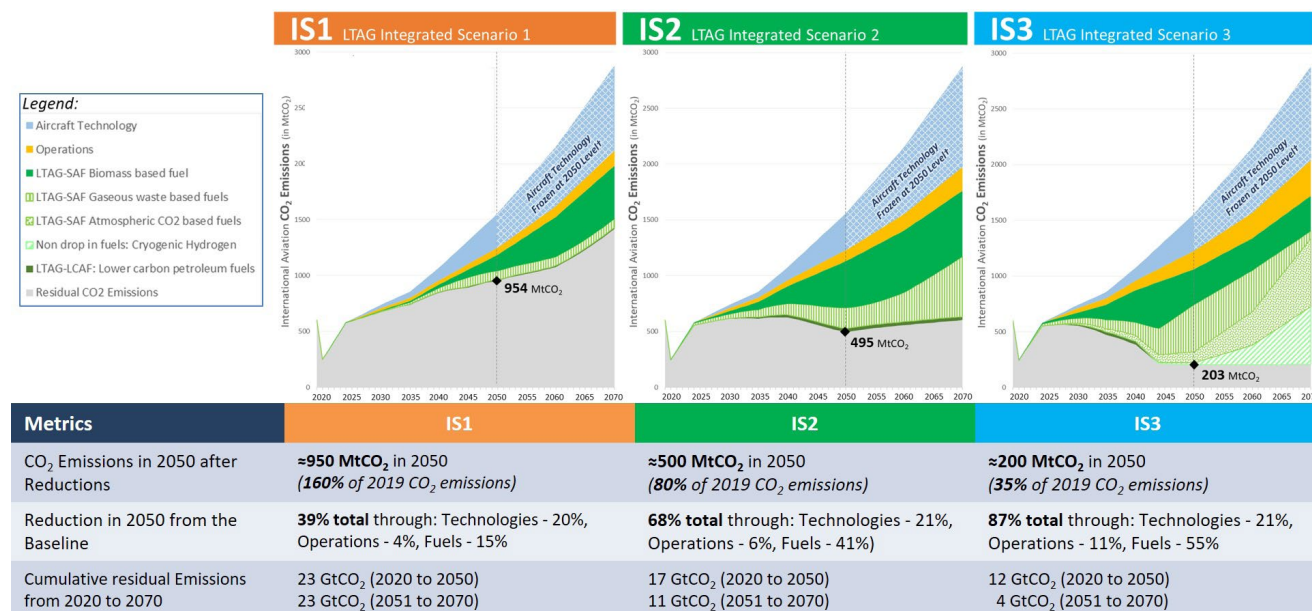


FIGURE 2: LTAG feasibility study results: reductions in CO₂ emissions from international aviation with the in-sector measures through 2050 and beyond for various scenarios (IS1-IS3).

As a result the CAEP/12 meeting agreed on making a total of 31 recommendations to ICAO Council, encompassing various standards, recommended practices, guidance materials and technical reports related to aviation environmental protection. Below please find a brief summary of the main outcomes of the CAEP/12 work.

Report on the feasibility of a long-term aspirational goal (LTAG)

CAEP unanimously adopted the technical report on the feasibility of an LTAG for international aviation CO₂ emissions, which describes the potential for substantial CO₂ reductions through the use of aviation in-sector measures. Three integrated scenarios were developed to cover a range of readiness, attainability, and aspiration. Figure 2 shows the scenario's outcomes, and the potential contributions from aircraft technology, operations, and fuels. For more details on this work, refer to the dedicated articles in Chapter 4 and in the LTAG Supplement of the Report.

Aircraft Emissions

CAEP agreed to recommend amendments to Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions, Annex 16, Volume III — Aeroplane CO₂ Emissions and their associated Environmental Technical Manuals. CAEP

also agreed to proposed amendments to the ICAO Doc 9889 - , including amendments related to the updated of information on aircraft nvPM emissions. More information is available in Chapter 3 and 5 of the Report.

Aircraft noise

CAEP delivered proposed amendments to Annex 16, Volume I, including new guidance material for measurement of helicopter hover noise. CAEP also recommended the publication of a report on Noise Technology Research for Fixed Wing Aircraft and agreed on future work on noise certification approaches for Emerging Technology Aircraft (ETA). More information is available in Chapter 2 of the Report.

Supersonic Aeroplanes

CAEP continued its work on Supersonic Transport Aircraft (SST) and approved the results of an Exploratory Study to better understand the environmental impacts resulting from the introduction of supersonic aircraft. CAEP agreed to develop Landing and Take-off Noise SARPs for Supersonic aeroplanes during the next cycle, as well as to update all elements of Annex 16, Volume II and ETM, Volume II, including the regulatory limits for modern supersonic engines (without afterburning technology) based on emissions data availability. More information is available in Chapter 2 of the Report.

Airports and operations

CAEP developed a wide range of materials related to airports and operations including 1) Operational Opportunities to Reduce Aircraft Noise; 2) Environmental Metrics of Relevance to the Global Aviation System; 3) Climate Change Risk Assessment, Adaptation and Resilience; 4) Sustainable Considerations for Airport Surface Access, as part of the Eco-Airport Toolkit e-collection⁵; and 5) Investigation on Possible Indicators for Encroachment. These are recommended to be published on the ICAO website, while the manual on Operational Opportunities to Reduce Aircraft Noise is recommended to be issued as an ICAO Document. More information is available in Chapter 6 of the Report.

CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation)

CAEP also agreed on amendments to the CORSIA SARPs, and its associated Environmental Technical Manual, in ensuring the smooth implementation of CORSIA. CAEP's regular updates to Council on CORSIA developments, such as COVID-19's impact on emissions, will also facilitate upcoming deliberations on CORSIA's periodic review. On sustainable and lower carbon aviation fuels, amendments to the ICAO documents⁶ which form part of the CORSIA Implementation Elements related to 'CORSIA Eligible Fuels', were also agreed by CAEP. The meeting also discussed the definition of a baseline for new entrants and agreed that there is a need to conduct further work on this item during the next CAEP/13 cycle. More information is available in Chapter 8 of the Report.

Sustainable and lower carbon aviation fuels

CAEP agreed to recommend amendments to four ICAO documents⁷ that are referenced in Annex 16, Volume IV and are part of the CORSIA Implementation Elements related to "CORSIA eligible fuels", including sustainability criteria and methodologies to calculate the life cycle emissions of CORSIA lower carbon aviation fuels (LCAF). In addition, CAEP also agreed on guidance material on potential policies and coordinated approaches for the deployment of Sustainable Aviation Fuels that could be used as a resource by Member States. More information is available in Chapter 7 of the Report.

Impacts and Science

CAEP developed and recommended the publication of three assessment reports on 1) the impacts of aviation NO_x emissions on air quality, human health and climate; 2) fuel composition effects on nvPM emissions; and 3) potential environmental impacts from supersonic aircraft. CAEP also agreed on a White Paper on non-acoustic factors related to community annoyance. More information is available in Chapter 2 and 3 of the Report.

Conclusion

These developments are indicative of the valuable contributions from all CAEP Members, Observers and nominated technical experts in advancing ICAO's efforts in aviation environmental protection. Moving into the new CAEP/13 cycle, CAEP will continue to monitor and review environmental issues associated with aviation, in order to continue to provide robust and technically sound recommendations to the ICAO Council.

⁵ <https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx>

⁶ ICAO document "Default life cycle emission values for CORSIA eligible fuels", ICAO document "CORSIA methodologies for calculating actual life cycle emissions values", ICAO document "CORSIA sustainability criteria for CORSIA eligible fuels", ICAO document on "CORSIA eligibility framework and requirements for sustainability certification schemes (SCS)"

⁷ ICAO document "Default life cycle emission values for CORSIA eligible fuels", ICAO document "CORSIA methodologies for calculating actual life cycle emissions values", ICAO document "CORSIA sustainability criteria for CORSIA eligible fuels", ICAO document on "CORSIA eligibility framework and requirements for sustainability certification schemes (SCS)"

Environmental Trends in Aviation to 2050

By Gregg G. Fleming (USA DOT Volpe), Ivan de Lépinay (EU EASA), and Roger Schaufele (USA FAA)¹

Background

At the end of each three-year work cycle, the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) conducts an assessment of future environmental trends in aviation that includes:

- Aircraft engine Greenhouse Gas (GHG) emissions that affect the global climate.
- Aircraft noise.
- Aircraft engine emissions that affect Local Air Quality (LAQ).

The environmental trends discussed in this chapter are based on data from the latest CAEP/12 air travel mid demand forecast. The forecast utilized a base year of 2018 and future years of 2019, 2020, 2024, 2030, 2040, and 2050. The passenger and cargo forecasts were derived from ICAO's Long-Term Traffic Forecast (LTF), while the business jet forecast was developed from a new International Business Aviation Council (IBAC) aircraft delivery forecast. COVID-19 forecast scenarios were developed to capture the possible trajectories of the aviation industry as it moves out of the pandemic-driven downturn.

Data presented for years earlier than 2018 are reproduced from prior CAEP trends assessments. Trends results presented for fuel burn and emissions represent international aviation only, while noise results include both domestic and international operations. In 2018, approximately 65% of global aviation fuel consumption was from international aviation. According to the CAEP/12 traffic demand forecast,

this proportion is expected to remain relatively stable out to 2050.

The trends presented here were developed in the context of a longer-term view, assuming no airport infrastructure or airspace operational constraints. However, these trends may be substantially impacted by a wide range of factors, including fluctuations in fuel prices, uptake of alternative jet fuels (AJF), and global economic conditions, including the COVID-19 recovery.

Three environmental models contributed results to the fuel burn and emissions trends assessment: US Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT), EUROCONTROL's IMPACT, and Manchester Metropolitan University's Future Civil Aviation Scenario Software Tool (FAST). In addition, the US Environmental Protection Agency's (EPA) fuel burn and emissions model provided results as a cross-check with the three CAEP-approved models.

Three models contributed results to the noise trends assessment: US FAA's AEDT, EC/EASA/EUROCONTROL's SysTem for AirPort noise Exposure Studies (STAPES), and UK Civil Aviation Authority's (CAA) Aircraft Noise Contour Model (ANCON).

Two distinct fleet evolution models were used: FAA's FleetBuilder (FB) and the EC/EASA/EUROCONTROL's Aircraft Assignment Tool (AAT). The AEDT, FAST and EPA results were based on FB operations, while the IMPACT estimates were based on AAT operations. Key databases

¹ Gregg G. Fleming and Ivan de Lépinay are Co-Rapporteurs of the Modelling and Databases Group (MDG) of the ICAO Council's Committee on Aviation Environmental Protection (CAEP). Roger Schaufele is Co-Rapporteur of the Forecasting and Economic Analysis Support Group (FESG).

utilized in this assessment include CAEP's Global Operations, Fleet, and Airports Databases.

During the CAEP/12 work cycle, a comprehensive introduction to the forecasting and environmental trends assessment process was developed and is available for reference at ICAO public website².

Traffic Demand Forecasts and COVID-19

The CAEP/12 environmental trends traffic demand forecast has a 2018 base year and 32-year forecast horizon through 2050. The outbreak of COVID-19 in early 2020 meant that the normal forecast development process had to be altered to account for the near- and long-term effects of the pandemic on the global economy and commercial aviation. Acknowledging the uncertainty surrounding the economic effects of the pandemic, a series of COVID-19 traffic demand forecast scenarios were developed to represent a plausible range of recoveries for the aviation industry.

An initial step in the COVID-19 forecast process was the development of a series of guiding assumptions by the Forecasting and Economic Analysis Support Group (FESG) forecasting and aviation economics experts on how the industry would transition out of the abrupt initial downturn. These assumptions included: expectations by market type—passenger, cargo and business jet—for the duration of the initial downturn in demand; the short-run return to 2019, pre-pandemic, demand levels; anticipated timing of a COVID-19 vaccine announcement and availability for wide-spread use; and any potential longer-term effects, such as on business travel demand due to the pandemic related uptake in remote working and video conferencing.

For the COVID-19 forecast scenarios, the ICAO LTF model was updated with macroeconomic forecast information incorporating the anticipated economic effects of the pandemic. Available historical data was used to inform the decline in demand in 2020 along with assumptions and industry input used to calibrate the point at which

each market is expected to return to their 2019 levels of activity, after which the updated LTF forecasts guide the longer-term trends.³ Business jet forecasts were updated to incorporate the effects of COVID-19 in a similar manner.

The **passenger market** COVID-19 traffic demand scenarios show the sharp decline in 2020 due to the pandemic (estimated 68% decline in global revenue passenger kilometres (RPKs)) (Figure 1-1). The near-term recovery trajectories have global traffic demand returning to 2019 levels in 2023, 2024 and 2027 for the high, mid, and low scenarios, respectively. Over the 32-year forecast period, the COVID-19 mid forecast has revenue passenger kilometres growing at an annual average rate of 3.6% for both global and international demand (compared with 4.2% for global and 4.3% for international RPKs from the pre-COVID-19 LTF mid outlook).

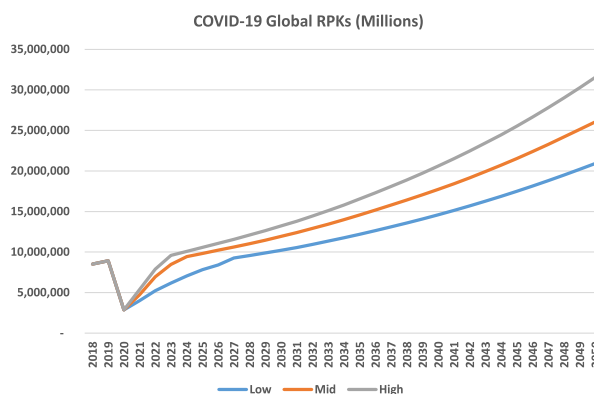


FIGURE 1-1: COVID-19 Global Passenger Forecast Scenarios

The **cargo market** COVID-19 forecast shows a decline in global demand of around 10% in 2020 with a return to 2019 levels by 2022 in the mid scenario (2021 in the high and 2023 in the low) (Figure 1-2). Over the course of the 32-year forecast global freight tonne kilometres (FTKs) are expected to grow by 3.5% per annum (unchanged from the pre-COVID-19 LTF outlook), with international FTKs increasing by 3.4% per annum (compared with 3.5% in the pre-COVID-19 outlook).

² ICAO environmental trends assessment: <https://www.icao.int/environmental-protection/Pages/Environmental-Trends.aspx>

³ The ICAO COVID-19 LTF forecasts are published here: <https://www.icao.int/sustainability/Pages/Post-Covid-Forecasts-Scenarios.aspx>

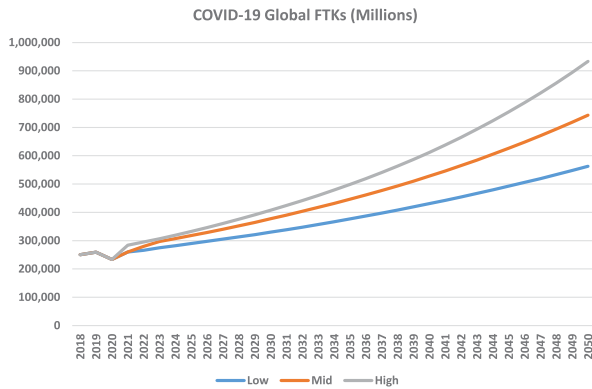


FIGURE 1-2: COVID-19 Global Cargo Forecast Scenarios

Business Jet operations experienced an estimated 21% decline in 2020 and are expected to return to 2019 levels in 2022, 2023 and 2024 for the high, mid, and low scenarios, respectively (Figure 1-3). Over the 32-year forecast period global operations are expected to register annual average growth at 2.7% for the mid outlook, compared with 2.9% for the pre-COVID-19 outlook.

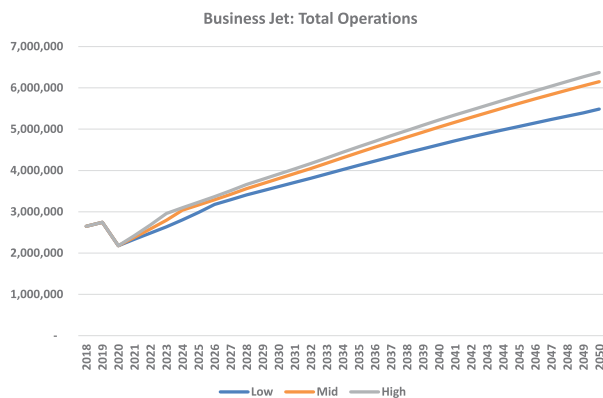


FIGURE 1-3: COVID-19 Global Business Jet Forecast Scenarios

Acknowledging the rapidly changing nature of the pandemic, at the end of CAEP/12 a qualitative review of the COVID-19 forecast scenarios was undertaken. The review concluded that the COVID-19 forecast scenarios used for trends remained reasonable when compared with more recent historical and forecast data. Over the near-term, and back to 2019 levels, the passenger RPK outlook was found to be broadly consistent with the International Air Transport Association (IATA) July 2021 forecast⁴. For cargo demand, while the actual recovery in FTKs outpaced the expected return to 2019 levels, the difference was not deemed significant.

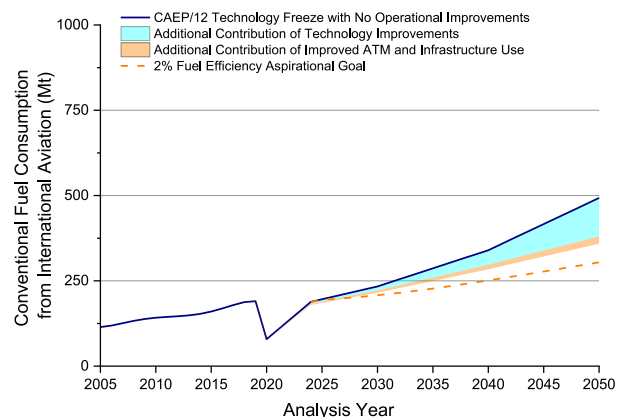
Finally, a quicker than expected recovery in the business jet market suggested that the high forecast scenario may better align with actual data, but the possibility of a moderation in leisure travellers using business jets may slow the recovery path. However, this qualitative assessment did not consider the effects of the recent Ukrainian crisis, which will need to be undertaken as part of the CAEP/13 work cycle.

Trends in Emissions that Affect Global Climate

Table 1-1 below summarizes the aircraft technology and operational scenarios developed for the assessment of trends for fuel burn and aircraft emissions that affect the global climate. The CAEP/12 trends assessment included full-flight fuel consumption, carbon dioxide (CO₂), nitrogen oxides (NO_x), and non-volatile particulate matter (nvPM).

Trends in Full-Flight Fuel Burn and CO₂ Emissions

Figure 1-4 shows results for full-flight (i.e., from departure gate to arrival gate) fuel burn for international aviation from 2005 to 2050. The analysis considered the impacts of aircraft technology, improved air traffic management, and infrastructure use (i.e., operational improvements) on fuel consumption. The dashed line in the figure illustrates fuel burn that would be expected if ICAO's 2% annual fuel efficiency aspirational goal were to be achieved.



Note: Results were modelled for 2005, 2006, 2010, 2015 (Prior CAEP work cycles), 2018, 2019, 2020, 2024, 2030, 2040, and 2050 (CAEP/12).

FIGURE 1-4: Fuel Burn from International Aviation, 2005 to 2050.

4 IATA provided FESG with data from their July 2021 forecast for the qualitative review.

Scenario	Aircraft Technology: Per annum fuel burn improvements for fleet entering after 2018	Aircraft Technology: Emissions Improvements against CAEP/7 IE NOx Goal	Operational Improvements
Fuel 1 - Tech Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
Fuel 2 - Moderate Aircraft Technology and CAEP/12 WG2 Conservative Operational Improvements	0.96 percent 2018 to 2050	NA	Migration to the latest operational initiatives (e.g., NextGen and SESAR) Fleet-wide CAEP/12 WG2 <u>conservative</u> operational improvements by route group
Fuel 3 - Advanced Aircraft Technology and CAEP/12 WG2 Medium Operational Improvements	1.16 percent 2018 to 2050	NA	Migration to the latest operational initiatives (e.g., NextGen and SESAR) Fleet-wide CAEP/12 WG2 <u>medium</u> operational improvements by route group
Fuel 4 - Independent Expert Integrated Review (IEIR) Technology and CAEP/12 WG2 High Operational Improvements	IEIR per annum (varies by aircraft type) 2018 to 2050	NA	Migration to the latest operational initiatives (e.g., NextGen and SESAR) Fleet-wide CAEP/12 WG2 <u>high</u> improvements by route group
NOx 1 - Technology Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
NOx 2 - Moderate Aircraft Technology, CAEP/12 WG2 Medium Operational, and 50% CAEP/7 IE Emissions Improvements	<u>Moderate</u> aircraft technology improvements	50 percent of CAEP/7 IE NOx Goal met by 2036 with no further improvement thereafter	Fleet-wide CAEP/12 WG2 <u>medium</u> operational improvements by route group
NOx 3 - Advanced Aircraft Technology, CAEP/12 WG2 High Operational, and 100% CAEP/7 IE Emissions Improvements	<u>Advanced</u> aircraft technology improvements	100 percent of CAEP/7 IE NOx Goal met by 2036 with no further improvement thereafter	Fleet-wide CAEP/12 WG2 <u>high</u> operational improvements by route group
nvPM 1 - Technology Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
nvPM 2 - Technology Freeze with CAEP/12 WG2 High Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	Fleet-wide CAEP/12 WG2 <u>high</u> operational improvements by route group

TABLE 1-1: Fuel Burn and GHG Emissions - Technology and Operational Improvement Scenarios.

For the year 2050, assuming Independent Expert Integrated Review (IEIR) technology with high operational improvements (Fuel Scenario 4), aircraft technology and operational improvements provide reductions in conventional fuel burn from international aviation of 113 million metric tonnes (Mt; 1kg x 10⁹) and 22 Mt, respectively, for a total reduction of 135 Mt out of 493 Mt under technology freeze (Fuel Scenario 1). Similarly for global aviation, aircraft technology provides a reduction of 177 Mt and operations provides an additional reduction of 38 Mt, for a total of 215 Mt out of 793 Mt under the technology freeze scenario.

Even under the most aggressive CAEP/12 fuel burn technology improvements scenario (Fuel Scenario 4), the average fuel efficiency improvement (2015-2050) is 1.53% per annum. This efficiency improvement falls short of the ICAO's 2% aspirational goal for international aviation fuel burn but is slightly higher than the 1.37% per annum efficiency computed in CAEP/11 for the same time period. Overall, technology and operational improvements result in roughly a 27% reduction in fuel burn for both international and global aviation in 2050 for the CAEP/12 IEIR scenario (Fuel Scenario 4).

Figure 1-5 depicts the uncertainties associated with the forecasted demand, which is the largest contributor to uncertainty in fuel consumption. The uncertainty in forecasted demand is roughly twice the size of the range in technology and operational improvements combined. Despite the range of uncertainties, the CAEP/12 forecast traffic trends are generally consistent with other published aviation forecasts. The forecast commercial market trend, which is for revenue tonne kilometres (RTK), shows a 20-year (2018-2038) compound average annual growth rate (CAGR) of 3.3%. By way of comparison, using revenue passenger kilometres (RPK) for all traffic as the forecast measurement, Boeing, Airbus and Embraer forecasts released in 2021 have 20-year (2019-2040) CAGRs of 4.0%, 3.9%, and 3.3%, respectively. The CAEP/12 RPK 20-year forecast (2018-2038) has a CAGR of 3.3%.

The delta between the CAEP/11 and CAEP/12 GHG trends baselines in 2040 is approximately 15%. Most of this variation can be attributed to differences between the central demand forecasts. Specifically, the CAEP/11 (2015) forecast was produced during a period of steady global economic growth with the expectation that this expansion would continue with global gross domestic product (GDP) growing at an annual rate of 2.8% over the ten years from 2015 to 2025 and 2.6% over the thirty-year period from 2015 to 2045. In contrast, the CAEP/12 forecast includes the effect of the COVID-19 pandemic both on the economic recovery path from 2020 and the long-term outlook and has a more tepid ten-year annual global GDP growth rate of 2.4% for 2018-2028 and 2.5% over the thirty-two-year period from 2018-2050.

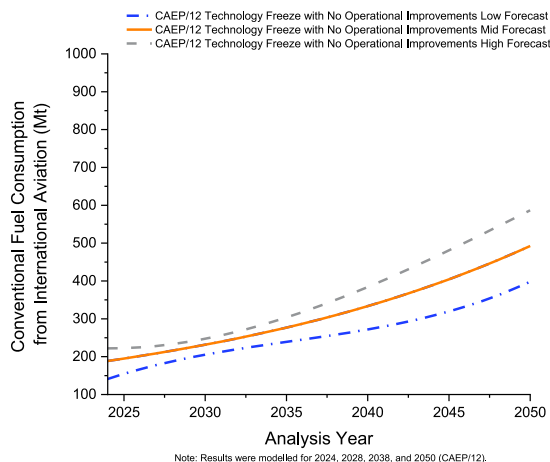


FIGURE 1-5: Range of Uncertainties Associated with Demand Forecast, 2024 to 2050.

Figure 1-6 presents full-flight CO₂ emissions for international aviation from 2005 to 2050; CO₂ emissions are based solely on the combustion of jet fuel, assuming that 1 kg of jet fuel burned generates 3.16 kg of CO₂. As with the previous fuel burn analysis, this CO₂ analysis considers the contribution of aircraft technology, improved air traffic management, and infrastructure use (operational improvements). Although not displayed here, the demand uncertainty effect on the fuel burn calculations shown in Figure 1-5 has a similar effect on the CO₂ results.

Considering the range of fuel consumption scenarios (Table 1-1), the difference between the highest anticipated fuel consumption in 2019 (Fuel Scenario 1) and the lowest anticipated fuel consumption in 2050 (Fuel Scenario 4) results in a minimum CO₂ emission gap of 532 Mt in 2050 compared to 2019 emissions.

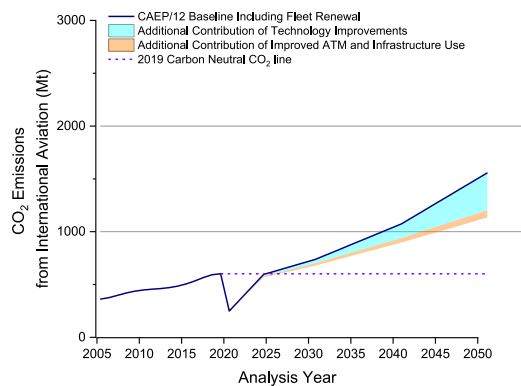
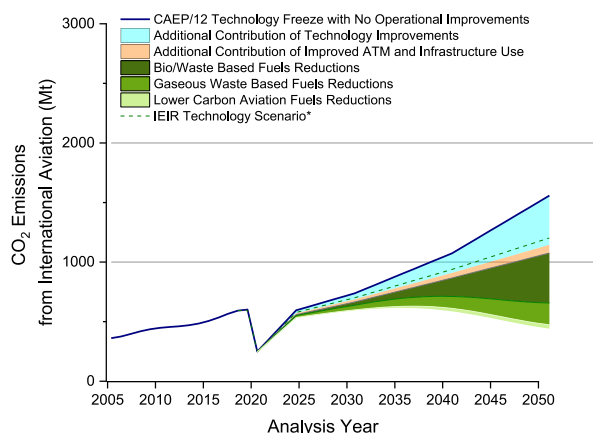


FIGURE 1-6: CO₂ Emissions from International Aviation, 2005 to 2050.

Contribution of Alternative Fuels to Fuel Consumption and CO₂ Trends

Figure 1-7 presents the net CO₂ emissions from international aviation, from 2005 to 2050, including alternative jet fuels lifecycle CO₂ emissions reductions. This portion of the CAEP/12 trends assessment work leveraged work undertaken by the CAEP Fuels Task Group (FTG), which conducted analyses to provide estimates of future bio- and waste-based sustainable aviation fuel (SAF-BIO/WASTE) production potential and associated lifecycle GHG impacts. It also drew from the Long-Term Aspirational Goal Task Group (LTAG-TG) analysis to extend SAF-BIO/WASTE projections and develop projections for additional SAF from waste CO₂ (SAF-CO₂) and for fossil-based lower-carbon aviation fuels (LCAF).

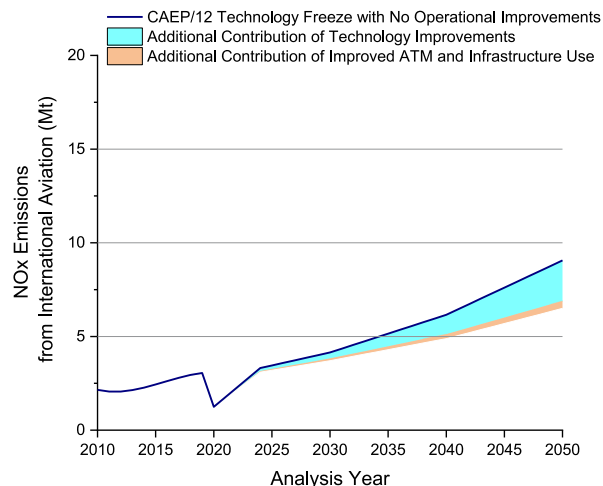


*Dashed line in technology contribution wedge represents the CAEP/11 Independent Expert Integrated Review (IEIR) Technology Scenario. Note: Results were modelled for 2005, 2006, 2010, 2015 (Prior CAEP work cycles), 2018, 2019, 2020, 2024, 2030, 2040, and 2050 (CAEP/12).

FIGURE 1-7: Net CO₂ Emissions from International Aviation, 2005 to 2050, Including Alternative Jet Fuels Lifecycle CO₂ Emissions Reductions (Based on 3.16 kg of CO₂ per 1 kg of fuel burn).

The LTAG-TG developed three future fuels scenarios. Integrated Scenario 2 (IS2), which is approximately the mid-point of the three scenarios, was used for the CAEP/12 trends analysis. IS2 assumes faster rollout of future technology and operational efficiency and assumes that electrification of ground transport leads to increased availability of SAF. It also assumes that waste gases are widely used for SAF production, blue/green hydrogen is available for LCAF production, and carbon capture, utilization, and storage (CCUS) is in use. IS2 does not include the use of cryogenic hydrogen or atmospheric CO₂ via direct air capture (DAC).

Potential future production of LCAF and SAF-CO₂ were also estimated by the LTAG-TG for use in the trends analysis. SAF-CO₂ projections were based on waste CO₂ availability for high-purity sources (ammonia and ethanol production). Other sources including electricity, iron, steel, and cement production and DAC of CO₂ were assumed to be too costly. LCAF projections were based on fuel conversion technology availability to mitigate CO₂ emissions during LCAF production, including carbon capture, renewable hydrogen and energy use, avoiding venting and fugitives, and reducing flaring, as well as crude oil carbon intensity. The final values used in the trends assessment include total global production and an average Lifecycle Analysis (LCA) value for three fuel types (SAF-BIO/WASTE, SAF-CO₂, and LCAF). The LCA values were not intended to be applied separately to regional forecasts.



Note: Results were modelled for 2010, 2015 (Prior CAEP work cycles), 2018, 2020, 2024, 2030, 2040, and 2050 (CAEP/12)

FIGURE 1-8: Full-Flight NO_x Emissions from International Aviation, 2010 to 2050.

To calculate the “green wedges” in Figure 1-7, international market shares of each fuel type were applied to fuel demand volumes to generate CO₂ reductions from SAF-BIO/WASTE, SAF-CO₂, and LCAF. LTAG-TG provided fuel inputs for 2035 and 2050; for the purposes of the trends assessment, linear ramp-up functions were used to estimate adoption of these fuels between 2020 and 2035 and between 2035 and 2050, assuming replacement of 0% of total fuel demand in 2020 and 100% replacement in 2050. In addition to the 27% reduction in CO₂ emissions provided by technology and operational improvements in 2050, these fuels may provide an additional 56% reduction in net life-cycle CO₂ associated with international aviation (Fuel Scenario 4).

Depending on the SAF type, level of maturity and available technologies, the investment required to achieve the projected fuel volumes range from 6 b\$ to 26 b\$ per million tonnes of fuel per year (in 2020 US dollars). The cost abatement for implementing lower carbon technologies for LCAF production would be approximately \$200/tCO₂ in 2050.

Trends in Full-Flight NO_x and nvPM Emissions

Trends in full-flight NO_x emissions from international aviation are shown in Figure 1-8. In 2018, NO_x emissions were calculated as 2.94 Mt. In 2050, NO_x emissions range

from 6.50 Mt under Scenario 3 to 9.06 Mt under Scenario 1, representing up to a 2.56 Mt (4.06 Mt for global aviation) reduction with technology and operational improvements.

Figure 1-9 shows trends in nvPM mass emissions from international aviation. Operational improvements (nvPM Scenario 2) are expected to result in 465 tonnes and 895 tonnes reduction of nvPM mass emissions for international and global aviation, respectively. This amounts to a roughly 5% reduction from the baseline (nvPM Scenario 1).

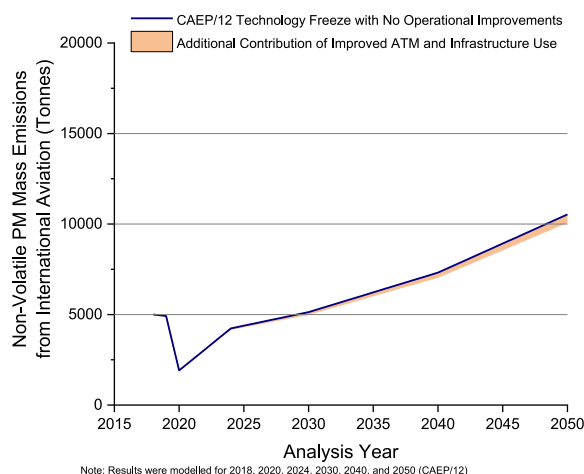


FIGURE 1-9: Full-Flight nvPM Mass Emissions from International Aviation, 2018 to 2050.

Trends in Aircraft Noise

Four scenarios were developed for the noise trends assessment, resulting in the total contour area and population inside the yearly average day-night level (DNL) contours (55, 60, and 65 dB) for 319 global airports, representing approximately 80% of the global traffic. Population counts for airports in the US, Europe, and Brazil used the latest available local census data. For all other airports, the NASA Gridded Population of the World, version 4 (GPW v4) was used.

Scenario 1 (CAEP/12 Baseline) assumes no further aircraft technology or operational improvements after 2018. Scenario 2 includes noise technology improvements of 0.1 EPNdB per annum for all aircraft entering the fleet from 2019 to 2050. Scenario 3 was meant to capture a COVID-19 delay, with no noise technology improvements for aircraft entering the fleet from 2019 to 2023, and technology improvements of 0.2 EPNdB per annum for

all aircraft entering the fleet from 2024 to 2050. Scenario 4 includes noise technology improvements of 0.2 EPNdB per annum for all aircraft entering the fleet from 2019 to 2050. For Scenarios 2, 3, and 4, an additional moderate operational improvement of 2% is applied for population inside DNL 55, 60, and 65 contours.

Figure 1-10 provides results for the total global 55 DNL contour area (i.e., for 319 airports) for 2018, 2019, 2020, 2024, 2028, 2038 and 2050 for the four scenarios. Historical data modelled in the prior CAEP/11 work cycle is also shown for 2015. The 2018 contour area is 16,486 square-km. This value decreases to 9,451 square-km in 2020 due to the COVID-19 downturn and increases to 15,530 square-km by 2024. In 2050 the technology freeze (Scenario 1) total global contour area is 31,407 square-km and decreases to 15,196 square-km and 21,570 square-km, with advanced and low technology improvements, respectively. The total population inside the 55 DNL contours was estimated to 37 million in 2018 and could range from 76 million under Scenario 1 to 38 million under Scenario 4 in 2050; this is under the assumption that population density around airports does not vary in time.

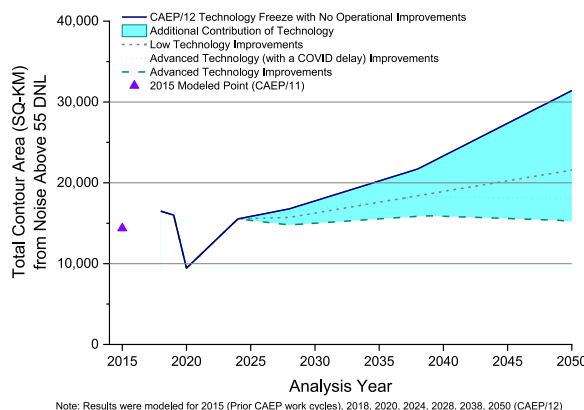


FIGURE 1-10: Total Aircraft Noise Contour Area Above 55 dB DNL for 319 Airports (km²), 2015 to 2050

Trends in Landing and Takeoff (LTO) Emissions

A range of scenarios was also developed for evaluation of aircraft emissions that occur below 3,000 feet above ground level; namely NO_x and total (volatile and non-volatile) particulate matter (PM). The NO_x and PM scenarios for LTO are equivalent to those used in the full-flight trends assessment (Table 1-1).

NOx emissions below 3000 feet from international aviation are shown in Figure 1-11. In 2050, technology improvements are expected to provide up to 0.17 and 0.38 Mt of reductions in NOx emissions for international and global aviation, respectively. Operational improvements are smaller than those that could be realized by technology, namely additional reductions of up to 0.03 and 0.08 Mt in 2050 for international and global aviation, respectively.

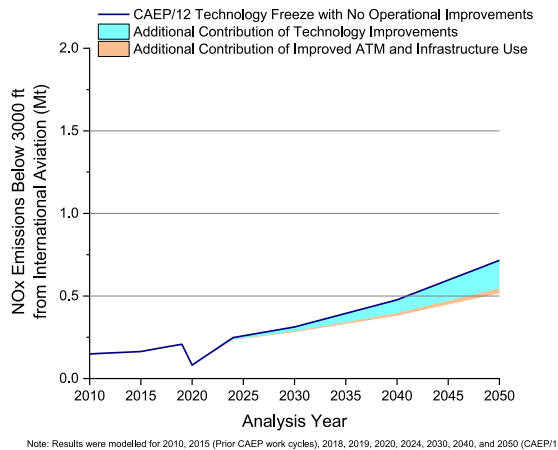


FIGURE 1-11: NOx Emissions below 3,000 Feet - International Aviation, 2010 to 2050.

Non-volatile PM emissions below 3000 feet from international aviation are shown in Figure 1-12. In 2050, operational improvements may provide additional reductions in nvPM emissions of up to 50 tonnes and 140 tonnes for international and global aviation, respectively (about 5% reduction). Total PM below 3000 feet from international aviation were estimated to 1360 tonnes in 2018 and could range from 3220 tonnes to 3070 tonnes in 2050.

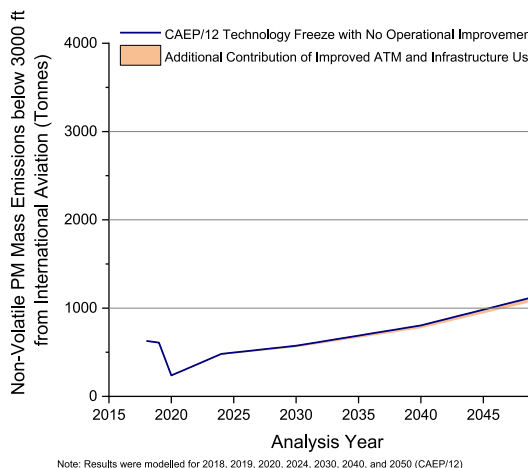


FIGURE 1-12: Non-volatile PM Emissions Below 3,000 feet —International Aviation, 2018 to 2050.

Conclusion

Full-flight and LTO emissions from international aviation are expected to increase through 2050 by 2 to 4 times 2018 levels, depending on the pollutant (CO₂, NOx, nvPM, or PM) and the analysis scenario. Specifically for the full flight technology freeze scenario (Fuel Scenario 1), CO₂, NOx, and nvPM are expected to increase by a factor of 2.6, 3.2 and 2.0, respectively. For LTO emissions (Fuel Scenario 1), NOx, PM and nvPM are expected to increase by a factor of 3.8, 2.4 and 1.8, respectively. These factors are generally consistent for both international and global aviation. The total DNL 55 noise contour area at the 319 airports in the analysis could stabilize after 2025 under an advanced technology improvements scenario.

In 2018, international aviation consumed approximately 188 Mt of fuel, resulting in 593 Mt of CO₂ emissions. By 2050, fuel consumption is projected to increase 1.9 to 2.6 times the 2018 value, while revenue tonne kilometres (RTK) are expected to increase 3 times under the most recent forecasts (the 32-year [2018-2050] compound annual growth rate for RTKs is 3.5%). Assuming the most optimistic fuel technology improvements (Fuel Scenario 4), international fuel efficiency (volume of fuel per RTK) is expected to improve at an average rate of 1.53% per annum (2015-2050). This indicates that ICAO's aspirational goal of 2% per annum fuel efficiency improvement is unlikely to be met by 2050. Aircraft technology, ATM and AJF combined have the potential to curb the growth in net CO₂ emissions from aviation in the longer-term (beginning in 2035), but this will likely necessitate significant investments. Furthermore, uncertainties associated with future aviation demand remain high.

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Boosting the adoption of green innovation for aviation

By ICAO Secretariat and the Solar Impulse Foundation

ICAO embraces innovation

The First Industrial Revolution used power from water and steam to mechanize the production of goods. The Second Industrial Revolution harnessed electric power to turn it into mass production. The Third one used electronics and information technology to unleash the full potential of automation.

Today, a Fourth Industrial Revolution is blurring the boundaries between the physical, digital, and biological spheres of innovation. It is marked by emerging advancements and breakthroughs in a number of fields, including robotics, artificial intelligence, nanotechnology, biotechnology, internet, 3D printing, and transportation systems.

While previous industrial revolutions were characterized by a negative spill over on the environment in terms of pollution and climate change, the revolution we are

experiencing today is placed to offer a viable, sustainable, and environmentally friendly approach to industrialization, through the use renewable resources, new materials, and recyclable bio-based products. This approach, boosted by a post COVID19 green recovery, is key to promoting and enabling a full decarbonisation of the society.

The Fourth Industrial Revolution is paving the way for transformative changes happening at an unprecedented pace, and is completely reshaping the way we live, work, and interact. It is radically affecting almost every business sector and aviation - by nature an innovative industry - is no exemption.

On environmental protection, fast-paced innovative and green solutions in aviation are being pursued to decarbonize the sector. Various types of drop-in sustainable aviation fuels (SAF) are already available for use in aircraft, and further *CO₂ reductions are being pursued via new aircraft technologies and operational procedures.*



FIGURE 1: ICAO Tracker Tool



FIGURE 2: Freedom Pines: The home of the successful AtJ Pilot and LanzaJet's future AtJ Commercial Plant



FIGURE 3: Pipistrel Velis Electro earns first all-electric aircraft type certification



FIGURE 4: In March 2021, ZeroAvia launched the development programme for a 2MW hydrogen-electric powertrain for full-size regional aircraft



FIGURE 5: Lilium electric vertical take-off and landing jet



FIGURE 6: Otto Aviation Celera 500L laminar fuselage aircraft

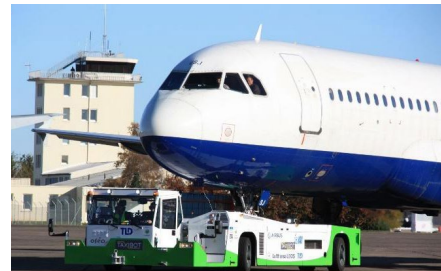


FIGURE 7: Taxibot

In the mid-to-long term, many innovations are looking into game-changing technologies including electric, hybrid and hydrogen-powered aircraft. ICAO has been tracking all these projects and developments under the ICAO Stocktaking Process¹, which has collected more than 100 existing and foreseen initiatives from aviation stakeholders.

A full overview of these initiatives can be found on the ICAO Tracker Tool², which is part of the ICAO Global Coalition for Sustainable Aviation³.

The tracker tools are organized in four main streams: Technology, Operations, Sustainable Aviation Fuels, and Net Zero Initiatives.

Some examples include:

- Several brand-new facilities being built around the world to produce next generation sustainable aviation fuels, for example by Shell, Fulcrum, LanzaJet, etc. **Figure 2**

- New production processes for Sustainable Aviation Fuels, such as the IHI Corporation Algae-based fuels, and the Applied Research Associates (ARA) Catalytic hydrothermolysis fuels
- Pipistrel Velis Electro, the first electric aircraft to obtain a type certification by the European Union Aviation Safety Agency. **Figure 3**
- Zeroavia zero-emission flight powered by hydrogen **Figure 4**
- Various vertical take-off and landing (VTOL) projects, for example by Bell Nexus, E-Hang, Kitty Hawk, Lilium, Uber Elevate, Volocopter etc. **Figure 5**
- Otto Aviation Celera 500L laminar fuselage aircraft, characterized by lower fuel consumption and reduction in operating costs. **Figure 6**
- Taxibot, a semi-robotic hybrid vehicle made for towing an aircraft without the use of the aircraft's engines, allowing fuel savings during taxiing for up to 95%. **Figure 7**

The ICAO Global Innovation Symposiums⁴ also regularly features sessions entirely dedicated to green innovation.

¹ <https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx>

² <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>

³ <https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx>

⁴ <https://www.icao.tv/global-symposium-on-the-implementation-of-innovation-in-aviation>

Innovation is, at its core, about solving problems — and there are as many ways to innovate as there are associated challenges to solve.

Sustainable Aviation Fuels (SAF) is today a proved and promising technology, with one of the greatest potential to reduce the sector's CO₂ emissions (up to 80% aviation CO₂ on a life cycle basis), while still contributing to the social and economic pillars of sustainable development. SAF is a perfect example of innovation and technology that can be transferred to all States to unlock their potential to contribute to the reduction of international aviation CO₂ emissions while ensuring that No Country is Left Behind.

The challenge expended for the coming years associated with these fuels is be in terms of feedstock and processes used, and production capacity. While the number of facilities capable of producing SAF is growing exponentially around the world, there is still significant uncertainty on the share of this capacity that can be directed to aviation, compared to fuels produced for other sectors of the global economy. The price gap with conventional fuels, coupled with policy incentives, also represent key drivers for the full deployment of SAF, taking also into consideration that the recent fossil fuel prices have risen the economic case for diversification of aviation energy sources.

For electric aircraft, the main challenge is to increase the energy density of batteries, which would allow electric aircraft to be used on longer routes, with higher payload capacity. Other challenges include the necessary infrastructure to recharge aeroplanes, the disposal of exhausted batteries and electronic components, as well as ensuring that the electricity used is generated from environmentally-friendly sources and processes.

Similar challenges surround the broader adoption of hydrogen to power aircraft, including storage, distribution, and clean sources of energy for its production. In addition, the production of green hydrogen at scale remains the biggest challenge to be addressed.

Regulatory challenges also need to be overcome in order to gradually introduce innovation and disruptive technologies in a manner which ensures that aviation retains the confidence of the public as the safest, most efficient, and most reliable mode of transport.

The capacity of the aviation community to face the challenges and address them efficiently stands with the fact that it has always endeavored to find global solutions through ingenuity and interdisciplinary cooperation, involving a variety of stakeholders, and ensuring that sustainability is maintained throughout the full lifecycle of the aircraft production and operation.

In 2014 Solar Impulse made aviation history when it completed the longest solo solar-powered flight ever achieved without fuel. The revolutionary plane flew around 40 000 km in 17 months, including one leg that lasted five days non-stop, using only the energy of the sun. The vision of the Solar Impulse project initiator Bertrand Piccard was to embrace clean technologies and energy efficiency to explore the unknown, while providing a benefit for the whole world. Together with co-founder and CEO André Borschberg, he made that a reality, looking beyond the realm of aviation to find the solutions they needed. While many doubts were initially raised on the feasibility of this project, its full success was the feat of visionary imagination, inspiration, and technical innovation.

Insights from the Solar Impulse Foundation

When Dr. Bertrand Piccard completed the first ever solar-powered flight around the world in July 2016, he emphasised that Solar Impulse had not been built to carry passengers, but to carry a message: that clean technologies exist today that can achieve more than we thought possible just a few short years ago, and help us to improve quality of life on earth. Further, the wide implementation of these solutions will be a fundamental driver of the economy of the 21st century, an economy based on efficient use of energy and resources and cleaner modes of production. By doing this across all sectors, the pilots envisioned that we can protect natural resources and improve the quality of life on Earth.

The Solar Impulse Efficient Solutions Label

To this end, Bertrand Piccard set out to identify these solutions, across multiple themes: energy, construction, mobility, freight, industry, pollution and waste management, and food & agriculture. The innovators behind these



FIGURE 8: Solar Impulse

solutions are invited to submit their solution for assessment by a community of experts, with those meeting criteria thereby receiving the *Solar Impulse Efficient Solutions Label*. As of early 2022, the Foundation had already identified some 1300 solutions, and all of them can be discovered and filtered on the entirely open Solutions Explorer that has been launched.

The Solar Impulse Foundation seeks to support these labelled solutions in various ways. This includes finding opportunities to engage with potential clients through events or direct matchmaking. The Foundation also seeks to shine a light on their activities through communications platforms and through advocacy work. It calls on policy makers to put in place regulations - such as more stringent energy efficiency requirements - that recognize the value of solutions and will draw them to market.

Lastly, the Foundation has recently launched two investments funds with its partners BNP Paribas for venture capital, and Rothschild & ALIAD for buyout growth. These two investment funds have already begun to select labelled solutions from the portfolio of the Solar Impulse Foundation which they are investigating further.

Considering its legacy of flying around the world in a solar plane, the Solar Impulse Foundation closely follows innovations emerging from the aviation industry. Air traffic

has a significant carbon footprint, and one that is only set to grow over the coming years. It is what is referred to as a “hard-to-decarbonise*” sector and thus it is a critical area to find ameliorations.

There are various measures that the Foundation supports so as to ensure aviation continues to evolve;

- Scaling up investment in the development and commercialization of Sustainable Aviation Fuels (SAF) and its infrastructure, thereby increasing its deployment over the 1% currently produced.
- Putting a price on carbon in the form of an eco-tax (collected by governments) on airline tickets as opposed to offsetting emissions (30-120\$ depending on final destination). The revenue from the tax would have to be spent on clean forms of transport.
- Massive investment from governments in technologies and infrastructure that can speed up the uptake of alternative propulsion, thus investing in storage and production of energy (electricity, hydrogen) for use in aircraft.

Partnership with Air France

The Solar Impulse Foundation seeks to partner with industry - including those with some of the most challenging sectors - to aid them in the ecological transition. With this

in mind, a partnership with Air France was established in 2019 to support the airline in this transition, to better understand the drivers and to inspire a way forward for the entire industry. Ecological and environmental issues have been a core concern for the airline for many years⁵.

With Air France, the innovation research is focused on 6 leverages covering a very broad field:

- The carbon footprint
- Energy efficiency
- Noise pollution
- Waste Reduction
- Ground Operations
- Future aviation and new energies

The outcome of this collaboration with Air France is reflected in a specific platform on the Foundation's website. Several dozen solutions have already been labelled in this "Cleaner Aviation"⁶ category. These solutions are aimed at the aviation industry in general and are intended to be disseminated for the benefit of the entire industry. Pursuing this engagement towards a more sustainable and virtuous aviation model calls for a collective and cross-functional commitment from all stakeholders. Several of these solutions have been adopted by Air France, in the areas of flight operations, ground operations, cargo or maintenance.

The platform

The Foundation's aviation platform shows how solutions that can be implemented today can drastically reduce the environmental impact of the sector while still being profitable for the users.

- A major leverage for cleaner aviation that can be deployed quickly is alternative fuels. For this reason, several SAF solutions have been labelled by the Solar Impulse Foundation, including eFuels, such as Synhelion's, SAF+ and Carbon recycling from Lanzatech.
- For the ground operations leverage for instance, the Smart Airport System (SAS) company has three

solutions labelled by the Solar Impulse Foundation. Engine OFF, also known as the Taxibot®, allows aircraft to be towed with the engine shut down, thus drastically reducing fuel consumption. The APU OFF solution, as its name indicates, allows the aircraft's auxiliary engine to be turned off during parking while maintaining the necessary electrical power supply. TractEasy is an autonomous electric baggage tractor that allows operators to save on operating costs while reducing their environmental impact. Maintenance is also a key element of ground operations and aircraft efficiency. Air France, for instance, has developed the predictive maintenance solution Prognos, which enables it to perform the required maintenance at the optimal time. This avoids grounding an aircraft and changing parts that are not necessary or, conversely, doing it too late and risking a failure that can be highly expensive. According to the company, this solution allows it to avoid up to 50% of cancellations and delays due to a malfunction. And since a breakdown often means chartering a replacement aircraft, the environmental benefit is also obvious.

- As flight efficiency is an essential leverage to reduce the impact of aviation, the Solar Impulse Foundation has several solutions in its portfolio of labelled solutions to optimize the flight. For instance, the Pancelab FPO solution gives recommendations to pilots to reduce flight consumption. DecisionX: Satavia's Netzero gives advice to the crew to avoid the formation of contrails in the atmosphere.
- Because of its history, the Solar Impulse Foundation also believes in the leverage that decarbonized energy represents for aviation, including electrification. As the technological spin off of the Solar Impulse project and its 16 years of experience in electric aviation, H55 supports the industry through certified electric propulsion solutions, integrating its technology in a range of applications suitable for both existing airplane designs and future concepts such as VTOLs and e-commuter aircraft. H55 develops patented, modular, and certified electric propulsion, battery storage and energy management systems. The

5 See here for more information: https://corporate.airfrance.com/sites/default/files/air_france_dossier_presse_uk_v3_modifs_21-04_0.pdf

6 solarimpulse.com/cleaner-aviation

company's products include: a fully integrated EPS system comprised of the motor, motor controller, and power controls, together with battery storage and energy management systems; and standalone battery packs and energy management systems. Its technology has been validated in 4 airplanes which have flown more than 1600 electric flight hours. Its EPS will be certified by the end of 2023.

The work of the Solar Impulse Foundation for cleaner aviation, supported by its partnership with Air France, shows that solutions exist. The Solar Impulse Foundation is constantly looking for new solutions to promote through its label and is calling on all innovators to reach out. Acting as a catalyst, the Solar Impulse Foundation's urges all stakeholders to implement solutions for an aviation industry at the forefront of the ecological transition. The pioneering spirit that has guided this industry from its very beginnings over a century ago must continue today by integrating the technologies that will enable it to perpetuate itself in a sustainable world.

Financing aviation decarbonisation

By Michael Halaby (MUFG Bank Ltd.)¹, Christian Pho Duc (SMARTENERGY Group AG)², and Clyde Hutchinson & Brian Marrinan (Team ABC)

Introduction

Aviation decarbonisation is associated with significant costs and investments for all stakeholders. For manufacturers, this implies research and development of aircraft with advanced tube-and-wing, or unconventional airframe/propulsion. Developments in Sustainable Aviation Fuel (SAF) beyond existing drop-in options towards hydrogen/electric powered aircraft will also require fundamental changes in airport infrastructure. To achieve these developments, massive public and private investments are required.

While access to finance is a critical factor in enabling the aviation sector to decarbonise, the market conditions driven by the COVID-19 outbreak, coupled with growing levels of sustainability ambition from States also bring about a unique set of challenges and opportunities.

Financial stakeholders are looking closely at the opportunities and taking action. This article provides perspectives from different but complementary private financiers.

Perspectives from large private banks, by Michael Halaby

Aviation remains one industry that is difficult to decarbonise.

Aviation is a capital-intensive industry in which commercial aircraft cost anywhere from single digit millions up to nearly USD200 million. As such, most airlines and aircraft leasing companies require outside financing to acquire

aircraft. These funds will generally come from equity and debt investors as well as from lenders. Market participants believe, despite Environmental, Social, and Governance (ESG) concerns over aviation, that the sector will continue to grow for the next several decades due to a rising middle class and the increasing inter-connectivity of our world. Boeing predicts ~43,500 new aircraft worth USD7.2 trillion in list prices to be sold by 2040³. While the “S” and the “G” are also important, the focus at the moment is on the “E” to meet the Paris Agreement of 1.5°C.

CO₂ emissions per passenger has reduced⁴ by 50% over the last 30 years and the industry has pledged net zero emissions by 2050. The sector is viewed as a transition sector – i.e., difficult to abate. In order to incentivise the industry to move to net zero, various participants – such as financiers – are working on strategies to assist airlines and lessors achieve this goal. It is, however, unclear if we will reach this milestone based on current technology.

What are financiers doing to assist in the drive to net zero? At present there are no national or international regulations to follow. In Europe, we see the emergence of the EU Taxonomy but the rules around aviation decarbonisation have yet to be implemented. It is early days still as debt and equity investors consider options but there are a few strategies emerging. One broad way to incentivise airline and lessors to reduce emissions is to offer a financial incentive or disincentive to airlines based on their (Scope 1) emissions which are the financiers’ (and lessors’) Scope 3. Tangible, measurable facts (KPIs, or key performance indicators) are required to objectively track emissions.

¹ Michael Halaby is the Managing Director - Head of Aviation Advisory at MUFG Bank, Ltd..

² Christian Pho Duc is CTO & Managing Director H2 & PtL Projects at SMARTENERGY Group AG

³ <https://www.boeing.com/commercial/market/commercial-market-outlook/index.page>

⁴ <https://www.iata.org/en/pressroom/pr/2019-12-12-01/>

As financiers begin to measure their Scope 3 emissions, some are constructing terms to encourage relative and absolute reductions in emissions from airlines. This needs to be done thoughtfully and carefully so as to avoid accusations of greenwashing. These KPIs need to be achievable but also challenging. For example, we have witnessed several transition debt financings in which the borrower would receive a discount on their borrowings if they reduce the grams of CO₂ per revenue passenger kilometre (“CO₂/RPK”) over a period of time (such as the life of the debt). While most of these loans and bonds do not disclose details for competitive reasons, we expect these will – and should – become more publicised over time.

We further witness airlines and lessors looking at new technology such as sustainable aviation fuel (SAF) as well as hydrogen- and electric-powered aircraft development. Financiers will likely consider SAF as something to incentivise airlines and lessors for financing. While these strategies are in their infancy at the moment, we expect financiers to consider these potentially mitigating investments as ways to reduce emissions over time. It is expected that by 2050, all aircraft could be flown using the above technologies. However, it will require significant and expensive investment. Other incentives could be to offer discounts to encourage behavioural change such as air navigation improvements, or green-electric-powered ground handling equipment and airport infrastructure.

Perspectives from a private investment firm, by Christian Pho Duc

For Smartenergy, the smartest investments for the decarbonisation of aviation are Renewable Energy Sources (RES) investments.

The nature of a private investor is the independence from other bodies in its decision to invest. This allows fast decisions, engaging into opportunities at an early stage with entrepreneurship and a risk-taking spirit. Since its first day, Smartenergy has focused into renewable energies and has added hydrogen (H₂) projects into its development portfolio as the missing link for full decarbonisation of hard-to-abate sectors, including aviation. By now the H₂ pipeline of approx. 700MW electrolyser capacity and approximately

1,2 GW of co-located RES for the production of over 30.000 tons of H₂ with projects in various development stages addresses applications in industry, mobility, and de-carbonizing the gas grid.

Current renewable hydrogen projects often lack the clear commitment and willingness to pay from the off taking. The decarbonisation of aviation will likely follow several paths but, as of today, renewable hydrogen is one of the future solutions for mid-range flights and, at least for long haul flights, there is no alternative to e-kerosene. For the decarbonisation of aviation, both products need to be sustainable, with zero emissions. The binding Sustainable Aviation Fuels targets set out in the proposed European Union ReFuelEU regulation are expected to solve the number one challenge for investment into H₂ projects: the off taking of high volumes.

Smartenergy has reviewed its H₂ project pipeline to make it suitable also for e-fuel and e-kerosene production and already has projects in active development, such as the “Montealegre” project.

Besides the availability of land, input materials (water, CO₂) and infrastructure, the direct access and control of a large amount of renewable power is key. Given the expected demand volumes of H₂, many consider using H₂ from fossil fuel with CO₂ capture (blue hydrogen) or H₂ generated from nuclear power (pink hydrogen). Fully committed to sustainability, Smartenergy has ruled out these options for its investments. Not only blue hydrogen still poses challenges related to methane and CO₂ leakages, but also the dependency on fossil fuel persists. Being dependent on fossil supply and volatile prices, this option also does not have a compelling cost down roadmap – for Smartenergy, such investments have the high risk to become stranded assets.

Although nuclear power can produce large volumes of energy, its production is associated with well-known safety and security risks, its environmental impacts (notably waste management) are not resolved, and the sector is highly dependent on uranium supply. Therefore, for Smartenergy, as for the blue hydrogen option, the option of nuclear power which on top is very expensive is unlikely to be a sustainable solution for the future.

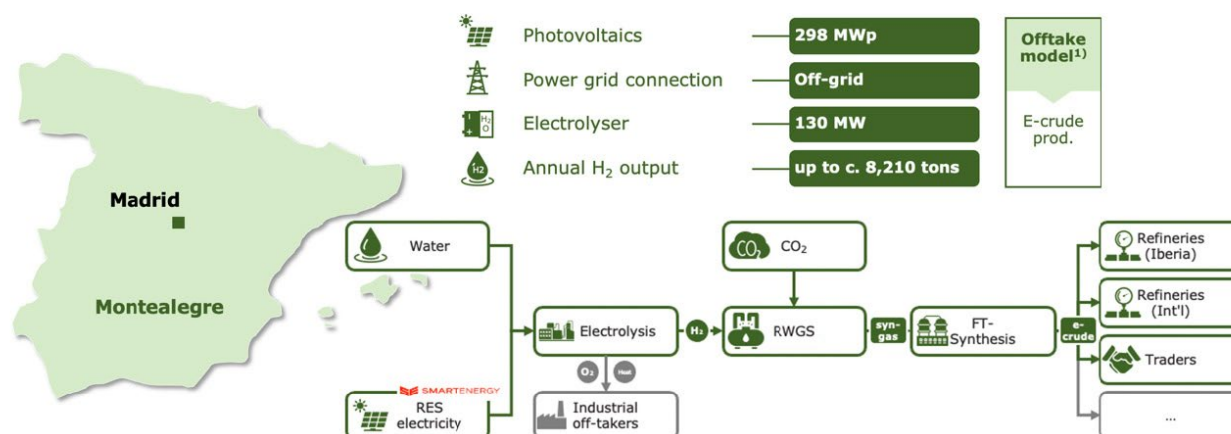


FIGURE 1: Scheme of the Montealegre project

Producing H₂ and e-kerosene from decentralised renewable power, using CO₂ from the air or re-using the emissions from industry, is the most elegant setup conceivable for Smartenergy.

Perspectives from a venture capital, by Clyde Hutchinson

2021 has been a landmark period for start-ups in Sustainable Aviation Fuels (SAF). We have seen momentous activities from airlines securing their largescale, long-term delivery pipeline to significant inflection investment points. In March 2022, Neste partnered with BP to pledge to deliver over 800 million litres of SAF to DHL Express by 2026. Previously, in September 2021 alone, we saw a flurry of airline deals from Delta, Jet Blue and United Airlines to secure \$3.5 Billion of SAF from for Aemetis, SG Preston, and Honeywell/Alder. Meanwhile, SkyNRG struck massive deals with Boeing, Bank of America and Alaska Airlines.

Staying with SkyNRG for a moment, the company marked another milestone in the history of SAF when they became are the first in the world to receive ICAO's RSB CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) certification, thus allowing their airline customers to reduce the need for external carbon offsets to count towards their CORSIA and other carbon reduction targets. SkyNRG also partnered with SAF technology company, Lanzatech, to develop Europe's first programme to convert waste-to-ethanol to SAF at a scale of over 30,000 tons/yr.

This is being funded using €20M grant from European Commission's Horizon 2020.

Such partnerships mark the significant inflection of SAF tech companies' valuations. In March 2022, LanzaTech announced their plan to go public in a SPAC deal, valued at \$2.2 billion. These orders, partnerships and evaluations have attracted major venture capital funds to the world of SAFs (Sustainable Aviation Fuels). The leading energy venture fund, Breakthrough Energy have partnered with American Airlines, Microsoft and GM to focus on SAF and green Hydrogen. American Airlines reported put \$100M into this initiative, a strong signal to the investment community of potential returns from investing in SAF and related technologies. This year has seen even traditionally sceptical airlines make moves in this space, such as Ryanair donating €1.5M for the development of the Ryanair Sustainable Aviation Research Centre at Trinity College Dublin. It might prove to be a smart move as some of the most interesting SAF start-ups, such as Dimensional Energy or Phycobloom, are university spinouts.

In terms of Team ABC, we see significant opportunity in funding start-ups with supportive technologies in the SAF space, from novel technologies to biotechnology, circular economy to digital platforms, to create the infrastructure for the SAF supply chain. With the recent US Securities and Exchange Commission (SEC) declaration that airlines will be required to report actual greenhouse-gas emissions in as little as two years, we see this upward investment trajectory continuing exponentially.

Training the youth on environmental challenges of aviation

By Suzanne Kearns (Waterloo Institute for Sustainable Aeronautics, University of Waterloo, Canada), Laurent Joly (Institute for Sustainable Aviation, ISAE-SUPAERO, France), David Zingg (Centre for Research in Sustainable Aviation, University of Toronto, Canada), Tim Ryley (Griffith University, Australia)

Introduction

Profound changes are needed to build the future of aviation. Young people will be the leaders of tomorrow's aviation. Their training in environmental issues is therefore essential to meet the challenge of sustainable aviation. This article brings together contributions from four universities around the world, focusing on their training programmes, research projects and certificates for sustainable aviation.

Training the Next Generation of Aviation Sustainability Leaders at the University of Waterloo

Emerging from the COVID19 pandemic, the aviation industry is facing unprecedented challenges associated with projected shortfalls of aircrew, the rapid evolution of technology, and associated negative environmental impacts. These challenges align with three pillars of sustainability – social, economic, and environmental. Keeping the sector viable tomorrow will require innovation in research and education.



FIGURE 1: Social, Economic, and Environmental Sustainability

Waterloo Institute for Sustainable Aeronautics (WISA)



To help address these challenges, the University of Waterloo in Canada launched the Waterloo Institute for Sustainable Aeronautics (WISA) in 2021. WISA is a multi-disciplinary research and teaching institute with more than 75 professors from all six Faculties at the university, cutting-edge facilities and labs, and hundreds of affiliated graduate students.

Research

Diversity of expertise and perspectives generate the fresh ideas necessary for meaningful change. WISA researchers collaborate across traditional disciplines, aligning with themes of sustainability. Waterloo experts in optometry are working with neuroscientists to study eye movements as an indicator of pilot competence, while psychologists analyze training scenarios to optimize learning retention. They work alongside engineers and mathematicians who use that data to build artificial intelligence models to optimize pilot training in the future, thus supporting social sustainability.

Environmental researchers are evaluating the design of flight paths and engine technologies for greater efficiency and fuel savings (which also benefit economic sustainability). Others are examining sustainable fuels, electric and hydrogen propulsion, and battery technology that will help the industry meet emissions targets.

Education

The University of Waterloo is home to Canada's largest university-level aviation program, which approximately 300 future pilots studying on campus. WISA researchers work directly with student pilots and industry professionals at the Region of Waterloo International Airport to understand pertinent challenges and collaborate on impactful research.

To support aviation education internationally, the University of Waterloo joined forces with ICAO's Global Aviation Training (GAT) office on the Aviation Fundamentals (AviFUN) e-learning course. This 22-hour course was designed to give new and transitioning professionals a broad introduction to the different sectors that make up the rich fabric of international aviation. In 2021 alone, AviFUN was completed by hundreds of learners from 99 different countries.

Collaborative Aeronautics Program

The aviation industry has a rich history of educating learners in the practices of aeronautics. However, some of the pressing challenges facing aviation extend beyond these boundaries. Cybersecurity, emissions modelling, artificial intelligence, green propulsion technologies and other sustainability factors will require new skillsets. Future leaders will require disciplinary expertise from parallel fields, along with competency in the acumen and practices of international aviation.



FIGURE 2: WISA research crosses disciplinary boundaries, designed to be different, instead aligning under the three pillars of sustainability

Towards this ambitious goal, the University of Waterloo will soon launch an entirely new approach to graduate aviation education. The Collaborative Aeronautics Program (CAP) will allow Master's and Doctoral students to enroll in one of a variety of programs from the six Faculties across campus (Environment, Health, Math, Engineering, Arts, and Science). During their studies, learners will come together to study aeronautics, tackle industry-provided design challenges, and complete aeronautics-applied research guided by world-leading professors in their specific discipline. Waterloo graduates will have their degree titles enhanced with “– Aeronautics”. With a target to enroll up to 50 graduate students each year, into a diverse range of disciplines at Waterloo, the CAP represents a pipeline of talent to future-proof our sector.

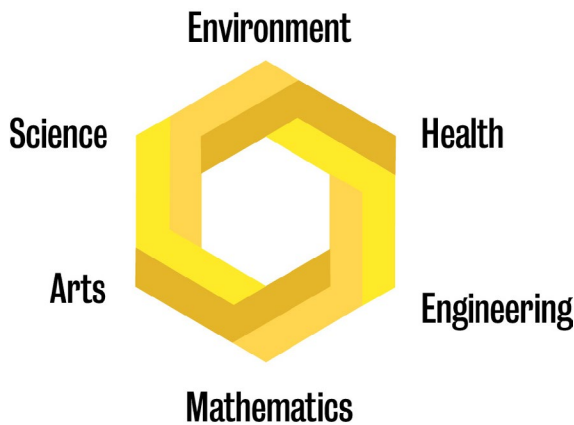


FIGURE 3: All six faculties at the University of Waterloo are participating in the Collaborative Aeronautics Program

Conclusion

Many voices can play a part in reimagining aviation for the sake of the planet, the industry and the people who rely on its viability. To achieve net-zero targets the aviation industry needs a combination of innovative new technologies, investment in talent, and cross-sector partnerships.

A sustainable future is within reach. With WISA's approach of fostering impactful research across disciplines and educating a new generation of leaders, from diverse fields of expertise, the prospects are even better.

Interdisciplinary research and training at ISAE-SUPAERO to address the systemic challenges of sustainable aviation



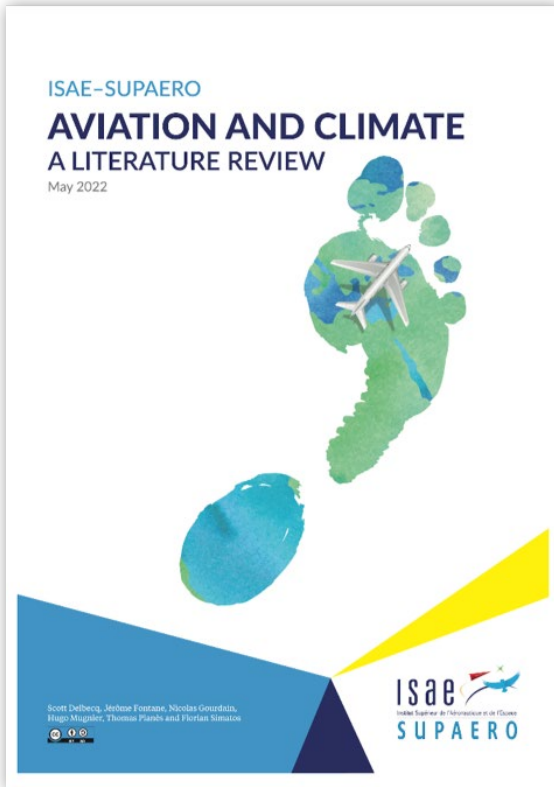
Faced with the environmental and social challenges of the 21st century, the aviation community has a contribution to make. Higher education and research are major levers for the- transition to a sustainable society. At the Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO) has placed these environmental challenges at the heart of our commitments. They are mobilizing their educational skills and their scientific expertise to contribute to the construction of aeronautical and space components for a sustainable society, notably to invent the decarbonized air transport of tomorrow. This so-called *Horizon commitment* towards the next generations takes many forms.

One of the first contribution to the *Horizon commitment* was to issue a reference document on the impact of aviation on the climate. Authored by 6 Faculty members, based on nearly 250 articles in the scientific literature, with a concern for rigor and a strong didactic ambition. The *ISAE-SUPAERO Aviation and Climate: a literature review*¹ (2022) shed light on this core matter and dives into details about the components of the impact and on the technological levers of action to mitigate this impact. The outcome of these science-based considerations takes the form of prospective sustainable scenarios for the future trajectory towards net-zero.

The section devoted to scenario analysis owes a “*debt of gratitude to*” a PhD student who developed the CAST platform (Climate and Aviation – Sustainable Trajectories²) for simulating and evaluating future scenarios for the aviation decarbonisation. Along with a “*what if approach*,”

1 https://oatao.univ-toulouse.fr/28978/1/ISAE-SUPAERO_Aviation_and_Climate_literature_review.pdf

2 <https://cast.isae-supaero.fr>



this open-source tool allows to play with the different levers of action to decarbonise aviation, such as the improvement of aircraft energy-efficiency, the substitution of kerosene by low carbon-intensity fuels and the volume of air traffic. It also includes simple climate and energy models in order to assess the environmental relevance of scenarios. In the future, the objective is to develop the capabilities of the tool to regionalise the scenario simulations of integrate social and economic analyses for a more systemic approach in the elaboration of transition scenarios.



The need for a systemic approach urged ISAE-SUPAERO to create the *Institute for Sustainable Aviation (ISA)*. The ISA aims indeed at addressing the aviation sustainability question by bridging disciplines at the crossroad of societal, economic, scientific, and technological challenges raised by aviation sustainability.

The ISA project is built around the idea of a holistic approach, which is essential to inspire action, not only on the technological and industrial breakthrough to provide a decarbonized aircraft, but also on sustainability of the technological trajectory. This will be against the likely transition of uses, operations and markets. The ISA aims to increase the impact of our first-rate academic pool by informing the multiscale socio-economic strategy with science.

At the core of this scientific enterprise is an *Integrated Assessment Model (IAM)* for the commercial aviation section. IAMs have grown a methodological paradigm in climate science. They are also at the center of research in industrial ecology. In the economic sphere, researchers have been developing models to better understand the functioning of the economy. In the environmental sphere, researchers have been developing analytical tools to improve the accuracy and completeness of environmental assessments.

Integrated models combine the two approaches and provide a consequential picture of decisions made on energy flows, environmental regulation, taxation, material, and financial resource flows, by linking the physics-technical causal sphere with the socio-economic sphere. Using data assimilation technics, ISA is growing a multi-scale digital twin of aviation with increasing spatiotemporal resolution. The short-term impact will come from the dissemination of the methodologies and findings into training programs. They want to train future generations of engineers in the holistic approach.

Among those programs the Environmental Engineering Certificate, set up with support of Airbus via the Chair for Eco-Design of AiRcraft (CEDAR), enables students from the ISAE group to complete their initial engineering training with global training in environment, the focus on the consequences and perspectives for the aeronautical sector. The objective is to train engineers capable of understanding environmental issues as a whole, and to master the tools, methods and regulations related to the subject. They follow three courses on Environment and Aeronautics (61h), the aviation of the future (70h) and the Engineer in action (43h).

Research and Education in Sustainable Aviation at the University of Toronto Institute for Aerospace Studies



Institute for Aerospace Studies
UNIVERSITY OF TORONTO
Centre for Research in Sustainable Aviation

Founded in 1949, the University of Toronto Institute for Aerospace Studies (UTIAS) is a graduate aerospace department at the University of Toronto that also teaches the Aerospace Major to undergraduate students in Engineering Science. UTIAS's mission is the pursuit of nationally and internationally recognized excellence in the education and training of students for research and leadership positions, discovery, and dissemination of new knowledge through research and scholarship, and application of knowledge to the benefit of society.

UTIAS has long recognized the importance of reducing aviation's impact on the environment and consequently formed the Centre for Research in Sustainable Aviation in 2012. Within this Centre, extensive research is undertaken toward technologies with the potential to reduce the environmental impact of aviation, including noise and emissions, with a particular focus on emissions contributing to climate change.

This research is conducted primarily by students, including Doctoral, Masters, and Undergraduate students, contributing greatly to their education on topics related to sustainable aviation. Current research projects include investigation of the combustion properties of sustainable aviation fuels, techniques for reducing noise generated by landing gear and high-lift systems, and active flow control for turbulent drag reduction. Other research includes the development of multi-fidelity multidisciplinary design tools for application to unconventional aircraft, and their application to investigation of hybrid wing-body, strut-braced wing, and box-wing configurations. It also includes the investigation of boundary-layer ingesting intakes and propulsors, design of natural laminar flow and variable-camber wings for reduced drag, and development of a solar-powered hybrid airship.

UTIAS has also hosted the UTIAS International Workshop on Aviation and Climate Change seven times since 2008. This workshop has an aim to stimulate dialogue among academia, government, and industry toward finding technological solutions to reduce the greenhouse gas emissions from aviation. The primary focus of the workshop is on technological and scientific issues. The goal is to bring together some of the world's leading experts in this area to exchange ideas, establish research priorities, and identify opportunities for collaboration.

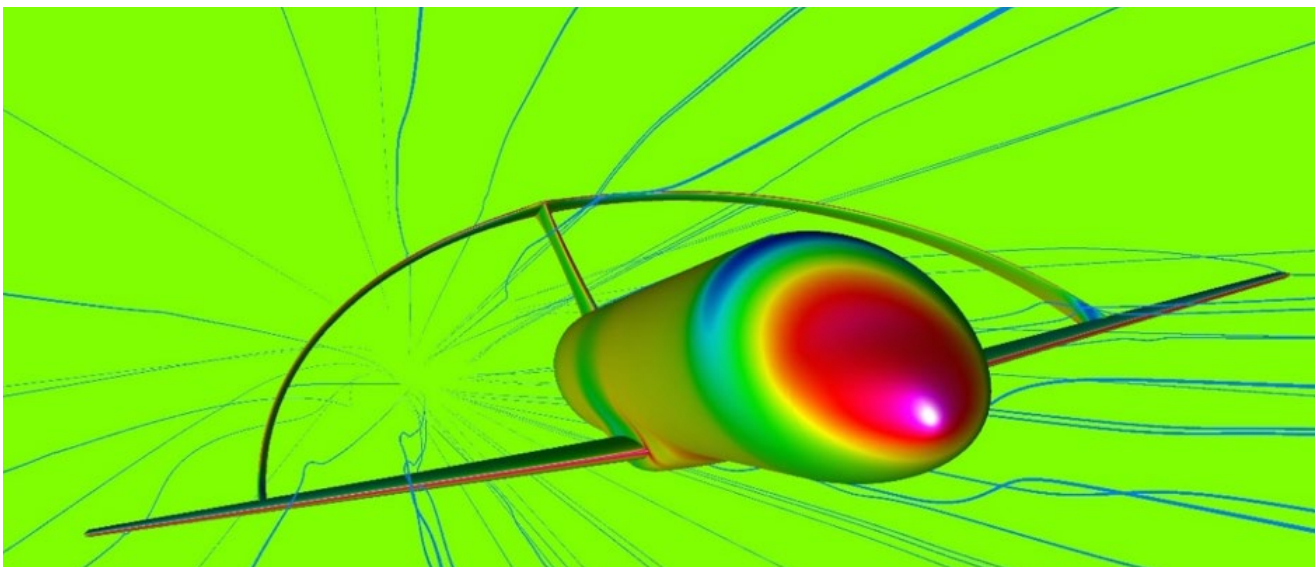


FIGURE 5: Investigation of a box-wing aircraft

All UTIAS students are invited to this event, which provides them with a comprehensive overview of current challenges and opportunities related to technological aspects of aviation and climate change. It includes speakers on topics including recent developments in atmospheric physics as well as speakers from NASA, DLR, and ONERA covering their latest research in this area.

UTIAS recognizes not only the need for new technologies to enable the elimination of fossil fuels in aviation and to improve the energy efficiency of future aircraft and engines, but also the need for graduates to have a deep understanding of environmental aspects of aviation.

The research programs in place combined with relevant courses and workshops such as the International Workshop on Aviation and Climate Change provide UTIAS graduate and undergraduate students with the necessary background in sustainable aviation. This includes policy, lifecycle analysis, atmospheric physics, alternative energy sources, and aircraft and engine technologies. Consequently, graduates of UTIAS are well prepared to play a leadership role in future efforts to address the urgent challenge to make aviation sustainable.

Developments in aviation sustainability from Griffith University



Griffith University has been providing qualifications to the aviation industry for over 25 years and is known worldwide for its innovative and student focused teaching. The aviation discipline, Griffith Aviation, based within the School of Engineering & Built Environment, has grown rapidly in recent years and now has over 800 students across undergraduate and graduate programs, the largest of its type in Australia. Its programs cover flight-training and aviation management, as well as double degree options with either engineering or information technology.

Study can either be at the Nathan campus in Brisbane or fully on-line. The on-line cohort is growing, particularly international students.

With aviation sustainability being a global challenge, there is a need for universities to lead internationally on delivering the skills and expertise in this area. Aviation is arguably economically and socially sustainable, but there are major concerns about the environmental impacts from air transport. Griffith Aviation is fully aware of the environmental implications of aviation and is planning accordingly in their teaching and program development.

Griffith Aviation currently has sustainable aviation, and associated topics such as the relationship between aviation and climate change, and sustainable aviation fuels, in courses within the aviation management program. There is an optional elective to aviation students on an introduction to environmental sustainability, delivered by Griffith University's School of Environment & Science. It is expected that a dedicated aviation and the environment course will be developed moving forward, plus a short course for industry professionals. The aviation industry certainly needs upskilling in environmental sustainability.

Griffith University has had two years of their annual Aviation Reimagined seminar series, focusing on the future of air travel given the environmental concerns. Over 400 individuals registered for Aviation Reimagined webinar (see the webinar series³) in September 2021 and hope to further develop the series in 2022 and beyond.

The aviation industry has always been dynamic and disruptive; however, it was exacerbated during the COVID-19 pandemic. The aviation sector recovery does present an opportunity to refresh and restart, hopefully to build back greener. Aviation industry partners are beginning to engage in environmental issues and solutions. Yes, there will be some turbulence, particularly with increasing climate change concerns and external calls for the aviation industry to respond more quickly, but at least there is some movement in the right direction.

3 <https://www.griffith.edu.au/institute-tourism/our-research/rethinking-aviation/aviation-reimagined-2021?fbclid=IwAR3Hd8xLJkEWMaHae8shoIMiSfV6TzbPbf30vo2fbJOCHMg-xdvyywNCmZbU>



FIGURE 6: Aviation Reimagined webinar series logo

There is also a need for universities to respond responsibly in the matter of environmental sustainability for aviation, particularly when many of them, such as Griffith University, have sustainability as a core value. Griffith University agreed to reduce university aviation emissions by 25% in time for 2030.

There is an associated implementation plan to work through the implications and practicalities. Much of the focus is on reducing staff air travel, but there are other elements incorporated in terms of underpinning research, engagement with stakeholders, and innovations in data and processes. In the area of environmental sustainability for aviation, like with other global challenges, it is right and appropriate for universities to be at the forefront of the responses and solutions.

Global Youth Engagement and Support

By ICAO Secretariat and Sustainable Aviation Youth Foundation (SAYF)

Introduction

It is critical for global youth to unite and have their say in aviation policy and development related to environmental protection, by actively engaging with the International Civil Aviation Organization (ICAO). At the same time, ICAO has an opportunity to bring new ideas for aviation de-carbonization with the objective of the long-term aspiration goal to be reached at the 41st Session of the ICAO Assembly in October 2022.

Background: ICAO's Youth Initiative

ICAO Stocktaking 2021



During the 2021 ICAO Stocktaking Event, held from 31 August to 3 September 2021, the informal engagement of universities, young entrepreneurs, students, and environmental activists on sustainable aviation, was launched through a series of presentations on the first day of the event. Following these presentations, a call was made for global youth participants interested in aviation and the environment, to come together under an independent umbrella organization. The goal would be to engage with ICAO, the aviation community at large, and to provide expressed viewpoints and idea on the sustainable future of aviation.

ICAO Global Youth Engagement – Facilitation Session



The ICAO Global Youth Engagement – Facilitation Session was held on 28 October 2021 and connected global youth focusing on aviation and its environmental impact. This facilitation event served as a call for youth all over the world to come together to engage with ICAO, inspire ideas, and drive the transition to a sustainable future for aviation. The event brought together academic institutions, aviation stakeholders, and most importantly, youth passionate about the transition to sustainable energy. The establishment of a global youth umbrella group for sustainable aviation would be open to all and aimed at global representation.

Sustainable Aviation Youth Foundation (SAYF)

Following the ICAO facilitation session, youth that participated in this session took the initiative to gather like-minded and enthusiastic students and young professionals to establish the Sustainable Aviation Youth Foundation (SAYF).

Brandon van Schaik, 22, from the Netherlands took the initiative in establishing SAYF stating:

“The fact that young people from around the world come together to form a cohesive foundation to work towards sustainable aviation shows the urge in which the climate crisis needs to be addressed. The youth of today is the first generation to know that the climate crisis will be catastrophic for them if not addressed properly in addition to being the last generation to be able to make a sufficient impact to mitigate this crisis. The Sustainable Aviation Youth Foundation exists to facilitate youth engagement within the aviation industry, inspire ideas, and drive the transition to a sustainable future for aviation.

The involvement of youth in the industry is paramount to the energy transition and the enthusiasm and abilities that I see in our young members strengthen my confidence that we can push the environmental priorities forward in the industry.”

In January 2022, SAYF originated as an independent international umbrella organization for youth representation in sustainable aviation. Since the establishment of SAYF, a group of twenty passionate aviation enthusiasts are working towards a common vision and mission, highlighting the most critical issues in today’s transition to green aviation.

“A voice for the youth, a vision for the future, a force for change in international aviation. With this organization, we aim to create a platform for young minds to start a dialogue on all aspects of sustainable development in aviation and bring about the necessary changes with their academic participation, industry-oriented skills, and innovative ideas.” —**Dirsha Bohra, 26, India**

“Working with other motivated young people, towards a future with a sustainable aviation sector, gives me a lot of experience which helps me later in my career. The creation of SAYF is crucial in this period, the younger generation must deal with the transition of a sustainable planet later in their lives, therefore we must motivate the youth to participate in the transition as soon as possible. I am certain that the youth generation can provide a significant impact as most of the younger people think creatively, and therefore, innovate when it comes to solving problems.” —**Thomas Driessen, 22, The Netherlands**

SAYF exists to facilitate youth engagement within the aviation industry, inspire ideas, and drive the transition to a sustainable future for aviation. “SAYF fosters future aviation by bringing stakeholders from the industry, academia, and future generations to influence aviation as an affordable, sustainable, and ecologically responsible sector.” —**Vamsi Krishna Undavalli, 27, USA**



SAYF will enable youth to build and strengthen the skills required to participate in the transition to sustainable aviation. It will accomplish this goal by promoting excellence in all aspects of sustainable aviation, continual on the job learning, and continued professional development.

Pierre Vigor, 23, from France explains, “We want to become a strong, global, and diverse network of young professionals and students all interested in working in the aviation industry. By using our network, sharing expertise and opportunities to reflect on the transition of the sector, both internally and with different industry players, SAYF’s vision is to become a known and trusted actor in the sustainable aviation ecosystem. SAYF will enable youth to raise their voices and bring their vision to the aviation industry to make sure youth always have their place around the decision-making table.”

“As a youth organization, sustainability is not the only thing we are passionate about - diversity and global representation are key values for us.” As **Myrthe van Dalen, 25, from The Netherlands** highlights, “The aviation industry is a hierarchical and largely male-dominated

industry, which often lacks diversity. I believe it is paramount to create a diverse and inclusive sector to change aviation. Therefore, I believe as youth we need to unite and demand diversity in background, geographical locations, and age to demand a more sustainable future for aviation.”

“It is high time for youth all over the world to get involved in sustainable aviation. We, as young passionate people, should not be afraid to have our say on how aviation is evolving about environmental protection and social inclusion. I was happy to join SAYF because it gives me the possibility to connect, unite and engage. In the next three years, I hope we will have youth representatives of every country in the world, and that SAYF will develop strong partnerships to facilitate youth to training relating to sustainable aviation and contributing to projects that bring innovative, sustainable solutions to aviation” — **Joel Kameni Toussom, 30, Cameroon**

As the participant testimonials have highlighted, youth involved in SAYF are determined to show their presence and bring the aviation industry and youth closer together.



| ICAO

CHAPTER TWO

Aircraft Noise

Setting the scene

By ICAO Secretariat

CAEP/12 work developments on aircraft noise

Significant developments have been achieved on aircraft noise over the last triennium, mostly through the work of the ICAO Secretariat and the Working Groups 1 and 2 (WG1 and WG2) of the Committee on Aviation Environmental Protection (CAEP). Besides proposed amendments to Annex 16 Vol I, progress have also occurred on supersonics, Emerging Technology aircraft, operational noise, and noise research. This article summarizes this progress and depicts the developments planned for the CAEP/13 cycle (2022-2025).

Annex 16 proposed revisions by CAEP/12

As a pivotal milestone of ICAO's environmental protection guidance, Annex 16 Volume I (Aircraft Noise) has been regularly updated through key amendments. Following its role of keeping ICAO noise certification standards up to date and effective, while ensuring that the certification procedures are as simple and inexpensive as possible, the Committee's Working Group 1 (WG1) proposed revisions to Annex 16, Volume I in terms of both guidance and recommended amendments throughout the document.

CAEP developed specific guidelines for helicopter hover noise measurement, for inclusion under Annex 16 Vol I, Attachment H - *Guidelines for Obtaining Helicopter Noise Data for Land-Use Planning Purposes*. The primary objective for these is to achieve sufficient commonality in measurement conditions and locations, including hover heights, radial measurement distance, meteorological conditions, azimuthal directions, and microphone configuration, in order to allow direct comparability between different hover noise datasets.

Following the identification of some limitations of Annex 16 specifications with respect to the adjustments of test-day sound pressure level (SPL) to reference conditions, WG1 proposed the inclusion of appropriate amendments that will not only provide the missing guidance, but also facilitate the future implementation of a layered atmospheric attenuation methodology with the SAE ARP5534 model.

In addition, various amendments were proposed with the intention to improve its adherence to the Air Navigation Commission (ANC) "Guide to The Drafting of SARPs (Standards and Recommended Practices) and PANS (Procedures for Air Navigation Services)" (the "Standard for Standards").

Supersonics

Regarding Supersonics, the industry is moving towards the development of a new generation of supersonic transport aircraft (SSTs). However, there are environmental concerns that need to be addressed. For more information on this topic, please refer to the articles provided in Chapter 2 of this Report.

In support of these developments, work is ongoing in ICAO to develop environmental standards for supersonic aeroplanes. In that regard, CAEP WG1 developed a set of reference day atmosphere and humidity standards for sonic boom, as detailed further in the article provided in Chapter 2. Work has also occurred in the context of further analyses that demonstrated two viable schemes and six noise metrics for defining boom noise certification levels. WG1 is also working to develop provisional content for acoustical measurements and data acquisition equipment specification.

In addition, the group is closely following NASA research which will support scientific data needs to establish a compatible, human response, low boom limit for the en

route SARPs. These NASA developments includes a Low Boom Flight Demonstration (Lbfd) aircraft which will perform community noise testing.

CAEP also approved the final results of an Exploratory Study (E-Study) of the environmental effects associated with the introduction of Supersonic Transport Aircraft (SST), which was recommended for publication after the inclusion of suitable caveats and introductory material, as well as removal of the sensitive information.

Noise from aircraft operations

Based on the work of the CAEP Working Group 2 (WG2), CAEP has recommended the publication of a new ICAO Document “*Operational Opportunities to Reduce Aircraft Noise*”, as detailed further in the article provided in Chapter 6 of this Report. The purpose of this new manual is to identify and review various operational opportunities and techniques for minimizing noise in civil aviation operations. Therefore, it was designed to be used in conjunction with ICAO Doc. 9829, Guidance on the Balanced Approach to Aircraft Noise Management published in 2008 and expands and offers further guidance on one of the principal elements of the Balanced Approach – “Noise Abatement Operational Procedures,” as outlined in Chapter 6 of Doc. 9829.

Emerging Technology Aircraft

New innovative technologies and energy sources for aviation are under development in a fast pace, and ICAO is closely following up these developments to prepare for timely environmental certification, as appropriate. The article provided Chapter 2 provides an overview of how industry is considering noise aspects in the development of these Emerging Technology Aircraft (ETA).

In that regard and specifically on aircraft noise, ICAO is closely following up possible environmental issues from the operation of ETAs, such as unmanned aircraft, remotely piloted aircraft, and urban air mobility concepts. For that, ICAO developed a tracker webpage¹ which contains a collection of relevant and recent information on new aircraft noise concepts and related information, covering

topics such as low noise eVTOL flight tests, drones noise emissions, Unmanned Aerial Vehicles (UAV) noise-related issues, as well as experiences from ICAO member States. The page also provides related material from multiple sector entities and useful references from ICAO material. ICAO encourages Member States and stakeholders to share their experiences in responding to these aircraft noise issues, so this information could be consolidated as a potential best practice guidance for States. These can be shared through the email: officeenv@icao.int.

Updates on noise research

CAEP also approved a review of the situation of noise technology research initiatives worldwide and a summary of the research activities for each region, covering an 18-year period (2006-2023), which provides an evolutionary perspective and clearly shows the renewed commitment of the countries involved. This Review will be published on the ICAO website² following approval by the Council.

Next steps

Aircraft noise-related impacts will keep as a priority topic in ICAO's continued efforts. In this context, the four pillars of the *ICAO Balanced Approach to Aircraft Noise Management* continue to be of paramount importance. ICAO's work will be focused on several topics related both to aircraft noise and broader noise management solutions. As examples, the following items are included in the work programme for the CAEP/13 cycle for WG1 and WG2:

- Conduct an integrated standard setting process for subsonic aeroplane CO₂ emissions and landing and take-off (LTO) noise, with the outcome being more stringent regulatory levels of CO₂ emissions and LTO noise.
- Continue to work on a new SARP (Standards and Recommended Practices) for en route noise/sonic boom certification for supersonic flight;
- Development of an Attachment to Annex 16 Volume 1 establishing noise measurement guidelines for use in the acquisition of Emerging Technology Aircraft (ETA) noise data.

1 https://www.icao.int/environmental-protection/Pages/noise_new_concepts.aspx

2 <https://www.icao.int/environmental-protection/pages/noise.aspx>

- Development of an eco-airport toolkit e-publication on the Environmental Impact of Unmanned Aircraft Operations at and around Airports, to be made freely available on the ICAO website

These and several other topics related to aircraft noise are going to be addressed by ICAO mainly through the coming CAEP cycles, in order to reinforce ICAO's role of providing international Standards, guidance material, technical documentation, and fostering their successful implementation.

Assessment of Noise from Emerging Technology Aircraft

By D. Josephson & R. Naru (Joby Aviation) and J. Caillet (Airbus)

Introduction

Since the development of the first practical helicopter in the 1940s, concepts have been proposed to make vertical takeoff and landing aircraft a part of daily life, bringing air transport into cities, suburbs, and remote areas without the requirement for airport runways. Despite their utility for applications such as medical emergency transport, obstacles have always emerged making helicopters impractical for general use. Noise is one of the most significant problems. During the last decade, aircraft have been proposed eliminating many of these obstacles, including high cost, mechanical complexity, and high noise emissions. Millions of small quadcopters have been sold as toys, camera drones and for agriculture -- these aircraft would not have been possible without the combination of battery, magnet and automation technology that has emerged in recent years. Several hundred of these designs¹ have been launched as commercial development efforts for cargo transport and passenger aircraft, and at least ten have reached Technology Readiness Level (TRL) 6 or greater at commercially useful payload, range, and speed², most of which have type certification procedures underway with the Federal Aviation Administration (FAA) of the USA.

In some jurisdictions, any aircraft used commercially requires type certification for airworthiness and noise emissions. Civil aviation authorities in several countries have begun considering the requirements, and at least one has published a certification basis including noise certification³ based on

modified light helicopter procedures. The International Civil Aviation Organization (ICAO) Annex 16, Volume I, Chapter 11 procedures were used with significant modifications as there is no existing noise standard that can be applied. The ICAO Committee on Aviation Environmental Protection (CAEP) Working Group 1 (WG1) has adopted⁴ the name “Emerging Technology Aircraft” (ETA) to mean “those aircraft that are not covered by existing categories in current Annex 16 Volume 1 Certification Procedures.” The definition does not include supersonic aircraft and may not cover all new aircraft configurations in the future. This article describes some of those aircraft, the challenges preventing the use of existing noise certification procedures, and a new CAEP WG1 subgroup formed to track and report on developments across member states’ civil aviation authorities for noise certification and operational noise assessment of ETA, leading potentially to new Standards and Recommended Practices (SARPs).

Reducing Environmental Footprint

Most Emerging Technology Aircraft (ETA) projects focus on enabling air transportation for short trips in areas of high congestion, at reduced environmental and economic cost compared with helicopters. Uber Elevate described an integrated ground/air ridesharing ecosystem⁵ that proposed to reduce car traffic by providing a low-cost, quiet airborne alternative to driving. Most projects propose operation with zero local carbon emissions, being enabled by rechargeable batteries. An underlying premise of most ETA proposals

1 <https://evtol.news/aircraft>

2 ICAO E-HAPI <https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx>

3 Matternet NPRM, <https://www.govinfo.gov/content/pkg/FR-2020-11-20/pdf/2020-25664.pdf>

4 CAEP12.WP.037

5 https://evtol.news/_media/PDFs/UberElevateWhitePaperOct2016.pdf

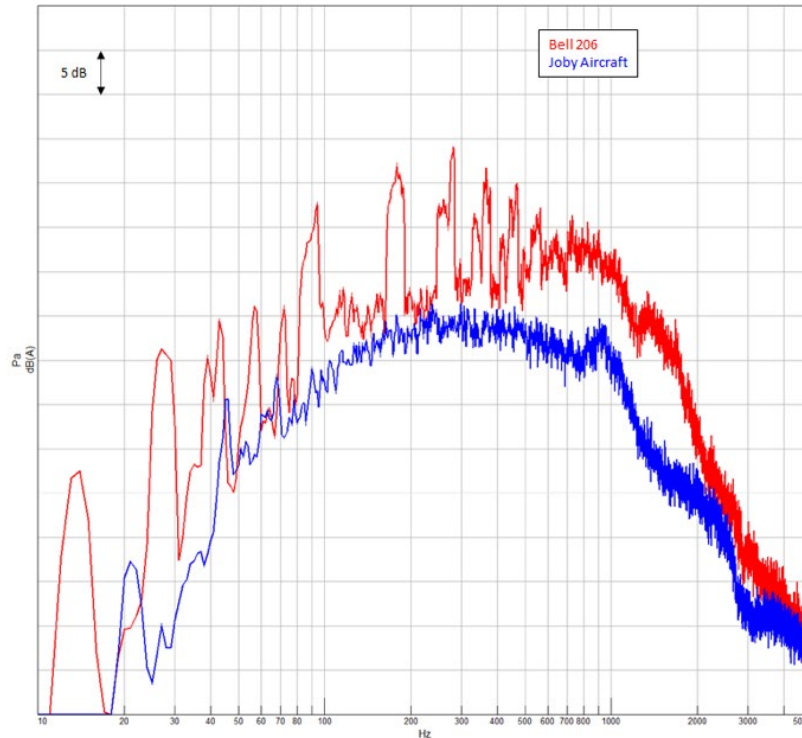


FIGURE 1: Comparison of spectra from the Joby JAS4-1 aircraft and a common helicopter of similar weight.

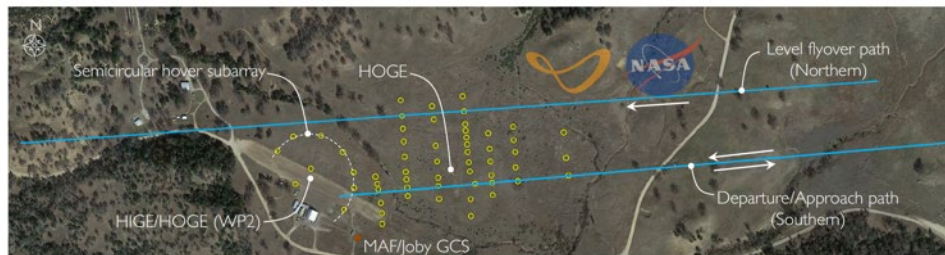


FIGURE 2: Diagram of the microphone array deployed by NASA for the Joby JAS4-1 acoustic tests⁶.

is greatly reduced noise compared with helicopters and tiltrotors, generally acknowledging that legacy Vertical Takeoff and Landing (VTOL) aircraft would be too noisy to be accepted for mass market use in communities.

Some ETA projects have identified a target of 15 to 20 dB reduction in noise emissions compared with helicopters of similar weight. In simplified terms, a reduction in noise emission of 20 dB results in the distance to any given sound level contour being 1/10 as far away, covering an area 1/100 as large. Given uniform population density, this can result in a similar reduction in the number of

people experiencing a given level of noise. This kind of potential for change suggests that work will be required to determine appropriate metrics for assessing human impact of this noise.

Joby Aviation is one of the ETA efforts that has advanced to flying a near-production version of its aircraft, having reached stage 4 of the G-1 issue paper process with the USA FAA in 2020⁶. In 2021 the company conducted joint acoustic tests with NASA⁷ confirming the company's measurements of around 45 dB(A) in overflight at 500

6 <https://www.compositesworld.com/news/joby-aviation-advances-toward-faa-certification-highlights-toray-prepreg-and-coriolis-afp-machines>

7 <https://www.businesswire.com/news/home/20220510005429/en/Joby-Confirms-Revolutionary-Low-Noise-Footprint-Following-NASA-Testing>

meters, and less than 65 dB(A) in takeoff at 100 meters (see Figures 1 and 2).

Emerging Technology Aircraft (ETA) Topologies

Current ETA VTOL projects are distinguished by the use of multiple electrically driven propulsors (rotors, propellers, or fans) to achieve vertical takeoff and landing using Distributed Electric Propulsion (DEP). DEP replaces the mechanical complexity of helicopters and tiltrotors with processor-controlled parameters that are varied automatically. In addition to noise and performance improvements, DEP can provide a high degree of fault tolerance through the elimination of single points of failure. Some of the concepts are all-electric, using batteries, while some are hybrid using a combustion engine to provide power.

ETA include multicopters, which use the same means for lift and forward translation through differential thrust, and aircraft that employ a wing to improve enroute speed and efficiency. Forward flight of wing-based ETA may be principally driven by distinct cruise propulsors or may be achieved by vectoring thrust from the same propulsors used for vertical flight. Unlike helicopters, the propulsors sometimes employ relatively slow changes in blade pitch (if the pitch is changed at all) and there is typically no cyclic pitch. No counter-torque thrust is used. Instead, the relative speed, blade pitch and/or tilt angle of the propulsors are modulated to effect stability and control. The simplest example of this is the quadrotor, first demonstrated in France in 1907, where two pairs of rotors, turning in opposite directions, can achieve hover, climb and descent. Slight variations in speed, pitch or tilt shift the direction of thrust, and differences in ratio of clockwise and counterclockwise rotation produce yaw.

Noise Certification Procedures

Some Emerging Technology Aircraft (ETA) seemed sufficiently similar to propeller-driven aeroplanes that initial proposals suggested using light propeller noise

certification procedures, under the premise that the landing and takeoff phase was a small proportion of total flight time. This approach was generally discounted because of the need to capture the noise characteristics of all relevant operating conditions to allow assessment of their potential community impact.

Helicopter and tiltrotor procedures were also considered because many ETAs have some characteristics of helicopters such as the ability to hover. However, the existing procedures were developed to permit comparison of the noisiest operating conditions of rotorcraft with cyclic and collective pitch control and require precise control of rotor speed and descent angle to maintain uniform test conditions. Most ETA cannot maintain locked rotor speed because it is constantly varied to achieve stability and control.

The only ETA noise certification basis published to date is the United States FAA's Notice of Proposed Rulemaking for the Matternet small package delivery Unmanned Aircraft Systems (UAS). It requires the use of a subset of FAA procedures that are initially equivalent to ICAO Annex 16, Volume 1, Subchapter 8, using the Rules of Particular Applicability concept permitted in the USA. A level flyover is required at 250 feet, with the certification metric and limit value being taken from the light helicopter procedures. Supplemental tests are also required (although no certification limit is stated) in hover, as public exposure to the Matternet aircraft is expected to be at close range in near hover conditions.

During the next three years of the ICAO CAEP/13 cycle (2022-2025), the authors anticipate that additional special procedures will be defined by certifying civil aviation authorities (CAAs), with adjustments to existing rules for early certification of ETA. The new ETA subgroup will track these developments and provide regular updates to the ICAO CAEP WG1 until enough has been learned that work can begin on procedures for general applicability. The subgroup hopes to build a general understanding of ETA noise, to enable development of new standards as a data-driven process, and to explore the need for noise measurement guidelines and adjustment formulas for ETA.

8 Pascioni, Kyle et al, "Acoustic Flight Test of the Joby Aviation Advanced Air Mobility Vehicle" presented at Aeroacoustics 2022 in Glasgow

Community Noise Assessment

Besides development of measurement protocols for noise certification, a major question remains as to the community tolerance of noise from ETA operations, given that while their individual noise footprints may be greatly reduced, there may be many more flights in close proximity to the community than has ever been possible. Existing CAEP WG2 tasks O.01 and O.11 are being refined to incorporate not only unmanned aircraft operations on and around airports, but other considerations on community engagement in assessing environmental impact of ETA. The WG1 ETA subgroup will monitor, and members may also participate in these activities.

Many ETAs are designed from the outset for low acoustic emissions, not only in terms of traditional noise metrics such as sound exposure level (SEL) and effective perceived noise level (EPNL), but for the ability to blend in with or be masked by urban ambient conditions. Significant developments have been made since EPNL was developed, in metrics for assessing the audibility, prominence and annoyance of complex sounds in the presence of background noise conditions. Research is ongoing on the best methods for quantifying these impacts, which may influence how noise emissions are measured for certification.

ICAO CAEP WG1 Subgroup on ETA

The ICAO CAEP/12 Meeting in February 2022 agreed on a new task for the CAEP WG1, in order to track and coordinate future work on noise certification of ETA. The effort will focus on tracking progress made by Member States in developing noise certification procedures for the range of ETA that require certification.

Low Sonic Boom Noise

Atmospheric Reference Day Standard for En-Route Noise Standard Development for Supersonic Aircraft

By **Stephane Lemaire (Dassault Aviation)**, **Sandy Liu (Federal Aviation Administration)**, **Alexandra Loubeau (National Aeronautics and Space Administration)**, **Pierre-Elie Normand (Dassault Aviation)**, and **Victor Sparrow (Pennsylvania State University)**¹

Introduction

The International Civil Aviation Organization (ICAO) Working Group 1 (WG1) – Noise Technical recently developed a new supporting atmospheric technical standard that was agreed to by the ICAO Committee on Aviation for Environmental Protection (CAEP). This atmospheric standard serves to prescribe reference atmospheric conditions that anchor a level playing field for applicants of en-route noise certification for future supersonic (low boom) aircraft.

Since 2004 as part of the CAEP/7 cycle, the WG1 Supersonic Task Group (SSTG) has been responsible for monitoring various aspects of Super Sonic Transport (SST) projects including: assessing their prospects for operation, monitoring research to characterize, quantify and measure sonic boom signatures and their acceptability, and developing noise certification standards for supersonic aircraft. After numerous sonic boom predictive noise analyses were performed with global atmospheric data and several reference day options, a technical recommendation was formulated that proposed the use of the Manual of the ICAO Standard Atmosphere (Doc 7488, 3rd Edition) for temperature and pressure, paired with the selection of ISO 5878 with extension humidity model. Unanimously WG1 and eventually the CAEP agreed and accepted it for establishing a Reference

Day standard for en-route, sonic boom certification, as a potential key component in the development of future noise standards for supersonic aircraft.

A Fundamental Element of the En-Route Noise Standard Development for Supersonic Aircraft

ICAO noise certification standards prescribe essential and relevant reference conditions that are imperative for uniform and fair noise characterization of a product. Such traditional noise standards have defined that reference conditions consist of reference flight trajectories, reference measurement points and a reference day atmosphere. Along with systematically establishing associated test tolerances and defining adjustment procedures that account for test day conditions, aircraft noise can be measured and adjusted to common reference conditions to establish accurate noise certification levels.

Following these procedures offers a comparison of aircraft certification noise levels for a category of type design from different designer/manufacturers. This guarantees a level playing field between applicants and the possibility to rank aircraft according to their intrinsic performance.

¹ The authors would like to acknowledge William Doebler and Sriram Rallabhandi of NASA for setting up the various standard atmosphere profiles and conducting the sonic boom predictions with those atmospheres.

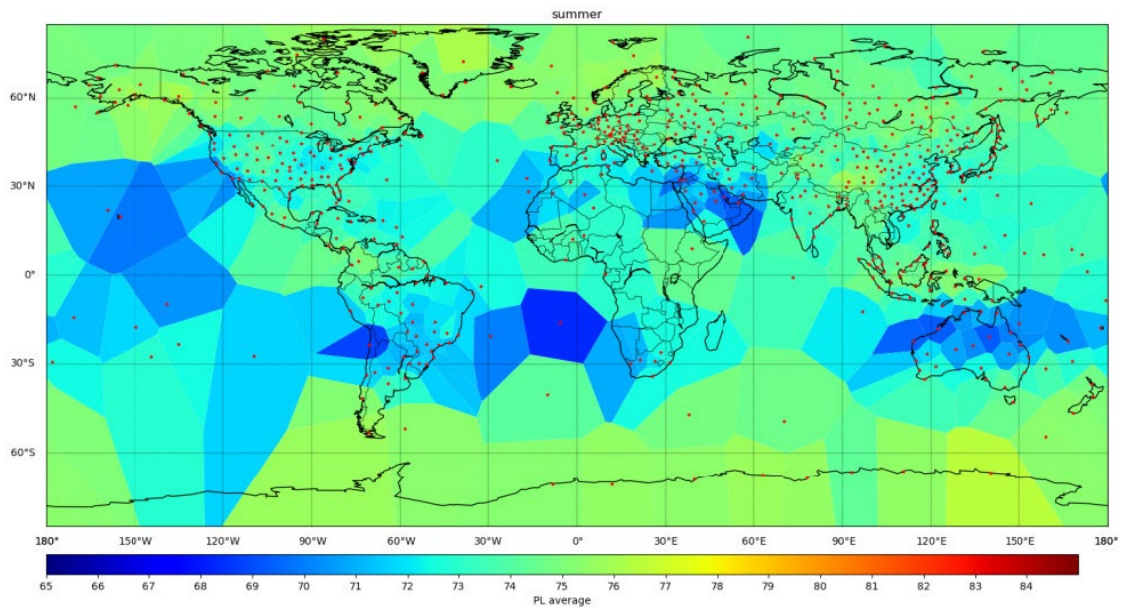


FIGURE 1: Mean PL noise metric values at various locations (red dots) in summer 2017, flying east – ERA5 database.

For a supersonic aircraft, a reference day atmosphere has important application when propagating the sonic boom noise levels generated in the near-field of the aircraft through the atmosphere towards the ground using sonic boom propagation prediction codes. It could also be used to either compute an acoustical adjustment factor for far-field measurements made in a Test Day atmosphere, to recreate the far-field noise levels in the Reference Day conditions, or to directly predict the sonic boom noise levels in the Reference Day condition (using a measurement-validated, proven code).

The specific values of temperature, pressure, and humidity as functions of altitude are absolutely critical for the accurate prediction of noise, particularly considering the long distances that sonic boom noises propagate, due to absorption and refraction of sound waves through the atmosphere which are controlled by the former parameters. Hence, WG1 carefully considered these profiles of the global atmosphere.

What Do Global Atmospheric Data Show?

Extensive analyses were performed during the CAEP/11 and CAEP/12 cycles to identify the most appropriate Reference Day Atmosphere. Technical discussions were held between many WG1 participants, including individuals from Europe, Asia, and North America. Worldwide meteorological conditions were considered.

Sonic boom levels have been predicted in different meteorological conditions, using existing models and real measurement meteorological data. Specifically, the analyses employed the worldwide ERA5 reanalysis database from the European Centre for Medium-Range Weather Forecasts and the Integrated Global Radiosonde Archive (IGRA) from the U.S. National Oceanic and Atmospheric Administration. An example of predictions in the PL (Perceived Level) noise metric are shown in Figure 1 for various locations around the world. These predictions were made available to WG1 courtesy of the RUMBLE consortium (rumble-project.eu).

While a “Conservative” Reference Day atmosphere was initially proposed with the objective of obtaining sonic boom levels on the upper range with an existing standard atmosphere, it was finally agreed that an “Average” atmosphere would be more appropriate considering that it would allow to minimize differences between Test Day conditions and Reference Day conditions. Therefore, any bias in the sonic boom predictions performed in Test Day conditions or in Reference Day conditions would also be minimized as well as a potential discrepancy between measurements and predictions both done in the Test Day conditions. To illustrate, Figure 2 shows the average PL values for a selection of possible aircraft certification test sites and the PL value for one definition of the standard atmosphere (ICAO 7488/3 with ISO9613 Annex C humidity model).

Why This Atmospheric Reference Day Standard?

Sonic boom levels obtained with different atmospheric models were compared to those obtained with the measured atmospheres dataset for the 6 ICAO down-selected noise metrics (ASEL, BSEL, DSEL, ESEL, PL and ISBAP). From the original 666 sites, ten potential noise certification sites for supersonic aircraft noise certification testing were considered in the analysis.

The ICAO 7488/3 standard atmosphere for temperature and pressure, with zero wind, was selected and paired with six different humidity models for the analysis. Three constant relative humidity profiles were considered, along with humidity models from three different standards, see Figure 3.

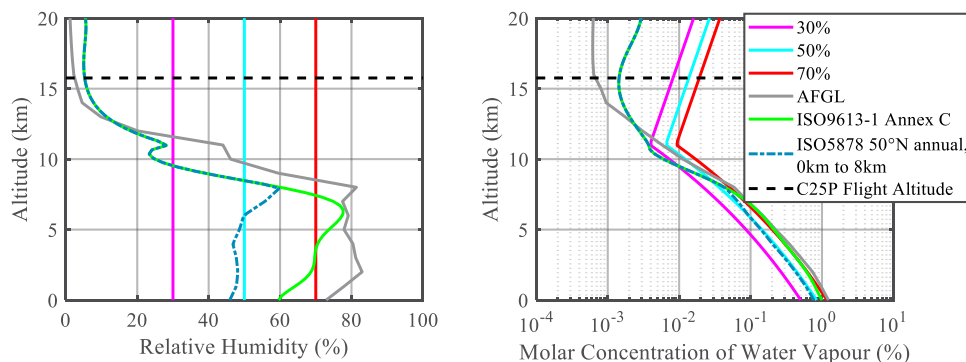


FIGURE 3 : Comparison of reference day humidity profiles. Relative humidity versus altitude is shown on the left and molar concentration of water vapour versus altitude is shown on the right. The dashed black line shows the flight altitude of NASA’s C25P concept aircraft, used in some of the analyses.

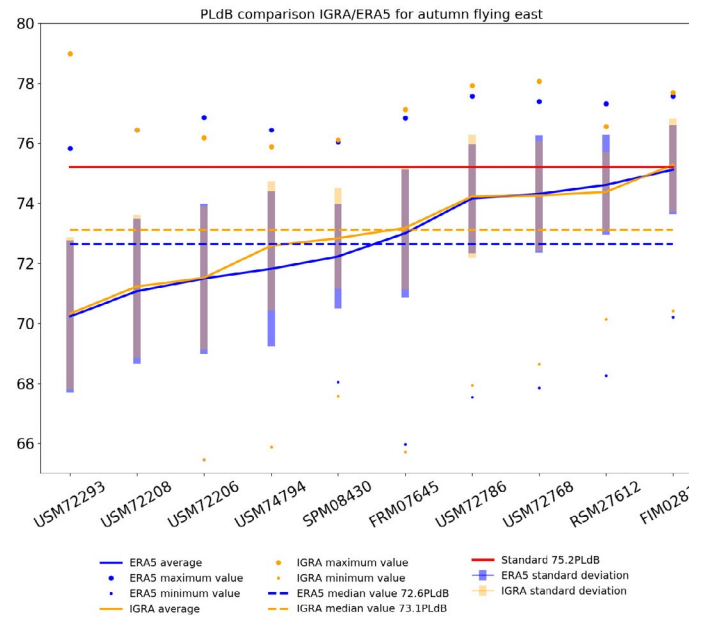


FIGURE 2: Subset of 10 aircraft certification test sites and their associated average, maximum, and minimum PL noise metric values compared to one definition of the standard atmosphere (ICAO 7488/3 with ISO9613 Annex C humidity model).

A modelling study was conducted to calculate the undertrack sonic boom from a low-boom demonstration concept aeroplane using each candidate reference day atmosphere. These results were compared to the worldwide dataset and the subset of 10 certification sites for all seasons and headings considered. The summary of all comparisons in Figure 4 shows that the mean difference values depend on the metric, but the same trends appear for each metric.

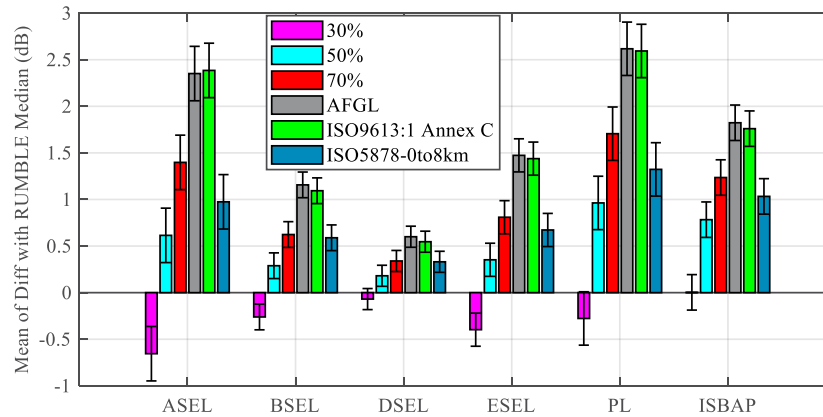


FIGURE 4 : Summary comparison of mean difference (and 90% confidence intervals) between candidate reference day option predictions and ERA5 subset medians for six noise metrics. All seasons, headings, and subset locations are included.

A mix of the ICAO 7488 standard atmosphere for temperature and pressure and the ISO 5878 (with ISO 9613-1 Annex C high-altitude extension above 8 km) standard atmosphere for humidity was selected by WG1 as providing small differences ($<1.3 \pm 0.3$ dB) with the median levels computed from the ERA5 meteorological database. This definition is preferred because the humidity is physically realizable at higher altitudes, while the constant relative humidity profiles, again see Figure 3, are not realistic.

The Next Three Years

In the next three years of the CAEP/13 cycle (2022-2025), the WG1 Supersonic Task Group will continue the development of a new Standards and Recommended Practices (SARP) for en-route low boom noise certification of supersonic aircraft. Following the successfully completed studies of atmospheric Reference Day standard and sonic boom metrics to-date, the supersonic work plan will focus on: scheme analysis/selection, data acquisition and instrumentation specification, and the definition of certification procedures for three flight conditions – design cruise, climb/acceleration (focus boom) and intermediate speed (off-design Mach numbers). Upon definition of the remaining SARP elements, the goal is to provide the preliminary SARP flight and test procedures to NASA to test with their X-59 demonstrator aircraft (and visa-versa, for resulting NASA X-59 data to be provided to SSTG to exercise/evaluate the effectiveness of the SARP) during its safety and performance validation, in addition to the acoustical validation periods.

For the CAEP/14 cycle (2025-2028), the remaining focus will hinge heavily on NASA research to establish data for defining a compatible human response of a low boom noise certification limit to complete the standard in support of WG1/SSTG.

In the meantime, WG1 will also continue to:

- Monitor and report on research to characterize, quantify and measure (including metric) climb and en-route noise from supersonic flight, including Mach cut-off conditions, and its community response while also assisting in promoting and defining such research.
- Gather data on which “other factors” need to be considered for SARPs development. These may include boom at “off design” Mach numbers, boom from accelerations and turns, secondary sonic booms, impacts on aquatic life, mammals and cruise ships, sleep and booms at night, rattle, effects on animals, and avalanches.
- Monitor, and report on, status of supersonic industry projects and OEM expectations of supersonic development.

The return of civil supersonic aircraft continues to become more apparent with recent news about the fabrication of demonstrators – Boom XB-1 and NASA X-59 airplanes. The major challenges will continue to be the reckoning of associated complex technologies and defining what constitutes a low boom supersonic airplane, with expected greater mission performance that achieves environmental protection sustainability.

Connecting the World through Environmentally Responsible Supersonic Flight

By International Coordinating Council for Aerospace Industries Association (ICCAIA)¹

Introduction

ICCAIA is a global aviation manufacturing trade association, dedicated to a safe, secure, efficient, and sustainable international air transportation system. Composed of nine global national and regional associations, ICCAIA member products ensure safe and efficient transportation of millions of people a day, resulting in a deeply connected world. The benefits of being able to hop on an airplane and safely travel thousands of miles in a matter of hours are innumerable.

Historically, global travel has been constrained by the speed of available technology. Two hundred years ago, transatlantic travel was only possible via an arduous, month-long steamship journey. It was not until the advent of commercial aviation in the 1930's that transoceanic travel became practical, albeit still a challenge. In the late 1950s, the jet age fundamentally changed travel, making long-distance flights a part of many people's lives. With the introduction of the jet, week-long transpacific business trips became practical, and tourist destinations previously too distant of became commonplace.

The speed of commercial aviation peaked in the 1970's with the supersonic Concorde and Tupolev Tu-144. While both were technological marvels of the day, neither was environmentally or economically sustainable. Consequently, supersonic flight never entered the mainstream: only fourteen Concorde entered service, and the Tu-144 flew a total of only fifty-five scheduled passenger flights.

Innovations in jet engines, advanced computational analysis, composite materials, noise reduction technologies, and net-zero carbon fuels are enabling a new generation of environmentally responsible supersonic civil aircraft. This supersonic renaissance offers tremendous benefits—bringing families, businesses, and cultures closer together; enabling global leaders to solve crises face-to-face; and providing socio-economic benefits from responsible travel to rarely visited cities

One of ICCAIA's strategic priorities is fostering the introduction of emerging technologies in civil aviation, and member manufacturers have announced projects that will unlock the benefits of traveling twice as fast, at speeds up to Mach 1.8. Three-day transatlantic business trips can shrink to a single day. And these modern supersonic aircraft manufacturers are addressing the environmental concerns of the first-generation supersonic aircraft, which flew more than half a century ago.

The International Civil Aviation Organization (ICAO), where governments, aviation stakeholders, and the NGO community all work constructively and collectively, is critical in setting international standards for the emerging supersonic industry. The standards and regulatory procedures set through ICAO require manufacturers to continually improve environmental performance through technologically feasible and economically reasonable means, and this process offers broad benefits. Notably, the Supersonic Exploratory Study completed during the CAEP/12 cycle led ICCAIA manufacturers to voluntarily update supersonic aircraft designs to achieve quieter noise levels, moving from Chapter 4 to Chapter 14

¹ Authors: This article was written and reviewed by Ben Murphy (Boom) and John Morgenstern (Exosonic), with assistance from a number of ICCAIA technical experts.

landing and takeoff noise limits using state-of-the-art noise reduction technologies and advanced operational procedures.

In addition to the landing and takeoff noise produced by all aircraft, supersonic aircraft produce sonic booms when traveling faster than the speed of sound. Industry is addressing sonic booms in two ways: first, by identifying hundreds of key markets that can be served through supersonic flight only overwater with subsonic flight over land, and second by undertaking innovative quiet boom research and development to reduce the intensity of a sonic boom to a “thump.” However, until quiet boom technology matures and international sonic boom standards are developed, supersonic aircraft will not fly at supersonic speeds over land to avoid unacceptable noise impacts.

ICCAIA supersonic aircraft members are fully committed to ICCAIA’s net-zero carbon goal by 2050, and supersonic airplanes and engines will be designed with fuel efficiency as a key consideration to enable economic and environmental performance. To achieve net-zero carbon, the aviation industry is taking active steps to help spur growth of the nascent sustainable aviation fuels (SAF) industry. Several supersonic aircraft manufacturers have partnered with e-kerosene producers, supporting one of the most scalable and environmentally friendly sustainable aviation fuel technologies. Supersonic engines are being designed to accommodate drop-in and non-drop-in sustainable fuels, maximizing the environmental benefits of SAF such as reduced particulate emissions.

Beyond carbon, leading climate scientists are developing a better understanding of the climate effects of stratospheric flight. Noteworthy recent publications from several institutions^{2,3} suggest that contrail formation and associated climate impacts are greatly reduced in the stratosphere. Supersonic manufacturers will continue monitoring the latest literature to better understand non-CO₂ impacts, including NO_x and water vapor, and mitigation strategies.

As with all new technologies, supersonic aircraft are starting near the beginning of the technology s-curve. The challenges of supersonic flight provide a catalyst for

innovation, with future iterations continuing to reduce the environmental impact of supersonic flight. These innovations, driven by necessity for supersonic flight, may also benefit subsonic aircraft and reduce the environmental impacts of aviation overall.

Announced ICCAIA Member Supersonic Aircraft

ICCAIA members, including Boom Supersonic and Exosonic, are developing commercial supersonic transports for business, airliner, and government uses, supported by engine manufacturers such as Rolls-Royce. Cruise Mach for project vehicles spans from 1.4 to 1.8, and all manufacturers are now targeting landing and takeoff noise equivalent to Chapter 14 subsonic limits using innovative advanced procedures. These manufacturers continue to contribute technical expertise, modeling resources, and data to ICAO’s Committee on Aviation Environmental Protection to inform future environmental standards for supersonic aircraft.

Boom Supersonic’s mission is to make the world more accessible, extending the benefits of supersonic travel to communities and the planet. Boom’s commercial airliner, Overture (shown in Figure 1), has undergone numerous design iterations and fidelity improvements over the past 3 years. Overture is a Mach 1.7, 4,250 nm (7,871 km), 65 passenger airliner. It is being designed to Chapter 14 noise levels using advanced procedures, balancing noise reduction with cruise fuel efficiency. Overture is expected to begin flight testing in 2026 and enter service by the end of the decade. The airplane is designed to accommodate 100% non-drop-in SAF, helping to enable net zero carbon operations. Boom is also committed to achieving net-zero carbon by 2040 as one of the first aviation signatories of The Climate Pledge. Boom’s scaled supersonic demonstrator XB-1 will further provide design validation of key characteristics of the project airplane. This demonstrator began engine runs in November 2021, with first flight expected in 2022.

2 Zhang, J. et al, *Stratospheric Ozone and Climate Forcing Sensitivity to Cruise Altitudes for Fleets of Potential Supersonic Transport Aircraft*, *Journal of Geophysical Research: Atmospheres*, Volume 126, Issue 16, 03 August 2021

3 NASA/CR-20205009400, *Global Environmental Impact of Supersonic Cruise Aircraft in the Stratosphere*, February 2022



FIGURE 1: Boom Supersonic Overture Commercial Airliner



FIGURE 2: Exosonic Large-Scale Low Speed Wind Tunnel Test Surface Flow Visualization

Exosonic is dedicated to creating environmentally friendly and efficient supersonic transportation. Quiet sonic boom technology is being rapidly integrated into a low boom flight demonstration, and Exosonic is leveraging both computational and practical tools to accelerate supersonic innovation. Flow-visualization techniques employed to understand force measurements and develop design refinements are shown in Figure 2. Engine OEMs and engine modeling are being developed to meet Chapter 14 noise limits with margin while minimizing fuel burn, emissions, and ticket cost, and Exosonic recently signed a memorandum of understanding to collaborate on developing sustainable

fuel for future supersonic aircraft. The Exosonic staff is rapidly growing and is expected to double next year. Exosonic hopes to have an aircraft certified by the end of the decade.

International Research Organizations

ICCAIA manufacturers also support the work being done by international organizations, national aviation authorities, and research institutions to advance state-of-the-art research and standards development for supersonic flight. These represent a global effort to increase the speed of aviation and facilitate the benefits of a more connected world.

ICAO

ICAO has the responsibility for developing global environmental standards for all aircraft, including emerging supersonic civil airplanes. ICAO completed a Supersonic Exploratory Study during the CAEP/12 cycle to improve understanding of the noise and emissions impacts of a representative supersonic fleet, based on industry project aircraft at the time. The result of the study contributed to ICCAIA members updating aircraft designs to Chapter 14 limits using advanced procedures, which is expected to reduce the overall noise impact of the fleet. Advancing

supersonic landing and takeoff noise and emissions standards is included in the CAEP/13 work programme, which is expected to provide the regulatory certainty ICCAIA members need to advance aircraft design and manufacturing.

Japan Aerospace Exploration Agency (JAXA)

JAXA has been making various R&D efforts on supersonic transport (SST) technologies to contribute to the realization of overland supersonic flight. Key technologies established to date include drag reduction technologies (NEXST-I project / 1997-2005) and sonic boom reduction technologies (D-SEND project / 2010-2015). Following the successful completion of the D-SEND project, JAXA has conducted the R&D program for System integration of Silent SuperSonic (S4) technology from 2016 to 2020 for future economically viable and environmentally friendly supersonic airliners. As a result of the S4 program, a 50-passenger supersonic airliner (S4 airliner) was designed as a technology reference aircraft whose performance was over 3500nm of range, less than 85PLdB of sonic-boom, and ICAO Chapter 14 criteria of LTO noise.

MORE&LESS

MDO and REgulations for Low boom and Environmentally Sustainable Supersonic Aviation (MORE&LESS) is an EU research and innovation programme, sponsored by the European Commission. The program aims to shape global environmental regulations for future supersonic aviation through high-fidelity modeling and testing, evaluating a wide range of supersonic speeds (Mach 2 to Mach 5) and a variety of aircraft configurations, propulsion technologies, and sustainable aviation fuels. The objectives are “MORE” sustainable fuels, environmental protection, and citizens protection with “LESS” pollutant emissions, noise emissions, and impact on air quality, ozone layer, and climate.

National Aeronautics and Space Administration (NASA)

NASA has conducted extensive supersonic airplane research, with a focus on low boom technologies. NASA developed the X-59 Quiet SuperSonic Technology (QueSST) aircraft

in partnership with Lockheed Martin. The X-59 is designed to fly at Mach 1.4 and create various sonic “thumps” between 70-80 decibels (PLdB), and will be used for a series of community response tests to inform potential future on-route supersonic noise standards. X-59 ground testing began in January 2022. Other NASA initiatives include shock-sensing probes, advancing Schlieren imaging techniques, and enhanced ADS-B system for supersonic aircraft.

SENECA

The EU programme noiSe and EmissioNs of supErsoniC Aircraft (SENECA) is focused on improved understanding, modelling, and quantification of noise and emissions in the vicinity of airports and the global climate impact of supersonic aviation. SENECA builds on experience from previous EU programmes such as HISAC and RUMBLE. Four different SST platforms (Mach 1.4 & 1.6 business jets and Mach 1.8 & 2.2 airliners) are subjects of multidisciplinary design optimization regarding landing and takeoff cycle noise, emissions, performance, and environmental impact. Finally, SENECA is expected to deliver reliable data and recommendations for emission and noise certification regulations ensuring environmentally friendly supersonic aviation.

CONCLUSION

Supersonic and subsonic aircraft have fundamental technical differences, and ICCAIA members are addressing these challenges head on to achieve environmentally responsible supersonic transportation. Industry and research organizations continue to innovate in noise reduction technologies, sustainable aviation fuels, engine efficiency, and aircraft design. All of these innovations will be critical to further enhancing the benefits of civil aviation through shorter travel times while also addressing the pressing climate crisis. This ongoing research will undoubtedly make sustainable, environmentally friendly supersonic flight a reality.

Supersonic aircraft in a net-zero world

By Dan Rutherford (International Council on Clean Transportation – ICCT)

Introduction

The aviation industry is under pressure from consumers and governments to slash emissions. At the International Air Transport Association 2021 General Assembly last October in Boston, global airlines committed to net-zero aviation by 2050 and have issued a series of technology roadmaps detailing how they will get there. In parallel, more than 200 ICAO experts have collaborated within the Committee on Aviation Environmental Protection (CAEP) on a comprehensive report to assess the feasibility of a Long-Term Aspirational Goal (LTAG) for international aviation. In February, CAEP met to finalize the LTAG report, and also to debate a parallel, related issue: attempts to revive supersonic transport aircraft, or SSTs.

These two goals are challenging to rectify. Flying faster than the speed of sound is inherently energy-intensive, in part because supersonics use powerful, narrow engines to produce the high thrust needed to break the sound barrier. This means high fuel burn—up to 10x more fuel per seat kilometer compared to subsonics according to a Massachusetts Institute of Technology (MIT) report to the National Aeronautics and Space Administration (NASA) — disproportionate climate impact, and the spectre of increased airport noise.

SAFs and supersonics: hand in glove, or oil in water?

Proponents of supersonics argue that low-carbon sustainable aviation fuels (SAFs) can throttle back supersonic emissions. SAFs can be used in today’s engines and aircraft at up to 50% blends and are energy-dense enough to power long-haul and high-speed flights. But SAFs remain expensive – two to five times that of fossil jet fuel – and rare, accounting for only 0.05% of global jet fuel supply in 2020. They are also controversial when generated from edible crops, which are linked to accelerated deforestation in the tropics.

Can the twin goals of zero emission aviation and supersonic aircraft be rectified? To date, no government or industry net zero roadmap has been able to do so. Waypoint 2050, the global roadmap released by the International Air Transport Association (IATA) didn’t model supersonic aircraft, calling them “niche” and waving away their excess emissions with strict standards that don’t yet exist. ICAO’s LTAG report also didn’t model their impacts, positing a small market size and industry claims that they will be operated on 100% SAFs “from day one”. But how likely is that, given the energy intensity of SSTs and their challenging economics?

To answer this question, ICCT joined forces with MIT’s Laboratory for Aviation and the Environment (LAE) in a joint study on the compatibility of supersonics and SAFs. Together, they modelled the economics, operations, and emissions of two potential supersonics designs – a “Small SST” seating 15 and operating at 1.4 times the speed of sound (MN 1.4) and a “Large SST” seating 75 designed for MN 1.7. Operations and emissions were estimated on both conventional “Jet A” fossil fuel and a synthetic “e-kerosene” generated from renewable electricity.

What did they find? In a nutshell, that supersonics are a poor use of scarce SAF supplies. Due to their underlying fuel intensity – 7 to 9x that of subsonics per seat-km – even an excellent SAF providing a 90% reduction in life cycle CO₂ would only modestly (-6% to -24%) reduce CO₂ relative to subsonic aircraft operated on fossil jet fuel (Figure 1).

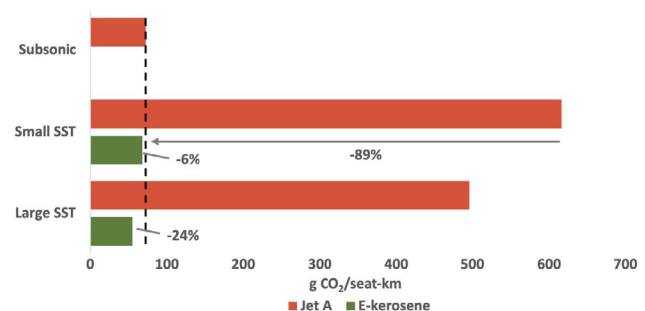


FIGURE 1: CO₂ intensity by aircraft type and fuel

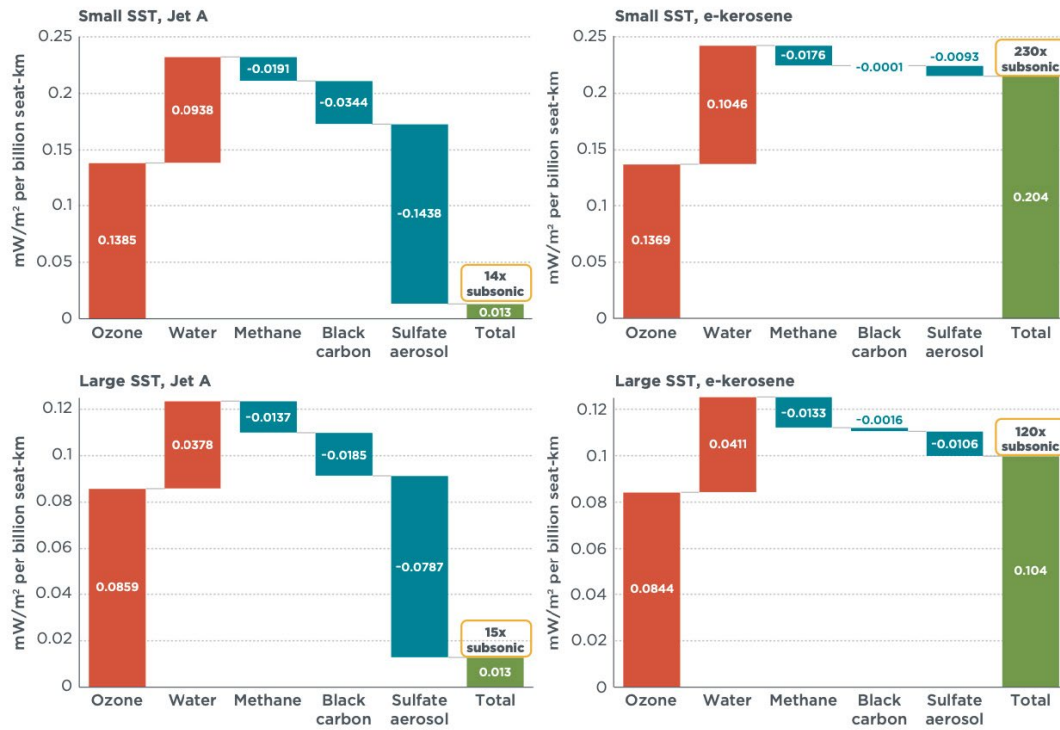


FIGURE 2: Medium-term radiative forcing by SST and fuel

More surprising, even if SAFs were widely available, their use in supersonic flight could actually backfire after accounting for the full atmospheric impacts of SSTs. Prior LAE research for NASA concluded that medium term (non- CO_2 , non-contrail) climate impact from fast supersonics can be up to 20 times that of subsonics¹. That's because the high cruise altitude of supersonics increases the residence time of emissions significantly. Moreover, aircraft exhaust contains a variety of pollutants with either warming or cooling impacts depending upon the elevation at which they are emitted.

SAFs are uniformly low sulfur and low aromatic content. Burning those fuels in the stratosphere could actually increase the net warming of supersonics by unmasking the warming effects of ozone destruction and water vapor (Figure 2, two right panels, compared to baseline impacts on Jet A in the two left panels). That diagram shows the cumulative radiative forcing impact, in mW/m^2 per billion seat-km, for warming species (red), cooling species (blue), along with the total, by SST and fuel type.

So operating supersonic on a low-sulfur, low aromatic jet fuel could actually exacerbate the medium-term climate impacts of supersonics, from about 15 times that of supersonics up to 120 to 230 times the subsonic baseline. The fleetwide result would be stark. Even a limited number of operations (less than 1% of seat kilometers in 2035) could potentially increase the medium-term climate impacts of commercial aviation by two-thirds. (Figure 3, top and bottom bars).

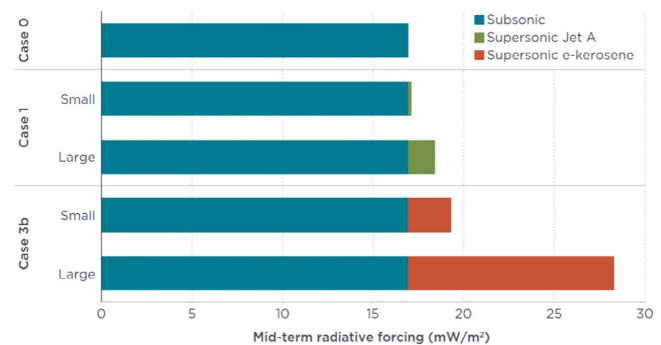


FIGURE 3: Fleetwide medium-term radiative forcing by case and SST

1 <https://ntrs.nasa.gov/citations/20205009400>

They conclude that assuming that SAFs can address the climate impacts of supersonics is premature. Moreover, economic modeling concludes that the high cost of SAFs will make them cost prohibitive for supersonics for the foreseeable future. The combination of SAFs higher cost and SSTs greater fuel intensity could increase fuel costs to 25 times that of subsonic aircraft burning Jet A, threatening the already questionable finances of supersonics. Their analysis suggests that any SSTs produced are likely to operate on fossil jet fuel, not SAFs, after being delivered as airlines search for profitability. That may turn out to be a blessing—given limited supplies, it would be preferable for scarce SAFs are earmarked for the most fuel-efficient subsonic planes – but any new, unabated emissions from SSTs will make net-zero aviation that much harder to achieve.

Conclusions

This work highlights that emissions from supersonic aircraft should be regulated on their own basis, without assuming that low carbon fuels will be sufficient. As the only accredited organization representing civil society at ICAO, ICASA members believe that SSTs should meet the same noise, air pollution, and CO₂ standards as subsonic aircraft. This approach will help ensure no net increase in noise or emissions due to the reintroduction of supersonic aircraft and is consistent with industry's goal of net-zero emissions in 2050. In tandem, governments should focus on promoting the highest-quality SAFs and targeting them to the best use, notably long-haul flights that require the most energy dense liquid fuels.



| ICAO

CHAPTER THREE

Local Air Quality

ICAO Standards and Recommended Practices: Annex 16, Volume II

By ICAO Secretariat

Since the late 1970s, the International Civil Aviation Organization (ICAO) has been developing measures to address emissions from aircraft engines in the vicinity of airports and from relevant airport sources. The objective is to attain a primary environmental goal “to limit or reduce the impact of aviation emissions on local air quality (LAQ)”. Relevant Standards and Recommended Practices (SARPs) are contained in Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions*, and technical guidance is provided in the Environmental Technical Manual (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines*, and other technical documentation. Provisions on LAQ deal with liquid fuel venting, smoke, non-volatile particulate matter (nvPM) and the main gaseous exhaust emissions from jet engines, namely: hydrocarbons (HC), oxides of nitrogen (NO_x), carbon monoxide (CO).

Engine emission certification

The engine certification process is based on the aircraft's landing and take-off (LTO) cycle, which consists of four operating modes with characteristic thrust settings and time-in-modes, as shown in Figure 1. This LTO cycle is procedurally similar to the aircraft engine operating modes in the airport vicinities, and is performed by the engine installed on a test bed. For each thrust setting, pollutant emissions are measured in line with Annex 16, Volume II. This certification data is collected and stored in ICAO's publicly available engine emissions databank¹.

SARPs Maintenance

During the last three years, the global pandemic affected the aviation sector worldwide in an unprecedented manner. Nevertheless, ICAO Committee on Aviation Environmental

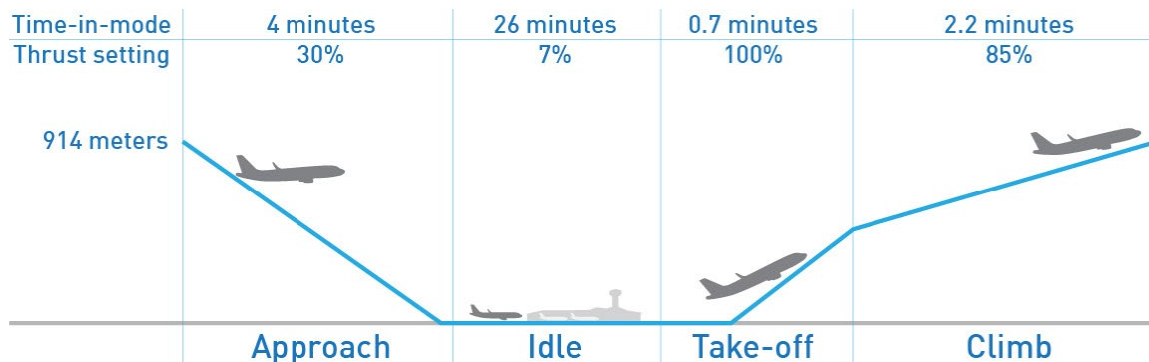


FIGURE 1: ICAO engine emission certification LTO cycle.

¹ <https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank>

Protection (CAEP) continued conducting its work in a non-disruptive mode, and, amongst other, completed under the environmental Standards and Recommended Practices (SARPs) maintenance task an extensive exercise on restructuring Annex 16, Volume II in accordance with ICAO Doc 8143 — *Directives to Divisional-type Air Navigation Meetings and Rules of Procedure for their Conduct*, Part II — *Formulation of Proposals for International Standards, Recommended Practices and Procedures*. The relevant sections of this Volume were either introduced as the new paragraphs of the Appendices or formed the new Attachments to the Annex 16, Volume II, depending on their contents. The work on Aircraft Engine Emissions SARPs also included language updates, consistency check across all the Annex 16 volumes, ensuring the validity of the technical basis underpinning the Standards and an overview of the current state of the science regarding LAQ.

New nvPM Mass and Number Standards

At the aircraft engine exhaust, particulate matter emissions mainly consist of ultrafine soot emissions. They are present at high temperatures at the engine exhaust, and are preserved as they mix and dilute with the ambient air. These particles are invisible to the human eye and are ultrafine; their mean diameter is much smaller than 2.5 microns (μm) (Figure 2). Gaseous emissions from engines can also condense to produce new particles, coat the emitted soot particles, and react chemically to produce secondary particulate matter.

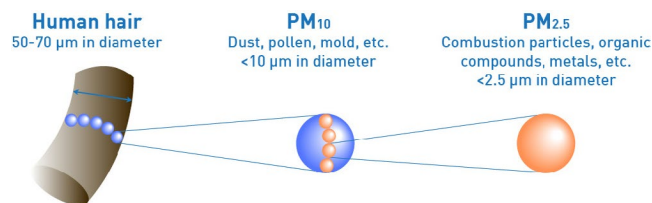


FIGURE 2: Comparison of particle sizes from various sources.

The first nvPM mass concentration Standard was adopted by ICAO in 2017. An important component of this Standard was the mandatory reporting of health and climate-relevant nvPM emissions measured during the certification process for in-production engines. This data was then used to set future regulatory limits.

In March 2020, ICAO adopted new Standards for nvPM mass and number, which were the culmination of six years of efforts. The new nvPM Standards will apply to new type and in-production engines with rated thrust greater than 26.7 kN. The limits for nvPM mass and number will provide some alleviation for engines with rated thrusts below 150 kN. These Standards are less stringent for engines in production, and a supplementary “no-backsliding” measure prevents less nvPM-efficient technologies from re-entering aircraft fleets.

Additionally, extensive calculations have been performed to ensure that the nvPM mass Standards maintain the limits for engine exhaust smoke number contained in Annex 16, Volume II. In March 2020, ICAO also set an end date for the Smoke Number (SN) Standard for engines with rated thrust greater than 26.7 kN.

This milestone achievement on nvPM SARPs completed a suite of environmental Standards for the certification of aircraft and engines, namely, for noise, LAQ and CO_2 , making the aviation industry the only sector with mandatory global environmental certification requirements for the operation of equipment. As of 1 January 2023, all new aircraft will have to meet the Standards in order to be certified and enter operation.

Innovations in Aviation Technology Improving LAQ

The extensive ICAO Stocktaking process showcased and demonstrated multiple technologies improving fuel efficiency and hence mitigating aviation impact on LAQ. The incremental improvements in the convenient tube-and-wing aircraft designs are made in various elements of the aircraft. For propulsion systems, the improvements in contemporary turbofan combustion engines are focused on increasing efficiency of all elements of the engines, including thermal management and low-emission combustors, while the propeller-driven layouts are being advanced as well. The engine manufacturers are also advancing on maximum Sustainable Aviation Fuel (SAF) compatibility for their products, of which during implementation decreases the nvPM emissions.

In regards to the aerodynamics and airframe, lighter and more reliable materials in combination with the structural upgrades using additive manufacturing in production result in decreased airframe weights. The aircraft manufacturers also investigate measures to minimize airframe drag using various technologies, such as, implementation of the laminar flow fuselage, or the transonic truss-braced wings.

More challenging novel aircraft concepts are being designed to meet the unprecedented fuel and therefore emission reduction benefits. Amongst these projects are: the flying wing aircraft, hybrid and electric-powered airships, cryogenic hydrogen-based and liquefied natural gas-powered transport.

Consideration of the new paradigm of routing allows early introduction of the novel concepts such as the short-range small hybrid, electric or hydrogen-powered aeroplanes, and the E-VTOL projects. These aircraft types allow zero-emission flights, but need scaling-up for pertinent contribution to the emissions reduction. All new aircraft technological solutions and concepts require corresponding certification procedures to ensure their entry into market.

Updates to ICAO Doc 9889

ICAO is continuously updating its *Airport Air Quality Manual* (ICAO Doc 9889), which focuses on the estimation of emissions from airport operations, specifically aircraft combustion engines. Other considered sources of airport emissions include ground service vehicles and airside ground transportation, as well as de-icing and refueling operations, which produce evaporative emissions of non-volatile organic compounds.

The latest edition of ICAO Doc 9889 contains methods to estimate the nvPM emissions more accurately from aircraft engines and aircraft handling operations. Data that had been collected during the Standard-setting process were used to develop improved methods for estimating nvPM mass emissions and the first method for estimating nvPM number. In the long term, these methods can also be used when nvPM measurement data cannot be obtained during certification, for example, for engines that are no longer in production but still in operation.

Future Work

The future work on LAQ related issues embraces a vast majority of topics and directions. Despite the current circumstances, ICAO continues to develop measures aimed at mitigating the impact of aviation on LAQ, by developing Standards, guidance material, and technical documents. This includes the maintenance of Annex 16, all volumes of ICAO Doc 9501, the ICAO engine emissions databank.

ICAO will continue to monitor and review developments in combustion technologies and engine combustor design, including the results from Combustion Technology Review Workshop planned for the new ICAO Assembly Triennium, to better understand how new technologies can affect gaseous and nvPM emissions in the future. ICAO will also further monitor trends in aviation fuels, including fuel composition and sustainable aviation fuels, since synthetic fuels with low aromatics content can help to reduce nvPM mass and number emissions at low thrust conditions.

During the ICAO Committee on Aviation Environmental Protection (CAEP/13) cycle, it is also planned to assess the existing NO_x and nvPM LTO metrics for relevance to modern engine designs and to full flight emissions, and to explore other metric systems that will ensure improvements in aircraft engine emissions in airport and cruise operation. With this regard, ICAO will conduct a scoping study on a possible integrated standard setting process that could be undertaken later in the CAEP/14 cycle for NO_x and nvPM emissions.

ICAO remains fully committed under its strategic objectives to reduce aviation's environmental impacts and achieve the United Nations Sustainable Development Goal 3 – *Ensure healthy lives and promote well-being for all at all ages*, by mitigating aviation's adverse effects on human health across the globe. The environmental work programme for the coming three years ensures that ICAO's leadership in this area will be accelerated with a high pace.

Impacts of Aviation NO_x Emissions on Air Quality, Health, and Climate

By Richard C. Miake-Lye (Aerodyne Research) and Didier Hauglustaine (Laboratoire des Sciences du Climat et de l'Environnement - LSCE)

Nitrogen oxides (NO_x) continue to be a key pollutant of concern for aviation, and that concern has resulted in improved combustor emissions performance from new aircraft engines as new NO_x standards have been adopted. There remains a strong push for higher core temperatures for better engine specific fuel consumption, which counter-balance combustor NO_x improvements.

Aviation NO_x emissions have impacts on local air quality and human health, both through emissions in and around airports, but also from emissions at altitude affecting background concentrations. NO_x emissions also affect climate by changing atmospheric ozone (O₃) and methane (CH₄) levels, two important greenhouse gases, thus affecting the Earth's radiative balance.

A recent report¹ was written by the Impacts and Science Group (ISG) within the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) that enlisted subject matter experts from the ISG to examine and summarize the current scientific understanding of the aviation NO_x impact upon the environment.

The understanding of the effects of aircraft NO_x emissions upon the atmosphere and climate continues to improve, resulting in a better understanding of the impacts of NO_x. The NO_x impact on climate results from a complex balance of offsetting effects and the current view is that the net aviation NO_x effect has likely resulted in a warming of the climate system. However, several recent studies suggest

that the net effect could turn into a net cooling when new processes or refined parameterizations are considered.

In contrast to aircraft emissions, reductions of surface O₃ precursor emissions are projected because of reduced use of fossil fuels in the power production, industrial, and transportation sectors. A cleaner background atmosphere may also to some extent mitigate the future aviation NO_x climate impact and provide a net cooling, which could significantly affect our view of the NO_x impact on climate. Despite significant advances in knowledge, the impact of NO_x on climate remains highly uncertain.

Aircraft ground operations and the landing and takeoff (LTO) cycle result in the emission of various gaseous and particulate pollutants or their precursors, which are known to affect human health. The key pollutants of interest from a human health perspective are essentially nitrogen dioxide (NO₂), O₃, and fine particulate matter. For ground level emissions, most other sources of NO_x are being reduced through clean air regulation and transition to alternative energy sources. For aircraft, recent studies show the pervasive influence of ground level emissions on the reduction of air quality around major airports and at the regional scale, indicating a significant health impact from these ground level emissions. Aircraft LTO emissions contribute to premature mortality around major airports and, at the local scale, NO₂ health impacts were shown to outweigh PM_{2.5} health impacts.

In addition, several studies indicate that cruise altitude emissions could significantly be recirculated to the lower

¹ To be published later in 2022: <https://www.icao.int/environmental-protection/Pages/environment-publications.aspx>

atmosphere and be an important source of O_3 and of particulate matter at ground level. Most NO_x emissions from aviation do not occur near the ground, and more than 90% occur above 3,000 ft. Those emissions still contribute to the background levels of O_3 and thus to the O_3 at the ground level. Some studies suggest that cruise emissions could potentially be a dominant source of surface level particulate matter globally and of aviation-related premature mortality.

Reducing aviation NO_x is challenging and is countered by the international growth in commercial aviation and by the mandate to increase engine energy efficiency by increasing engine core temperatures. In the recent past, aviation NO_x emissions have been reduced by technology improvements in combustor design, driven by increased stringency in NO_x emissions regulations. However, continued reductions in NO_x may have the potential to increase fuel burn and the resulting emissions of carbon dioxide (CO_2) if no technological advances are made. Thus, there could arise a trade-off between reducing impacts on climate due primarily to CO_2 or reducing impacts on air quality due primarily to NO_x (and particulate matter). An important issue affecting the trade-off issue is the much shorter atmospheric lifetime of NO_x (and the resulting effects on O_3 and CH_4) relative to that of CO_2 . However, the NO_x/CO_2 trade-off is not a fundamental limit and technological progress is possible with new combustor architectures and other technical solutions being considered.

In response to the important challenges raised by climate change, several studies have focused on how to reduce the climate impact of aviation through changing flight operations. This is particularly the case for reducing contrail formation and the contribution to climate change from contrails and induced cirrus. In the case of NO_x , the climate impact varies strongly with flight altitude and location as the lifetime of pollutants increases higher-up. Lower flight altitudes provide another possible mitigation option for reducing the climate impact of NO_x , although this would likely entail an increase in CO_2 emissions. These trade-offs and mitigation options are discussed in the ISG NO_x Report.

The current view is that aviation NO_x emissions over the 1940-2018 period have contributed to a net warming of the climate system. However, the uncertainty associated with the estimates of the net climate forcing remains high. The

estimated impacts of NO_x emissions on the climate system relative to other forcing agents are dependent on the choice of the climate metric and time horizon considered.

Aircraft ground operations and the landing and takeoff cycle (LTO) emit various gaseous and particulate pollutants or their precursors, which are known to affect human health. A few studies suggest that cruise emissions could potentially be a dominant source of surface level particulate matter globally and of aviation-related premature mortality.

The options for controlling aviation NO_x are limited and are countered by the international growth in commercial aviation and by the mandate to increase engine energy efficiency by increasing engine core temperatures. Historically the continued reductions in NO_x have tended to increase fuel burn and the resulting emissions of carbon dioxide (CO_2), the primary gas of concern to the changing climate. Thus, there arises a trade-off between reducing impacts on climate due primarily to CO_2 and reducing impacts on air quality from NO_x . Countering these increasing NO_x impacts, in the short term there was a large reduction in transportation activity that arose in 2020, due to the global COVID-19 pandemic and the subsequent travel restrictions.

The key messages of the Impacts and Science Group (ISG) Report on NO_x impacts are:

- Based on a recent assessment, aviation NO_x emissions over the 1940-2018 period have contributed to a net warming of the climate system. The uncertainty associated with the estimates of the net NO_x climate forcing remains high.
- A recent study suggests that the net climate impact of aviation NO_x might switch to a net cooling depending in particular on future background atmospheric composition, aircraft emissions or when new processes or refined parameterizations are considered in the atmospheric chemistry models used to assess NO_x emissions.
- The climate impacts associated with the O_3 and CH_4 responses to aircraft NO_x emissions occur at very different time scales. The estimated impacts of NO_x emissions on the climate system relative to other forcing agents are dependent on the choice of the climate metric and time horizon considered.

- Key pollutants for air quality are nitrogen dioxide (NO_2), ozone (O_3), and fine particulate matter ($\text{PM}_{2.5}$). Cruise emissions are estimated to be the dominant aircraft source of surface level ozone (increase relative to other emissions sources of 0.3 to 1.9% globally) and $\text{PM}_{2.5}$ (increase relative to other emissions sources of 0.14 to 0.4% in high traffic regions) and hence a dominant cause for aviation-induced premature mortality globally.
- Particle number concentration (PNC) is a good marker for traffic and aircraft emissions and increasing number of studies are reporting elevated PNC due to aircraft emissions in the vicinity of airports. Aviation-attributable NO_2 health impacts are estimated to outweigh $\text{PM}_{2.5}$ health impacts.
- The global COVID-19 pandemic and resulting lockdowns led to large reductions in transportation activity and associated emissions impacts in 2020. Due to the pandemic, all-sector CO_2 worldwide emissions in 2020 decreased by -4% and the emissions from aviation fell by nearly -50%.
- Past studies suggest reducing climate impacts increases the emissions of NO_x , and reducing NO_x increases fuel burn and resulting emissions of CO_2 . Moving forward, new technology may allow both CO_2 and NO_x emissions to be reduced.
- Effects on O_3 due to NO_x last for less than a month in the upper-troposphere and lower-stratosphere while the lifetime of CO_2 is centuries to millennia. Therefore, even a small increase in CO_2 that could accompany technological NO_x emission reduction could have a significant effect on climate.
- Studies on how to reduce the climate forcing from aviation include improving engine efficiency, reducing NO_x emissions, reducing contrail formation and/or technology development for contrail avoidance.
- There remain many uncertainties, and a more complete assessment of trade-offs considering recent technological developments is needed.

Update of ICAO's Airport Air Quality Manual (Doc 9889)

By S. Daniel Jacob (USA FAA) and Martin Plohr (DLR)¹

Introduction

The International Civil Aviation Organization (ICAO)'s Airport Air Quality Manual (Doc 9889)², provides guidance and essential information for ICAO Member States to implement best practices with respect to airport-related air quality. This information is related to ICAO Member State requirements, emissions from airport sources, emissions inventories, and emissions allocations (up to 3,000ft above ground).

Since this guidance material was developed to potentially assist all ICAO Member States in implementing best practices in relation to airport-related local air quality, it is necessarily broad and extensive. Accordingly, some States may already have some, or many, of the processes and measures in place that are addressed in this guidance material. In such cases, this guidance material may be used to supplement those processes and measures or used as an additional reference.

During the 12th cycle of Committee on Aviation Protection (CAEP/12), a complete and full review of ICAO Doc 9889 was performed. All the chapters of the document were revised. This revision included updates to ambient air quality pollutant limits worldwide, changes to the emissions modeling methodologies, recommendations to account for engine deterioration more accurately, estimation of emissions at low speeds below the 7% thrust level, and updates to dispersion modelling methods.

The updates were completed using the latest information from a number of stakeholders, including engine

manufacturers, aircraft manufacturers, the Airports Council International (ACI), and governmental agencies. The guidance material was streamlined to remove obsolete information and to provide up to date guidance.

ICAO Doc 9889 Structure

The opening chapters of ICAO Doc 9889 provide introductory material and information on local air quality (Figure 1). Chapter 2 describes the regulatory framework and drivers in detail. The complexity of the airport environment is outlined in the context of the various emissions sources including aircraft, ground support equipment (GSE), terminal buildings, and ground vehicular traffic. Despite the complexity involved, airports are subject to the same regulations and standards that are established to define acceptable levels of local air quality. The chapter concludes summarizing local air quality regulations in different countries. The evolving nature of the local air quality regulations is also noted.

Chapter 3 focuses on the airport emissions inventory to develop baselines and emissions mitigation programs. Guidance is provided on a number of key subjects including: emission inventory construction, emissions parameters and species, airport-related sources, local and regional sources, forecasting, and quality assurance procedures. An emissions inventory can be conducted at various levels of complexity, depending on the required fidelity of the results as well as the availability of the supporting knowledge, data, and other resources. The guidance in Chapter 3 is intended to be a framework for conducting studies at

¹ S. Daniel Jacob and Martin Plohr are Co-Leads of Working Group 3 Emissions Characterization Task Group of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

² ICAO's Airport Air Quality Manual (Doc 9889): https://www.icao.int/publications/Documents/9889_cons_en.pdf

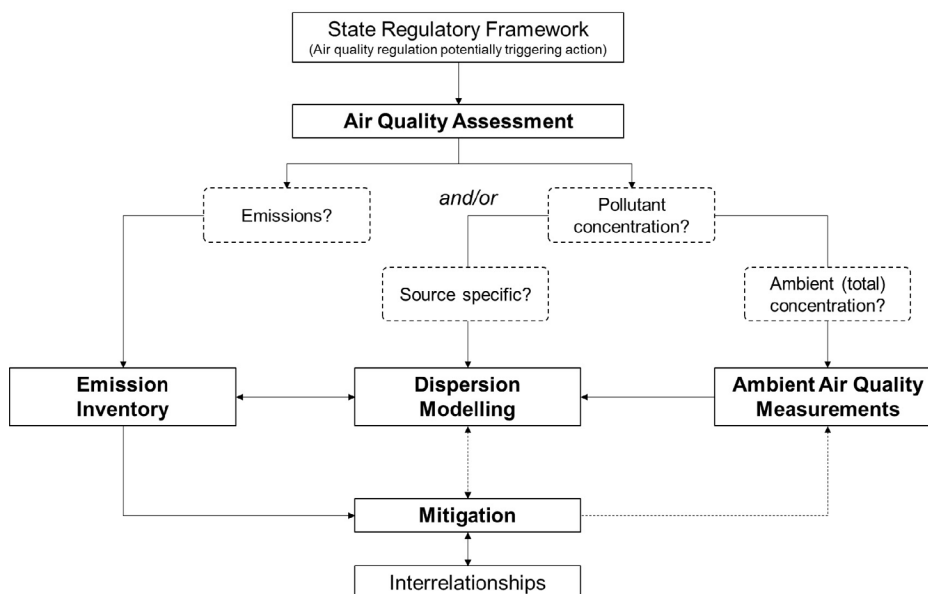


FIGURE 1: Local Air Quality Elements and their Interactions

various levels of complexity and guidance is given for three different levels of complexity (e.g. simple, advanced, and sophisticated). New information and methodologies were added to Appendix 1 to Chapter 3 during CAEP/12 and these updates are described in detail in a following section.

The spatial and temporal allocation of emissions provides information on locations and times with high emissions, and the relevance of different emission groups. As the pollutant concentration is proportional to the emission, such an allocation provides a first estimate of pollutant hot spots and source apportionment with respect to pollutant concentration. Transport effects due to exhaust dynamics, wind flow, atmospheric diffusion, deposition and physical or chemical conversion processes can be accounted for in a dispersion calculation which requires a detailed spatial and temporal allocation of the emissions from the various emission sources at and around the airport. Based on the calculation of emissions described in Chapter 3, guidance on spatial and temporal allocation of the calculated emissions is provided in Chapter 4.

Atmospheric dispersion models are an important complement to pollutant measurements. They provide comprehensive three-dimensional concentration distributions, insight into relevant transport mechanisms, and a clear source apportionment. In addition, they allow studies of future or other scenarios for which measurements

are not available or not possible. Chapter 5 describes the general dispersion modelling approaches, input parameters and outputs. CAEP (Committee on Aviation Environmental Protection) approved dispersion models are listed in Appendix 1 to Chapter 5.

Chapter 6 describes ambient air quality monitoring for airports. Guidance is provided on the design process of a measurement plan, airport local and external factors affecting the measurements, measurement locations, measurement methods, data management, analysis of data and data quality assurance.

The document concludes with Chapters 7 and 8. Chapter 7 provides guidance on mitigation methods of environmental impacts and Chapter 8 on interrelationships associated with methods for mitigating environmental impacts.

Rationale for ICAO Doc 9889 Updates

The technical emissions work undertaken by ICAO CAEP in support of the standard setting process involves state-of-the-art data analyses and the development of emissions quantification methodologies. This technical work enables ICAO to conduct global assessments of the incremental effects of aviation-related emissions. In addition, Member

States would also benefit from the use of already developed emissions methodologies to quantify aviation-related emissions for their domestic regulatory and planning purposes. ICAO Doc 9889 is the guidance document that allows ICAO to provide Member States with state-of-the-art emissions quantification methodologies to assess air quality in the vicinity of airports. To this end, ICAO continues updating ICAO Doc 9889 periodically to reflect the evolutionary nature of technology in the civil aviation industry.

Driven by potential adverse health effects of ultrafine particulate matter concentrations in the ambient air, there is an increasing need to estimate gaseous and particle emissions more accurately from aviation activities, as part of the broader set of emissions sources. In general, airports have a reasonable understanding of gaseous emissions from airport related sources and their impacts on local and regional concentrations, and based on this understanding, they have developed and implemented mitigation plans that have successfully yielded benefits to local air quality. The non-volatile particulate matter (nvPM) emissions standards adopted by ICAO and implemented by Member States have resulted in the reporting of certified nvPM mass and number emissions indices (EIs). Appropriate guidance in ICAO Doc 9889 on using the reported EIs will aid in a more accurate estimation of nvPM mass and number concentrations. Improving the quantification of the relative contribution of engine emissions and other airport sources in the context of wider transport sources will aid in understanding the potential reductions necessary. Ultimately, these methodologies may also be used to quantify the impacts of policy measures aimed at reducing PM emissions.

ICAO Doc 9889 provides worldwide harmonization of methods, which allows proper comparison between airport inventories and other sources.

ICAO Doc 9889 Updates

The first two chapters of ICAO Doc 9889 were revised to remove out of date information and to include latest changes to local air quality standards worldwide. The overall regulatory framework and drivers were updated to reflect latest regulatory landscape around the world.

Use of Measured nvPM EIs:

Comprehensive updates were made to Chapter 3. In particular, Appendix 1 to Chapter 3 was updated to provide guidance on the use of measured nvPM EIs. It was noted that the issue 28 and later, the ICAO EEDB contain information on the nvPM mass and number emissions, together with the associated fuel flow rates at the four specified LTO reference points, both as individual engine data sheets and as a spreadsheet containing the data for all certified engines. A sample ICAO Engine Emissions Data Sheet containing nvPM EIs was added to the document. Use of these newly reported nvPM mass and number EIs using inventory generation methods of varying complexities was also described in detail. The description of the methodology to estimate nvPM emissions using Smoke Number (SN) measurements for older engines was revised for clarity (Figure 2).

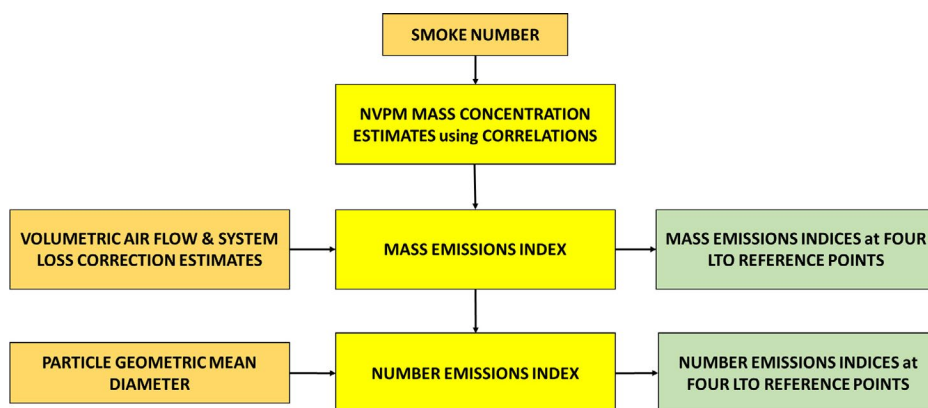


FIGURE 2: Estimation of nvPM mass and number EIs from Smoke Number

Effects of Engine Deterioration on Airport Emissions:

In-service airframe and engine deterioration has a small but real effect on fuel burn and NO_x emissions. There is no evidence that indicates deterioration effects on CO, HC. While there is measurement evidence of deterioration effects for some of the tested engines for smoke, quantification of this effect for fleet wide application needs more information. For nvPM mass and number, there is a modest increase in emissions due to engine deterioration that can be considered for airport inventories. Based on analyses of theoretical and actual airline data, the magnitude of engine deterioration effects for fleet-wide application for nvPM mass and number emissions were included in the update.

Actual Idle Emissions:

In some cases, actual idle conditions have been observed as being below the ICAO LTO reference thrust point of 7% and provisions may be taken to estimate fuel flow and emissions below 7% thrust. In particular, there may be an increase in the idle nvPM emissions below 7% thrust. The document was updated to provide guidance on estimating actual idle nvPM mass and number emissions for airport inventories.

Emissions Distribution and Dispersion Modelling:

Chapters 4 and 5 were revised to remove out of date sections and update other sections of these chapters with the latest technical information. The guidance for spatial emissions allocations was revised comprehensively to include aircraft induced emissions sources at aprons and other related locations and sources. The temporal allocation section now includes a clearer focus on aircraft and emissions sources connected to their operations. Guidance on dispersion modelling was updated to include general concepts of dispersion modelling. Elements updated include emissions models, plume models that capture exhaust dynamics more accurately, airport setup models, meteorological models, deposition models and the core dispersion model.

Ambient Air Quality Measurements:

Guidance for ambient air quality measurements is provided in Chapter 6. With the advent of low cost air quality monitors, ad hoc measurements are being made and emissions attributed to aircraft and airports. In this context, guidance provided in ICAO Doc 9889 is of great importance for systematic measurements of pollutants in and around the airports. Updates made to this chapter include revisions to the measurement plan, location of the instruments and description of new instrument types. Information in this chapter will assist airports in considering ambient air quality measurements for demonstrating compliance to local air quality regulations and evaluating the performance of dispersion models.

Air Quality Mitigation Options and Interrelationships:

Significant updates were made to Chapters 7 and 8 to remove out of date material and to include latest mitigation approaches. Interrelationships of different factors in mitigating environmental impacts were described in detail. Both Chapters 7 and 8 were streamlined and focused to be more useful for the airport community.

Summary

The ICAO Doc 9889 provides guidance on two main areas to enable airport local air quality assessments: a) emissions inventories; and b) dispersion modelling of pollutant concentrations. The revised Doc 9889 contains the following updates:

- Inclusion of up to date material and removal of outdated information throughout the document.
- Guidance on the use of reported non-volatile particulate matter emission indices in airport nvPM mass and number emissions inventory generation.
- Recommendation to account for engine deterioration effects for nvPM emissions fleet wide.
- Estimation of nvPM emissions for actual idle below the 7% idle LTO mode.
- Dispersion modelling, ambient air quality measurements, air quality mitigation options and interrelationships.

The Next Three Years

ICAO Doc 9889 will be continually updated as civil aviation technology evolves and modelling methodologies improve. The nvPM mass and number EIs are starting to become available, and this will lead to improvements in the modelling methodologies for more accurate modelling of emissions inventories. More information is expected to be available on the effect of ambient atmospheric conditions on nvPM mass and number emissions in the near future.

Further work planned on ICAO Doc 9889 includes an assessment of the current volatile PM (vPM) estimation method. A more sophisticated methodology under development during the CAEP/12 cycle is currently being evaluated for inclusion into ICAO Doc 9889.



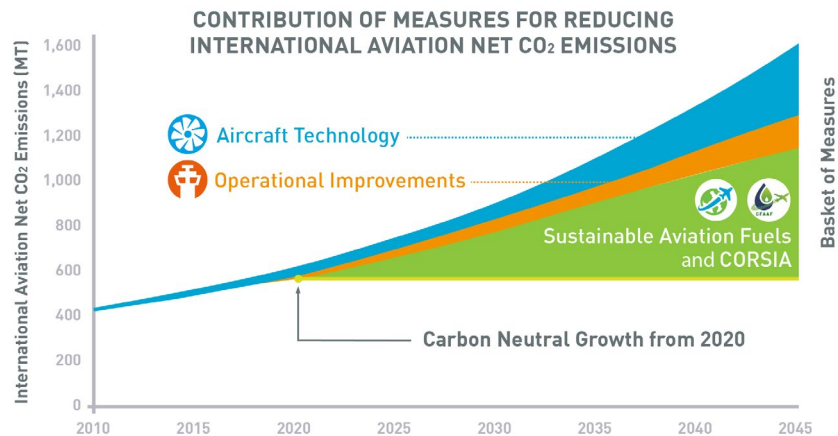
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CHAPTER FOUR

Climate Change Mitigation: Overview

ICAO's Work on Climate Change Mitigation

By ICAO Secretariat



ICAO has been working on climate change mitigation through various work streams¹. With a view to minimize the adverse effects of international civil aviation on the global climate, ICAO formulates policies, develops and updates Standards and Recommended Practices (SARPs), publishes guidance documents and conducts outreach activities. These activities are conducted by the Secretariat and the Committee on Aviation and Environmental Protection (CAEP)². In pursuing its activities, ICAO also cooperates with other United Nations bodies and international organizations.

The ICAO Assembly at its 40th Session in 2019 adopted Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change³. It reiterated the two global aspirational goals for the international aviation sector of

2% annual fuel efficiency improvement through 2050 and carbon neutral growth from 2020 onwards, as established at the 37th Assembly in 2010.

To achieve the global aspirational goals and to promote sustainable growth of international aviation, ICAO is pursuing a basket of measures including aircraft technology improvements⁴, operational improvements⁵, sustainable aviation fuels⁶, and market-based measures (Carbon Offsetting and Reduction Scheme for International Aviation - CORSIA⁷).

ICAO is also exploring the feasibility of a long-term global aspirational goal for international aviation (LTAG⁸), as requested by the 40th Session of the ICAO Assembly (Reference: ICAO Assembly Resolution A40-18, paragraph 9).

¹ <https://www.icao.int/environmental-protection/Pages/default.aspx>

² <https://www.icao.int/environmental-protection/Pages/Caep.aspx>

³ https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf

⁴ https://www.icao.int/environmental-protection/Pages/ClimateChange_TechnologyStandards.aspx

⁵ <https://www.icao.int/environmental-protection/Pages/operational-measures.aspx>

⁶ <https://www.icao.int/environmental-protection/Pages/SAF.aspx>

⁷ <https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx>

⁸ <https://www.icao.int/environmental-protection/Pages/LTAG.aspx>

ICAO collects information and facilitates the involvement of all relevant stakeholders, ensuring that the best expertise is available for assessment and decision-making processes. The ICAO Stocktaking Process⁹, the ICAO Global Coalition for Sustainable Aviation¹⁰ and the Tracker Tools website¹¹ were established in this end.

In the spirit of the No Country Left Behind initiative, ICAO provides support, assistance and capacity building to its Member States, in particular with the development of their State Action Plans¹².

More details are provided in dedicated articles throughout this edition of the ICAO Environmental report.

⁹ <https://www.icao.int/environmental-protection/Pages/Meetings-Events.aspx>

¹⁰ ICAO Coalition: <https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx>

¹¹ ICAO Tracker Tools website: <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>

¹² https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

State of Consensus Climate Science

By ICAO Secretariat

Introduction

The International Civil Aviation Organization continues to keep abreast of developments in other United Nations (UN) bodies, including the work of the Intergovernmental Panel on Climate Change (IPCC). According to the IPCC Sixth Assessment Report (AR6)¹, it is unequivocal that human influence has warmed the atmosphere, ocean and land: widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. From a physical science perspective, the global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO₂) and other greenhouse gas emissions occur in the coming decades.

The IPCC AR6 states that limiting human-induced global warming to a specific level requires limiting cumulative CO₂ emissions, reaching at least net zero CO₂ emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in methane (CH₄) emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.

IPCC AR6 Emissions trends and Continuing Challenges

According to the IPCC AR6², the rate of global greenhouse gases (GHG) emissions growth has slowed in recent years, from 2.1% per year between 2000 and 2009, to 1.3% per year in between 2010 and 2019. Nevertheless, GHG emissions have continued to grow at high absolute rates.

Emissions increased by 8.9 GtCO₂eq from 2000-2009 and by 6.5 GtCO₂eq 2010-2019, reaching 59 GtCO₂eq in 2019.

Aviation grew particularly fast on average at 3.3% per annum between 2010-2019. During that period, transport emissions have remained roughly constant, growing at an average of 2% per annum due to the persistence of high travel demand, heavier vehicles, low efficiencies, and car-centric development. Globally, energy efficiency has improved but carbon intensities have not. The full decarbonisation of e-vehicles requires that they are charged with zero-carbon electricity, and that car production, shipping, aviation and supply chains are decarbonized.

Lockdown policies in response to COVID19 led to an estimated global drop of 5.8% in CO₂ emissions in 2020 relative to 2019. Energy demand reduction occurred across sectors, except in residential buildings due to teleworking and homeschooling. The transport sector was particularly impacted and international aviation emissions declined by 45%. However, atmospheric CO₂ concentrations continued to rise globally in 2020 and emissions have already rebounded as lockdown policies are eased. Economic recovery packages currently include support for fossil fuel industries.

IPCC AR6 Scenarios and ICAO Long Term global Aspirational Goal (LTAG) Observations

The emission scenarios considered by IPCC in AR6 are presented in Figure. 1. Based on the assessment of multiple lines of evidence by IPCC, under the five illustrative

1 IPCC Sixth Assessment Report: <https://www.ipcc.ch/reports/>

2 Table TS.1: Signs of Progress and Continuing Challenges, https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

Future emissions cause future additional warming, with total warming dominated by past and future CO₂ emissions

(a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios

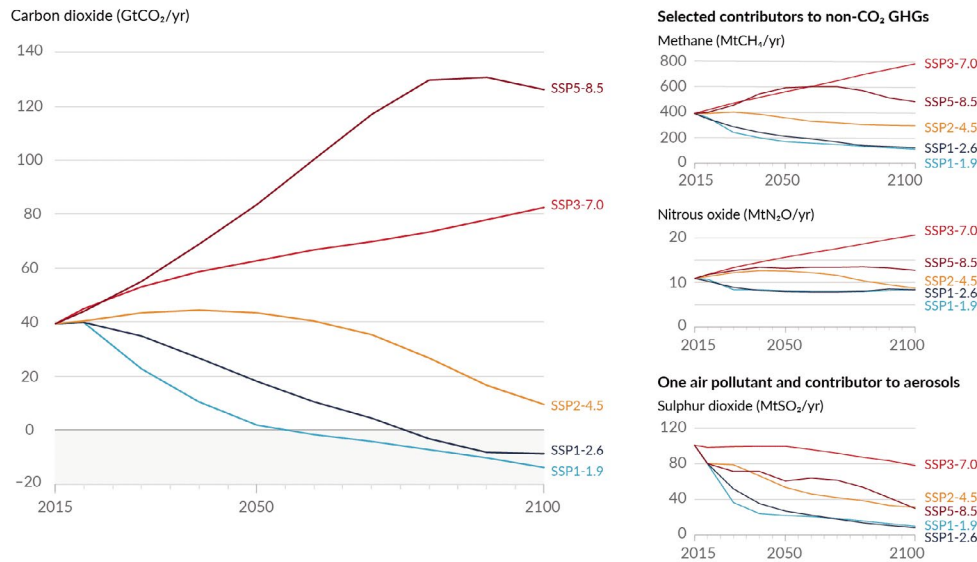


FIGURE 1: Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five IPCC AR6 illustrative scenarios (Figure SPM.4 (part of) from IPCC AR6 WG1, 2021).

scenarios, in the near term (2021-2040), global warming of 2°C, relative to 1850-1900, would be exceeded during the 21st century under the high and very high greenhouse gas (GHG) emissions scenarios considered (SSP3-7.0 and SSP5-8.5, respectively). Global warming of 2°C would extremely likely be exceeded in the intermediate scenario (SSP2-4.5). Only under the very low (SSP1-1.9) and low (SSP1-2.6) GHG emissions scenarios, global warming of 2°C is extremely unlikely to be exceeded or unlikely to be exceeded, respectively.

For the ICAO Long-Term Aspirational Goal (LTAG) feasibility study³, ICAO used the “very low GHG emissions scenario”, under which it is more likely than not that global temperature would decline back to below 1.5°C towards the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

The IPCC AR6 utilized an approach based on the carbon budget, which is the maximum amount of cumulative

net global anthropogenic CO₂ emissions that would result in limiting global warming to a given level with a given likelihood, taking into account the effect of other anthropogenic climate forcers. For the IPCC AR6 estimated cumulative residual global anthropogenic CO₂ emissions (400 GtCO₂ at 67% probability) from the start of 2020 to limit global warming to 1.5°C, the international aviation share varies between 4.1 and 11.3%, depending on the LTAG Integrated Scenarios in the ICAO LTAG Report⁴. Similarly, for a warming limit of 2°C with the remaining allowed carbon emissions estimated to 1150 GtCO₂ at 67% probability, the international aviation share is between 1.4 and 3.9%, according to the ICAO LTAG Report.

Non-CO₂ effects (e.g., largely from methane, nitrous oxide⁵, and fluorinated gases) are included in the above estimates and introduce in an uncertainty in the allowed CO₂ emissions for a given temperature limit and probability for staying at or below this limit. The total aviation forcing effect was approximately 3.5% of the total anthropogenic

³ ICAO Environmental Report 2022, LTAG Special Supplement.

⁴ ICAO LTAG Report: <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx>

⁵ ICAO Environmental Report 2022. Chapter 3 – Local Air Quality. Impacts of Aviation NO_x Emissions on Air Quality, Health, and Climate.

climate forcing in 2011. Aviation non-CO₂ climate effects are currently estimated to be about 2/3 of the total aviation forcing based on historical data although future projections are uncertain.

Achieving net zero global CO₂ emissions by around 2050 will provide the best chance to keep the global average temperature increase below 1.5°C, and that the 1.5°C temperature goal is beyond reach without immediate and deep emissions reduction across all sectors, while achieving net zero global CO₂ emissions by around 2070 will provide the best chance to keep the global average temperature increase below 2°C. Accelerated and equitable climate action in mitigating, and adapting to, climate change impacts is critical to sustainable development.

IPCC AR6 and Aviation Sector

The IPCC AR6 states that demand-side options and low-GHG emissions technologies can reduce transport sector emissions in developed countries and limit emissions growth in developing countries. Demand-focused interventions can reduce demand for all transport services and support the shift to more energy efficient transport modes.⁶

The IPCC AR6 also states that while aircraft efficiency improvements (e.g., optimised aircraft designs, mass reduction, and propulsion system improvements) can provide some mitigation potential, additional CO₂ emissions mitigation technologies for aviation will be required. For the aviation sector, such technologies include high energy density biofuels, and low-emission hydrogen and synthetic fuels, while electrification could play a niche role for aviation for short trips and can reduce emissions from airport operations. Improvements to national and international governance structures would further enable the decarbonisation of aviation. Such improvements could include, for example, the implementation of stricter efficiency and carbon intensity standards for the sector.⁷

According to the IPCC AR6, international environmental and sectoral agreements, institutions, and initiatives are helping, and in some cases may help, to stimulate low GHG emissions investment and reduce emissions. Current sectoral levels of ambition vary, with emission reduction aspirations in international aviation and shipping lower than in many other sectors.⁸

Many regulatory and economic instruments have already been deployed successfully. Such instruments could support deep emissions reductions and stimulate innovation if scaled up and applied more widely. Policy packages that enable innovation and build capacity are better able to support a shift towards equitable low-emission futures than are individual policies. Economy-wide packages, consistent with national circumstances, can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability.

In light of the IPCC's latest assessment, it is clear that while current ICAO global aspirational goals for international aviation in Assembly Resolution A40-18 (i.e. fuel efficiency improvements and carbon neutral growth) will keep the net CO₂ emissions from international aviation at a certain level, these goals will not align with a path in support of the 1.5°C temperature goal or the 2°C temperature goal.

Conclusion

According to the IPCC AR6, global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans. The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation. Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all.

6 C.8 section, https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

7 C.8.4. section, https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

8 E.6.4 section, https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

The evidence of observed impacts, projected risks, levels and trends in vulnerability, and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Comprehensive, effective, and innovative responses can harness synergies and reduce trade-offs between adaptation and mitigation to advance sustainable development. The cumulative scientific evidence is unequivocal: climate change is a threat to human well-being and planetary health; and any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all.

Therefore, ICAO enhances cooperation with other UN bodies and international organizations involved in policy making on climate change, notably with the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the UNFCCC is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Under ICAO's continuous leadership, Member States work together to limit or reduce emissions from international aviation, including the adoption at the 2010 Assembly of the ICAO global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 at the same level.

Due to the cross-national-boundary nature of international aviation emissions, the ICAO global aspirational goals including a potential LTAG set out the international aviation sector's collective goals, without attribution of specific obligations in the form of emissions reduction goals to individual States, and Member States contribute to the achievement of collective goals by planning and implementing different sets of measures to reduce CO₂ emissions from international aviation, under the umbrella of ICAO coordination.

Overview of Climate Goals and ICAO's Work on a Long Term Aspirational Goal for International Aviation (LTAG)

By ICAO Secretariat

Introduction

The 2010 International Civil Aviation Organization (ICAO) Assembly adopted the existing global aspirational goals for the international aviation sector of 2% annual fuel efficiency improvements and carbon neutral growth from 2020. Since then, much has happened in the aviation industry with regards to climate change action, with multiple commitments for further action from ICAO Member States and industry partners. This article provides an overview of the current aviation goals related to climate, with a focus on the ICAO's work on the feasibility of a long-term global aspirational goal for international aviation (LTAG). Extensive details on this process are provided in the special LTAG supplement to this ICAO Environmental report.

Commitments by States and Industry

In 2009, the world's major aviation industry associations, including the Airports Council International (ACI), the Civil Air Navigation Services Organization (CANSO), the International Air Transport Association (IATA), the International Business Aviation Council (IBAC), and the International Coordinating Council of Aerospace

Industries Associations (ICCAIA) announced their collective commitment to reduce aviation carbon emissions by 50 per cent by 2050 compared to 2005 levels. In light of recent scientific findings and in support of the 1.5°C temperature goal, in 2021 the aviation industry had further raised their level of ambition and collectively committed to achieve net-zero carbon emissions by 2050¹. This would be supported by accelerated efficiency measures, energy transition, and innovation across the aviation sector and in partnership with governments around the world.

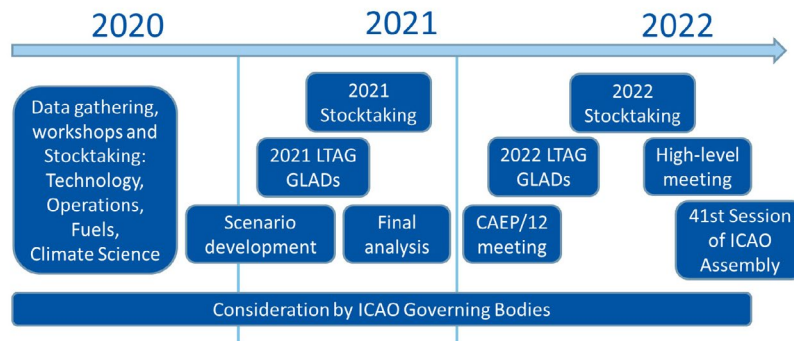
Several ICAO Member States have also committed towards the decarbonization of aviation, including 27 ICAO Member States which are signatories of the "International Aviation Climate Ambition Coalition"², and 37 Member States (27 EU Member States and 10 other Member States of the European Civil Aviation Conference (ECAC)), which are the signatories of the "Toulouse Declaration" in support of the goal of carbon neutrality in the air transport sector by 2050³.

1 Commitment to Fly Net Zero: <https://aviationbenefits.org/FlyNetZero>

2 International Aviation Climate Ambition Coalition: <https://www.gov.uk/government/publications/cop-26-declaration-international-aviation-climate-ambition-coalition>

3 Toulouse Declaration: <https://presidence-francaise.consilium.europa.eu/en/news/european-aviation-summit/>

ICAO LTAG process and timeline



LTAG overall process

In line with that momentum on climate change action, ICAO made dedicated efforts to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation, including data collection and information sharing; technical assessment of aviation CO₂ emissions reduction scenarios with analyses of costs and necessary investments; consultation and dialogues among stakeholders; and engagement of high-level representatives to facilitate decision. The overall ICAO process and timeline related to LTAG during the triennium is illustrated in the Figure above.

Data Collection and Information Sharing

As part of the ICAO LTAG work, the 2020 and 2021 ICAO Stocktaking events were convened in September 2020⁴ and September 2021⁵, respectively, for data collection and information sharing on aviation in-sector carbon dioxide (CO₂) emissions reductions. Further details on the Stocktaking Events are provided in the dedicated article in Chapter 4.

Additionally, with a view to providing one single source of information that is frequently updated to access all the latest CO₂ reduction innovations for aviation, ICAO developed a series of Tracker Tools⁶. They provide the latest information on aviation CO₂ emissions reduction initiatives, and are updated from three streams – technology, operations and

fuels, as well as on aviation net zero initiatives. Further information on these trackers are provided in the dedicated article in Chapter 4.

The ICAO CAEP LTAG Report

Over the last two years, the ICAO Committee on Aviation Environmental Protection (CAEP) undertook its technical work on the feasibility study on LTAG. It has focused on the attainability and readiness of aviation in-sector CO₂ reduction measures, including innovative aircraft technologies, operations and fuels, as it would be necessary to assess the in-sector CO₂ reduction potentials before considering the need and extent of any complementary measure.



⁴ 2020 Stocktaking website: <https://www.icao.int/Meetings/Stocktaking2020/Pages/default.aspx>

⁵ 2021 Stocktaking website: <https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx>

⁶ ICAO Tracker Tools website: <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>

The LTAG report, which was unanimously approved at the CAEP/12 meeting in February 2022, consolidates cumulative efforts of over 280 experts over nearly 2 years of intensive work. The LTAG report, which is available on the LTAG report website⁷, includes scenarios that highlight the potential for substantial CO₂ reductions from innovative aircraft technologies, operations, and fuels, with the assessment of required costs and investments. More details on the LTAG report are provided in the special LTAG supplement to this ICAO Environmental report.

LTAG consultative process

As part of the consultative process on LTAG among ICAO Member States and stakeholders, ICAO organized the LTAG Global Aviation Dialogues (GLADs) as a series of five regional events held both in May 2021⁸ and March/April 2022⁹. The goals and objective so of these events were to share information and raise awareness on the LTAG process and technical analyses, as well as to allow for the exchange of views and expectation to facilitate further LTAG work and decision-making.

The GLADs supported the well-informed deliberations at the High Level Meeting on LTAG (HLM-LTAG), held in June 2022, and the subsequent 41st Session of the Assembly which will deliberate on the LTAG. The GLADs participants also exchanged views on possible building blocks for LTAG considerations, such as: scientific understanding and context, expected potential contribution of technology, operations and fuels, and the level of LTAG ambition. The participants also discussed on possible means of implementation, expected support to ICAO Member States with action plans, roadmaps, and ways of monitoring progress.

Conclusion

Aviation is moving to address its responsibilities on the climate crisis. ICAO is steadily following up on these developments, with the extensive work associated with the feasibility of a long-term global aspirational goal for international aviation. The LTAG deliberations at the ICAO 41ST Assembly will be of crucial importance to consolidate the aviation's efforts towards decarbonization.

7 ICAO LTAG report website: <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx>

8 2021 GLADs website: <https://www.icao.int/Meetings/2021-ICAO-LTAG-GLADS/Pages/default.aspx>

9 2022 GLADs website: <https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Pages/default.aspx>

ICAO Stocktaking on Aviation in-sector CO₂ Emissions reductions

By ICAO Secretariat

Background

The 40th Session of the International Civil Aviation Organization (ICAO) Assembly in October 2019 requested the ICAO Council to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation CO₂ emissions reduction, for consideration by its 41st Session. In response to this request, the ICAO Council's Committee on Aviation Environment Protection (CAEP) established the LTAG Task Group (LTAG-TG) to provide technical support in exploring the feasibility of a LTAG.

An important cornerstone of the LTAG work by the Organization was the ICAO Stocktaking Seminar on aviation in-sector CO₂ emissions reductions. Building upon the success of the first ICAO Stocktaking Seminar toward the 2050 Vision for Sustainable Aviation Fuels (SAFS 2019), held in 2019, the 2020 Stocktaking Seminar on aviation in-sector CO₂ emissions reductions was organized by ICAO. The 2020 Stocktaking Seminar provided an opportunity to further enhance the basis for the quantification of current and future sustainable aviation fuels (SAF) availability and to expand the scope of the stocktaking process. In addition to sustainable aviation fuels, the 2020 Stocktaking collected information from Member States and aviation stakeholders on the aviation in-sector emissions reduction opportunities through innovations in aircraft technology improvements and operational improvements.

2020 ICAO Stocktaking Seminar

The 2020 Stocktaking Seminar¹ was convened as a virtual event from 8 to 11 September 2020. Nearly 100 stakeholders, including aeronautical pioneers, industry leaders, technical experts, researchers, innovators, civil society advocates, and States shared their ambitious plans for decarbonizing international aviation, some of which committing and presenting concrete roadmaps to zero emissions. Numerous concepts and measures were discussed, including advanced and novel aircraft technologies, operational improvements both in the air and on the ground, and opportunities for scaling up sustainable aviation fuels.

As a large-scale ICAO Webinar, there was simultaneous streaming of the event via the ICAO TV platform. A recording of the seminar is accessible at ICAO TV². The innovative solutions addressed, as well as the high-level panellists, and the extent of outreach through coordination and liaison with States and various aviation stakeholders, as well as promotional and marketing activities, sparked significant interest with over 1,000 registered participants. At the 2020 ICAO Stocktaking Seminar, more than a hundred solutions to reduce in-sector aviation emissions were submitted, and all innovative initiatives with the potential to play a significant role in the future of aviation were considered.

1 <https://www.icao.int/Meetings/Stocktaking2020/Pages/default.aspx>

2 <https://www.icao.tv/stocktaking/season:3>



FIGURE 1: Some of Speakers from 2020 ICAO Stocktaking Seminar

ICAO Member States and other stakeholders were also encouraged to contribute quantitative input by returning a completed stocktaking questionnaire to ICAO as part of the Stocktaking process. The data collected via the questionnaires allowed ICAO to develop a more accurate picture of global trends and forecasts for in-sector CO₂ emission reductions through the work of the ICAO CAEP LTAG-TG, which was critical to the work on the feasibility of a long-term global aspirational goal for international aviation CO₂ emissions reduction.

ICAO Global Coalition on Sustainable Aviation

At the 2020 ICAO Stocktaking Seminar, it was demonstrated that a variety of evolutionary and revolutionary changes are taking place as a result of innovations to reduce carbon emissions from aviation, and that this endeavour involves worldwide stakeholders, some of whom are new to aviation. ICAO has extended an open invitation to all interested parties to join the ICAO Global Coalition on Sustainable Aviation³ in order to assist bring all stakeholders together. The ICAO Global Coalition for Sustainable Aviation

(Coalition) brings together stakeholders working on aviation technology, operations and infrastructure, and sustainable aviation fuels, as well as the CORSIA as a complementary measure to accomplish the environmental goal.

The Coalition's goal is to promote awareness of the sector's continued efforts in reducing CO₂ emissions from international aviation, by building on current leadership and advocates and strengthening existing collaborations and innovations. New stakeholders are encouraged to join the Coalition to display their CO₂ emission-reduction activities and begin collaboration with all Coalition Members. Interested parties can join by sending an email to stocktaking@icao.int or filling out the online form⁴ on the ICAO Coalition webpage⁵.

As part of the Coalition initiative, ICAO also developed the ICAO tracker tools of aviation CO₂ emissions reduction initiatives⁶ to closely follow up the development of innovations that can generate in-sector CO₂ emissions reductions. The tracker tools are developed to track innovations from four main streams: technology, operations, sustainable aviation fuels, and net zero initiatives. States and stakeholders are invited to share relevant information by emailing officeenv@icao.int.

³ <https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx>

⁴ <https://docs.google.com/forms/d/e/1FAIpQLSdZxW1PYOHX0w7laXpromgkgK90cliYMwP8GF18xqeOqeKraA/viewform>

⁵ <https://docs.google.com/forms/d/e/1FAIpQLSdZxW1PYOHX0w7laXpromgkgK90cliYMwP8GF18xqeOqeKraA/viewform>

⁶ <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>



FIGURE 2: The ICAO Global Coalition for Sustainable Aviation

2021 ICAO Stocktaking Seminar

In response to the great success of the 2020 Stocktaking and the need to address the challenges of transitioning to decarbonization of the sector while keeping up with the latest innovations and breakthroughs in aviation technology, operations and infrastructure, and sustainable aviation fuels; the 2021 ICAO Stocktaking⁷ was organized and held virtually from 31 August to 3 September, 2021.

In preparation for the 2021 ICAO Stocktaking Seminar between March and August 2021, a series of six Pre-Stocktaking Webinars were held with the themes of battery technology and fuelling aviation electrification, hydrogen and getting to zero carbon flights, synthetic fuels for aviation, e-VTOL and urban air mobility, infrastructure development for supplying clean energy for air travel, and the 2021 ICAO Stocktaking preview. These Pre-Stocktaking Webinars paved the way for the 2021 ICAO Stocktaking Seminar and provided unique opportunities to discuss important challenges and practical tools by bringing together experts, leaders, and innovators. The monthly Pre-Stocktaking webinars demonstrated how innovation is effectively and realistically implemented into ICAO's

work, in this example in the discovery of pathways to decarbonize the sector and address climate change. The recordings of the Pre-Stocktaking webinars and the main Stocktaking event are available at ICAO TV⁸.

The 2021 ICAO Stocktaking Seminar was organized as a four-day event with a Policy Day at the end of the Seminar. This enabled participants to link the information and discussion by aviation sector innovators in the first three days, to the government policies needed to achieve the green recovery transition.

The event was launched with an opening address by the ICAO Secretary General, followed by keynote remarks from Robert Courts MP, UK Aviation Minister, Amina J. Mohammed, Deputy Secretary General of the United Nations & Chair of the United Nations Sustainable Development Group, and Fatih Birol, Executive Director, International Energy Agency (IEA). During the closing session, the President of the ICAO Council provided an overview of the way forward on the work of ICAO on the feasibility of an LTAG, followed by a special video message from John Kerry, Special Presidential Envoy for Climate, United States, and a statement from Gonzalo Muñoz, High-Level Climate Champion, COP25.

⁷ <https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx>

⁸ <https://www.icao.tv/stocktaking/season:1>

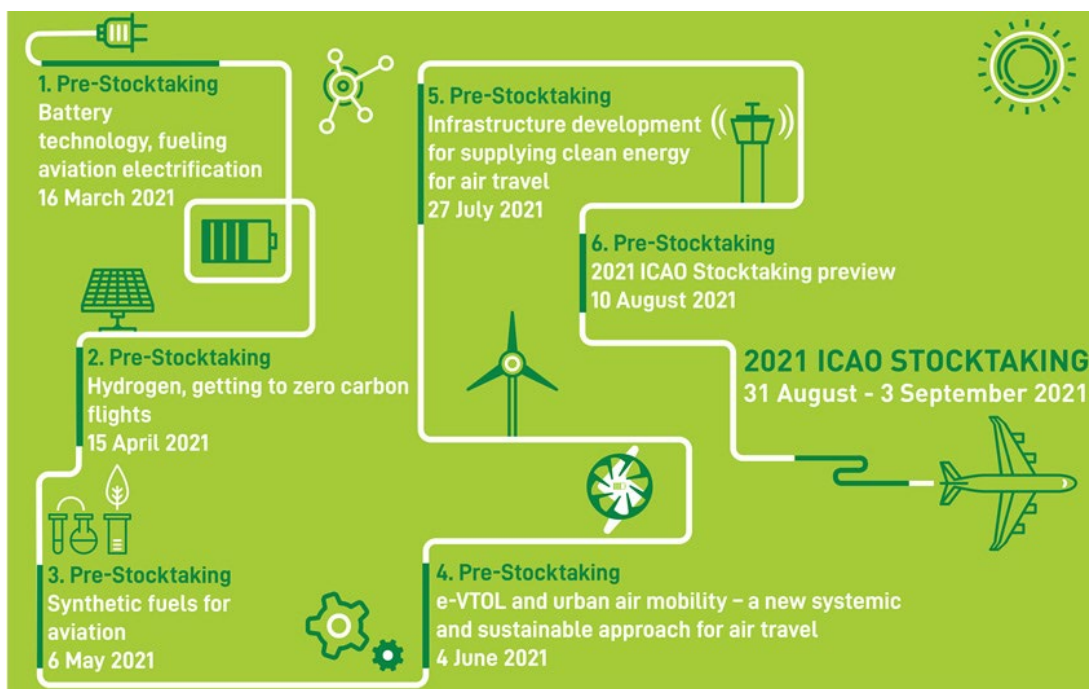


FIGURE 3: Monthly Pre-Stocktaking Webinars thorough 2021 ICAO Stocktaking

The 2021 ICAO Stocktaking Seminar provided a forum for youth involvement, including young entrepreneur initiatives. This forum provided a base in the event ICAO issued an open call for the establishment of a youth umbrella group to allow young people from around the world to engage with the aviation community on sustainable aviation. A number of other announcements were made during the event, including the Institut Supérieur de l'Aéronautique et de l'Espace, ISAE- SUPAERO's announcement of the establishment of their Institute for Sustainable Aviation, Germany's announcement of funding and demonstration projects for Power to Liquid (PtL) fuels as part of a 1.5 billion euro funding scheme, and Air Liquide's announcement of a partnership with Airbus and Group ADP to develop a first study of 30 airports to assess liquid hydrogen production, supply and distribution.

The 2021 ICAO Stocktaking Seminar confirmed the strong momentum for more ambitious action on climate change by underlining the importance of cooperation, inclusivity and transparency. The significance of multi-stakeholder collaborations was underlined on the Green Policy Day, which underlined the crucial need for green policies for aviation innovations.

2022 ICAO Stocktaking Seminar

The ICAO Secretariat aims to continue to facilitate the monitoring of the latest environment-driven technologies and innovations to reduce aviation CO₂ emissions, through the continued ICAO Stocktaking process toward the 41st Assembly. ICAO will organize a 2022 ICAO Stocktaking Seminar⁹ virtually from 18 to 19 July 2022.

The 2022 ICAO Stocktaking Seminar will provide another opportunity to hear from the ICAO Coalition partners about the achievement of innovations in aviation CO₂ emissions reduction by allowing the exchange of the most up-to-date relevant information on technology, operations, and fuels.

The 2022 ICAO Stocktaking Seminar will also set the scene for the subsequent ICAO High-level Meeting on the Feasibility of a Long-term Global Aspirational Goal (HLM-LTAG), which will take place as a hybrid event from 20 to 22 July 2022. All stakeholders who wish to showcase their latest initiatives during the ICAO Stocktaking Seminar are encouraged to join the Coalition by emailing stocktaking@icao.int.

9 <https://www.icao.int/Meetings/Stocktaking2022/Pages/default.aspx>

Environmental Tools

By ICAO Secretariat

The International Civil Aviation Organization (ICAO) develops and maintains many environmental tools that are made available to States and the general public. These tools support the development of State Action Plans, support initiatives to reduce aviation's carbon footprint and the implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The following paragraphs provide an overview of the ICAO tools designed to support various ICAO environmental protection projects.

ICAO Carbon Emissions Calculator



Background—ICAO has developed a publically available methodology¹, through the ICAO Committee on Aviation Environmental Protection (CAEP), to calculate carbon dioxide (CO₂) emissions

from air travel. This methodology provides the basis for the ICAO Carbon Emissions Calculator² (ICEC), which allows the estimation of CO₂ emissions from passenger air travel on a specific route. The ICEC is an internationally approved and user-friendly tool that requires only a limited amount of information from the user (origin and destination airports and the cabin class). The ICEC is available free of charge on the ICAO website. The methodology applies the best publicly

available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried. The fuel consumption based on distance flown is estimated with the ICAO Fuel Formulas (IFFs) which are regularly updated. The fundamental principle of the IFFs is to estimate in-service aircraft fuel consumption based on aircraft manufacturers handbooks and corrected with available in-service fuel consumption data.

New seat class configurations—Currently, the ICEC supports two cabin classes, economy class (the base class) and premium class (representing all other higher cabin classes). These assumptions can potentially underestimate the carbon footprint per seat. In order to address this issue, the Aviation Carbon Calculator Support Group (ACCS) reviewed a proposal from the ICAO Secretariat for a new approach, based on pitch and abreast seat information, to allocate passenger CO₂ emissions on the basis of an extended cabin class, such as economy class, premium class, business class and first class. This new approach is currently under development.

New interface—In order to improve data visualization, user experience, and compatibility with mobile devices, ICAO developed a new ICEC interface (Figure 1) to be launched in 2022.

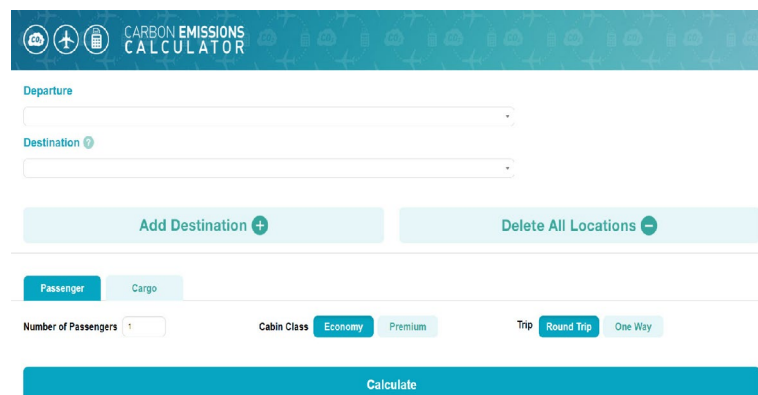


FIGURE 1: ICEC new interface

1 https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v11-2018.pdf

2 <https://applications.icao.int/icec>

Application Programming Interface—ICAO has also developed a new Application Programming Interface (API) for the ICEC that allows its automatic integration with software, webpages, or mobile applications released by third party organizations. A version of the ICEC API has been published for public use and another version for the UN usage is also available to consolidate emissions on mission travel. Depending on the licensing agreement with ICAO, the API will allow the user to execute a certain number of calls to compute emissions inventories. For more information on the ICEC API, please contact icecapi@icao.int.

ICAO Green Meetings Calculator



Similar to the ICEC, the ICAO Green Meetings Calculator (IGMC) is a tool designed to support decision-making in reducing CO₂ emissions from air travel to attend meetings.

An enhanced version of the IGMC, incorporating a mobile interface, was launched in April 2020. The IGMC can be used to estimate air travel related CO₂ emissions for a specific meeting, and to assist in identifying an optimal location for a meeting in terms of CO₂ emissions. The methodology for IGMC takes into consideration the city of origin of each meeting participant and the total number of participants. While many factors may affect the decision for where a meeting should be held, the calculator helps facilitate the planning process for an international meeting/conference.

ICAO Fuel Savings Estimation Tool

ICAO Fuel Savings Estimation Tool



The ICAO Fuel Savings Estimation Tool (IFSET) has been developed by the Secretariat with support from States and international organizations to assist the States to estimate fuel savings in a manner consistent with the greenhouse gas models approved by CAEP and the ICAO Global Air Navigation Plan (GANP). IFSET is not intended to replace the use of detailed measurement or modelling of fuel savings, where those capabilities exist. Rather, it is provided to assist those States without such facilities to estimate fuel savings benefits from operational improvements in a harmonized way. IFSET provides a robust platform for estimating the

incremental fuel burns from adopting procedures different from the baseline. IFSET has demonstrated that it is capable of providing a reasonable estimate of changes in fuel consumption in a manner that is consistent with more sophisticated approaches. In IFSET, scenarios are defined by climb/descent phases, level phases and taxi phases. Climb and descent rates are not specified with the IFSET default values used. The estimates generated by IFSET can be improved if savings in distance or time inputted into IFSET comes from empirical radar tracks and or using the domain expertise of the air navigation service provider.

ICAO CORSIA CO₂ Estimation and Reporting Tool

The ICAO CORSIA CO₂ Estimation and Reporting Tool (CERT) is detailed in chapter 8 of the report.

ICAO Tools for the State Action Plan Focal Points

To facilitate the State Action Plan (SAP) development process, all State Action Plan focal points have been granted access to the Action Plan on Emissions Reduction (APER) website. APER is a secured, web-based platform that can be used to interact with ICAO, upload administrative and quantified information related to State Action Plans and consult guidance material, such as Doc 9988, and the following tools:

Environmental Benefit Tool (EBT)—For the purpose of supporting States to establish a quantified State Action Plan, ICAO developed the EBT helping States to estimate fuel burn and CO₂ emissions baseline and forecast scenarios with a selection of mitigation measures up to 2050. While requiring minimal data inputs (historical international Revenue Tonne Kilometres (RTK) data and associated fuel burn), the EBT estimates a baseline scenario and a forecast scenario of CO₂ emissions with the quantifiable benefits resulting from the selected mitigation measures and provides estimated expected results. The EBT could be considered as the transformation of Doc 9988 into an interactive, structured and easy-to-use tool. The tool allows generating a robust and complete State Action Plan



FIGURE 2: AES graphical user interface

with a minimum of information provided by the users. A new version of the tool is being developed to increase the compatibility with Excel architecture.

ICAO Carbon Emissions Calculator for State—In order to support States in the preparation of the Actions Plans, ICAO has also developed a standalone application allowing SAP Focal Points to generate a State-level emissions inventory by simply importing batches of flights containing the airport pair, the number of flights in the year, and the aircraft type. This application uses the same methodology than the one underpinning the ICEC.

Aviation Environmental System (AES)—In the scope of the ICAO-European Union Project from 2014 for the monitoring of expected results from the implementation of the SAP, ICAO developed the AES to allow Civil Aviation Authorities (CAAs) to collect, monitor and consolidate CO₂ emissions from international aviation at the State level. The AES consists of the AES 1.0 application and the AES Data Visualisation website to enable the group of 14 beneficiary States to collect aeroplane emissions data and monitor the progress of the SAPs. The AES is composed of a user

Graphical User Interface (GUI) (Figure 2) and a database, integrated in one single user-friendly tool.

Marginal Abatement Cost (MAC) Curve—Under the partnership with the United Nation Development Program (UNDP) and financing from the Global Environment Facility (GEF) (ICAO-UNDP-GEF project), ICAO has designed the MAC Curve tool to support States and their stakeholders prioritize the most appropriate international aviation CO₂ emissions mitigation measures. This tool was developed to support States with the process of selecting mitigation measures as a part of the SAP development process. It offers the possibility for States to identify and rank up to 20 mitigation measures across all elements of the ICAO Basket of Measures in order to facilitate future decision-making. The tool includes a user-friendly interactive interface embedded into the APER website and is fully customizable to fit the State's situation. Based on the analysis of the mitigation measures included in the SAPs submitted by ICAO Member States, ICAO has developed global MAC curves, which simplify the process of assessing the CO₂ emissions reductions and the costs for individual measures and put them in priority order. The MAC Curve

Tool can be tailored to the individual reality of States, allowing them to input their local data, create MAC curves and therefore prioritize the measures to be implemented at the national level in light of their own circumstances and conditions (Figure 3).

Next developments

Cargo emissions calculator—The ICEC new interface was also designed to integrate cargo emissions calculations, according to the CAEP approved cargo methodology. Following the growing interest from the UN, general public and freight forwarders to receive CO₂ information on

cargo shipped by air, the capabilities of the ICAO carbon calculator methodology has been further extended to estimate carbon emissions associated with these activities. The implementation of the cargo methodology is currently under development.

New display—Moreover, in response of several requests from UN organizations and the general public to further update the level of detail in the Carbon Emissions Calculator and the recent launch of publically available calculators (such a Google Flights³ or Atmosfair⁴), the ICAO Secretariat is developing a new approach to display CO₂ emissions. The goal is to display specific CO₂ emissions per aircraft type compared to the weighted average currently computed.

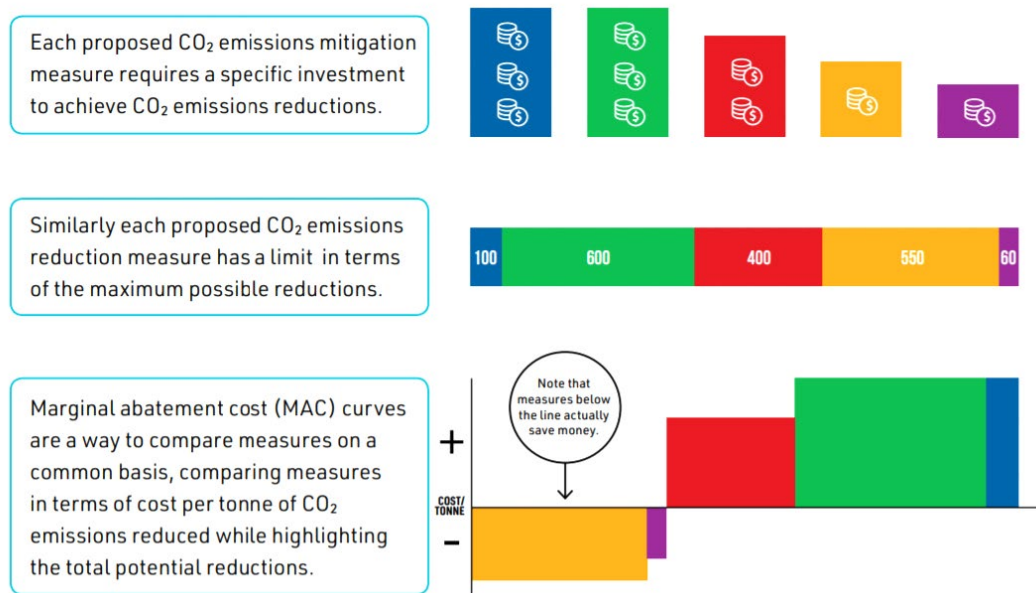


FIGURE 3: MAC curve tool structure

3 <https://www.google.com/travel/flights>

4 <https://www.atmosfair.de/en/offset/flight/>

ICAO Aviation CO₂ Reduction Initiative Trackers

By ICAO Secretariat

Introduction

This article provides an overview of the ICAO aviation CO₂ emissions reduction initiatives tracker tool¹, which is intended to facilitate the green innovation technologies in the aviation sector and to support the ICAO Long-Term Aspirational Goal (LTAG) process.

ICAO aviation CO₂ emissions reduction initiatives tracker tool

ICAO Secretariat developed a CO₂ emissions reduction initiatives tracker tool that provides a variety of information related to initiatives to reduce the environmental footprint of aviation, including details on past and ongoing measures and initiatives, and information about partner projects within the ICAO Global Coalition for Sustainable Aviation². For information, the tracker tool is published on the ICAO public website.

The ICAO Coalition for Sustainable Aviation is a forum of stakeholders working on innovations and breakthroughs on aviation Technology, Operations and Infrastructure, and Sustainable Aviation Fuels. The ICAO Global Coalition aims to promote the sustainable growth of international aviation in facilitating the development of new ideas and accelerate the implementation of innovative solutions that will further reduce greenhouse gas emissions at source, on the ground or in the sky. As of May 2022, 52 Coalition partners have joined the ICAO Global Coalition for Sustainable Aviation - from the industry, Academia and Non-Governmental Organizations.

The tracker tool is organized in three main streams (Technology, Operations and Infrastructure, and Sustainable Aviation Fuels) to closely follow up the development of the innovations and breakthroughs that can generate in-sector CO₂ emissions reductions in international aviation. The tracker tool was developed with Google Data Studio which allows capturing statistics such as the number of initiatives/projects by country, by category or by year (Figure 1).



FIGURE 1: Overview of the ICAO tracker tool structure and main indicators

¹ <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>

² <https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx>

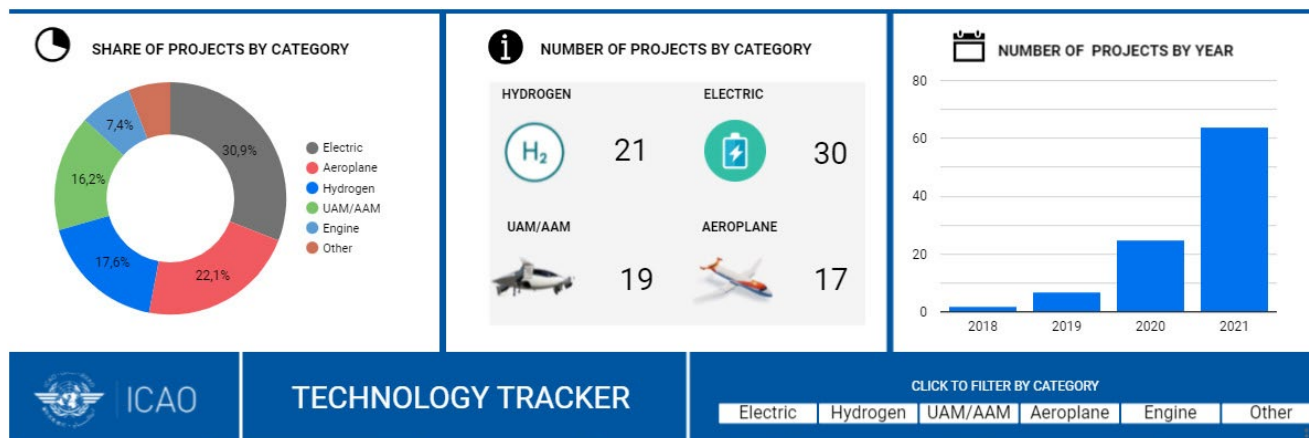


FIGURE 2: Overview of the ICAO technology tracker tool

The Technology tracker (Figure 2) tool³ provides an up-to-date platform on initiatives related to technologies and aircraft innovation projects reducing the environmental footprint of aviation, retrospective from 2018. The information on technological initiatives is categorized into major streams such as hydrogen- and electric powered aircraft, aeroplane- and engine-specific projects, urban/advanced air mobility (UAM/AAM) and others. As of May 2022, the Technologies tracker includes 102 initiatives (27 from Coalition partners) worldwide.

The Sustainable Aviation Fuels tracker (Figure 3) tool⁴ provides a variety of information on airports distributing SAF, numbers of policies adopted or under development, volumes of offtake agreements, number of conversion processes certified for aviation. The tracker also provides

an aviation up-to-date feed, based on publically available information from airports and airlines in on-going alternative fuel purchase agreements. As of May 2022, the Sustainable Aviation Fuels tracker includes 940 news and initiatives (19 from Coalition partners) across the globe.

The Operations tracker (Figure 4) tool⁵ provides a variety of information on initiatives related to operational and infrastructural measures aimed at reducing the environmental footprint of aviation. As of May 2022, the Operations tracker includes 97 initiatives (20 from Coalition partners) worldwide. These initiatives are distributed into the following categories: latest news, green infrastructure, ground operations and air operations. The tracker also provides information on geographical and retrospective parameters of the innovations.

SAF Tracking tools (click on the drops for details)

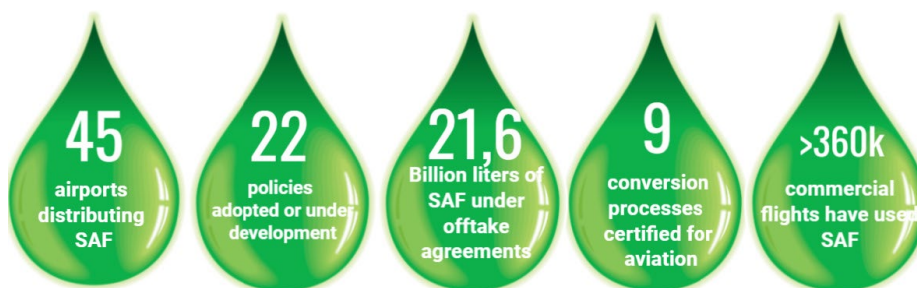


FIGURE 3: Overview of the ICAO Sustainable Aviation Fuels tracker tool

³ <https://www.icao.int/environmental-protection/SAC/Pages/Technology.aspx>

⁴ <https://www.icao.int/environmental-protection/Pages/SAF.aspx>

⁵ <https://www.icao.int/environmental-protection/SAC/Pages/Operations.aspx>



FIGURE 4: Overview of the ICAO operations tracker tool



FIGURE 5: Overview of the ICAO aviation net zero tracker tool

Aviation net zero trackers⁶ (Figure 5) records initiatives and relative news releases on the national, regional, and international levels since 2019. This tracker also provides share of the initiatives by scope and their geographical distribution. These initiatives were taken according to the basket of measures by member states, international organizations and industry.

The fifth tracker shares a link⁷ to the CORSIA news release page for parties with the latest update in the ICAO initiative in international civil aviation carbon offsetting and reduction scheme.

⁶ <https://www.icao.int/environmental-protection/SAC/Pages/Aviation-net-zero.aspx>

⁷ <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-News.aspx>



| ICAO

CHAPTER FIVE

Climate Change Mitigation: Aircraft Technologies

Introduction

By the ICAO Secretariat

According to the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6), near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change, in both human systems and ecosystems, compared to higher warming levels. The International Civil Aviation Organization (ICAO) took sound actions in advance, and in 2010 adopted two sectoral aspirational goals: 2% annual fuel efficiency improvement and carbon neutral growth from 2020 onwards. In 2010, international aviation became the first sector that committed to carbon neutral growth – this was a milestone for aviation marking the realization of this commitment.

A concrete strategy was developed to achieve it – an ICAO basket of measures, which consisted of a set of actions to mitigate CO₂ emissions; including aircraft new technologies, air traffic management and operational improvements, and sustainable aviation fuels. The main objective was to achieve the necessary CO₂ emissions reductions within the sector to the greatest extent possible. In addition,

acknowledging that these measures alone were not enough to meet carbon neutral growth from 2020, ICAO adopted CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) in 2016.

In October 2010, the 37th ICAO Assembly requested the development of an ICAO CO₂ Emissions Standard. Following seven years of development and coordination with ICAO Member States, civil aviation authorities, aviation industry and other stakeholders, on the 6th of March 2017, the ICAO Council adopted a new aircraft CO₂ emissions standard, contained in Volume III “Aeroplane CO₂ Emissions” of the Annex 16 “Environmental Protection”. These new requirements assist in tracking the environmental gains achieved by new aeroplanes, and the benefits accrued via specific technology evolutions.

In January 2020, the ICAO CO₂ Standard became applicable to New Type aeroplane designs, and in June 2021, the Standard adopted globally through ICAO was applied by the European Union Aviation Safety Agency (EASA) for its

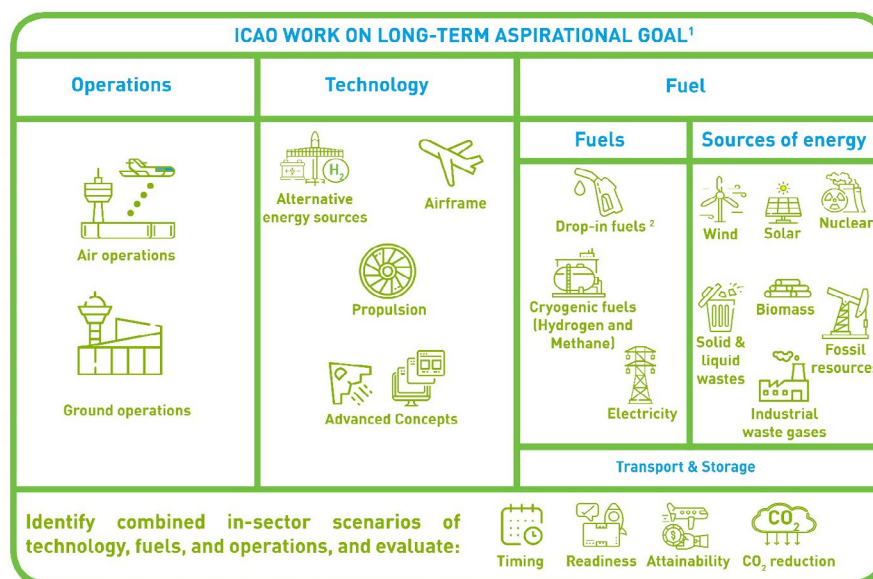


FIGURE 1: ICAO LTAG work elements and its technology-relevant components.

latest type certificate issuance for the new Airbus A330-941neo. EASA's application of the new ICAO provisions assured aircraft compliance with the latest and most stringent environmental standards, addressing the full spectrum of aircraft impacts on the environment and the climate.

Moreover, ICAO's outlook has been directed into the future, with innovations at its core. The ICAO Stocktaking process for in-sector CO₂ reductions, which has been significantly enhanced in recent years to support the feasibility study of a long-term aspirational goal (LTAG) for international aviation (Figure 1), revealed strong calls for high ambition from governments and industry leaders. It also emphasized the importance of new innovations in technology, operations, and fuels to accelerate the realization of sustainable aviation.

Aviation technologies are constantly evolving, from engines, to airframes, and to aerodynamics. These are incremental advances, such as more fuel-efficient combustion jet engines, or winglets for retrofitted aircraft, or new aircraft. There can also be entirely new concepts and technological breakthroughs. From the short- and mid-term perspectives, the current air fleet is being upgraded with continuous development of the conventional technologies in airframe and propulsion towards cleaner and greener operations. From the mid and long-term standpoint, manufacturers and researchers are featuring new aircraft designs and propulsion to reduce CO₂ emissions, and a wide range of options on sustainable aviation fuels and clean energy sources, such as hydrogen and electrification.

The gradual electrification of aircraft is also a reality. Some urban electric and hybrid transport flying systems are performing test flights and start entering the market. Hybrid electric aircraft have been researched and considered by major manufacturers to enter service around 2030. To support such a transition, aviation infrastructure is switching to renewable energies originating from solar panels, wind turbines and geothermal energy, of which some can be deployed directly at airports. Solar-at-Gate pilot projects in Cameroon and Kenya, implemented by ICAO through external funding, allow aircraft to avoid the use of fossil fuels while on the ground. The objective is to replicate these types of projects broadly at other airports.

To facilitate the promotion of sustainable growth of international aviation, ICAO has also created the Global Coalition for Sustainable Aviation, closely following up the development of innovations that can generate in-sector CO₂ emissions reductions. To complement this Coalition, ICAO is closely following up the development of innovations that can generate in-sector CO₂ emissions reductions by means of Tracker Tools.

These are organized in four main streams: Technology, Operations, Sustainable Aviation Fuels, and net zero initiatives. The Technologies tracker¹ provides a variety of information on initiatives related to technologies and innovation, aimed at reducing the environmental footprint of aviation, including details of past and ongoing initiatives. ICAO will continue to facilitate and promote all aviation innovations and technological advancements towards the sustainable future of the aviation sector.

1 ICAO in-sector aviation CO₂ emissions reduction initiatives – Technology Tracker tool: <https://www.icao.int/environmental-protection/SAC/Pages/Technology.aspx>

Advancing aviation technology towards industry decarbonisation

By Scott Goobie, Rudy Dudebout, Gregory Steinmetz, Eric Upton, Bruce Parry, Leo Knappen, Miguel F. Garcia Claro, Mark Huising, William Lee, and Arnaud Bonnet (ICCAIA and IBAC)

Introduction

The International Coordinating Council of Aerospace Industries Associations (ICCAIA) and the International Business Aviation Council (IBAC) members are committed to advancements in all fields including aerodynamics, propulsion, aircraft systems and structures technologies, aircraft manufacturing technologies¹ and all types of potential energies (sustainable aviation fuels, electricity and hydrogen). Aircraft technologies are focused on increased efficiency and carbon emissions reductions as a way to reduce aviation's climate impact over the long term. In the short term, Sustainable Aviation Fuels (SAF) have a greater role in decarbonisation than other mitigation measures as these “drop in” fuels will reduce carbon emissions from thousands of aircraft already flying. In 2021, the Air Transport Action Group (ATAG) released the second edition of its *Waypoint 2050* report¹. This report highlighted the commitment of its members to net zero carbon emissions operations by 2050. Business aviation, represented by IBAC, General Aviation Manufacturers Association (GAMA)², National Business Aviation Administration (NBAA)³ and their global members, likewise committed to decarbonisation by 2050 via the Business Aviation Commitment on Climate Change (BACCC)⁴. In addition to demonstrating industry's

broad commitment to net zero carbon by 2050, both documents provide a credible roadmap towards reaching this target. Both reports follow a structure similar to that provided here, with high level technology categories, SAF, and alternate energy sources showing the improvement possible by 2050. The shape of aviation's decarbonisation curve is shown in Figure 1.

With aircraft service lives measured in decades, and SAF blends applicable to the entire fleet, increasing the use of SAF is our priority. The urgency to introduce advanced carbon-reduction technologies to new aircraft and engines is simultaneously high.

In 2019, ICCAIA and ICAO (International Civil Aviation Organization) shared a technology perspective⁵ for 2014 to 2019 by showcasing technology advancements on newly introduced and updated commercial aircraft. These aircraft are currently in service and providing substantial reductions in fuel burn relative to the previous generation of airliners. Expanded use of these aircraft continues to reduce the rate of emissions per revenue passenger kilometer (RPK). In the Business Aircraft and Regional Aircraft markets, a host of new technologies were also introduced in this period on new, more efficient aircraft. In addition, expansion of SAF

1 ATAG Waypoint 2050: Aviation: Benefits Beyond Borders (aviationbenefits.org) <https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/>

2 <https://gama.aero/>

3 <https://nbaa.org/>

4 <https://www.gama.aero/wp-content/uploads/GAMA-IBAC-Joint-Position-on-Business-Aviation-Tackling-Climate-Change-1.pdf>

5 ICAO 2019 Environmental Report, Chapter Four, Climate Change Mitigation: Technology and Operations, Advancing Technology Opportunities to Further Reduce CO2 Emissions, ICCAIA, pages 116 to 121, <https://www.icao.int/environmental-protection/pages/envrep2019.aspx>

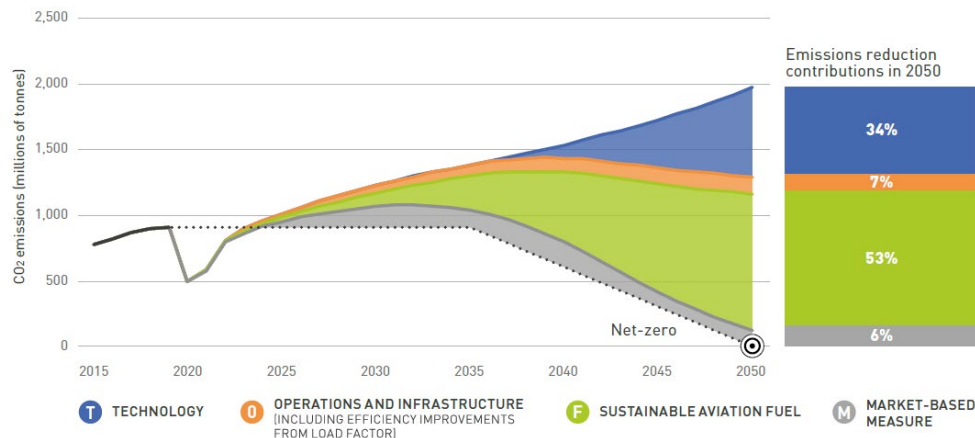


FIGURE 1: Decarbonisation of aviation by 2050

use and market-based programs like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA⁶) and Book and Claim⁷ programs for maximizing efficiency of SAF distribution are already helping accelerate progress to net zero emissions.

We continue to benefit from national and international research programs, with cooperation between industry, governments and academia essential to rapidly mature advanced carbon reduction technologies and new generations of aircraft⁸. We have seen, for example, prototyping with smaller aircraft used in the development and testing of technology demonstrators with hydrogen fuel cells⁹, hydrogen propulsion¹⁰, advanced battery technology¹¹, more electric or electric hybrid propulsion¹², and aircraft systems technologies¹³. Engineers in these collaborative environments will leverage cooperation to advance development, testing, and demonstration of readiness of new technologies to speed the years-long development process for new airplanes without sacrificing safety or reliability.

Aircraft Configuration (new concepts) – Full Vehicle

The “traditional” (pre-2010 generation) and “advanced” (current generation) tube and wing aircraft will begin to be superseded in the 2035 to 2050 timeframe by “advanced concept” aircraft. These concepts will produce a step change reduction in fuel burn, based on the vehicle aerodynamic configuration, improvements from advanced flight controls using stability augmentation to reduce drag, achieve structural optimisation, and enhance propulsion system integration.

Various new aircraft types and configurations from Urban Air Mobility¹⁴ to light jets and turboprops to large civil single aisle and twin aisle aircraft are expected to make wide and varied use of a range of more specific technologies, explored below. Figure 2 shows an example of an advanced configuration business aircraft.

6 CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation, <https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx>

7 Book and Claim – <https://doi.org/10.1016/j.enpol.2019.111014>

8 Efficiency research across the globe, <https://www.iea.org/reports/net-zero-by-2050>

9 Fuel Cells, <https://www.airbus.com/en/newsroom/news/2020-10-hydrogen-fuel-cells-explained>

10 All Electric Private Aircraft, <https://www.greenbiz.com/article/6-electric-aviation-companies-watch>

11 Batteries, <https://www.flightglobal.com/airframers/what-would-it-take-to-power-airliners-with-batteries/145370.article>

12 Hybrid Electric Propulsion, <https://link.springer.com/article/10.1007/s40313-021-00740-x>

13 Energy Efficient Systems, <https://moreelectricaircraft.com/>

14 UAM, Urban Air Mobility, <https://www.easa.europa.eu/what-is-uam>



FIGURE 2: Potential future business aircraft configuration (Bombardier)

Aerodynamics (Specific Aero Technology applied to Local Aircraft Geometry)

In addition to full vehicle configuration reshaping, there are many local (i.e. wing, fuselage, stabiliser) geometry improvements expected in the next 15 years. These include improved wingtip devices, laminar flow control, morphing wing shapes and skin surface riblets¹⁵ (See Figure 3).

Systems (More Electric + more efficient)

Many significant systems-level improvements are emerging in the next generation of advanced concept aircraft. Systems opportunities include low power wing anti ice; improved battery energy efficiency and energy density maturity for systems energy; single pilot operations¹⁶; advanced fly-by-wire; hydrogen fuel cells for systems; and “fly-by-wireless” and “fly-by-light”, partially tied to miniaturisation of avionics.



FIGURE 3: Airline based testing of skin riblet drag reduction (Deutsche Lufthansa, Oliver Roesler)

Structures (Load Reduction, Structural Efficiency, Topological Optimisers)

Airframes of advanced concept aircraft are benefiting from optimal structural topologies. The efficiency of structures capable of withstanding extreme loads is ever increasing, reducing the overall weight and influence of the airframe on aircraft emissions¹⁷. Newer and better load alleviation technologies are emerging, and so are beneficial weight reductions inherent in improved manufacturing processes. The enhanced ability to apply these technologies and improved production processes across a wider range of aircraft sizes also broadens their benefit to the overall fleet.

Materials (Lightweight Materials and Alloys)

Lightweight materials and alloys have continuously improved in the ratio of weight to load carrying capacity over past generations of aircraft, and this trend is expected to continue and diversify for development of future. The use of new alloys requires processes that are closely linked to the load alleviation technology mentioned above. Structures addressing the types of loads and necessary characteristics of materials will be produced as “designed composite materials” in place of past reliance on available “raw” materials¹⁸.

¹⁵ <https://aviationweek.com/aerospace/program-management/lufthansa-cargo-equip-777-freighters-fuel-efficient-surface-technology>

¹⁶ Single Pilot Operations, <https://hsi.arc.nasa.gov/flightcognition/research/spo.html>

¹⁷ Structural efficiency, <https://www.cfnotebook.net/notebook/aerodynamics-and-performance/aircraft-components-and-structure>

¹⁸ New materials for aircraft components, <https://www.aerospacemanufacturinganddesign.com/article/amd0814-materials-aerospace-manufacturing/>

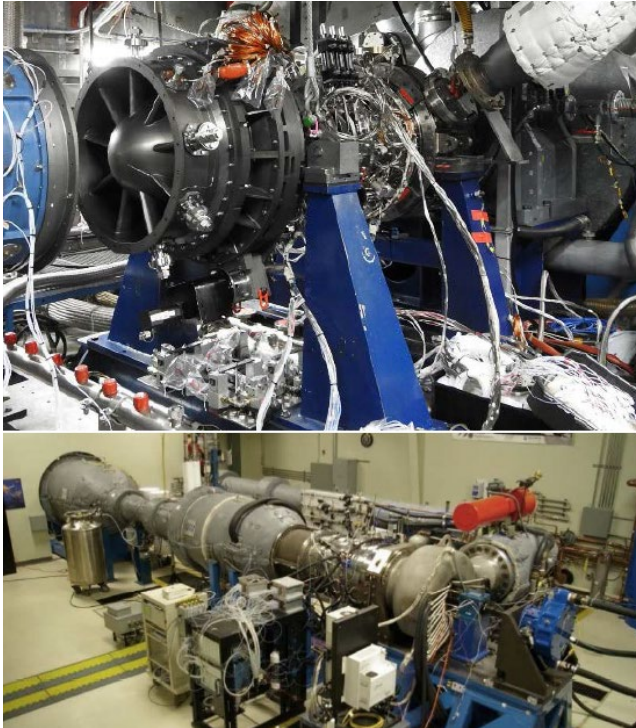


FIGURE 4: a. FAA CLEEN Phase II compressor, b. Turbine Core Technology Rig

Engines (including BLI¹⁹, Hybrid Electric, Increased Efficiency of Gas Turbines)

Gas turbine engines are the primary propulsion system for aviation today. Three technology paths can reduce gas turbine engine fuel consumption (and CO₂ emissions): increase thermal efficiency by increasing the compressor Overall Pressure Ratio (with consequent increasing engine temperatures); increase propulsive efficiency by increasing the engine Bypass Ratio (BPR); and reduce installed engine weight and drag. In the short term, ensuring aircraft fuel systems and engines can safely use SAF is essential. Other approaches, including using hydrogen as a fuel, or augmenting/substituting the gas turbine with electric, hybrid-electric or fuel cells, are being developed for mid- to long-term application, especially for shorter-range aircraft.

Major research programs continue to provide important contributions to develop, mature and demonstrate promising propulsion technologies along the engine efficiency, alternate fuels, and alternate power source paths:

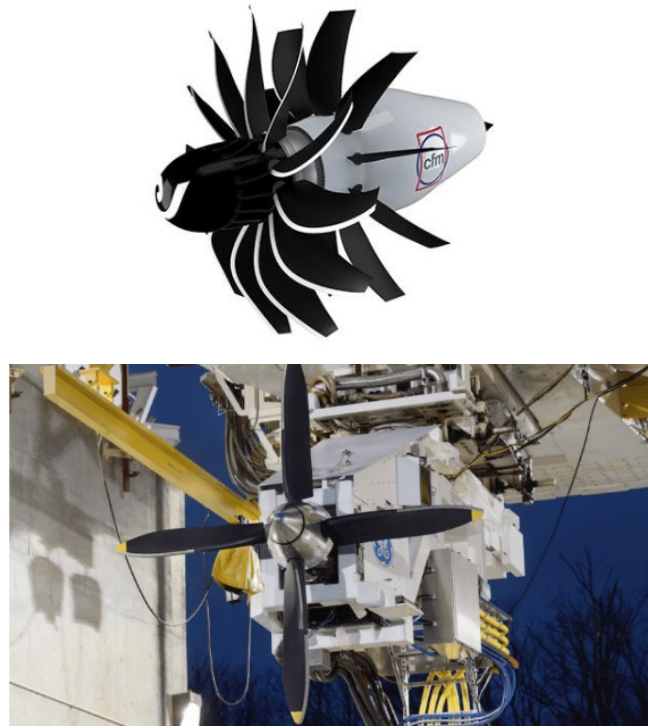


FIGURE 5: a. FAA CLEEN Phase III Open Fan b. Electric Propulsion concepts

Within the US, the national research program CLEEN²⁰ (Continuous Lower Energy, Emissions, and Noise) is an FAA-led public-private effort to accelerate development and deployment of promising certifiable technologies towards reducing fuel burn by up to 40%. CLEEN research has demonstrated potential for significant fuel burn reductions through the development & application of advanced materials, sealing, and improved engine architectures (see Figure 4).

The recently launched CLEEN Phase-III focus areas include fuel burn reduction via fan module technology, combustor and HPT technology, open fan technology, and highly integrated hybrid-electric systems (see Figure 5). Another focus area is SAF development – both qualification/ASTM standards maturation and increasing blend ratios to up to 100%.

Europe's Clean Sky 2 joint technology initiative aims to develop and demonstrate breakthrough technologies for civil aircraft that could reduce CO₂ emissions by 20%

19 BLI, Boundary Layer Ingestion, <https://ntrs.nasa.gov/citations/20130010733>

20 CLEEN, https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen



FIGURE 6: a. & b. Clean Sky 2 Demonstration engines showing advanced Low Pressure (LP) and High Pressure / core technology



FIGURE 7: a. Future Hybrid Electric Aircraft Demonstration (courtesy Airbus), b. Future Hydrogen Aircraft Demonstration (courtesy Airbus), c. Transonic Truss-Braced Wing (TTBW) concept (courtesy Boeing)

(2025) to 30% (2035). Focus areas have included contra rotative open rotor (CROR) demonstration, design/test of a turbofan LP spool and nacelle technologies demonstrator, and testing of very high bypass geared engine technology for widebody aircraft (Figure 6).

The new Clean Aviation² framework will further mature key engine concepts linked to three main pillars. The first pillar is focused on ultra-efficient aircraft and concepts such as truss-braced wings, boundary layer ingestion²¹ and the open fan engine. The second pillar is dedicated

to electric and hybrid-electric engines covering a wide range of power and energy levels. The third pillar addresses hydrogen powered aircraft with a focus on compatibility of engines and fuel systems (Figure 7).

Finally, the EU Horizon 2020²² program is funding disruptive concept studies such as ULTIMATE (propulsion concepts including topping/combined/recuperative cycles), IMOTHEP (distributed electric propulsion), and ENABLEH2 (addressing H₂ challenges such as combustion & fuel system design).

21 BLI, Boundary Layer Ingestion, <https://ntrs.nasa.gov/citations/20130010733>

22 EU HORIZON 2020, https://ec.europa.eu/info/research-and-innovation/projects/project-databases_en

Alternative Fuels (Their Impact on Aircraft Design Configuration, i.e., AC size and shape)

Technologically advanced alternative fuels (i.e. Stored Electricity, Hydrogen, etc.) are certain to be introduced to achieve the ultimate net zero targets. These technologies will influence the aircraft shape, size, and safety provisions. The use of alternative fuels for propulsion in place of Jet fuel with highly advanced gas turbines and electrically produced thrust will drive research, development and the ultimate design of many of the advanced aircraft referenced above. These alternative fuels offer game-changing environmental benefits.

The associated regulations and highly integrated functional requirements linked to these technologies will heavily influence future design concepts. Important guidance for this effort is provided in the latest revision of SAE document ARP 4754²³ (Guidelines for Development of Civil Aircraft and Systems) and ARP 4761²⁴ (Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment). Accompanying measures for these technologies will be co-developed by ICAO, by national and international regulators (EASA, FAA, etc.), global research partners, airframers, engine suppliers and aircraft systems suppliers in harmony with the timely progression of the new energy technologies themselves.

Summary

The aviation industry is changing rapidly. ICCAIA and IBAC have described areas that support our commitments to net zero carbon emissions by 2050, via (1) SAF, (2) emerging technologies, (3) infrastructure and operational improvements and (4) carbon credits for the net zero forecast shown in Figure 1. These improvements are already having an impact on fleet carbon emissions, with some all-electric private aircraft already certified and in service, and the benefits will grow continually.

Much of the aviation community has committed to net zero carbon operations by 2050 via uptake of SAF and

e-fuels or direct use of alternative energies in concert with efficiency improvements driven by new technologies. Witnessing aviation products and services achieve emissions reduction targets provides confidence in the long-term success of all market segments of the aviation industry.

Authors: This article was written and reviewed by the following ICCAIA and IBAC members: Scott Goobie (Bombardier); Rudy Dubeout (Honeywell); Gregory Steinmetz (GE); Eric Upton (Gulfstream); Bruce Parry (European Business Aviation Association); Leo Knappen, Miguel F. Garcia Claro, Mark Huising and William Lee (Bombardier); and Arnaud Bonnet (Embraer).

The International Coordinating Committee of Aerospace Industries Associations (ICCAIA) brings together international aerospace industry associations to create a global community of over three thousand companies engaged in the design, development, manufacture and in-service support of aeronautical and space products and technologies, including ground-based systems and services. ICCAIA aims to foster growth of the world's aerospace manufacturing industry by supporting the development of effective standards for safe, secure, sustainable and efficient air transport, growing international civil aviation capacity and providing technical expertise.

The International Business Aviation Council (IBAC) provides expert advocacy and intelligence on behalf of the global business aviation community. IBAC advocates at the global level on behalf of the worldwide business aviation community to keep business flying around the world, accelerating economic growth, development, and environmental sustainability across all regions.

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The Next Logical Step: Integrated ICAO Environmental Standards

By Bethan Owen (UK) and Ralph Iovinelli (USA)¹

Introduction

With the adoption of the Committee on Aviation Environmental Protection (CAEP/11) nvPM mass and nvPM number engine emission standards in 2019, the full range of the International Civil Aviation Organization (ICAO) environmental standards are complete. However, the challenge now is keeping this range of regulations up to date within the CAEP programme of work, taking into account high pace of technology progress. Furthermore, the integrated nature of the technological improvements required to meet more and more stringent regulatory levels, across noise, fuel efficiency/CO₂ emissions and engine emissions is clear. The most recent ICAO Independent Expert review of technology goals was undertaken as an integrated review in acknowledgement of the growing significance of interdependencies between noise and the various emissions regulations².

One solution to the timing of updating regulations is to conduct stringency analysis work for more than one regulation at a time within a single triennial CAEP cycle in the traditional manner. However, this approach does not address the technology integration question and a more elegant solution proposed is to conduct a stringency analysis for technology improvements for example, at an aeroplane level and then at an engine level, in an integrated manner. In view of these challenges, at the

CAEP/12 meeting, the CAEP agreed to the following new task: “Conduct an integrated standard setting process for subsonic Aeroplane CO₂ Emissions and LTO Noise with the outcome being more stringent regulatory levels of CO₂ emissions and LTO noise”. This is a new task for the technical Working Groups of the Committee and requires the development of new approaches whilst adhering to the CAEP Terms of Reference, including CO₂ and noise stringency interdependencies.

ICAO Aeroplane CO₂ Standard

The standard governing subsonic aeroplane CO₂ emissions adopted by ICAO in 2017 was the first of its kind, a global design certification standard and is contained in the Volume III³ to Annex 16 (Environmental Protection) of the Chicago Convention. This standard applies to new aeroplane type designs from 2020, and to aeroplane type designs already in-production as of 2023. Those in-production aeroplanes, which by January 1, 2028, do not meet the CO₂ standard, will no longer be able to be produced unless their designs are sufficiently modified, and the modified designs demonstrate compliance with the regulatory requirements of Annex 16, Volume III.

The CO₂ standard covers a broad range of aeroplane Maximum Take-off Masses (MTOMs) and types and is

¹ Bethan Owen and Ralph Iovinelli are Co-Rapporteurs of Working Group 3 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

² ICAO Independent Expert Review process: https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg24-38.pdf

³ ICAO Climate Change Technology Standards: https://www.icao.int/environmental-protection/Pages/ClimateChange_TechnologyStandards.aspx

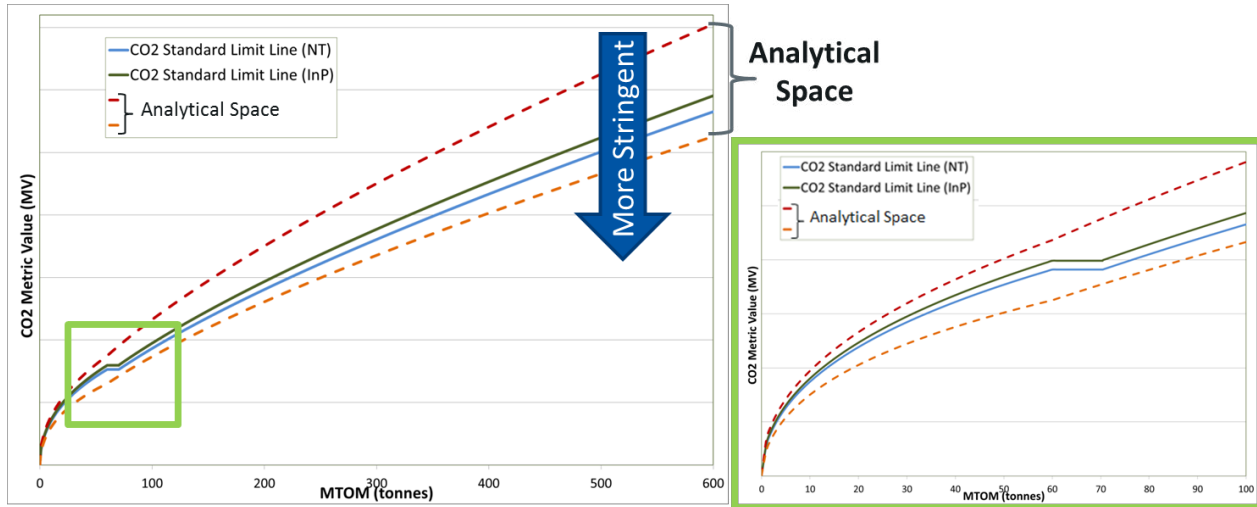


FIGURE 1: Aeroplane CO₂ standard regulatory limits and the analytical space used for CAEP/10 standard setting process.

especially stringent where it will have the greatest impact: for larger aeroplane types with an MTOM of greater than 60 tonnes, since the larger aeroplane designs have access to the broadest range of CO₂ emissions reduction technologies. Figure 1 shows an overview of the CO₂ standard regulatory limit lines for both new type (NT) and in-production (InP) CO₂ standards. With a major support from the civil aviation authorities the corresponding aeroplane CO₂ certification database is being developed and more data entry submissions are expected in the coming years with the new aeroplane types entering the market.

into engine and airframe designs which led to incremental improvements units' noise performance, as well as in aeroplane fuel efficiency. This resulted in a gradual noise standard stringency (Figure 2), with the latest adoption of Chapter 14 in 2014. This new standard is applicable to new aeroplane types submitted for certification on or after 31 December 2017, and on or after 31 December 2020 for aeroplane with MTOM less than 55 tonnes. The latter was also included to recognise that the smaller jet aeroplanes have not to date seen the same noise reduction technologies as the larger aeroplanes.

ICAO Aircraft Noise Standard

The first meeting of the ICAO Committee on Aircraft Noise (CAN,1971), developed a noise standard which aimed at ensuring that any new aeroplane entering service would use the best available noise reduction technologies and measures. That standard became applicable in 1973, setting noise limits as a direct function of MTOM in order to recognise that heavier aeroplanes, which were of greater transport capability, produce more noise than lighter aeroplane types. This was the Chapter 2 noise standard contained in the Annex 16, Volume I⁴.

Over the years that followed the introduction of Chapter 2, further noise reduction technologies were incorporated

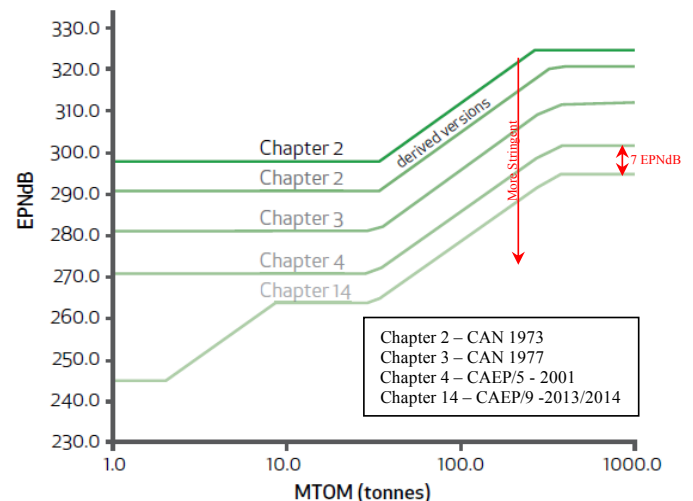


FIGURE 2: ICAO noise standard stringency progression over the last 50 years.

4 ICAO Aircraft Noise Standards : <https://www.icao.int/environmental-protection/Pages/Reduction-of-Noise-at-Source.aspx>

The extensive data on noise levels and associated characteristics for the aeroplane types certified in accordance with Annex 16, Volume I is collected in the Noise dB database⁵. This data is publicly available and would serve as a firm and transparent basis for the new stringency analysis.

Approach to the Dual Standard Setting

ICAO environmental standards are designed to be environmentally effective, technically feasible, and economically reasonable, while considering environmental interdependencies. These four pillars of CAEP analysis will guide CAEP in carrying out a comprehensive assessment of the costs and benefits of all the options which could be selected to form the new stringencies for noise and CO₂ standards. Such dual standard setting process requires

deep coordination across CAEP technical Working Groups and other pertinent technical representatives to guide the technical steps of this integrated standard setting process.

The various elements of the analysis, such as, for example, the applicability to new types of aeroplanes, the options for the regulatory limits, the associated cost elements and the applicability dates, will be developed in a consistent and data-driven environment. The interdependency factor in this analysis will play a key role and will require thorough investigation to ensure the analytical space is complete to support an informed decision-making on the dual standard stringency by ICAO.

The preparations for this crucial, comprehensive and timely work are well underway and with broad support from the Member States and stakeholders, involving the best subject matter experts, with the aim that this analysis will be conducted during this triennium.

5 ICAO NoisedB certification database: <https://noisedb.stac.aviation-civile.gouv.fr/>

Flying V: An Efficient Airframe for Long-Haul Transport

By Roelof Vos (Delft University of Technology)

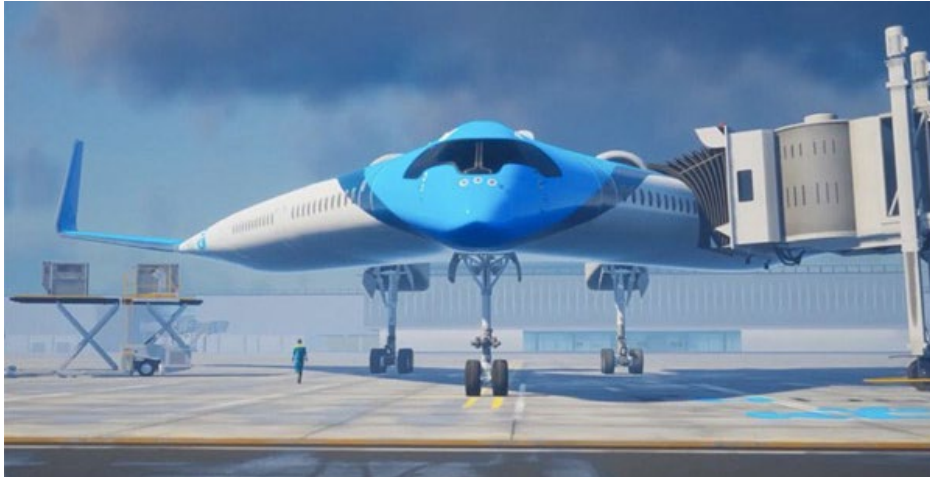


FIGURE 1: The Flying V reduces energy consumption per passenger-kilometer by 20% due to its unique shape.

Introduction

To achieve climate-neutral aviation in an affordable way, future airplanes need to consume as little energy as possible. Therefore, future airplanes need to benefit from more efficient engines while the airframes need to produce less drag. The latter can be achieved by reducing weight and improving the aerodynamic efficiency of the airplane. While improving the aerodynamic efficiency has been a priority for airframers for many years, new airframe technologies are required to make the desperately needed improvement in fuel efficiency. One example of such a new airframe is Otto Aviation's Celera 500L, a propeller-powered business aircraft for six persons with a range of 4,500 nmi. Its design features a natural laminar-flow fuselage, wing and tail. The wing has a high aspect ratio and features large winglets resulting in a glide ratio of 22.

Having the same goal as the Celera 500L, i.e. to minimize energy consumption per passenger-kilometer, a new configuration for long-haul aircraft is being thoroughly researched by Delft University of Technology. The Flying V is a flying-wing configuration designed for long-haul passenger transport (Figure 1). The passengers, cargo and fuel are located in the wing. Due to its shape, it consumes 20% less energy per passenger-kilometre than its tube-and-wing counterpart for the same top-level aircraft requirements¹. This is caused by three factors: First, the absence of a distinct fuselage and tail reduce the wetted area by 5% leading to reduced friction drag. Secondly, the large winglets increase the effective span of the wing leading to a reduction in lift-induced drag. Finally, the lateral distribution of the payload and fuel reduce the bending moment and thereby the structural weight of the airplane. These benefits stem directly from the shape of the airplane and can be further complemented by innovations in the airframe or the propulsion system.

¹ Oosterom, W. and Vos, R., "Conceptual Design of a Flying-V Aircraft Family," Proceedings of AIAA Aviation Forum, Chicago, IL, June 27 – July 1st, 2022.

While the Flying V is not the only innovation in airframe technology in recent years, it is radically different from anything we have seen before in civil aviation. Also, the introduction of this new airframe could result in a significant reduction in aviation emissions, as long-haul widebody aircraft have large share herein. In the subsequent paragraphs, the Flying V design is further described and the associated challenges with this new configuration are discussed.

An Efficient Use of Interior Volume

One of the key features of the Flying V is its high volume-to-wetted-area ratio. This benefit is exploited by efficiently using the available interior volume without compromising the comfort level of the passengers.

As can be seen in Figure 2, the cabin of the airplane features a 3-4-3 configuration in both legs yielding four aisles. This reduces the boarding and deboarding time.² A large cross aisle is present that connects the legs of the cabin with a large galley located in the middle. The door distribution is chosen such that the emergency evacuation can be ensured within 90 seconds for a high-density configuration of the cabin.³ The cargo compartment is located behind the cabin. To allow for the cargo nets to expand during a forward deceleration of 9g, space is reserved between the cargo containers and the aft cabin wall. The cargo containers that are used are of the LD4 type and are located in a tapering part of the wing. The fuel tank is located behind the cabin in the trailing edge of the wing as well as in the wing box of the outer wing. The economy seats are rotated by 9 degrees with respect to the cabin aisles to stay within certification constraints. The business class seats have seat belts with embedded airbags. By removing wing plugs (denoted in green and yellow in Figure 2), smaller versions can be created such that a family of Flying V aircraft results.

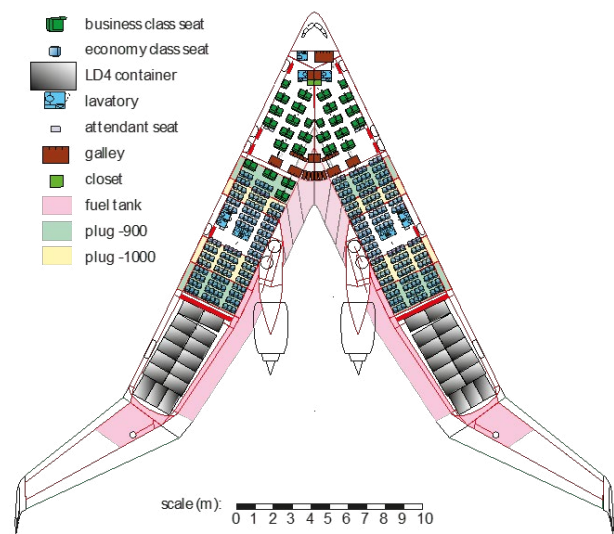


FIGURE 2: Planform view of the largest version of the Flying V configuration with 52 business class seats (55" pitch) and 309 economy class seats (32" pitch) [1].

Aerodynamics and Flight Control

The Flying V has a crescent wing planform with a 64-degree leading-edge sweep on the inner wing and a 40-degree sweep on the leading edge of the outer wing. The large inboard sweep angle allows for a cabin height of 2.1 meters without the formation of strong shock waves in the design condition.⁴ The outer wing is designed as a traditional transport wing with supercritical wing sections. The low aspect ratio (around 4.5) combined with the high sweep angle result in a low lift-curve slope. Due to the large sweep angle of the inner wing, the stall of the Flying V is quite gradual with a maximum lift coefficient of around 1.5. Depending on the Reynolds number, large vortex structures are formed beyond a critical angle of attack that result in vortex lift. Since the outboard wing stalls first, there is a risk of a strong nose-up pitching moment. Therefore, a leading-edge slat or droop nose might be necessary to ensure acceptable low-speed stall characteristics.

² Isgro, F., Fuselage Design Studies to Improve Boarding Performance of Novel Passenger Aircraft, Delft University of Technology, 2020.

³ Gebauer, J. and Benad, J., "Flying V and Reference Aircraft Evacuation Simulation and Comparison," www.researchgate.net/publication/349309406_Flying_V_and_Reference_Aircraft_Evacuation_Simulation_and_Comparison, accessed 30 March 2022.

⁴ Faggiano, F., Vos, R., Baan, M. and van Dijk, R., Aerodynamic Design of a Flying-V Aircraft, in 17th AIAA Aviation Technology, Integration, and Operations, Denver, Colorado, 2017.

⁵ Palermo, M. and Vos, R., Experimental Aerodynamic Analysis of a 4.6%-Scale Flying-V Subsonic Transport, in AIAA SciTech 2020 Forum, Orlando, FL, 2020.



FIGURE 3: Large vortex structures appear at high angles of attack over the inner wing of the Flying V.⁶



FIGURE 4: Flight control was experimentally verified using a 5%-scale flight-test demonstrator. Photo: Joep van Oppen for KLM and TU Delft

The outer wing features various types of control surfaces. The most outboard control surfaces on the wing are multifunctional. They act as drag rudders as well as elevons. Together with the “normal” rudders on the large winglets, they provide sufficient yawing moment to control the aircraft in a one-engine-inoperative condition.⁷ The inner two control surfaces act as elevons controlling both pitch and roll. Secondary flight control surfaces in the form of spoilers are added on the inboard and outboard side of the engine. They ensure that 20% of the lift can be dumped upon landing. To ensure adequate flying and handling characteristics the airplane is statically stable in pitch, roll and yaw. With the addition of a simple yaw damper and auto-throttle also dynamic stability is ensured in all modes (see Figure 4). However, due to the absence of a tail a strong coupling between the pitching and heaving movement is experienced which warrants the introduction of dedicated flight control laws for this configuration.⁸

Flight Performance

While the flight performance during climb, cruise and descent are not notably different from a tube-and-wing aircraft, the take-off and landing characteristics are quite different. Due to the low lift-curve slope of the wing, the airplane has a maximal approach attitude of 14 degrees. Note that the airplane does not feature any trailing-edge flaps to reduce its landing attitude. To allow the airplane to have sufficient clearance at the tip during an 8-degree banked landing, large landing-gear legs are required and perhaps even an outrigger wheel (see Figure 2). However, operational constraints place the maximum height of the cargo door at 5.5 meters when the airplane is completely empty. To stow the main landing gear efficiently in the wing, a double hinged mechanism is required.⁹ Furthermore, for a maximal approach speed of 140kts at the maximum landing weight, an overnose angle of 31 degrees is required to satisfy certification constraints on pilot visibility.¹⁰ This drives the shape of the cockpit, which is further complicated by the stowage of the nose wheel combined with the relatively low height of the fuselage.

6 Viet, R., Analysis of the flight characteristics of a highly swept cranked flying wing by means of an experimental test, Delft University of Technology, Delft, 2019.

7 Cappuyns, T., Handling Qualities of a Flying V Configuration, Delft University of Technology, Delft, 2019

8 Garcia, R., Vos, R. and de Visser, C., Aerodynamic Model Identification of the Flying V from Wind Tunnel Data, in AIAA Aviation 2020 Forum, Virtual Event, 2020

9 Bourget, G., The effect of landing gear implementation on Flying V aerodynamics, stability, and controllability. Delft University of Technology, Delft, 2020.

10 Van der Pluijm, R., Cockpit Design and Integration into the Flying V, Delft University of Technology, Delft, 2021.

The Next Three Years

Research on the Flying V is still relatively recent, and it is still to be confirmed whether this configuration can meet all the certification requirements, while still achieving the improvement in payload-range efficiency. Therefore, multiple studies are currently ongoing to prove that this design can successfully replace widebody aircraft in the future. Active areas of research performed at Delft University of Technology, in conjunction with partners such as KLM and Airbus GmbH, include noise assessment, engine integration, landing gear integration, aerodynamic design, aeroservoelasticity, flight control, and climate impact assessment.

Electric Aircraft

By Susan X. Ying (Ampaire)

Introduction

Electric aircraft hold tremendous potential to improve emission, noise, and operating economics across a range of different applications in support of the aviation industry's goal of achieving net-zero CO₂ emissions by 2050. In this section, we will draw from the industry's state-of-the-art research and flight demonstrations to illustrate the technology challenges and opportunities, and how it intersects with Sustainable Aviation Fuel (SAF) that will be necessary for achieving net zero. The following sub-sections are organized to introduce these key elements including enablers for electric aircraft operations.

Emission and Economics of Electric Aircraft

The exciting development of electric aircraft has been referred to as “the Third Revolution in Aviation”¹. The first revolution was the Wright brothers’ very first successful powered flight, the second one, the invention of jet propulsion which allowed us to fly faster and farther. The growth of aviation that followed introduced the big carbon emission problem. The advent of electric aircraft propelled by clean electricity marks the dramatic transformation to zero carbon emission for aviation, and the “third revolution”. The benefit from this revolution goes well beyond the emission reduction.

The operation of these revolutionary electric aircraft already demonstrated significant cost savings. For example, the energy cost of the two-seat Pipistrel aircraft (Figure 1) per hour is at 0.9 € while a conventional Cessna two-seat aircraft C152 commonly used for training is approximately \$34 (pre-Ukraine war estimate), which is equivalent to

34X that of the Pipistrel Alpha Electro². An estimate of the per hour total operating cost for the C152 vs the Alpha Electro is approximately 3.6:1; that is, the conventional two-seat fossil fuel propelled aircraft is almost *fourfold more expensive* to operate than the equivalent two-seat electric aircraft ! In March 2022, the aviation industrial conglomerate Textron, parent company of Cessna, decided to underwrite the expansion and success of electric aviation for commercial use with its acquisition of Pipistrel.

By April 18, 2022, Textron completed acquisition of Pipistrel for a cash purchase price of €218 million. This deal will dramatically accelerate the development, deployment and adoption of electric aircraft.



FIGURE 1: Pipistrel Electric Aircraft

In the span from 2016 to 2022, there have been over 300 Electric Aircraft projects and up to 200 electric aircraft start-ups around the world, similar to the renaissance of aviation period in the early 1900's. The overall electric aircraft service domain is loosely referred to as “Advanced Air Mobility” (AAM), which covers the “Urban Air Mobility” (UAM) and part of “Regional Air Mobility” (RAM). electric aircraft for UAM are primarily equipped with vertical lift

1 “Could electric airplanes propel a third revolution in aviation?” Miles O'Brien, PBS News Hour, May 26, 2021. <https://www.pbs.org/newshour/show/could-electric-airplanes-propel-a-third-revolution-in-aviation>

2 “Alpha Electro, the first serially produced electric trainer”, Tine Tomažič, AIAA-IEEE Conference, Aug, 2020.

capability, also referred to as eVTOL (electric Vertical Take-Off and Landing), while the RAM electric aircraft take advantage of the runway to gain momentum (hence less energy demand) for take-off and landing, and are referred to as eCTOL (C for Conventional) or eSTOL (S for Short). The eVTOLs operate similar to rotorcraft and require heliports (or “vertiports”) in urban environment. Examples of eVTOLs include projects from Joby, Volocopter, Lilium, Archer, EHang, Wisk, and many more. In contrast, eCTOLs and eSTOLs are fixed-wing aircraft that can use the massive number of existing airports, transforming the regional travel due to the unprecedented economic and environmental benefits. These electric aircraft are developed in several start-ups and OEMs, e.g. Airbus, Ampaire, Electra.Aero, Heart Aerospace, MagniX (with Eviation), Rolls Royce Electric, VoltAero, ZeroAvia, etc. NASA’s white paper on RAM³ outlined how the application of electric aircraft will dramatically increase the accessibility and affordability of regional travel while building on the extensive and underutilized US local airports.

Electric Aircraft Innovation – Challenges and Opportunities

Aviation has witnessed the shift toward “more electric aircraft” since the introduction of Boeing’s 787 in 2011. For the traditional airplane, power is extracted from the engines in two ways to power other airplane systems: one, the generators are driven by engines to create electricity (e.g., to power avionics system); second, a pneumatic system “bleeds” air off the engines to power other systems (e.g., hydraulics). The B787’s more electric aircraft approach uses electric instead of the pneumatic system and provides much more efficient power generation and distribution for use and reduces systems weight, including the adoption of a higher capacity electric energy storage system (ESS e.g., Li-ion battery). The evolutionary change towards more electric aircraft for large transport aircraft such as the B787 is a very slow process. However, the significant technology

development and adoption of ground Electric Vehicles (EV) in the last decade has made the electric aircraft more feasible. In addition to the relevant technological advances, the economy of scale and new supply base growth have driven down the component systems cost tremendously. These potentially common component systems include, e.g., electric motors and inverters which when operating together in an electric aircraft are defined as the “electric engine⁴” (e-engine) and ESS (battery or fuel cell) instead of the conventional “fuel system”. Three key challenges and opportunities are highlighted here.

Today’s state-of-the-art commercial lithium batteries are ~50X heavier than aviation fuel. Even accounting for the much lower losses through an e-engine leaves a ~25X net energy weight disadvantage. However, an e-engine weighs a lot less than a combustion engine. ARPA-e’s ASCEND project seeks to extend this advantage leading to 12 kW/kg for an e-engine compared to a MW-class gas turbine at ~3 kW/kg⁵, or 4X the power-to-weight performance! Additionally, there is a rapid development in solid-state batteries (SSB), which will reach 4X higher energy density and power density, substantially surpassing the performance, safety, and processing limitations of Li-ion batteries. It is estimated that these SSBs will become commercially available in 2030’s in the electric vehicles and aircraft market respectively.⁶ Some eVTOLs, (hybrid) eCTOLs and eSTOLs such as Ampaire’s 9-seat Eco Caravan and Outlander with compelling emission reduction and meaningful range performance of up to 500+ miles are already on the horizon to enter service by 2025.

The hydrogen fuel cell is another energy storage system (ESS). It is an electrochemical device that converts hydrogen directly into electricity supply for the e-engine while releasing heat and water. Boeing’s hybrid-electric and fuel-cell demonstrator flew in 2007 for approximately 20 minutes on energy from the fuel cell ESS. However, Boeing “does not envision that fuel cells will ever provide primary power for large commercial airplanes”⁷. It should be noted

3 “Regional Air Mobility: Leveraging Our National Investments to Energize the American Travel Experience”, Kevin Antcliff et. al., April 2021, <https://ntrs.nasa.gov/citations/20210014033>

4 “Taxonomy, Architecture, Safety, Endurance Testing”, SAE E-40 Electrified Propulsion standard publication, ARP8689, Q1, 2023.

5 <https://arpa-e.energy.gov/technologies/programs/ascend>

6 “Solid-State Batteries: The Technology of the 2030s but the Research Challenge of the 2020s”, Faraday Insights, Issue 5: Feb 2020. https://faraday.ac.uk/wp-content/uploads/2020/04/Faraday-Insights-5_Updated.pdf

7 “Boeing makes history with flights of Fuel Cell Demonstrator Airplane”, Tom Koehler, Boeing Frontiers, May 2008, https://www.boeing.com/news/frontiers/archive/2008/may/ts_sf04.pdf

that the hydrogen supply for the fuel cell requires storage tank(s). The electric vehicles and truck industry uses a 700 bar compressed hydrogen gas tank. Even at 700 bar, the volumetric energy density of hydrogen will take 7X more volume to store the hydrogen for the equivalent mission. The placement of such fuel tank would not be inside the conventional wing, but more likely in the fuselage which would reduce the passenger load capacity unless new airframe configuration is applied.

The second key challenge is unique to the aerospace industry, as it is a highly regulated industry for an important reason, safety. All the new (and retrofit) electric aircraft must be type certified for air worthiness by regulatory bodies, e.g. FAA and EASA. With over 200 projects of new electric aircraft (or even a fraction of them) going to the regulatory bodies for certification, the regulators will have not only a resource issue but also knowledge and experience issue which is necessary to address the gaps of existing standards and rules. In 2022, the FAA's Center for Emerging Concepts and Innovation (CECI) that leads the early certification stages for electric aircraft has 8 program managers and already ~70 projects in the pipeline.⁸

The Pipistrel two-seat “Velis Electro” is the world’s first electric aircraft to receive a Type Certificate from EASA in June 2020, approved for pilot training in Day Visual Flight Rule operations. The knowledge and experience gained from the Pipistrel’s certification activities have been used to develop the Special Condition SC E-19 “Electric/Hybrid Propulsion System” to further enable electric aircraft certification projects. In the US, the FAA also released Special Conditions for e-engine Airworthiness in October 2021. These Special Conditions are based on a new American Society for Testing and Materials standard and are a mix of 14 CFR Part 33 standards and special conditions applicable to the magni250 and magni500 model engines from MagniX that applied for the type certificate in April 2019. Due to the more integrated airframe and propulsion system of the electric aircraft, it is not clear

at this point how different the certification process would be compared to the conventional one for “airframe” (e.g. Part23 or CS23) vs. “engines” (Part33 or CS-E). A certain outcome is that there will be more “Special Conditions” going forward.

The third challenge area is in the eco-system readiness for enabling the electric aircraft operation, e.g. clean energy availability and distribution to the plug-in electric aircraft for charging. This eco-system includes stakeholders such as airports from an infrastructure and operations perspective, airlines who may need to modify their existing process on ground and flight routing to take advantage of the electric aircraft capabilities, and the energy industry which could be the supplier, on-site storage, or distributors for the energy management. While all RAM airports are already powered by electricity, most are directly from the grid which may not have complete renewable sources for the electricity. These infrastructure feasibility considerations and recharge strategies for electric aircraft operations have been reported in several studies.^{9,10}

Infrastructure and Flight Demonstrations

Electric aviation offers a great opportunity to better integrate airports as “energy hubs” into both urban and rural transit networks, providing clean energy and charging to local communities (e.g. charging buses overnight), and grid storage plus resiliency to power outage for critical infrastructure. Examples of airport solar farms include New Zealand’s Christchurch airport¹¹ which will provide 150 MW to power the airport and local communities, Japan’s Kansai airport with largest solar farm in Asia at 11.6 MW, UK’s Glasgow airport at 15 MW, and the US Chattanooga airport that has already been operating at 100% on-site solar energy at 2.64 MW. Other forms of renewable energy for airports include for example UK’s East Midlands Airport wind farms, Sweden’s Stockholm Arlanda airport¹² using

8 SAE AeroTech 2022 Digital Summit, FAA CECI.

9 “Power optimized battery swap and recharge strategies for electric aircraft operations”, Cedric Y. Justin et. al., Transportation Research Part C 115 (2020) 102605, Elsevier journal. <https://doi.org/10.1016/j.trc.2020.02.027>

10 Connected Places Catapult, Zero Emission Flight Infrastructure (ZEFI) programme in collaboration with the Department for Transport. https://cp.catapult.org.uk/project/zero-emission-flight-infrastructure-preparing-uk-airports-for-zero-emission-aircraft/?utm_campaign=zefi-&utm_source=linkedin&utm_medium=roadmap-and-blueprint-

11 <https://renewablesnow.com/news/new-zealand-airport-plans-150-mw-solar-park-as-part-of-wider-project-764032/>

12 <https://www.swedavia.com/arlanda/environment/#>



FIGURE 2: Ampaire's Hybrid Demonstrator, Electric Eel

biofuel, wind, and other renewable sources, which are stored in the world's largest thermal energy storage unit, an "aquifer" underground that provides 8MW power. The European Marine Energy Centre is collaborating with Highlands and Islands Airports Limited (HIAL) in Scotland to decarbonise heat and power at Kirkwall Airport through green hydrogen technology.

Electrifying aviation at airports to date includes plugging planes into gate power for Auxiliary Power Unit, electric taxi to the runway, as well as electric tugs and ground equipment. Moving forward, this means investing in development and scaleup, from adoption of electric trainer aircraft to integrating the plug-in (hybrid) electric aircraft. This is where the demonstration projects such as 2ZERO (Towards Zero Emission Regional Aircraft Operations) and SATE (Sustainable Aviation Test Environment) sponsored by the Future Flight Challenge program of Innovate UK are extremely valuable as the public and the private sectors' are brought together to solve the systems problem collaboratively. Ampaire's participation on these projects allowed us to work together with HIAL, Exeter, and Newquay airports and chart the course of aviation electrification roadmap. In August 2021, the hybrid demonstrator "Electric Eel" (Figure 2) was able to achieve the longest non-stop flight of 418 nautical miles in UK, at a 38% reduction to fuel

emission. A mobile charger was used for the demonstration flights, which incorporates the standard plug-in interfaces both on aircraft and to the airport energy outlet with advanced coordination. This Eel demonstrator is a hybrid of independent parallel architecture, which is not optimized. We estimate that for an optimized parallel hybrid electric aircraft using sustainable aviation fuels (SAF) (at 50% blend) for the combustion engine, it can achieve 90% emission reduction with today's technology. As batteries and electronics improve, smaller planes can move to all-electric and larger planes can convert to hybrids over time, using a combination of SAF and clean electricity.

If we want to mitigate climate change, decarbonizing aviation is a must — electric aviation needs to be an important part of the solution. But launching the electric aircraft operations widely will require the combined vision and focus of both the public and the private sectors. This must be a collaborative effort joining the creativity of the private sector and the long-term perspective and decarbonization goals of the public sector. The time to act is now. By building a strong foundation to support the electric aircraft development and infrastructure for enabling the electric aircraft, we can achieve something truly revolutionary in our industry!

Next-generation batteries to enable electric aviation

By Bruno Vanzielegthem (Cuberg)

Introduction

Cuberg is developing a next-generation battery technology to power the rise of electric mobility, particularly addressing growing demand in electric aviation. Early developments in electric aviation include both the emerging electric vertical take-off and landing (eVTOL) market and electrification of conventional take-off and landing aircraft (eCTOL). Both applications need next-generation battery technology to provide competitive range and payload capacities. Cuberg's batteries deliver a step-change improvement in energy density and safety compared to the best lithium-ion (Li-ion) batteries in the world today. When equipped with our technology, electric aviation solutions will deliver greatly improved flight range, payload capability, and operational cost, providing better capabilities for firefighting, cargo delivery, urban and regional transportation, search-and-rescue efforts, logistics missions, and monitoring for agriculture, oil and gas, and utilities. Cuberg's batteries will enable the commercialisation and democratisation of clean aviation services based on renewable technologies.

Cuberg technology

Cuberg's technology addresses the shortcomings of conventional Li-ion batteries in two ways. First, Cuberg's batteries combine a high-energy cathode with an energy-dense Li metal anode to dramatically increase energy density by about 80% compared to the best Li-ion battery technology. Second, Cuberg has developed a non-flammable and thermally stable liquid electrolyte, thus replacing flammable organic solvent-based electrolytes responsible for the poor safety profiles of Li-ion batteries. Cuberg's proprietary electrolyte chemistry lies at the heart of our innovation. The chemical stability and

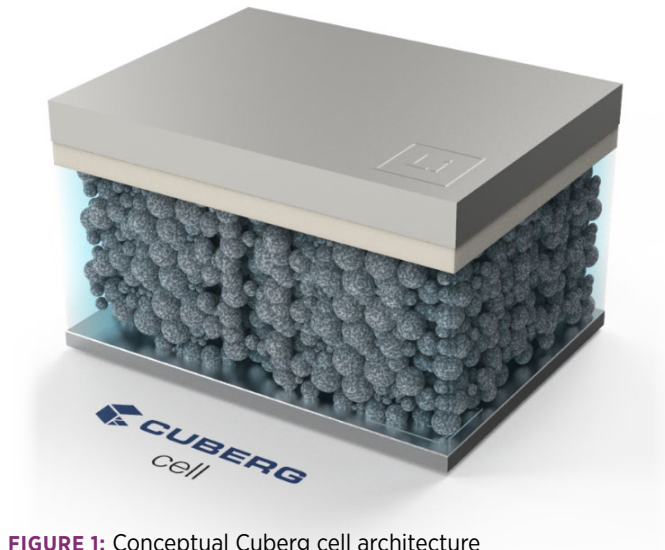


FIGURE 1: Conceptual Cuberg cell architecture

unique properties of our electrolyte lead to enhanced compatibility with both high-capacity metal oxide cathodes and lithium metal anodes.

In 2019, Cuberg performed the world's first eVTOL drone flight with a lithium metal battery, increasing flight time by 70% to 90% compared to a similar drone powered by Li-ion batteries. Also, the Cuberg battery performance was independently validated by the Department of Energy in 2020. Three key battery performance measures need to be optimised in balance for successful aviation commercialisation: specific energy, which allows for longer flight times and ranges at a given weight; specific power output, which enables greater aircraft weights and payload capacity; and cycle life, which impacts cost of ownership. The testing by the Department of Energy's Idaho National Laboratory on Cuberg's 5-Ah (amp-hour) battery cells indicated specific energy of 369 Wh/kg, specific power of 2,000 W/kg, and 370 cycles with C/2 charging before the cells reached end of life at an 80% capacity cut-off.



FIGURE 2: Cuberg 5Ah pouch cell batteries

Cuberg's batteries, based on its breakthrough lithium metal technology, are optimally designed for successful commercialisation. Cuberg has achieved industry-leading results in a pouch cell using technology that capitalises on the scale and quality of the existing Li-ion manufacturing ecosystem. These strengths allow Cuberg to bring next-gen batteries to the aviation market, delivering significant improvements in range and payload while preserving the substantial deployed capital base of Li-ion manufacturing.

While Cuberg has demonstrated a pouch cell battery with exceptional performance, it is crucially important to integrate the cell into, and manufacture a lightweight, high-performance battery module for validation by aviation customers. Cuberg is carrying out an ambitious work plan consisting of cell component studies, pilot production set-up, module design and engineering, module prototype manufacturing, and customer validation. The modules are being designed to incorporate in eVTOL and eCTOL applications, powering the early forays into electric aviation over the next few years.

What Benefits Are Expected?

The electric aviation sector is still nascent, and direct benefits are difficult to estimate, especially for the emerging urban air mobility applications. However, a comprehensive study by the National Renewable Energy Laboratory (NREL)¹ highlighted the potential of electric aviation to reduce operational costs, open previously uneconomical regional destinations, reduce emissions, reduce noise, increase accessibility, and be a driver for economic development activity. Cost reductions can be attributed to a significant decrease in fuel costs and a reduction in maintenance costs. Emissions reductions are a second key drivers for electrifying aviation. The replacement of fossil-fuel powered short-haul aircraft with their electric equivalent promises significant emissions reductions, including green-house-gas reductions. A case study in the NREL report evaluated the impact of electrifying routes within 300 miles of Denver International Airport. One of the key conclusions showed that replacing a fossil fueled aircraft with a similar electric aircraft would reduce fuel cost from approximately \$400 to \$50, combined with a reduction in CO₂ emissions as much as 95%. While no mandates have been put in place in the United States yet, Norway is one of the countries taking a lead in this area, mandating that by 2040 all civil domestic aviation will be electric.²

The Next Three Years

For Cuberg, the next three years promise to be a period of accelerated growth, with a singular focus on maturing the Cuberg battery into a viable product for storing energy to power electric aircraft. Hand in hand with maturing the battery, it is critically important to mature the battery module and pack towards a system that can be used safely in an aircraft and deliver the performance parameters to enable this new era of electric aviation. This development is happening in close collaboration with our eVTOL and eCTOL partners.

¹ Electrification of Aircraft: Challenges, Barriers, and Potential Impacts <https://www.nrel.gov/docs/fy22osti/80220.pdf>

² Electric aviation ready for take-off in Norway by 2030, report says <https://thebarentsobserver.com/en/travel/2020/03/electric-aviation-should-be-ready-take-norway-2030>

Hydrogen power – boldly going to the heart of climate-neutral aviation

By Glenn Llewellyn (Airbus), Val Miftakhov (ZeroAvia)

Introduction

Hydrogen fuel offers significant potential for eliminating aircraft greenhouse gas emissions. Early concepts for smaller commercial aircraft are already flight testing gaseous hydrogen as a fuel, while larger airframes (50 plus seats) are likely to leverage liquid hydrogen due to its improved energy density.

With hydrogen as a fuel, either in combustion engines or used in a fuel cell, there are no in-flight carbon dioxide (CO₂) emissions whatsoever. Hydrogen can be made through electrolysis powered by renewable energy, ensuring there are no direct CO₂ emissions in fuel production. Hydrogen can thus be the pathway towards “net zero” in aviation.

In this two-part article, Airbus’ Glenn Llewellyn (VP, Zero Emission Aircraft) and ZeroAvia’s Val Miftakhov (CEO), both leaders in the development of hydrogen aircraft technology, explain their respective companies’ solutions, and the benefits and challenges of the approach they are taking to develop hydrogen aircraft propulsion in depth.

Airbus-ZEROe – from concept designs to the real thing

Liquid hydrogen’s high energy density makes it suitable to fuel large aircraft as a replacement for kerosene. To this end Airbus is evaluating several hydrogen approaches for future aircraft designs, which include ‘direct hydrogen combustion’ and ‘hydrogen fuel cells’. The latter, which produce zero emissions, convert energy stored in hydrogen atoms into electrical power via an electro-chemical reaction.

Hydrogen is also a key ingredient for a third category: power-to-liquid synthetic fuel which is even compatible with existing aircraft – whereby ‘green’ hydrogen is combined with carbon dioxide to form a synthetic fuel with net-zero carbon emissions.

For the direct combustion approach, hydrogen is injected and ignited in a modified turbofan’s combustor to generate thrust – a process which is identical to that in traditional jet engines. With hydrogen replacing kerosene, the direct combustion products are water vapour (H₂O) + energy, plus some trace gases. The upside is that CO₂ and the majority of soot emissions are eliminated. The challenge is to significantly reduce NO_x and persistent contrails. To this end, Airbus is working with its technology partners to eliminate this potential climate impact of hydrogen combustion.

Airbus and its partners are already working on four hydrogen-powered concept aircraft – known as ZEROe – which were unveiled to the world in 2020 (Figure 1). These designs correspond to mission ranges of 1,000 nm or 2,000 nm and capacities of between 100 and 200 passengers, thus representing a large portion of the market including transcontinental flights.

Three of the concept aircraft would use hydrogen combustion engines in combination with a megawatt scale hybrid-electric component. The latter comes from fuel cells rather than batteries due to the overall performance benefit especially given that there is already hydrogen on board the aircraft. The fourth ZEROe concept is a fully fuel-cell powered aircraft, for which the propulsion system as well as all non-propulsive energy needs are powered by fuel cells.



FIGURE 1: Introducing Airbus ZEROe

A down selection on ZEROe’s technology choices and aircraft configurations is expected to start as early as 2025, which means that the first hydrogen-powered airliner could be certified and ready for service entry by 2035.

While liquid hydrogen has a specific energy-per-unit mass which is three times higher than traditional Jet-A1 kerosene, its volumetric energy density is actually lower, therefore the visual appearance of future aircraft will likely need to adapt accordingly – with more internal volume devoted to storing the liquid hydrogen. This is reflected

in the respective ZEROe concept configurations whereby, in the turboprop and twinjet designs for example, extra fuselage length is devoted to storing liquid hydrogen in cylindrical tanks. Meanwhile, the largest concept aircraft takes advantage of its exceptionally large internal volume afforded by the “blended-wing” itself for accommodating the hydrogen.

Airbus is also adapting and evolving existing hydrogen storage technology for use inside aircraft. Several new research and development facilities across Europe have



FIGURE 2: Hydrogen hub at airports by Airbus.

recently begun work on liquid hydrogen storage tanks for its ZEROe concept aircraft. These ‘cryogenic’ tanks will be insulated to keep the hydrogen in liquid form at around -253 degrees Celsius.

In February this year, Airbus signed a partnership agreement with CFM International to collaborate on a ZEROe hydrogen propulsion demonstration. In terms of hardware this comprises an A380 testbed onto which is mounted a hydrogen-fuelled test engine provided by CFM. The programme’s objective is to initially perform tests on the ground. Subsequently there will be in-flight trials starting in 2026 with a direct combustion turbofan engine fuelled by hydrogen. Airbus’ A380 flying testbed, dubbed “FlightLab”, will be equipped with four cylindrical tanks housed inside the rear fuselage which will contain the liquid hydrogen fuel.

In parallel with the development activities regarding engines, cryogenic fuel tanks and aircraft platforms, Airbus is also working alongside its airline and airport and energy supplier partners on “Hydrogen Hub At Airports” – an initiative which is investigating ground infrastructure requirements for hydrogen. Specifically, Airbus is collaborating with airports to plan a stepped approach to deployment, including using hydrogen to decarbonise all airport-associated ground vehicles. To date, agreements have been signed with partners in Paris, Seoul and Singapore, with more to follow.

ZeroAvia - hydrogen-electric powertrains for aviation

ZeroAvia has decided to develop exclusively hydrogen-electric engine technology in its bid to deliver zero-emission flight, initially focusing on retrofitting existing airframes. From the outset, the company has been targeting delivering electrification to the aviation market to remove all emissions (both CO₂ and non-CO₂), but realised very early in a first principles analysis that battery-electric power was not viable due to the significant weight limitations.

Hydrogen-electric powertrains – utilising hydrogen fuel cell systems to produce electricity from hydrogen fuel in order to power electric motors – offer significant advantages over other alternative propulsion types. According to the US Department of Energy, a fuel cell coupled with an electric motor is two to three times more energy efficient than an internal combustion engine running on gasoline. In a fuel cell propulsion system the only emission is water vapour, and mitigations to contrail impacts are also possible given the relatively low temperature and slower exhaust of the water. For ZeroAvia this is crucial, as there are no carbon emissions in the system, but also none of the other non-carbon emissions that are present in current turbine engines like NO_x, SO_x, particulates and soot, now known to contribute significantly to aviation’s full climate impact.

There are challenges in bringing hydrogen fuel cell powered propulsion systems to market, such as the volume required for hydrogen fuel storage, but these are not insurmountable and there is no theoretical limitation in physics as to why hydrogen-electric propulsion cannot power the largest airplanes or the longest flights in service today.¹

ZeroAvia has already demonstrated its hydrogen-electric powertrain technology in a six-seat Piper Malibu using a 250kW system, with gaseous hydrogen as the fuel. The company is also well advanced in the development of a 600kW system (ZA600), capable of supporting 10-20 seat aircraft with an initial range of 300 nautical miles. The company plans to certify this technology in time for entry into service by 2024 and has signed an initial deal with Hindustan Aeronautics Ltd, enabling the



FIGURE 3: ZeroAvia

1 See CleanSky report https://www.fch.europa.eu/sites/default/files/FCH%20Docs/20200720_Hydrogen%20Powered%20Aviation%20report_FINAL%20web.pdf

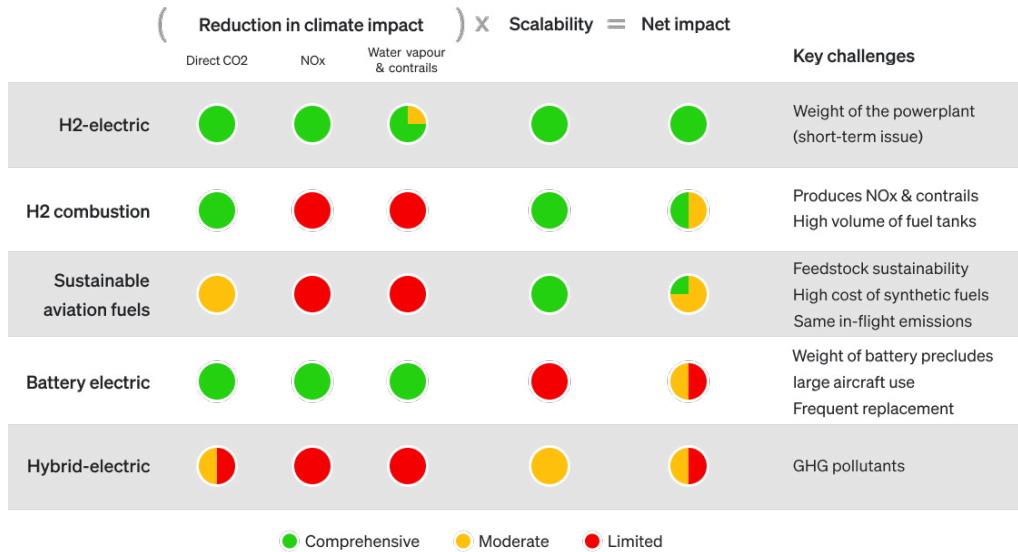


FIGURE 4: Why hydrogen-electric?

Indian manufacturer to offer retrofits to existing Dornier & Hindustan-228 Aircraft and line fit new manufactured Dornier & Hindustan-228 aircraft with hydrogen-electric powertrains.

ZeroAvia is concurrently working on research, design, certification and production of a modular 2-5 megawatt (MW) hydrogen fuel cell powertrain between now and 2026. This powertrain would be capable of powering 40-80 seat aircraft over distances up to 1,000 nautical miles – equivalent to Washington DC to Dallas, or London to Reykjavik. Sub 1,500 nautical mile flights cover more than 50 per cent of all aviation greenhouse gas emissions and 80 per cent of all trips – showing that as the technology advances it can have a meaningful impact this decade. The technology also promises lower operational costs

meaning more viable regional routes, better connectivity (boosting local economies) and lower costs for passengers. This is a big reason why major airlines such as Alaska Airlines, United Airlines and British Airways are backing the companies' technology.

For both hydrogen combustion and hydrogen fuel cell powered flight, refuelling infrastructure is a major challenge. ZeroAvia has been working to demonstrate the use case for airport refuelling, having developed its Hydrogen Airport Refuelling Ecosystem (HARE) in collaboration with the European Marine Energy Centre (EMEC). Using an onsite electrolyser at its R&D bases to produce compressed hydrogen gas which is then passed into its mobile refuelling truck, the company has been demonstrating the infrastructure for gaseous hydrogen



FIGURE 5: Green hydrogen powers electric propulsion using the fuel cells

refuelling in its flight testing programme over the last two years. The company has also been working on concept studies to support larger aircraft programmes with liquid hydrogen refuelling infrastructure.

Over the next three years ZeroAvia expects to achieve certification of its 600kW hydrogen-electric powertrain system, and begin working with airline and airport partners on zero-emission commercial routes carrying 10-20 passengers. The company has already struck a deal with Royal Schiphol Group and Rotterdam The Hague Airport Group to develop a route between the Dutch airport and a London airport, for example.

Simultaneously, the company will further develop its ZA2000 product to the point of certification within the next three years, supporting 40-80 seat turboprop aircraft such as the Dash-8 Q400 which it will be working to demonstrate over the period as part of a partnership with Alaska Airlines. ZeroAvia is targeting market entry for this powertrain to support larger aircraft in 2026.

Further to its propulsion R&D, ZeroAvia will conduct additional research, development and demonstration of its HARE programme, developing a stronger body of knowledge on the provision of liquid hydrogen fuel in an airport context, and building on its hydrogen generation and refuelling infrastructure at its Hollister, California and Kemble, UK airport locations supporting the company's flight testing programmes. The installation of gaseous hydrogen production at airport sites to support routes and ancillary use cases will further demonstrate to a wide audience the economic and environmental opportunities of hydrogen within aviation.

Collectively driving industry's transition to hydrogen

Airbus and ZeroAvia are two out of a rapidly expanding group of proactive aviation players, who, collectively, are driving the major industry shift – from simply viewing hydrogen as a potential opportunity to showing how the fuel has an integral part to play in reducing the environmental impact of operations both on the ground and in the air. Moreover, by working together with industry partners and authorities the resulting momentum is already bearing fruit: Demonstrations of hydrogen combustion, zero-emission fuels cells and hybrid hydrogen-electric combined configurations are accelerating. These will be closely followed with the first certifications for technology enabling net-zero-emission and beyond commercial flight.

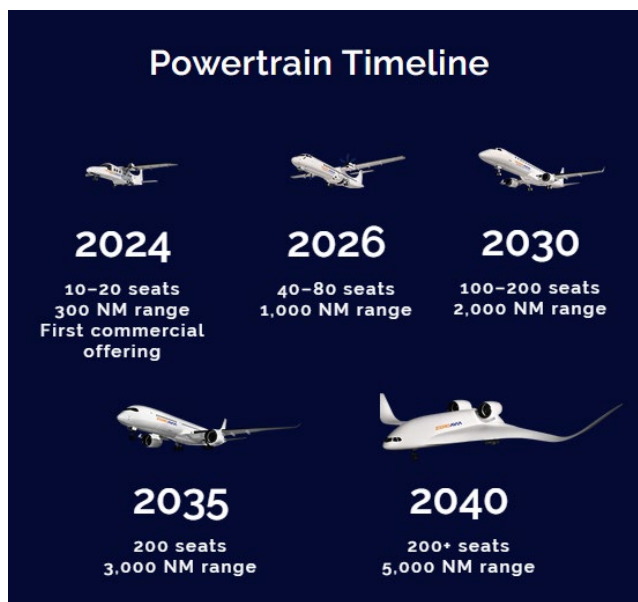


FIGURE 6: Powertrain Timeline

Sustainable City Travel

By Archer



Archer¹ Aviation, based in Palo Alto, California, USA, is working to build an electric vertical takeoff and landing (eVTOL) aircraft and aerial ridesharing service, that will move people throughout congested cities in a quick, safe, sustainable, and cost-effective manner. Through their work both on their eVTOL aircraft, and with partner cities such as Los Angeles and Miami, they are laying the groundwork to curb the growth of urban congestion, and the resulting historic levels of emissions in populous areas.

Modern cities are in a transportation environment crisis, struggling to provide solutions for the evolving urban landscape. As urban populations grow, the crisis will be exacerbated by magnifying the negative health and environmental impacts experienced by millions of urbanites. By 2050, the United Nations (UN) projects that 68% of the world's population will live in urban areas². This will create nightmarish traffic jams, painstaking commutes, and the pollution they will create, more impactful than today. Beyond the mere stress and inconvenience of traffic, a study³ revealed that long commute times lead to a lowered quality of life for urbanites. Increased congestion exposes the population

to higher levels of pollution and, as a result, a climbing mortality rate.

Current solutions are limited and not always a clear path to eliminate the growing health and environmental concerns. There are various modes of transportation which will reduce emissions, however, not all benefits will be achieved. Electric vehicles will reduce emissions, although the existing congestion problems will remain. Rail will decrease the need for multiple, individual vehicles, however, in modern urban environments physical space is at a premium, making even subterranean routes non-starters. Current aircraft options provide for more open paths around the city, however their negative contributions are well-documented.

A modern helicopter, though vastly improved in efficiency, is still responsible for significantly higher emissions than an automobile, despite a similar passenger payload. Looking beyond the negative impacts to air quality, helicopters are a major contributing factor to increased noise levels in modern urban environments. Multiple studies have shown a clear correlation between these increased noise levels and a decrease in cardiovascular health⁴.

1 <https://www.archer.com/>

2 <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html#:~:text=News-,68%25%20of%20the%20world%20population%20projected%20to%20live%20in,areas%20by%202050%2C%20says%20UN&text=Today%2C%2055%25%20of%20the%20world's,increase%20to%2068%25%20by%202050.&text=The%20Urban%20population%20of%20the,to%204.2%20billion%20in%202018>

3 <https://blogs.lse.ac.uk/usappblog/2016/05/12/the-bigger-and-denser-the-city-you-live-in-the-more-unhappy-youre-likely-to-be/>

4 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3971384/>



Archer is aiming to redefine the future of urban commuting. Minimal takeoff and landing space requirements allow for the use of existing structures, such as parking garages and airports, to provide service throughout a city. Integration into existing urban landscapes will address the shortcomings of current transportation networks, creating broader multi-modal options that reduce the need for cars, thus transforming the daily lives of millions of commuters. Beyond its impact on commuters, Archer's eVTOL aircraft has the potential to positively impact the lives of every urbanite.

Archer is taking aspects of modern aircraft, expanding technological boundaries, and creating the next generation of air travel. Their current demonstrator aircraft, Maker, is powered by six independent battery packs, each independently powering a pair of motors. This design allows for propulsion redundancy and, unlike helicopters, has zero catastrophic single points of failure. Purely electric propulsion, in addition to eliminating flight emissions, allows for a dramatic decrease in noise pollution. The sound produced from their aircraft is anticipated to be 30dB quieter than a helicopter at cruising altitude, causing it to virtually disappear into the background noise of the street below.

While others in the space have chosen to tailor their product to regional and long-haul travel, Archer is singularly focused on intra-city mobility, working to reduce traffic congestion, reducing the impact of growing emissions, and by connecting people to their extended communities. Based on Archer's data estimations, the target route of 20-60 miles will accommodate over 95% of trips taken in urban areas today. The dedication to innovative and efficient design and operations, Archer believes their aerial ridesharing service will deliver an affordable alternative method to complete those trips safely and efficiently.

The next three years are expected to be among the most exciting in the company's history. The plan to debut their production aircraft design, build and begin production in their sustainably designed manufacturing facility, solidify initial infrastructure in their partner cities, and welcome commuters to a whole new form of travel. While that might sound like far more than three years can fit, Archer believes their pace of innovation, development, and design will be attained. Archer has started flying their first aircraft⁵, have established partnerships with United Airlines⁶, Stellantis⁷, and REEF⁸, and are well-capitalised as a result of being publicly traded⁹ company as of 2021. A safer, more sustainable solution to urban mobility is possible, and Archer looks forward to making it a reality.

5 <https://archer.com/news/archer-takes-to-the-skies-with-first-hover-flight-of-maker-aircraft>

6 <https://archer.com/news/archer-a-leading-urban-air-mobility-company-to-list-on-nyse-through-merger-with-atlas-crest-investment-corp>

7 <https://archer.com/news/archer-taps-fcas-scale-and-expertise-to-accelerate-electric-vertical-take-off-and-landing-aircraft-evtol-production>

8 <https://archer.com/news/archer-and-reef-team-up-to-tackle-urban-congestion-with-vertiports-and-urban-air-mobility-networks>

9 <https://archer.com/news/archer-begins-trading-on-the-new-york-stock-exchange-under-the-symbol-achr>

Airships

By Tom Grundy (Hybrid Air Vehicles) and Sébastien Bougon (FLYING WHALES)



Introduction

Hybrid Air Vehicles¹ and FLYING WHALES² are both aiming to accelerate aviation's transformation into a low-carbon industry by designing and manufacturing hybrid and lighter-than-air (LTA) aircraft respectively.

The two companies have pursued their common goal by collaborating on the development of industry-specific regulation, working closely with the European Union Aviation Safety Agency (EASA) to produce the certification

basis for airship-based aircraft designs. EASA is the first aviation authority to have published a complete set of dedicated certification specifications in a document called Special Condition "SC Gas" Airships³.

The leadership displayed by these two organisations should encourage other companies to develop their own innovative solutions to the pressing challenges currently posed by the aviation industry. This article explores the environmental and other benefits of hybrid/LTA aircraft and marks a new stage in the companies' ongoing cooperation.

1 Hybrid Air Vehicles is the company behind Airlander technology. Its first production aircraft, Airlander 10, will deliver up to a 90% reduction in carbon emissions compared to other aircraft in its various roles, before attaining zero emissions by 2030. The company's vision is to be the future of zero-carbon aviation. It expects Airlander to be the first large scale aircraft (capable of carrying up to 100 passengers or 10 tonnes) to achieve zero-emissions flight. <https://www.hybridairvehicles.com/>

2 FLYING WHALES is a French company developing the LCA60T, a rigid airship with a 60-ton cargo capacity. Originally designed to meet longshoring needs for the renewable wood industry in difficult-to-access areas, this LTA aircraft aims to provide a response to numerous logistical and isolation problems worldwide with a very low environmental footprint, thanks to its unique characteristics of loading and unloading while hovering. FLYING WHALES is also developing FLYING WHALES SERVICES, the company operating the LCA60T. <https://www.flying-whales.com/>

3 <https://www.easa.europa.eu/downloads/134946/en>

The case for developing entirely new categories to accelerate aviation's transformation

Looking beyond the norm and thinking differently is not always easy but, in the case of aviation, it is crucial for progress.

The International Air Transport Association (IATA) has recently agreed to achieve net-zero carbon emissions by 2050, in line with Paris Agreement targets to limit global warming to 1.5°C. Meanwhile, globalisation means that more people will want to fly and move goods by air: forecasts from ICAO (International Civil Aviation Organization) and IATA signal a strong growth trajectory in the run up to 2050 (typically around 4.5% CAGR)⁴.

There are significant opportunities for radical innovation to make major contributions to emissions reductions, enabling the aviation industry to outperform current industry targets. These technological changes may require or promote changes in transport networks to enable existing services to be replaced, and new services to be grown, while severing the link between growth and emissions.

By rapidly deploying radical innovations in roles that can accommodate them, improved overall sector emissions outcomes can be achieved. Improvements in conventional airframe, propulsion and sustainable fuel technologies can then be optimised for those applications and sectors that cannot feasibly be addressed in other, less energy-intensive, ways.

Radical change does not and should not mean putting an end to air travel.

Aviation is a critical part of our society and economy: it enables trade, creates millions of jobs and, most importantly, connects people and cultures – as a society, we are better unified and connected. Radical change in this context means providing transport with solutions that maintain

and build on the benefits delivered by aviation without the associated impacts.

Now more than ever, new categories of aviation are needed. This does not necessarily mean 'flight reimagined' through conventional incremental innovation. Achieving low-carbon aviation (or zero-carbon emissions in flight) means we need to rethink how and where conventional aircraft operate, and what alternative aircraft configurations and networks could deliver beyond today's air transport system.

For example, hybrid and LTA aircraft with hovering or short take-off and landing capabilities offer clear pathways towards sustainable aviation in easily addressable roles such as sub-regional air transport, long-haul logistics and special air services. Through radically different physics of lift, these aircraft produce up to 10 times fewer harmful emissions than fixed wing alternatives⁵ in the case of hybrid options, and use up to 50 times less fuel than helicopters for LTA aircraft performing hovering manoeuvres⁶. These new categories of aviation offer a world of opportunities, ranging from delivering rapid decarbonisation of growing domestic air travel markets to enabling low-emissions air freight and the transport of outsize equipment such as sustainable energy-generation infrastructure to remote places with less impact.

A new category offering new possibilities: Transforming logistics, air travel and global equality

Hybrid or LTA aircraft create lift in radically different – and more energy efficient – ways than conventional aircraft. This allows them to fly more slowly, delivering very low energy use per revenue km.

Many of today's air services do not require high speed to deliver economic benefits. For example, regional aviation often covers short distances in which the flying time is a small percentage of the overall passenger journey. A hybrid or LTA aircraft can offer more convenient connections and

4 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg17-23.pdf

5 Based on HAV analysis of Airlander's CO₂ production on a pax.km or tonnes payload.km basis vs the UK Gov CO₂ creation figures for airplanes - <https://www.hybridairvehicles.com/news-and-media/overview/insights/airlander-10-will-provide-a-new-option-for-regional-travel/>.

6 Based on FLYING WHALES' analysis of LCA60T's CO₂ production on a tonnes payload.km basis vs public data from helicopters.

less lost time in security and airport protocols, delivering near-equivalent journey times to the passenger or payload at only 10% of the carbon footprint. Likewise, the speed of medium- and long-haul freight services is often diluted by handling services and other frictions at source and destination.

In both cases, the next best alternative is often seaborne or road-borne transit, delivering far longer journeys. This leaves a large gap in which hybrid or LTA aircraft can fulfil rapid deliveries and short journey times, at lower costs, with order-of-magnitude reductions in emissions.

The COVID-19 pandemic exposed major vulnerabilities across our global supply chain. One way of adding flexibility and resilience is to supplement conventional systems using low-emissions aircraft that are independent of fixed infrastructure for their operation. In this application, not only do LTA aircraft with hovering capabilities reduce carbon emissions, but they also improve biodiversity by reducing soil artificialisation – these aircraft do not need runways⁷.

Both hybrid and LTA aircraft have the potential to provide capacity and flexibility, avoiding reliance on roads and ports by significantly increasing aviation's capacity to deliver goods via air freight.

They can also reinvent point-to-point logistics alongside services and energy infrastructure in more remote regions, unlocking new opportunities by going where other modes of transport are unable to or struggle to access. Hybrid aircraft, and LTAs capable of hovering while loading and unloading, can tap into new territories and groups of people living in remoter parts of the world by minimising the need to access expensive airport infrastructure. While helping to democratise access to goods and produce within more remote territories, these aircraft can also help to boost global equality by enabling people living in isolated places to trade goods and produce across the world.

This capacity to reach landlocked areas makes hybrid and LTA aircraft a key contributor to the United Nations Sustainable Development Goals, including:

- SDG7: Affordable and clean energy – for example, by supporting the complex logistical operation needed to install wind turbines and the creation of high voltage electricity networks
- SDG8: Decent work and economic growth – by unlocking whole regions of the planet
- SDG13: Climate action – by proposing a low-carbon means of transportation

Efficiency, energy sources and green benefits

Hybrid and LTA aircraft offer helicopter-speed air transport with order-of-magnitude improvements in efficiency. With this new development come new possibilities for both sustainability and energy efficiency.

Whether running on conventional fuel, sustainable aviation fuel or hydrogen, the energy source is used efficiently, preserving limited energy and emissions budgets for other aviation sectors such as long-haul aviation, where there are currently no known, available alternative technologies.

Inherently efficient in their design, hybrid aircraft combine buoyant lift with aerodynamic lift and vectored thrust. The lifting gas offsets the weight of the aircraft, meaning that less energy is required to fly. This allows the aircraft to carry substantial cargo while burning very little fuel or to fly for a long time, creating a significant efficiency gain over conventional fixed and rotary wing aircraft – in real terms, this can mean hybrid aircraft typically require 25% or less of the energy of alternate aircraft performing the same task. Adoption of hydrogen-electric technology to deliver most of this energy leads to an expected 90% reduction in emissions per revenue km in most roles at service entry in 2026⁸.

⁷ <https://youmatter.world/en/soil-artificialization-erosion-ecosystem-biodiversity/>

⁸ Based on HAV analysis of Airlander's CO₂ production on a pax.km or tonnes payload.km basis vs the UK Gov CO₂ creation figures for airplanes. <https://www.hybridairvehicles.com/news-and-media/overview/insights/airlander-10-will-provide-a-new-option-for-regional-travel/>



Pushing the limits further, a 100% LTA aircraft relies only on buoyancy to stay airborne. This aerostatic, as opposed to aerodynamic, lift means that the LTA needs no energy to fly. Its propulsion system will be dedicated to cruise – as it has no need to fight gravity – while airborne and maintains a stationary position during hovering, to load and unload cargo. In this perspective, an LTA aircraft can save up to 98% of carbon emissions depending on the type of mission.⁹

Deploying these aircraft into those sectors that can be most easily addressed can deliver significant reductions in overall emissions. For example, 50% of air freight, and the 12% shortest-sector air travel, are together forecast to generate 639 million tonnes of CO₂ per annum by 2050.¹⁰ Hybrid and LTA aircraft can minimise these emissions while enabling continued growth in these sectors.

⁹ According to a FLYING WHALES' internal study conducted on the basis of a Life Cycle Analysis and the data that are today available on the propulsion system soon to be implemented in the LCA60T

¹⁰ Based on HAV analysis of [predicted freight demand](#), [total passenger operation figures](#) and [the proportion of that number committed to short haul](#).



| ICAO

CHAPTER SIX

Climate Change Mitigation: Operations

Airports and Operations Working Group Report

By David Brain (EUROCONTROL), Iryna Kustovska (Ukraine)¹ and the ICAO Secretariat

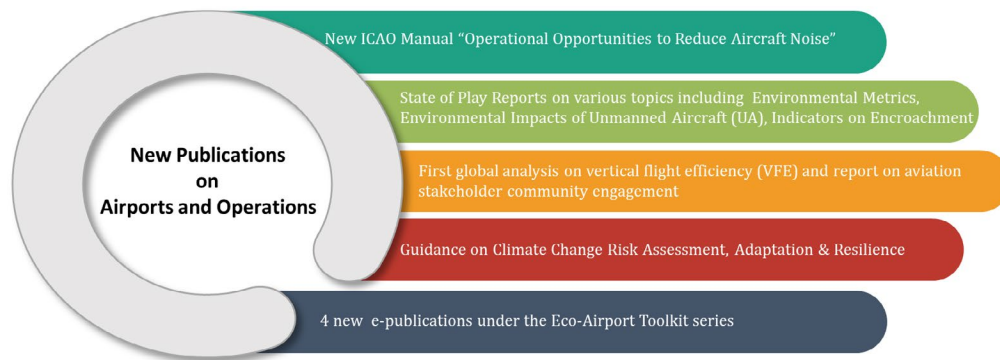


FIGURE 1: New Publications on Airports and Operations

Introduction

The Committee on Aviation Environmental Protection (CAEP)'s Working Group 2 - Airports and Operations (WG2) addresses environmental issues relating to airports, aircraft operations near airports, and aircraft operations in general. The objective of the work programme of WG2 is to develop and disseminate guidance to States, aviation authorities and planners on environmental issues related to airport expansion, construction, and operation, and to define operational procedures, strategies, and opportunities. The development of global best practices in these areas continually evolve and can lead to the improvement of environmental management policies.

When visualizing the ICAO basket of measures to reduce CO₂ emissions, Air Traffic Management (ATM) and operations are often overlooked as one of the main measures to support the decarbonization process. However, despite being depicted as a small wedge, ATM and operations offer the highest potential for reducing CO₂ and related

emissions in the short to medium term. This has clearly been demonstrated in the work of the CAEP Long Term Aspirational Goal (LTAG)-Task Group (TG) work whose results are elaborated in the LTAG Supplement of this report.

WG2 – Airports and Operations - is the operational working group of CAEP and has been responsible for delivering some of the key analyses to support the calculation of the benefits that may be realized from implementing the operational measures defined in the ICAO-GANP Aviation System Block Upgrades (ASBU) framework together with new innovative measures looking out to the coming decades.

In the CAEP12 cycle, WG2 undertook a very ambitious work programme. This included the delivery of a new ICAO Manual "Operational Opportunities to Reduce Noise" (a sister manual to ICAO Doc.10013 "Operational Opportunities to Reduce Fuel Burn and Emissions"), three State of Play reports: "Environmental Metrics"; "The Environmental Impacts of Unmanned Aircraft (UA) at and Around

¹ David Brain and Iryna Kustovska are Co-Rapporteurs of Working Group 2 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

ICAO Region	CDO		CCO	
	Excess fuel / CO ₂ (kg)	Fuel costs (million \$)	Excess fuel / CO ₂ (kg)	Fuel costs (million \$)
APAC	47/149	336.9	13/41	94.2
ESAF	23/73	8.2	2/6	0.6
EUR/NAT	37/117	218.7	4/13	22.5
MID	60/190	50.9	9/28	7.9
NAM	43/136	336.6	5/16	41.2
CAR/SAM	24/76	44.3	3/9	6.4
WACAF	20/63	2.7	1/3	0.1
Total	41/130	992.2	7/22	161.5

Table 1: Results of the climb and descent parts of the global VFE study per ICAO region

Airports”; and, an “Investigation of Possible Indicators on Encroachment”, as well as several reports on the first global analysis on vertical flight efficiency (VFE) and a report on aviation stakeholder community engagement. In addition, WG2 delivered guidance material on “Climate Change Risk Assessment, Adaptation & Resilience” and four e-publications under the eco-airport toolkit series, both of which are elaborated in Chapter 9 of this report.

The development of the new ICAO Manual “Operational Opportunities to Reduce Aircraft Noise” encompassed the identification, and review of both standard and innovative operational opportunities and techniques for minimising noise in civil aviation operations. The manual provides background on current practices that are available to aircraft operators, airport operators, air navigation services providers (ANSPs), other industry organisations and States to reduce aircraft noise impacts. It also highlights recent developments - resulting from emerging innovation - and considers what concepts and enabling technologies currently being developed by the aerospace manufacturing industry and airspace service providers may become available in the near future.

In the CAEP/11 cycle, WG2 delivered the first ever-global Horizontal Flight Efficiency (HFE) analysis² that demonstrated that global HFE levels in 2017, based on the data studied, varied between 94% and 98%. In CAEP/12, WG2 followed on this thread of work with the first global Vertical Flight Efficiency (VFE) analysis with the work initially focusing on the climb and descent phases with the availability of sufficient global data from Flightradar24.

This analysis revealed that for the descent phase, the average per flight inefficiency (or non-optimised Continuous Descent Operation (CDO)), generated an average extra consumption of 41kg fuel per flight across all ICAO regions. The ratio between the extra consumption in the most efficient regions and least efficient regions was three-fold (20-60kg per flight). The costs of fuel of the inefficiencies per region were determined by multiplying the additional fuel burn with the kerosene price and number of flights for each region. For the climb phase, the average per flight inefficiency (or non-optimised Continuous Climb Operation (CCO)), generated an average extra consumption of 7kg fuel per flight across all ICAO regions. As seen in Table 1, the inefficiencies are larger in the descent phase by a ratio of approximately six to one on a global basis, in fuel burn and fuel costs values between the descent and climb phase. The total estimated benefit pool for 2019 was estimated to be around \$1,000 Million (USD) for the descent phase and \$160 Million (USD) for the climb phase.

Unfortunately, sufficient time and effort was not available to continue the work on the en-route phase within WG2. Despite this, a small group of WG2 experts worked together to initiate the development of two new methodologies to measure global vertical flight efficiency in the en-route phase and now the aim will be to complete this work through EUROCONTROL, the European Organization for the Safety of Air Navigation.

From these global analyses together with studies previously undertaken by the International Panel on Climate Change (IPCC), Civil Air Navigation Services Organization (CANSO) and CAEP, it can be seen that horizontal and vertical flight

2 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg138-144.pdf

inefficiency is estimated to contribute to around 6-7% of total fuel burn when using such proxy metrics based on distance and/or time. However as noted at the 2020 ICAO Stocktaking event, it is likely that further operational inefficiencies exist that may be demonstrated by the use of indicators that are based directly on fuel burn or CO₂ emissions. In addition, the introduction of novel and innovative measures into the ATM system may result in a larger efficiency benefit pool than what is currently the case with the integration into the ATM system of new measures that effectively remove fuel burn from the ATM system e.g. electric taxi.

As well as supporting the CAEP LTAG Task group on the feasibility study for a long term aspirational goal on CO₂ emissions, WG2 was also responsible for the Global ASBU (Aviation System Block Upgrade) Environmental Benefits Assessment in CAEP/11, a study detailed on pages 131-137 of the 2019 ICAO Environmental Report.

In CAEP/12, WG2 was asked to assess the 2019 updated ASBU documentation detailed in the GANP for potential to support further detailed analyses. Although, there were additional benefit mechanisms identified in the 2019 ASBU documentation (later to be included in the LTAG analysis), it was concluded that overall, these potential benefits were likely already covered to a large extent by the benefits identified in the ASBU analysis looking out to 2025. In addition, implementation data would be difficult to obtain based upon timeframes of 2031+. Therefore, WG2 concluded that there was little added value in undertaking further ASBU analyses in the CAEP/12 cycle.

To assess the benefits of any operational measures, developing new environmental metrics is currently at the forefront of stakeholder thinking as the environmental KPA takes center stage in the performance of a post-COVID aviation system. If new metrics based on fuel burn / CO₂ emissions are to be developed, they should focus on fuel efficiency related to the actions of all stakeholders involved in the ATM system. CAEP/12 approved a State of Play “Report on Environmental Metrics” delivered, with the objective to provide an overview of common metrics used by States and operational stakeholders to assess the environmental performance of aviation. This report detailed thirty-eight environmental metrics - categorized into one of four main categories: Airline Fleet Operations, ATM Operations, Airport Operations, State/Regional/Global

Levels and linked to one of four categories: Sustainable Aviation Fuel (SAF), Greenhouse gases (GHG), (Local) Air Quality and Noise - that could be considered as widely applicable to describe environmental performance at the global level. However, whether or not they are appropriate to describe a specific performance depended on the specific circumstances of the stakeholder(s) themselves, including Local/State/Region regulations, resource constraints, data availability, etc. States and operational stakeholders that do not yet use such metrics or are considering revising such metrics if already in use would be able to refer to the state-of-play document as a basis for further work.

It is likely that work on metrics will be a key priority at both the global and regional level in the coming years. At the global level, the GANP - PEG (GANP - Performance Expert Group) has been set up to define the performance framework of the ASBU framework, with the current emphasis on the Environment KPA. It is expected that in the coming months there will be a need to develop this framework to include new environmental performance ambitions, objectives and indicators together with focus areas around which to build the framework. At the regional level, groups are working to further develop environmental metrics that are based on fuel burn. For example, in Europe, the EASA / EUROCONTROL Transparency Working Group is looking into defining new environmental indicators that can more accurately measure and communicate fuel efficiency (e.g. through individual airspaces, phases of flight and operational scenarios) and the measures undertaken to mitigate fuel inefficiency. This includes highlighting the interdependencies between the different actors and ensuring that all stakeholders understand how collaboration is required to optimise the operational response.

Innovation in ATM is one of the areas where ICAO is focusing the GANP, one area of which relates to new entrants, in particular those at the lower altitudes (e.g. drones in U-Space) or operations at higher altitudes (e.g. Higher Airspace Operations (HAO) above the traditional flight levels of conventional aircraft types). Whilst ATM actors are cognizant of the need not only to undertake a careful assessment of the potential environmental impacts of any new vehicle or operation type and to assess to what extent these operations may be considered sustainable, it should be emphasised that an assessment of the extent to which traditional manned aviation traffic will be impacted

by the integration of the performance characteristics of the HAO vehicle or operation into the current manned aviation system, will also have to be undertaken.

WG2 delivered another State of Play report on the “Environmental Impact of Unmanned Aircraft” at and around Airports”. WG2 found that this subject matter was extremely dynamic with new material on the subject emerging monthly, exacerbated by a wealth of new use cases appearing during the pandemic. This report will be further detailed in a following article of this Chapter.

Operational noise issues also need to be addressed at and around airports. ICAO advocates the use of the balanced approach to noise management which provides a simple framework for airports to address noise issues by focusing on the core aspects of noise management namely: reduction of noise at source, land-use planning, noise abatement operational procedures and operations restrictions. Whilst much of the focus remains with operations restrictions, encroachment on land-use around airports can have a significant impact on the ability of the airport to manage its noise impact.

WG2 delivered a third State of Play report at CAEP/12 on the “Investigation of Possible Indicators on Encroachment”, focusing on the challenges and good practices related to population encroachment into the noise contours at airports, including the metrics used to measure this challenge. WG2 reviewed both ICAO documents and non-ICAO (i.e. State) documents to collect and aggregate all relevant available information into a single report, which set out some common challenges for airports relating to the issue of encroachment. These included accessing data and information to track levels of encroachment, maintaining positive dialogue and negotiations between the airport and municipality, competing economic interests, and competing planning priorities between the airport and the municipalities, as well as addressing conflicts with the interests of residents and property owners in the vicinity of airports.

Amongst the recommendations of this report were the importance of maintaining continuous dialogue with communities, local governments, and aviation stakeholders to ensure the correct application of land-use planning techniques in the development of airports and the need for any new guidelines to be based on technically robust and up-to-date scientific evidence and coordinated through

extensive collaboration and community engagement with the relevant stakeholders.

WG2 also delivered a report on understanding aviation stakeholder community engagement needs in the context of delivering ATM change with the objective to understand States’ needs and preparedness in terms of information, processes, and tools to effectively engage communities for further deployment of Performance Based Navigation (PBN) and airspace change/modernisation. This study deployed a global survey which initiated 42 responses across all ICAO regions with a number of key observations identified. These included that, even though most respondents felt prepared for the community engagement process, 12% of respondents did not feel prepared to engage communities. In addition, most respondents suggested that there was likely to be information, processes and tools that would be helpful to them as they embarked upon community engagement. The respondents also highlighted that the preferred media for the dissemination of details about such information, processes and tools would be through a Regional Module and/or a Circular or Manual.

Considering the experiences observed in the CAEP/12 cycle together with emerging priorities identified by CAEP WG2 Members and Observers and ongoing engagement with aviation stakeholders, WG2 plan to continue some current threads of work during the CAEP/13 cycle whilst also addressing several of these priorities. These include:

- Reviewing the ICAO CCO and CDO Manuals with a view to updating them;
- Identifying operational opportunities to reduce non-CO₂ emissions;
- Identifying best practices of noise monitoring systems;
- Considering the experiences / outcomes of the CAEP/12 reports to deliver enhanced community engagement guidance;
- Undertaking an analysis of environmental interdependencies in various operational scenarios;
- Updating the 2019 climate adaptation synthesis; and,
- Continuing developing the eco-airport toolkit e-publications to support global aviation environmental practitioners at and around airports.

For more information on WG2 membership and activities, contact officeenv@icao.int

Fly Responsibly, an airline perspective

By Vincent Etchebehere (Air France) and Hedwig Sietsma (KLM)

Introduction

The climate crisis continues to intensify, as highlighted in the 6th Assessment Report of the Inter-governmental Panel on Climate Change (IPCC) from their Working Group 1 (IPCC, 2021). The report links human-caused activities to global warming, highlighting that global temperatures, on average, have been 1.1°C degree higher during the decade 2010-2019 than in the pre-industrial era. Consequences of such warming include rising sea levels, extreme heat waves, floods, severe droughts, and irreversible trends such as glaciers and polar ice caps melting away.

Aviation is one of the hardest-to-abate sectors vis-a-vis carbon emissions. Over the past three decades, the sector's carbon intensity decreased by 1.5% per year on average.

Yet, annual global aviation CO₂ emissions have increased steadily, from 400 million tonnes in 1990 to 900 million tonnes in 2018 (for scope 1 emissions), as seen in Figure 1 below. The increase in absolute emissions has been driven by worldwide air traffic growing at an average annual rate of approximately 5%. From 2005 to 2019 aviation emissions have grown by +42% in absolute terms.

Time is of essence in the global race to fight the climate crisis. To limit the temperature increase to less than 2°C, and strive for 1.5°C by the end of this century, CO₂ emissions worldwide must start to decline immediately, at an average rate of 5% per year. For aviation, this calls for a break in a structural emissions growing trend towards stabilization, and steady decline at a rate compatible with a well below 2°C climate trajectory.

(Carbon intensity in grams CO₂ per passenger-km)

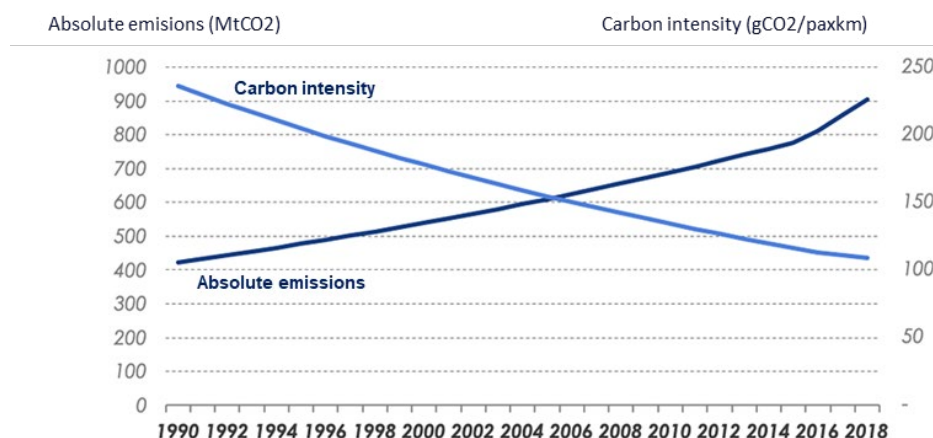


FIGURE 1: Change in Absolute Emissions and Carbon-Intensity in Aviation: 1990-2018¹

¹ ICAO, IATA, ATAG; Carbone 4 analyses (Meunier & Amant, 2020)

This article aims to shed light on the experience from Air France and KLM while embarking towards a Paris Agreement compatible decarbonisation trajectory, on the latest enhancement of emissions reductions levers to reach this goal, and on the necessity for all sector's actors to join forces under a credible, science-based emissions reduction ambition.

The Science Based Target initiative as the emerging reference in climate objectives

Over the past years, Air France and KLM have been working on her own climate ambitions and reporting their emissions. Both air carriers have been, and are active, at a national, European, and global level, to cooperate, innovate and define agreements. However, they both acknowledge that they should go beyond ambitions that they see as feasible, and work towards ambitions that are needed to operate inside the limits of our planet.

The earth has clear limits as to how human-kind use their resources and the volume of emissions that they generate. Therefore, both air carriers committed to the Science Based Target initiative (SBTi) in November 2021 and updated their emissions reduction targets accordingly in April 2022.

In Table 1 below, Air France-KLM's current CO₂ reduction target is presented, portraying -30% relative reduction, and based on this a forecast of -12% absolute. These are based on the scientific guidelines and calculations for the aviation sector specifically from the SBTi², and thus creates a roadmap to reach the Paris Agreement objectives.

TABLE 1: "Overview CO₂ Reduction Targets AF-KLM Group."

CO ₂ e reduction targets AF-KLM group	CO ₂ reduction in 2030 compared to 2019 (scope 1 & 3)
Intensity target (ppkm)	-30%
Projected absolute reduction (based on SBT forecasts)	-12%

Three aspects of these targets are important to note. First, these current targets cover Air France and KLM's scope 1 and 3 jet fuel emissions, Well-to-Wake (Figure 2) as

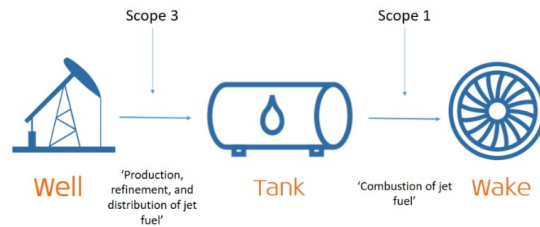


FIGURE 2: "Visualisation Well-to-Wake."

named by SBTi. Second, following the SBTi guidelines, to achieve these, market-based measures, and offsetting, that both are not counted towards the overall CO₂ reduction. This is in-line with the consensus within the scientific community that the priority to fight climate change should be put towards strict GHG emissions reduction. Third, industry-wide growth should be considered in the forecasts.

The Initiative

The SBTi is a partnership between four Non-Government Organizations (NGOs) and knowledge institutions: the Carbon Disclosure Project (CDP), World Resources Institute (WRI), and the United Nations (UN) Global Compact and World Wide Fund for Nature (WWF).

SBTi helps private-sector organisations to set climate targets in line with the Paris Climate Agreement, based on what science tells them is necessary to honour the Agreement, and to give aid in the development of concrete short and medium-term targets. These guidelines are based on scientific data and assumptions from the International Energy Agency (IEA) and latest IPCC report, and are developed in collaboration with industry experts. To keep the sector's decarbonisation pathway aligned with the Paris Climate Agreement goals, the SBTi introduced guidelines specific to aviation for target development in August 2021^{are well below 2°C}. By establishing this SBTi pathway, both air carriers can further reduce our CO₂ emissions systematically in a transparent manner.

Currently, a 1.5°C pathway is currently under development for the aviation sector by the SBTi, which will be integrated into the SBTi Aviation Guidance and accompanying target-setting tool. Once the pathway is updated, both Air France

² SBTi tool Aviation, 2021.

and KLM will update their targets in line with SBTi guidance accordingly to 1.5°C. Both air carriers' current projections are based on a below 2°C scenario.

Air France and KLM decarbonisation levers

Defining science-based Green House Gas (GHG) emissions reduction goals is a critical step for air sector actors to engage in climate change mitigation. The biggest challenge, for a sector considered as one of the most hard-to-abate ones, will then be to fulfill those goals. As there is no silver bullet, achieving aviation decarbonisation will require a combination of GHG reductions levers, with different emissions reduction potential, levels of development, and challenges associated with implementing each of them.

Capitalizing to the largest extent on short term levers: fleet modernisation, Sustainable Aviation Fuel (SAF) operational measures, and other measures like intermodality are highlighted as follows:

- **Fleet modernisation:** Fleet renewal is the most impactful short term lever to reduce CO₂ emissions as new generation aircraft generate 20 to 25% less CO₂ per seat kilometer vs the aircraft they replace. Despite the COVID crisis Air France maintained a €1 billion annual investment cycle to add 60 short- and medium-haul Airbus A220s, as well as 38 long-haul Airbus A350s. It is also worth noting that new generation aircraft offer significantly lower noise footprints (34% lower in the case of the Airbus A220 compared to Airbus A319-A320s), a significant environmental externality affecting communities living near airports. From late 2023 onwards, KLM will replace their existing Boeing 737 NG by new Airbus A320neo/A321neo aircraft will begin replacing KLM and Transavia's existing Boeing 737 NG aircraft on European routes. Having previously opted for the Embraer 195-E2 aircraft for intra-European flights, this new order is an important step in enhancing sustainability. The Airbus A320neo family not only produces 50% less noise than the current, older generation of aircraft, but also reduces fuel consumption and CO₂ emissions to 15%.
- **Sustainable Aviation Fuel:** SAF will be key to supporting Air France and KLM's energy transition. By mobilizing the eco-system, Air France-KLM has established innovative partnerships with corporate clients, suppliers, airports, and logistics partners. Furthermore, as part of its WWF-Netherlands partnership and Green Deal commitment, in 2012 KLM launched the KLM Corporate Biofuel program, a first for aviation. Furthermore, in 2022 KLM voluntarily announced to start blending 0.5% SAF for flights departing from Amsterdam. Finally, since the start of 2021, cargo customers can also aid the development and production of SAF through the Air France-KLM-Martinair Cargo SAF Program. Customers can now buy SAF for their loads in the cargo flights. To reach their goals, they need to go beyond their current commitments. They have already made a commitment of 10% worldwide, however they realise that this may be not enough. Therefore, the options to be evaluated are whether more SAF can be purchased, or whether SAF with a higher sustainability level than 75% is opted for. The latter significantly impacts the reduction potential of SAF.
- **Operational measures:** From reducing as much weight on board to eco piloting; operational measures seem to have a small CO₂ reduction potential, but cumulatively, they make a significant impact. One of these measures' worth mentioning is eco-piloting: Pilots apply, whenever possible, the most fuel efficient procedures; Flight Plan precision, speed adjustments and optimized trajectories, and, on the ground, taxiing with half of the engines shut down. New Artificial Intelligence (AI)-based tools can help ensure the best application of such fuel efficiency practices for each flight. For example, Air France cockpit crews use SkyBreathe®, developed by Openairlines, a French start-up company. Further flight optimization measures could also be deployed, driven by regulators, airports, and airlines. Significant CO₂ emissions reductions, for example, can be achieved through traffic and airspace optimization. In Europe, the Single European Sky project aims for the better management of air traffic that could lead to 10% CO₂ reduction for intra-Europe traffic. Air France and KLM are proactively involved in the SESAR program, which contributes to the targets of the Single European Sky (SES) for the better management of air traffic.

- **Intermodality:** Collaboration with railway systems can have short-term benefits in terms of overall GHG emissions as well as meeting a growing customer demand that favors low-carbon alternatives when they exist. In the case of Air France, the past year has seen a reinforcement in its cooperation with the French railways operator SNCF, with the extension of joint product “Train + Air”, offering high speed short haul train service on 33 routes in connexion with medium or long haul flights. This service offered by KLM provides transfer passengers the option of boarding a Thalys high-speed train instead of a flight on the Brussels-Schiphol leg of their journey (or vice versa). Before the Covid-19 pandemic, 20 to 25% of these passengers (some 36,000 customers) chose this option. KLM and Thalys would like to increase this percentage, and KLM is consequently purchasing enough seats from Thalys, which makes one of its daily services between Brussels and Schiphol redundant. Customers are now welcome to book these seats on KLM.com for travel dates starting 17 July 2022.

From ambitious targets to industry action

For both air carriers, it is clear that they should strive towards ambitious targets together with the whole industry. However, it is important that they should also take action together. As Air France and KLM, they are not looking for only reaching their own targets, they both want to create a sustainable industry. A good example of working towards a sustainable aviation industry was the participation of Air France and KLM in the Sustainable Flight Challenge presented by SkyTeam in May 2022.

The Sustainable Flight Challenge was the “brainchild” of a group of KLM employees called the Bold Moves, who in a quest for ambitious new ways to make flying more sustainable, drew inspiration from the 1934 ‘Greatest Air Race’ from London to Melbourne. During this race, flight pioneers proved how long-distance commercial aviation was possible. The Sustainable Flight Challenge takes up the baton from these early innovators to make sustainable air travel a reality.

SkyTeam was so inspired by The Sustainable Flight Challenge idea, that they brought it under the alliance

umbrella to encourage all member airlines and their partners to take part. The Sustainable Flight Challenge is one of the ways SkyTeam and its members are supporting their recent partnership with the United Nations Sustainable Development Goals (UNSDGs), which also forms the basis for the initiative.

Although sustainability is not a game, gamification will push the boundaries and encourage creativity. That is why the air carriers initiated The Sustainable Flight Challenge: 17 airlines have given it all, to fly their most sustainable flight and, most importantly, share their experiences, innovations, and ideas, as the challenge is working with an open-source principle.

The Sustainable Flight Challenge is not really about the rewards. It is about putting their collective heads together, being responsible, and finding innovative ideas and practical solutions. Everyone wins. As members of SkyTeam, they do not compete on safety, nor should they on sustainability. With this challenge, they want to bring about faster innovation for sustainable aviation. So that reuniting with loved ones on the other side of the world or growing your business in Europe will still be possible in a sustainable way in the future.

Hopefully, they can invite all airlines to step up their game and join this challenge with Air France and KLM in the years to come.

Opportunity for the industry to embark on a sustainable journey

Both Air France and KLM agree that the aviation requires the entire industry to embark on a sustainable journey. As civil aviation’s share of emissions is only increasing, the industry needs to act on a global level in order to effectively reduce absolute emissions. As an aviation sector, in goal setting, the sector has the tendency to focus on feasibility but is their obligation to move towards goals that are needed to avoid a climate crisis. SBTi is an independent body which helps them set these goals.

It is a difficult journey, but only together can the possibility to create sustainable aviation for every global citizen become a reality.

Driving sustainable aviation through software

By Airspace Intelligence, OpenAirlines, Signol

The importance of safe and operational technology systems cannot be understated for the aviation sector. Advancements from the simple compass to satellite guidance systems over the past century have not only ensured safe passage to global destinations, but also have increased operational efficiencies in the areas of safety and environmental protection.

But for some time, many players in the aviation industry have built new hardware on top of outdated, legacy software systems that have not kept up with advances in technology. For example, until recently the software for routing aircraft through our skies was far less advanced than consumer road navigation applications like Google Maps or Waze. Simply put, this means that the industry has given up gains in a number of core areas including operational efficiency, safety, sustainability, and passenger experience.

However, that void has created a great opportunity. This has been successfully demonstrated by three companies—Airspace Intelligence, OpenAirlines and Signol—who are driving innovation in the aviation industry through software solutions.

Each company has taken its own approach to add new and unique value to the aviation sector, in particular regarding driving fuel use and emissions reductions. Using pure software products as their basis, they have innovated and deployed solutions in a much faster way than traditional industry players. This results in faster value delivery to their customers through software solutions versus hardware products, and the results speak for themselves.

Airspace Intelligence — Artificial Intelligence (AI) for Air Operations

Airspace Intelligence is on a mission to help the world's most complex air operations succeed. Airspace Intelligence has developed an AI-enabled operating system for modern airlines that already optimizes routes for thousands of commercial flights in the U.S. everyday—saving fuel, time and emissions while improving passenger experiences. The self-learning platform moves the aviation industry away from manual processes and dated technologies that use hard-coded rules to route aircraft with a single-flight focus towards a predictive software solution that enables network-wide optimization. From the operations control center to the flight deck, Airspace Intelligence empowers human decision makers with the information and applications needed in order to make safer, smarter, and more efficient decisions.

In just over three years of development and one year since the commercial launch with Alaska Airlines, Airspace Intelligence is completely changing the way of thinking in the industry and driving substantial impact. Airspace Intelligence has optimized more than 38,000 flights with an average per flight savings of approximately 5 minutes. This has led to an estimated fuel savings of 21 million pounds or nearly 34,000 tons of carbon emissions reductions.

As the company expands over the next 3-5 years, Airspace Intelligence could drive savings of over 200,000 hours of flight time, 1 billion pounds of fuel, and 1.8 million tons of CO₂ emissions per year by serving all U.S. airlines, assuming pre-COVID passenger demand. Although time and fuel savings are more easily quantifiable, Airspace Intelligence's impact on flight safety and passenger satisfaction should also be highlighted. By providing future-state, predictive

situational awareness that was previously not possible, decision makers in the air and on the ground can more accurately route flights around bad weather or rough turbulence, or around inefficient traffic flow restrictions to help minimize airborne holding, diversions, and delays. Passenger satisfaction is also improved due to often landing 5 minutes or earlier than expected due to the platform's optimization recommendations.

As Airspace Intelligence continues to advance, the software will optimize across more dimensions such as airspeed and altitude, which will further expand the operational and sustainability benefits that the company provides to their airline partners. Airspace Intelligence's goal is to not only have the software fundamentally improve airline operations across the industry, but also to positively impact the world through fuel and emissions reductions.

OpenAirlines — SkyBreathe® 360° eco-flying Platform

Over the past decade, OpenAirlines led the first Clean Sky project, the largest European research program developing innovative and cutting-edge technology to reduce CO₂ gas emissions, and noise levels produced by civil aviation. As an outcome of this research project the SkyBreathe® is developed which is the first eco-flying solution for airlines. SkyBreathe® is a software that collects all the data from the black boxes, weather, air traffic control, and maintenance. Through big data algorithms and artificial intelligence, it produces recommendations for airlines and pilots that has allowed them to reduce their fuel consumption by up to 5% without any aircraft modifications.

These recommendations, concern the aircraft preparation with aircraft performance monitoring or engine wash optimization. They may also concern the flight preparation by dispatchers by proposing the best routes based on weather and traffic, or the execution of the flight.

Fuel consumption depends not only on all phases of flights (taxi, climb, cruise, and descent) but also on dispatch, maintenance, ground activity, commercial services. It also affects legal aspects such as the European Union Emissions Trading System (EU ETS) or CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation).

Factor in the threat of climate change on the industry, fuel efficiency at an airline must be a team effort whereby every department contributes to a safe and efficient fuel culture. SkyBreathe® offers an all-in-one platform that connects all airline workers in order that airlines can control the whole loop of their fuel program.

For example, pilots are critical players in a fuel efficiency project as many fuel initiatives are related to flight operations. SkyBreathe® empowers pilots with a mobile application that acts as a virtual coach at their side. It gives them a deeper insight into their individual performance by showing how much fuel they saved, and where they could have saved more. The maintenance and dispatch teams are also engaged and can analyze the fleet's actual performance, act on its degradation, and be more precise in fuel planning.

In the three years that followed SkyBreathe® implementation, several airlines have demonstrated success in improving fuel efficiency. Volotea, a fast-growing low-cost airline in Europe, managed to reduce its fuel consumption by more than 3%. Norwegian, have saved more than 27 M USD in 2019 using SkyBreathe®, representing 140,000 tons of CO₂. By putting MyFuelCoach™, the briefing and debriefing app dedicated to pilots, at every pilot's fingertip, Transavia has saved 3,200 tons of fuel in 2019, representing between 4 and 5 % of their total fuel consumption. On another example, after implementing MyFuelCoach™, Ukraine International Airlines pilots increased their application rate of Reduced Acceleration Altitude (another popular green operating procedure) from an already excellent 76% level to an almost perfect 95% level.

Today, SkyBreathe® is the most widely used eco-flying solution in the world. Its active community federates more than 50 airlines across the globe, including Air France, easyJet, DHL, Norwegian, IndiGo, flydubai, and Atlas Air. In 2019, its customers saved more than 590,000 tons of CO₂ and 150 million USD. In 2022, they will save more than 1 million tons of CO₂, equivalent to planting 125 million trees.

In 2022 OperAirlines added SkyBreathe® OnBoard to the platform, an EFB app, connected in the cockpit, that gives real-time eco-flying advice such as direct route recommendations, taxi assistant, etc. The work on an adaptation of SkyBreathe® designed for Air Navigation

Service Providers is ongoing. It has been seen that using SkyBreathe® data and analyses, some of the customer airlines have engaged in fascinating discussions with their local Air Traffic Control authorities leading to more fuel-efficient approaches in Iceland and Dubai. This results in all airlines flying in and out of these destinations benefiting from the improvement.

Signal — “Nudging Captains to Save Carbon”

Airline pilots are highly skilled, trained professionals who continuously digest information to complete their flights safely, on time, and ideally, in a carbon-efficient manner. While external variables may hamper a pilot’s ability to implement carbon-saving practices, Signal’s analyses suggest that individual pilot decision-making still plays a significant role in fuel burn and carbon emissions, even after statistically accounting for factors such as time of day, aircraft type, temperature, and destination. Thus, how can researchers encourage each pilot to reduce their carbon emissions? Behavioral science holds the key.

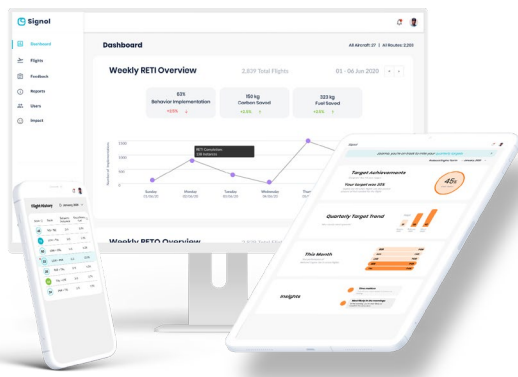


FIGURE 1: Signal software dashboard

Signal is a software application and communication service that delivers carbon and fuel savings using cutting-edge behavioral and data science. Signal motivates pilots to consistently implement carbon-saving operational best practices, including routine practices such as Reduced Engine Taxi, Idle Reverse Thrust, Continuous Descent, and Discretionary Fuel Weight Calculations, as well as custom practices developed in collaboration with each airline. Signal processes operational data from airlines and their third-party data providers to deliver personalized targets

and feedback to pilots. Pilots gain access to user-friendly, bite-sized updates on the direct social and environmental impact of their actions - empowering them to consistently cut emissions for their airlines.

By “nudging” 335 Virgin Atlantic Airlines captains via postal letters, Signal has already saved over 24,000 tons of CO₂ emissions and 6.1 million USD (1% of fuel costs) in an eight-month trial. Signal’s feedback and incentives also significantly improved captain job satisfaction. The study results were published in the top-ranked Journal of Political Economy (Gosnell et al, 2020).

Signal complements powerful fuel analytics platforms by focusing on the final mile of user engagement. From dynamically updating positive reinforcement and memorable visual designs in our dashboard to proactive communications sent to pilots across multiple channels, Signal applies the latest behavior change research in every touchpoint with pilots. Moreover, Signal continuously experiments with and optimizes the timing, content, and design of the feedback for different groups of pilots. Not all pilots are the same, and Signal is built to offer a unique experience for each pilot.

In the next three years, Signal will integrate with existing third-party fuel analytics providers in the aviation industry – allowing a quicker setup for airlines who are keen to realize carbon savings. Moreover, Signal will refine the platform’s predictive models of pilot decision-making – ensuring that the company’s “nudges” remain engaging and relevant for each pilot.

Together, the three companies provide unique examples of how a software-first approach can drive significant operational and sustainability improvements in aviation. Moving forward from here, these industry players hope to see the sector continue to embrace the power of software to create positive change.

Economic Fuel Tankering: A Threat to Aviation Decarbonisation

By Laurent Tabernier & Robin Deransy (EUROCONTROL), and Dan Rutherford (ICCT)

Introduction and Background

Tankering is a practice whereby an aircraft carries more fuel than required for its safe flight in order to reduce or avoid refuelling at the destination airport for subsequent flight(s). The 2014 edition of the ICAO Doc. 10013, which deals with “Operational Opportunities to Reduce Fuel Burn and Emissions”, highlights the economic benefit of fuel. However, it does not highlight its environmental implications.¹ It should be noted that fuel tankering has a significant environmental impact by increasing aviation emissions and should be avoided when undertaken purely for economic reasons. As governments and industry work to address climate change, they should ensure that new policies do not promote tankering, which would have the net effect of increasing aviation emissions.

Airlines tanker fuel for two main reasons:

- When it is operationally not possible or desirable to refuel at the destination airport, due to circumstances such as social disruptions, technical failures of the refuelling facility, shortages of or contaminated fuel, or to achieve short turnaround times or avoid the risk of delays. In that case, it could be called “Operational tankering”; and,
- To save money when the cost of fuel and associated services at the departure airport is significantly lower than at the destination airport. In that case, it is called “Economic tankering”.

There are two types of fuel tankering:

- Full (fuel) tankering, when all the fuel needed for the return flight is uplifted at the departure airport to avoid refuelling at the destination airport, and
- Partial (fuel) tankering, when only part of the fuel needed for the return flight is uplifted at the departure airport, followed by partial refuelling at the destination airport.

Under the European Aviation Safety Agency (EASA) regulations (CAT.OP.MPA.150 Fuel policy), before departure, the pilot-in-command must ensure that the amount of fuel on board is sufficient to cover the entire flight, including deviations from the planned operation.

The usable fuel to be on board for departure should be the sum of the following:

- Taxi fuel: The fuel necessary for taxi, which should not be less than the amount expected to be used prior to take-off;
- Trip fuel: The fuel required from the start of take-off, through climb, cruise, descent, and approach to landing at destination;
- Reserve fuel consisting of:
 - Contingency fuel (3 to 5%): This fuel is carried to cover unforeseen variations from the planned operation, for example, different winds/temperatures from forecast or air traffic control restrictions on

¹ ICAO Doc. 10013 “7.5.2 There may be some potential for reducing the amount of tankering. Aircraft operators should take into account the full cost of carrying extra fuel when making decisions on tankering. The full cost includes the additional fuel required to carry the tankered fuel. Aircraft operators should also check fuel prices frequently to ensure that tankering is still justified by any fuel price differentials.”

levels and speed. It can be used any time after dispatch (once aircraft moves under its own power). It cannot be planned to use before. More likely, it is used for delays on departure or arrival;

- Alternate fuel: The fuel to cover a possible “Go around” or a landing at an alternate airport;
- Final reserve: For 30 min at ISA 1,500 feet above the alternate airport;
- Discretionary fuel (or 15 min of holding fuel) if the flight is planned with no alternate (go-around at destination, climb, cruise, descent, approach and landing at the selected alternate airport); and,
- Extra fuel, which should be at the discretion of the commander.

Fuel tankering is done as part of the “extra fuel” component; this is the amount of fuel in excess of the precautionary part at the discretion of the commander. In other words, fuel tankering is the practice of adding more fuel than what is required by the fuel policy for a safe flight.

The Environmental Impact of Economic Tankering

ICAO Doc 10013 4.1.2 indicates that “*The extra fuel burn attributable to additional weight carried on board an aircraft is typically on the order of 2.5 to 4.5% of the additional weight, per hour of flight, depending on the characteristics of the aircraft.*”

As the practice of economic tankering significantly increases the weight of the aircraft, it also increases its fuel consumption during its operation compared to a same flight carrying only the fuel needed for its journey. Figure 1 illustrates this phenomenon. When a return flight between two airports A and B, carries part or all the fuel needed for its return flight (B-A), an “extra” amount of fuel is burnt just to carry that additional fuel on the first leg (A-B). Consequently, this also results in additional carbon dioxide (CO₂) and non-CO₂ climate impacts.

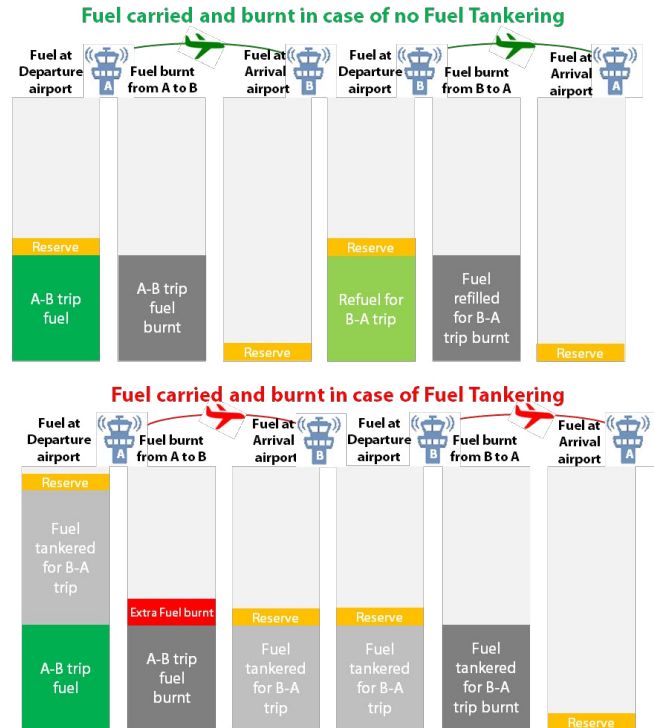


FIGURE 1: Example of extra fuel burn for a return flight between two airports with and without fuel tankering.

Although only economic tankering performed on a return flight between the same pair of airports is considered in the studies presented below, it can also be performed on a one-way flight serving more than two airports/legs.

EUROCONTROL Research on Current Tankering

In 2018, EUROCONTROL conducted a study limited to flights up to 1,500 and 2,500 NM to/from the European Civil Aviation Conference (ECAC²) airspace, corresponding mainly to short and medium-haul flights. According to EUROCONTROL research, operational tankering is considered necessary for the proper functioning of the aviation system and represents only about 10% of fuel tankering performed. On the other hand, economic tankering to reduce operating costs represents 90% of tankering performed. As fuel cost represents 17% to 25% airline operating expenses, and even up to 50% for some

2 ECAC is currently composed of 44 Member States: Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine and United Kingdom.

low-cost carriers, airlines use tools for identifying the value of performing economic fuel tankering.

It was estimated that fuel tankering could have resulted in a net saving of 265 million € per year for the airlines but would have generated 286,000 additional Tonnes of fuel burnt (equivalent to 0.54% of ECAC jet fuel used) and 901,000 Tonnes of carbon dioxide (CO₂) emissions in the ECAC airspace per year. This is equivalent to about 2,800 round trips between Paris and New York or the annual emissions of a European city of 100,000 inhabitants.

However, the practice of full or partial tankering is not limited to flights between 1,500-2,500 NM (2,780 to 4,630km). Aircraft fuel tanks are usually designed to allow maximum range. As aircraft are not systematically used to fly their maximum range, it becomes possible to carry much more fuel than required to limit or avoid refuelling at the destination airport. For example, some modern and efficient long-haul aircraft could perfectly perform full fuel tankering carrying the fuel for the return flight up to a 7,000-km flight carrying all the fuel (approx. 32 Tonnes to 45 Tonnes) to make the return trip depending on the aircraft types. EUROCONTROL intends to conduct a future study on the use of fuel tankering for long-haul flights.

Therefore, economical tankering goes against the decarbonisation path that aviation is on and should be avoided. Some airlines have apparently already committed to eliminating economic fuel tankering. However, many airlines may be tempted to maintain it to save money.

The decision to use economic tankering is based on the savings that can be made from arbitraging the negotiated fuel price between the departing and arriving airport. Consequently, any measure that influences the increase in the cost of fuel uplift in the EU compared to the cost of fuel outside of the European Union (EU) risks promoting economic tankering and undermining the decarbonisation of aviation.

International Council on Clean Transportation (ICCT) Research on Tankering Under a Sustainable Aviation Fuel Mandate

Sustainable Aviation Fuels (SAFs) are expected to play a major role in decarbonizing aviation. SAFs are renewable “drop-in” hydrocarbons that can be used in existing planes and engines as an alternative to fossil jet fuel. SAFs remain expensive (2 to 5 times fossil jet fuel) and rare (~0.05% of global jet fuel supply in 2020), so European Union (EU) policymakers are developing a mandate for their use. ReFuelEU, when finalized, will require jet fuel providers to blend an increasing share of SAF into their fuel supply at EU airports starting in 2025.

Since ReFuelEU will raise the cost of fuel, it raises concerns that airlines may uplift additional fossil fuel at non-EU airports to avoid purchasing more expensive SAF blends at EU airports. To assess the likelihood of this occurring, ICCT researchers used their Global Aviation Carbon Assessment

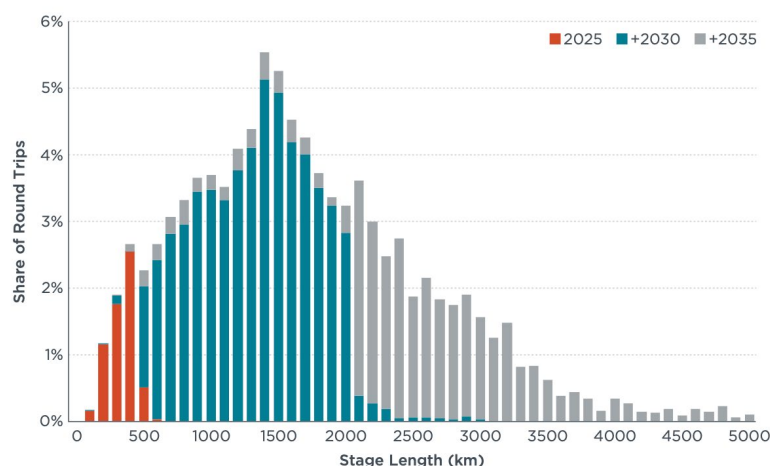


FIGURE 2: Stage length of international tankered flights by year (ICCT, 2021).

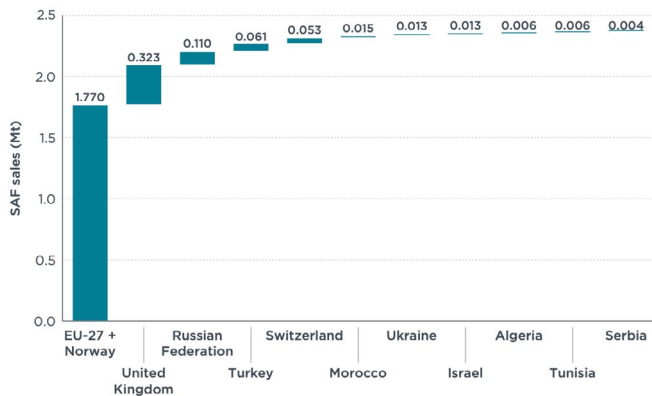


FIGURE 3: EU SAF sales under a 2030 mandate by eliminating tankering from select nations.

(GACA) model to estimate the emissions and fuel sales impacts of additional economic tankering on flights arriving at EU airports through 2035. Only full tankering, not partial tankering, was considered.

ICCT found that economic tankering should be minimal in 2025 but could increase substantially as the relative share of SAF in the fuel mix increases; by 2035, tankering could reduce SAF sales by 22% at EU airports and increase system wide fuel use by 0.9%. Considering both reduced SAF sales and increased system wide fuel consumption, CO₂ reductions attributable to an EU SAF mandate could fall by about one quarter as a result of tankering fossil jet fuel into the EU. This assumes that adjoining countries do not adopt similar mandates for SAF at the same pace as the EU.

The ICCT study investigated which flights are likely to tanker fuel into the EU to avoid purchasing SAF. It concluded that tankering could occur on most flights under 500 km in 2025, expanding to 2000 km flights and beyond starting in 2030 as the cost of fuel rises in tandem with required blend volumes (Figure 2). The study concluded that flights originating from the United Kingdom could be responsible for about half of tankered flights (52%) and excess fuel (49%) consumed (Figure 3). The study concluded that the integrity of the EU SAF mandate could be safeguarded by obligating airlines to purchase SAFs; by defining, and then prohibiting the carriage of, “excess” fuel; and if neighbouring

countries like the United Kingdom and Switzerland adopt comparable SAF mandates. Ultimately, the EU adopted a first approach under ReFuelEU by proposing that at least 90% of the fuel used on flights departing EU airports be purchased locally.

Conclusions

Tankering is an existing practice under which airlines upload excess fuel at their departure airport to avoid purchasing fuel at their destination airport for continuing operations. The study conducted by EUROCONTROL showed that economic tankering is a common practice used by airline operators that reduces operational costs but results in higher than necessary fuel consumption, and a significant increase in aviation emissions. This runs against the efforts that the whole aviation sector is making to meet the targets set by the EU Aviation Green Deal and should therefore be banned. Only operational tankering is acceptable. As ICCT research has shown, economic tankering could expand and ultimately undermine regional SAF mandates that increase the cost of blended fuels above that of conventional fossil jet fuel.

Although both studies presented here are based on European traffic and the possible implementation of future EU green aviation policy measures, the climate threat posed by economic tankering is global. The authors therefore advocate that similar studies be conducted in other countries/regions of the world and that appropriate measures be put in place to limit or even ban the use of economic tankering. As further evidence is gathered on its impacts, and as policies like SAF mandates that raise the price of jet fuel expand, ICAO might consider developing an international Standard and Recommended Practice (SARP) to strictly limit tankering to avoid carbon leakage and undermining regional climate policies.

Acknowledgments: Laurent Tabernier and Robin Deransy would like to underline the major contribution of their colleague Esther Calvo Fernandez in the completion of their study on economic tankering. Brandon Graver, Sola Zheng, and Nikita Pavlenko contributed modelling to ICCT’s research.

fello'fly: Airbus' Wake Energy Retrieval concept shows promise for operational fuel savings

By AIRBUS



FIGURE 1: fello'fly in practice

Introduction

With environmental performance of commercial aircraft being a top-level priority for Airbus, a remarkable new way of operating aircraft is being demonstrated to the industry and regulators, which could significantly contribute to the decarbonisation of aviation. The demonstrator project, “fello'fly,” recently proved the technical, operational, economic, and commercial feasibility of using “Wake Energy Retrieval” (WER) to reduce fuel consumption, and without compromising safety. The concept was inspired from nature, whereby large migrating birds fly together in a ‘V’-shape formation. When flying in this pattern the leading bird's wings generate whirling masses of air, allowing their companions to benefit from extra ‘free lift’ by which the up-current provides.

‘Follow the leader’

fello'fly in practice features a ‘follower’ aircraft – separated longitudinally by 1.0 to 1.5 nm from the ‘leader’, and at a shared altitude and speed – which ‘rides’ on the smooth updraft of air present in the wake of the leader (Figure 1).

By doing so, it enables the follower aircraft to reduce engine thrust, thus reducing fuel consumption in the range of at least five percent per trip. Notably, the leader aircraft would be able to save fuel if the formation flight's modified separation distance resulted in a more optimum altitude than would have otherwise been the case.

The most obvious and immediate applications for WER would be on trans-Atlantic routes greater than 2,000 nm – since these oceanic airspaces are composed

of mono-directional corridors which offer high potential for fuel reductions and are managed by a relatively small number of Air navigation Service Providers (ANSPs). Along with other oceanic airspaces, WER operations could also be beneficial in continental long-haul flows such as those in North America, and between Asia and Europe – which are mostly bi-directional Reduced Vertical Separation Minima (RVSM) airspace designs. A number of shorter-range continental flows such as Europe-Middle East also offer potential.

Project timeline and flight demonstrations

The fello'fly project was launched in November 2019 to demonstrate the technical, operational, and commercial viability of two aircraft flying together for long-haul flights. The fello'fly operation is made possible with new flight-control and pilot-assistance systems developed by Airbus. This enables the follower aircraft to identify, approach, 'join-up' with and track the aircraft wake updraft of the leader aircraft. The systems also assist the pilots of both

leader and follower aircraft in monitoring and managing the parameters of collaborative flights.

The first flight tests took place in July 2020 with Airbus aircraft, followed by further exploratory flights throughout 2021. The campaign culminated on the 9th of November 2021, with the first long-haul demonstration of formation flight in general air traffic (GAT) regulated transatlantic airspace. It involves two A350s flying at around 1.2 nm (2.2 km) apart from Toulouse, France to Montreal, Canada. The formation's flight path traversed through the airspaces of France (Brest), the UK (Shanwick), and Canada (Gander and Montreal). Over six tonnes of CO₂ emissions were saved on the trip, equivalent to more than a five percent fuel saving on long-haul flights.

Pilots from Airbus' partner airlines SAS Scandinavian Airlines and Frenchbee participated in the transatlantic flight as on-board observers. Furthermore, Airbus and its air traffic management partners and navigation service providers (DSNA, NATS, NAV CANADA, Eurocontrol and IAA), with the support of the DGAC, together proved that wake energy retrieval flight technology leveraged in a fello'fly flight could be achieved without compromising safety.

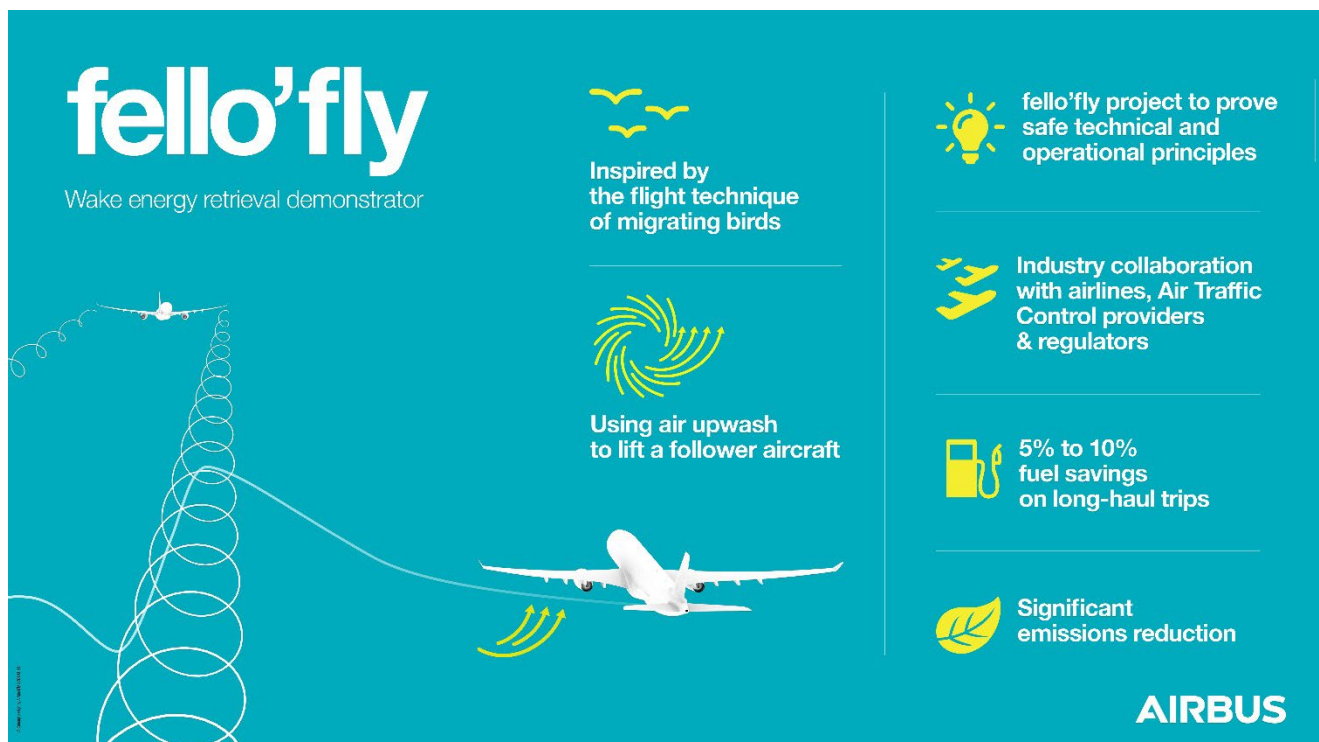


FIGURE 2: Operational fuel savings from fello'fly

Upon their arrival in Montreal, the two aircraft were welcomed by the Council President and Secretary General of the UN aviation agency, ICAO. Council President Salvatore Sciacchitano said that the fello'fly demonstration represented *"an inspiring example of the level of current commitment to reduce aviation emissions,"* while ICAO Secretary General Juan Carlos Salazar remarked on how it reflected *"the incredible diversity of air transport innovations now being realised to meet the sector's targets and ensure flying becomes more and more sustainable."*

Moreover, based on the measured fuel savings achieved during this and the preceding WER flights, Airbus reckons that its environmental potential over the North Atlantic could amount to a reduction of around two million metric tonnes of CO₂ emissions per year if all aircraft were equipped with the technology (based on 2019 traffic).

Next steps

Over the next few years, the multi stakeholder team led by Airbus will focus on the concept maturation. This will include complementary simulation and modelling, involving external partners (airlines, authorities, ANSPs). New flight tests are anticipated in 2023, losing no time in the race towards sustainable flight.

In parallel, Airbus will identify a timeline with industry and regulators to have regulations in place for the application of WER in mainline commercial operations. The common objective is to ensure that sufficient progress has been made to enable a controlled entry into service around the middle of this decade.

Green taxiing solution at Delhi Airport

By M. Muthukrishnan and Rekibuddin Ahmed (Delhi International Airport Limited – DIAL)

Climate change and Greenhouse Gas (GHG) emission management at Indira Gandhi International (IGI) Airport is one of the key sustainability aspects of Delhi International Airport Limited's (DIAL).

DIAL has embraced Airport Carbon Accreditation (ACA), the only framework helping airports globally to manage and reduce carbon emissions. In 2016 Delhi Airport became the first airport in the Asia Pacific region to achieve “Level 3+” and in 2020 DIAL achieved “Level 4+” as the first Airport in Asia Pacific and only the second Airport globally.

Delhi Airport is progressing strongly on environment and is committed to become a ‘net zero carbon emission’ airport by 2030. Towards this direction, DIAL has initiated various environmental sustainability programs. The measures identified by DIAL are- energy efficiency and conservation, green building programs, renewable energy, operational efficiency measures, airline programs, clean transportation, develop carbon sink and ACA. With these initiatives, DIAL is targeting to reduce scope 1 & 2 as well as scope 3 emission in the near future.

Background

The objective of the “airline program” is to work with airlines and other stakeholders to create opportunities and find solutions to reduce aircraft related ground emissions. As part of this initiative, DIAL promoted green taxiing “TaxiBots” usage at the Airport. TaxiBot¹ is the only operational alternative taxiing system that has been certified till now in the industry. Delhi Airport is the first airport globally to adopt commercial operation of Taxibot in 2019.

Green Taxiing Solution: TaxiBot

In a conventional aircraft taxi process, an aircraft is tugged by a ground vehicle to the Tug Disconnection Point (TDP). From the TDP, the aircraft starts its main engine and continues its Taxiing journey while burning precious Aviation Turbine Fuel (ATF) and emitting ground noise and ground carbon emissions before taking off from the runway. Use of TaxiBots eliminate the requirements of TDP and eliminates the requirements of switching on the main engine during the taxiing process. Figure 1 shows a comparison of conventional taxiing vs taxiing using TaxiBot.

In case of taxiing with TaxiBots, once the TaxiBot is attached to the aircraft, pushback operation and procedures are performed by the TaxiBot operator. After that, the control is taken over by the aircraft pilot. A patented TaxiBot-aircraft Nose Landing Gear (NLG) interface mechanism provides the pilot steering capability, using the airplane's existing controls in the cockpit. The TaxiBot system provides the pilot with the same handling characteristics as if taxiing with engines. It has unique NLG interface clamping mechanism (Figure 2) mounted on a “rotating turret” for:

- Load alleviation during pushback, acceleration, and braking
- Transferring pilot tiller steering commands to the tug wheels via a steering control system

In most cases, no modification to aircraft is required, and minor if any modifications to airports infrastructure are required. The pilot is always in control (after pushback) using airplane tiller and brake pedals (transparent to pilot as in regular taxiing). For braking purposes, the Main Landing Gear System is used and thus, there is no damage

1 The TaxiBot's are designed by Israel Aerospace Industries and manufactured by TLD of France. (<https://www.taxibot-international.com/concept>)

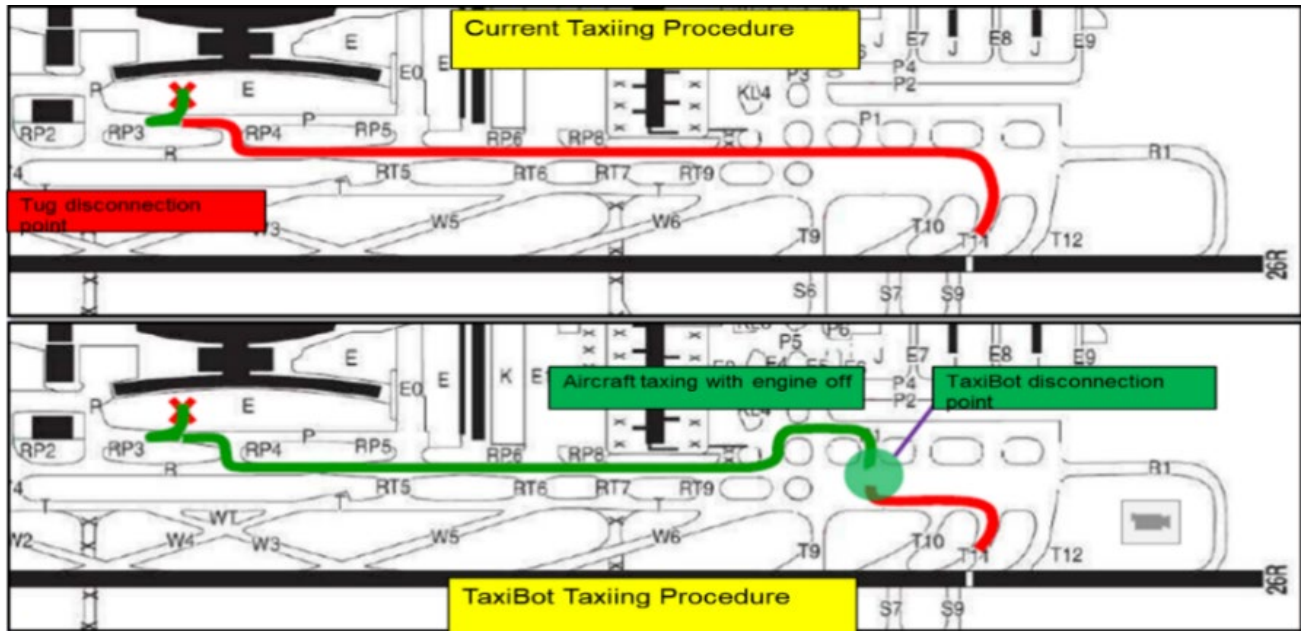


FIGURE 1: Comparison of conventional taxiing vs taxiing using TaxiBot

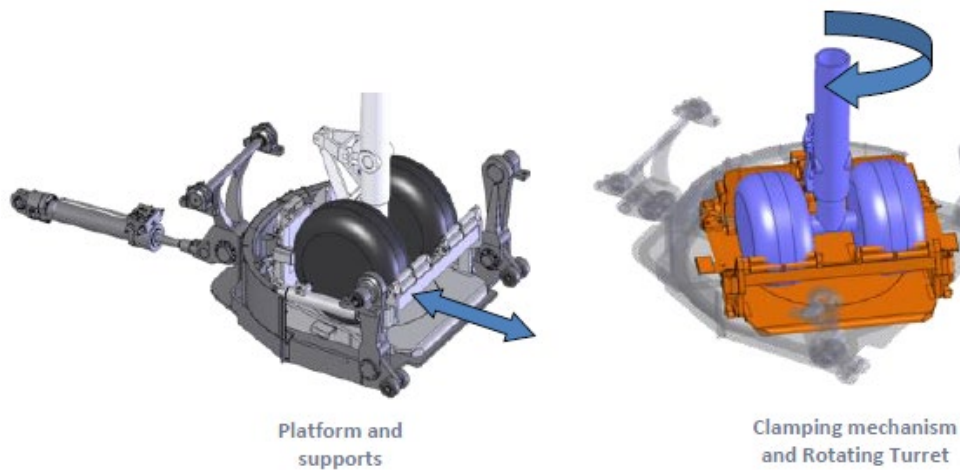


FIGURE 2: Nose Landing Gear (NLG) interface clamping mechanism

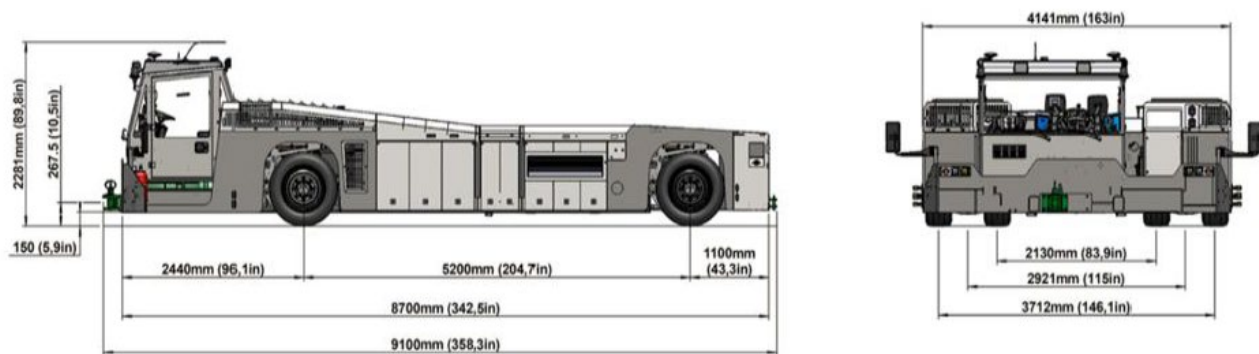


FIGURE 3: TaxiBot dimension

to the NLG of the aircraft because of the external load. With TaxiBots, aircraft can perform taxiing at 23 knots, same as current airplane ground taxi speed.

Once the aircraft reaches a pre-designated point on the taxiway, the aircraft stops and the TaxiBot is disconnected. It then returns to apron area and gets ready for its next operation. After TaxiBot disconnection, the aircraft will be ready for take-off as per Air Traffic Controllers (ATC) guidance. The list of complaint aircraft and TaxiBot dimensions are detailed below.

Compliant Aircraft

Boeing Aircraft Types	Airbus Aircraft Types
737-700	A318
737-800	A319
737-900	A320
737-900ER	A321
757-200 (only push back)	A320 (CEO & NEO Family)
757 – 200 F	A321 (CEO & NEO Family)
B737 – 8MAX	

Implementation

This project was delivered in three phases at IGI Airport which is shown in the Figure 3.

Phase I- Regulatory approval <ul style="list-style-type: none"> DGCA conducted a series of discussion with Airlines, DIAL, Air Traffic Control, and TaxiBot service providers. DIAL played a major policy advocacy role in this project. Based on the Ministry of Civil Aviation, India's recommendation, DGCA, India, allowed and approved for Pilot Phase of TaxiBots in August 2018.
Phase II- Pilot phase <ul style="list-style-type: none"> Starting from October 2018- February 2019, a project member Airlines completed pilot phase. All possible operational scenarios were successfully enacted in a live environment with TaxiBot.
Phase III- Commercial Operation <ul style="list-style-type: none"> In October 2019, Air India flying from Delhi to Mumbai became the first airline in the world to use TaxiBot on A321 with passenger on board. DIAL has completed the implementation of this project in a concessionaire model with M/s KSU Aviation Pvt. Ltd. in collaboration with all the Airlines who have decided to deploy TaxiBot as part of regular Taxiing operations.

FIGURE 3: Three phases of implementation

Project Benefits

DIAL always strives to adopt newer technologies/best practices for enhancing operational excellence. The successful implementation of TaxiBot in Delhi Airport is an excellent case of technology adoption, stakeholder Engagement and innovation for pollution prevention. Key environmental benefits are:

- Reduction in Fuel Consumption** - Use of TaxiBot ensures significant reduction in fuel consumption during aircraft taxiing. The fuel saving is a function of fuel flow rate during taxiing (kg/sec) and time taken during the taxing process (sec) and would also largely depend upon number of stop and turns and the amount of creeping traffic the aircraft encounters during ground taxiing. Currently the TaxiBots in Delhi Airport are compatible with Airbus A320 Family and Boeing B737 Family of aircraft. With the existing set up at Delhi Airport, the use of TaxiBot ensures ATF savings in the range of 230- 260 Litres per aircraft per taxiing event.
- Reduced Environmental Footprint** - Fuel saving also leads to environmental benefits in terms of emission reduction, improved local air quality and reduced noise footprint. Currently, the TaxiBot is being used for taxiing out purposes. A breakup of Landing and Take Off cycle emission at Delhi Airport, based on 2019 data (pre-covid) shows, the share of taxi out emissions is highest (Figure 4).

This initiative is ensuring reduced taxi out emissions at Delhi Airport. Use of TaxiBot leads to approximate emission saving of 532 kg CO₂ per aircraft taxiing for an average TaxiBotting Time of 14 minutes. Apart from this local air quality benefits of TaxiBots are- 1.05 gm of hydrocarbon, 4.65 gm of carbon monoxide and 0.57 gm of nitric oxide emission reduction per aircraft per taxiing. These values are based on emission estimation procedures by ICAO Doc 9889 and ICAO Aircraft Engine Emissions Databank².

2 <https://www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank>

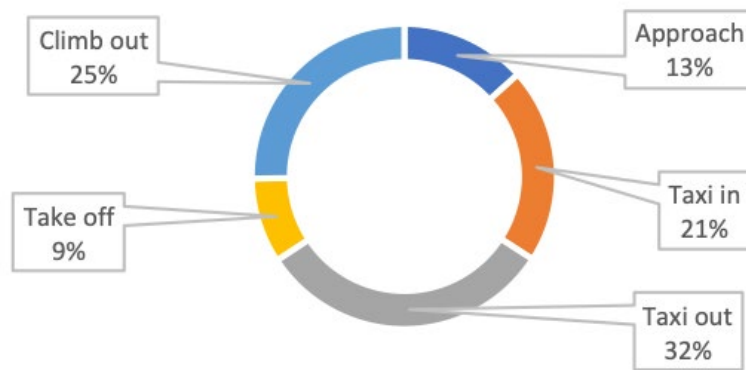


FIGURE 4: Break Up of LTO Emission at IGIA

As of March 2022, Delhi Airport has completed more than 2000 TaxiBot missions³ and achieved ATF savings of 371 Tons, CO₂ emission reduction of 1,173 Tons. In addition to this, the 2000 TaxiBot missions have also helped in 140 hours of ground time saved, 467 hours engine life saved.

The savings in ground time further ensures improved operational efficiency by reducing turnaround time and increased throughput at airport gates benefiting both the Airport Operator and Air Traffic Control while enhancing apron safety quotient during the taxiing phase. This has also resulted in significant financial benefit to airlines to the tune of 44.27 million INR (as per today's ATF cost to Airline) in terms of fuel cost savings.

Way forward

Currently 2 TaxiBots are deployed at Delhi Airport, which can handle 30-40 aircraft/day. In addition, DIAL is planning to add 15 more TaxiBot's in a phased manner over the next 3 years, which will further multiply the carbon emission as well as local air quality benefits in the region.

Following the success of Delhi Airport, a number of Indian airports as well as few global airports are planning to adopt TaxiBot to support the business sustainability.

³ <http://taxibot-india.com/services/>

The Eco-Airport Toolkit e-Collection

By Thomas Cuddy (US FAA), and Julianna Scavuzzi (ACI World)¹

Introduction

Airports have a critical role to play in the sustainable development of the aviation eco-system. Understanding the importance of this role, the airport industry committed to reach net zero carbon emission by 2050 in June 2021. Concurrently, the 31st ACI World Annual General Assembly approved a Resolution that supports the integration of sustainability at the core of airports' business strategies.²

With the devastating impacts of the COVID-19 pandemic, most sectors have had to rethink business strategies and models. Sustainability is no longer an option that is 'nice to have' – it must be an integral part of every facet of an organization. On one hand it is the right thing to do, and on the other, stakeholders are expecting it: customers, passengers, shareholders, investors, regulators, and governments, are looking at airports and expecting them to reduce their environmental impacts and increase socioeconomic benefits.

Airports have been working tirelessly to limit and repair the economic damages brought on by the pandemic, while also ensuring and promoting the wellbeing of employees and passengers and delivering positive impacts on the communities they serve.

Innovation is taking place around the globe as airports seek to expand the services they can provide to customers while ensuring their activities align with the social, environmental, and economic pillars of sustainability. Creative solutions have been seen in airport sustainability, making facilities

resilient to climate impacts, reducing fuel burn through operational efficiencies, and much more.

The Eco-Airport Toolkit

In order to amplify the benefits of this innovation, ICAO established a task group to identify examples of airport environmental leadership and share these successes worldwide. This Eco-Airport Toolkit task group sits under Working Group 2 – Airports and Operations, within ICAO's Committee on Aviation Environmental Protection (CAEP). The Eco-Airport Toolkit E-collection is a series of short publications accessible from ICAO's Environment website that have a quick turnaround between report production and dissemination.³ The papers in the toolkit are a set of practical and ready-to-use information documents to support the planning and implementation of airport infrastructure projects that promote significant environmental benefits.

To date, seven papers have been published on the website, each focused on a specific example of environmental planning at airports. Most of the papers also include case studies that provide real-life examples to illustrate the topics. The e-collection began during the CAEP/11 cycle with four e-publications:

1. A Focus on the production of renewable energy at the Airport site
2. An Environmental Management System for Airports
3. Waste Management at Airports
4. The Eco Design of Airport Buildings

¹ Thomas Cuddy and Julianna Scavuzzi are Co-Leads of Working Group 2 Task Group "Eco-Airport Toolkit" of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

² ACI World renews its commitment to the sustainable development of the aviation ecosystem at 31st WAGA, 25 November, 2021. Online: <https://aci.aero/2021/11/25/aci-world-renews-its-commitment-to-the-sustainable-development-of-the-aviation-ecosystem-at-31st-waga/>.

³ See: <https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx>

Website analytics showed these pages were among the most accessed on the ICAO system. As a result, the CAEP/11 meeting approved another four e-publications to be developed in the CAEP 12 cycle (2019-2021), on the following topics:

1. Climate Resilient Airports
2. Water Management at Airports
3. Air Quality Management at Airports
4. Sustainable Considerations for Airport Surface Access

1. Climate Resilient Airports

Climate change presents many challenges for aviation, and the impacts of changing climate are felt at airports worldwide. Strengthening airports to be more resilient to the impacts of climate change has become a major theme of airport planning. A climate resilient airport is one that has taken steps to prepare for the challenges that climate change and severe weather bring. ICAO's Climate Change Synthesis describes at least nine primary climate impacts that can affect airports. Many airports have undertaken a climate risk assessment to understand their vulnerabilities and prioritize, using a number of methods to assess climate risks and develop a plan of action for future improvements and upgrades. The Master Plan is commonly used for planning and offers an excellent format for studying climate resilience actions. Consult this publication for additional resources and guidance on how to assess risks, plan and prioritize facility upgrades, and build resilience to climate impacts. The case studies from Canada, Mexico, France, Netherlands, and others, provide rich detail.

2. Water Management at Airports

Water is a critical resource with many environmental implications. Safe aircraft operation requires effective water management practices. Airports must use water and must be good stewards of water resources at their facility and within their region. Water considerations vary from supply issues, to managing stormwater and storm surge events, to the responsible disposal of water back into the watershed. Airport siting and the design of drainage systems will have a large influence on how efficiently water is managed and used at a facility. Good planning for water management in the initial stages of airport development can significantly reduce potential future environmental

impacts. Airports may choose to follow proven programs, such as the Integrated Water Resources Management (IWRM) approach, or the Water Sensitive Airport framework, to reduce impacts and costs. There are many options to ensure water leaving the facility is clean. Limiting the use of contaminants and pollutants is a major first step. Good management of de-icing fluids during operations is another, along with proper spill prevention and effective on-site water treatment facilities. Many areas have regulations that require water quality monitoring and sampling on a regular basis, and airports can save time and money if it is accomplished efficiently and easily. Examples of good practices come from Malaysia, China, India, Cambodia, Canada, Brazil, Spain, and Portugal.

3. Air Quality Management

Air quality is one of the most important environmental issues for airport operators. Aircraft engine emissions are a large source of air pollutants, however emissions also come from power generation, motor vehicles and ground support vehicles, fuel handling and storage, and other sources. Air quality is often regulated by states, and a systematic air quality management plan can help reduce major sources of pollutants while also helping the operator successfully meet their regulatory compliance requirements. Several options exist to improve local air quality, from technological changes like electrifying vehicles, to more efficient airfield operations that reduce fuel burn. A valuable first step towards managing emissions is to have an inventory of emission sources at the airport. With this information, a plan can be developed to manage and/or minimize the emissions. Many airports have an air quality management plan that lays out the measures they are taking to improve their local air quality. Innovations at airports in terminal heating and cooling, water management, and waste treatment also have a positive effect on reducing pollutant emissions. Read about examples from Turkey, Australia, India, China, Netherlands, and more. In addition to this publication, several other resources and guidance documents are available, such as the ICAO Document 9889: Airport Air Quality Manual, to facilitate successful airport air quality management, reduce emissions, and improve local air quality.

4. Sustainable Considerations for Airport Surface Access

Customers appreciate convenient, affordable, and accessible means to access and leave the airport. Increasingly, they also expect airports to operate sustainably. Surface movement to, from, and around the airport is critical, but it also has several environmental impacts including water runoff, noise from road and rail traffic, and air pollution. Strategic planning and implementation of surface access is therefore an important consideration for mitigating environmental impacts and bring social and economic advantages. Surface access is also a primary consideration in the airport Master Planning process, which will generally consider the needs for access to the terminal curb, parking, rental car facilities, and other capacity constraints. Several sustainable solutions address the issues associated with airport surface access. For instance, many methods have emerged to reduce driving times at the airport, thereby reducing engine emissions. Where traffic congestion is a problem, creative tactics have been used to reduce the number of single-occupant private vehicle trips and encourage low-emission vehicles. Many airports are also working to improve public transportation connection, in some cases building and operating rail lines themselves. Other considerations include the materials that road surfaces are constructed with and that can make a difference, for example porous asphalt or recycled pavement. In terms of innovation, there are many examples for moving people, bags, and cargo around an airport in a swift and sustainable manner, and new digital tools continue to transform surface access, for example by allowing drivers to find open parking spaces quickly, customers to hail rideshare services, and more. Examples are provided from Belgium, UK, US, France, Switzerland, and Colombia.

Future Developments

While the first part of the Sixth Assessment Report from the IPCC released in 2021 emphasized the increased urgency of taking action to tackle climate change globally, the second part of the report, published in February 2022, assesses the impacts of climate change through ecosystems, biodiversity, and human communities at the global and regional levels. This highlights the pressing need for increased collaboration between all aviation and non-aviation stakeholders. As this ecosystem faces a continuously accelerating pace of change, a systemic approach is crucial. Governments and regulators must recognize and enable the vital role of aviation in the sustainable development of their nations, public-private partnerships need to be more frequent and stimulate innovation. In addition, interconnected sectors such as transport, energy, hospitality, destination management, etc., should work together on finding long-term solutions.

One of the greatest challenges for aviation is decarbonization, something that airports have been, and continue to address with recognized leadership. The Airport Carbon Accreditation programme⁴ and the ACI World global net zero goal by 2050⁵ are excellent demonstration of this commitment. However, more work needs to be done. For instance, by continuing the research on the impacts of integrating new sustainable aviation fuels at the airport or exploring ways to produce renewable energy onsite.

Other essential topics of interest to the airport community include emerging technology aircraft and their environmental and social impacts at and around airports, the protection of biodiversity, and the use of nature-based solutions to mitigate and adapt to climate change.

Finally, the role of innovation and technology should not be underestimated by the industry. Paired with true collaboration and transparency, these two enablers have the potential to help airports and all their stakeholders be more resilient, limit their footprint on the environment, and serve their customers and communities in the best and most sustainable way possible.

4 Airport Carbon Accreditation. Online : <https://www.airportcarbonaccreditation.org/>

5 <https://aci.aero/2021/06/08/net-zero-by-2050-aci-sets-global-long-term-carbon-goal-for-airports/>

Solar photovoltaics in airports

By Johannes Deimel-Zelenka (Austrian Federal Ministry for Transport, Innovation and Technology) & Mario Santi (Vienna Airport), Roberto de Oliveira Luiz (Inframérica), and Francis Mwangi (Kenya).

Introduction

Several airport operators around the world are implementing climate initiatives at their airports, such as installing photovoltaic plants and powering aircraft on the ground with renewable energy. This article presents three examples of concrete renewable energy projects being implemented in Austria, Brazil, and Kenya. They are ready to be replicated worldwide today.

Vienna Airport's Push on photovoltaics and energy efficiency

The Austrian Federal Government has ambitious climate and energy goals, including 100% clean electricity in and from Austria by 2030. The Renewable Energy Expansion Act provides the legal framework and is part of a legislative package by the European Union, which supports our activities to combat climate change. To achieve these goals, Austria relies on investments, innovation, and cooperation.

Vienna Airport has defined an even more ambitious goal and is committed to achieve CO₂ neutrality in its operations by the year 2023 despite its future growth. In order to achieve this target, Vienna Airport, among other initiatives such as energy efficiency programs and other measurements to reduce CO₂ emissions, already obtains CO₂-free electricity from its supplier. Vienna Airport also relies on the use of photovoltaics to secure this development in the long-term.

Photovoltaics: What is it all about?

Photovoltaics is the direct conversion of light into electrical energy using semiconductor materials such as silicon. The photovoltaic effect is an important phenomenon that is being researched in physics and chemistry.

The word photovoltaic (PV) was first mentioned around 1890 and is composed of the Greek words photo, “phos” for light and “volt” for electricity. Photovoltaic technology uses semiconductors to generate electricity based on photo electricity. By harnessing the photovoltaic phenomenon, solar energy is converted into electricity and used as an alternative to conventional means of power generation. Photovoltaic systems are sometimes also referred to as solar cells. When several solar cells are electrically connected within a supporting structure, a photovoltaic module is created.

Construction of Austria's Largest Photovoltaic Plant

Since 2016, Vienna Airport has operated seven photovoltaic plants on the roofs of Hangar 7, the old winter service hall, the Air Cargo Centre, the area of the former sewage treatment plant, the new Office Park 4, on the roof of multi-storey car park 8 and, most recently, on the roof of multi-storey car park 3.

In the autumn of 2021, the ground-breaking ceremony for the construction of an eighth photovoltaic plant took place. This plant will extend over an area of 24 hectares and will provide an output of approximately 24 megawatts peak. With its around 55,000 photovoltaic panels this plant will be Austria's largest ground-mounted plant.

After commissioning in spring 2022, the photovoltaic plants at the Vienna Airport site will generate an output of around 30 million kilowatt hours of solar power per year, and thus will cover around 30 per cent of Vienna Airport's annual electricity consumption - the same amount as consumed by 7,000 households.

Further measures of the energy-efficient operation of the airport

The expansion of the photovoltaic systems is just one of many measures within the framework of energy-efficient environmental management at Vienna Airport. For example, the airport is increasingly focusing on e-mobility and operates an e-fleet with currently around 400 e-vehicles. The use of fossil fuels will be gradually reduced and, where the use of such fuels is currently still without an alternative, compensated for accordingly. The lighting systems at Vienna Airport are gradually being converted to energy-saving LED systems. The new Office Park 4, which was commissioned in 2020, uses geothermal energy and has received several awards as the most sustainable office building in Austria. A Smart City control software developed together with the Vienna University of Technology supports the energy optimisation of existing and future buildings.

District heating: 21,000 tonnes of CO₂ Savings per Year in the Airport System

The Austrian energy company OMV, will expand the existing supply of the district heating network by expanding the district heating hub at the Schwechat refinery. In doing so, OMV will use the waste heat from the desulphurisation plant. This is a diesel production plant with a vacuum distillation plant at the OMV Schwechat refinery and convert it into environmentally friendly district heating. The heat recovery plant will go into operation in the first half of 2022. One of the largest consumers of this new environmentally friendly district heating is Vienna Airport. Connected to a direct line from the OMV refinery in Schwechat, the entire airport site with approximately 150 buildings is supplied with CO₂ free heat. This will save around 21,000 tonnes of CO₂ per year in the airport system.

All this effort brings Vienna Airport a large step closer to its goal of becoming CO₂-neutral by the year 2023.

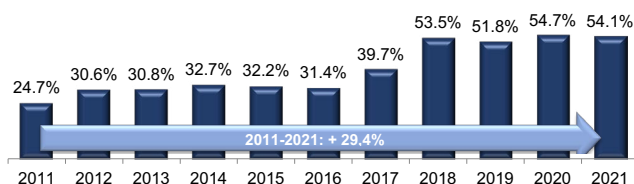


FIGURE 1 : Share of renewable energy as a percentage of total energy demand FWAG



FIGURE 2: Members of the Board of Flughafen Wien AG: CFO Günther Ofner and COO Julian Jäger 24 hectares and approximately 55.000 photovoltaic panels

Renewable energy to power planes on the ground: a Brazilian international airport experience

With the goal of cooperation and to reduce the airport's carbon footprint and assist the airlines with sustainability, Inframerica, the company that manages Brasília International Airport (BSB/SBBR), located in the capital of Brazil, together with ENGIE, a global leader in energy and solutions, entered a partnership to supply energy from renewable sources to power the electrical and air conditioning requirements of planes parked at the terminal of Brasília Airport.

This new technology replaces the diesel-powered external generators, known as GPUs (Ground Power Unit), and supplies the aircraft's micro turbine, called APU (Auxiliary Power Unit), which normally uses kerosene from the aircraft itself. The equipment is used by the airlines to keep the aircraft connected during the time it spends on the ground in the sun, and to save on kerosene, which is expensive for airlines.

This new solution, in addition to reducing the carbon footprint and eliminating the use of generators on the airport apron also makes the operation safer, as it dispenses with the obstacles of generators filled with fuel in areas where vehicles manoeuvre, and people work. There is also a reduction in the noise level at the airport which is a bonus for the health of the employees who are exposed to high levels of noise daily. The system also significantly contributes to improving the operational efficiency of aircraft while parked on the airport apron.

The project was developed by ENGIE together with Inframerica, and the equipment was installed at 22 air bridges at the airport (Figure 3). Installation took 10 months to complete, and the work began before the pandemic, and the equipment went into operation in January 2021. Even with the reduction in air traffic caused by the effects of the second wave of pandemic restrictions, more than 22,000 aircraft have used the service over the past year.

This new technology allows for a significant reduction in airport's associated greenhouse gas emissions. The projection is that the equipment will reduce CO₂ emissions by at least 20 thousand tons per year, which is equivalent to planting more than 120 thousand trees, making the operation of Brasília Airport more economical and sustainable. This is a commitment made by Inframerica and highlights the companies' policy to reduce greenhouse gases and develop sustainable operational solutions.

The new system is part of a sustainability project that the concessionaire has been investing in to reduce CO₂

emissions from airport operations by including clean energy sources. In September 2020, the administration started using energy from a photovoltaic plant installed at the air terminal. The city of Brasília benefits from a high solar incidence, and the airport has a vast open area with no buildings nearby, all of which favour the situation of the project.

The concessionaire dedicated an area of 18,300 square meters to the project, close to the airport access area (Figure 4).

The system is operated by a Japanese start-up company, Shizen Energy, which operates in Brazil under the name of FazSol Energias Renováveis, in partnership with the Brasília real estate company Espaço Y. Solar energy is already being used to supply part of the airport's consumption. The 3,360 photovoltaic modules produce 2 million kWp of energy per year, which supplies 7% of the airport's demand, a load, that for example, would be enough to supply electricity to 1,462 average homes.

The sustainability measures adopted by Brasília Airport were recognized in the First edition of the Sustainable Airports Project by the National Civil Aviation Agency (ANAC). The terminal at Brasília was also awarded the seal of Advanced Sustainable Aerodrome, being one of only four among the 23 airports evaluated in the survey. In addition to this seal, the terminal in Brasília was also recognized, for the first time, with a gold seal by the Brazilian GHG Protocol (Greenhouse Gas Protocol) Program, which publishes inventories of greenhouse gas (GHG) emissions. The Airport



FIGURE 3: Brasília International Airport 400Hz in operation at airport's air bridges.



FIGURE 4: Photovoltaic plant near airport's main road access (Source: Google Earth Pro).

Council International (ACI) has also awarded the airport with an international certificate of carbon management, the Airport Carbon Accreditation (ACA).

Solar At The Gate Project At The Mombasa International Airport, Kenya

A pilot project was implemented in Kenya with strong support from the International Civil Aviation Organization (ICAO). It consisted of a ground-mounted photovoltaic system of 507kW solar power generation facility and mobile airport gate electric equipment. This innovative project was launched on 12th December 2018 at Moi International Airport in Mombasa, Kenya.

The facility provides pre-conditioned air (PCA) and compatible electricity that runs on solar energy to service aircraft during ground operations which eliminate carbon dioxide emissions from aircraft parked at the gate. The system has been in operation since April 2019, when the site acceptance tests were conducted, and the system commissioned.

The project installed an auxiliary power unit (APU) and a ground power unit (GPU) for use by aircraft at Moi International Airport that are powered by clean energy from solar. This has helped to reduce the use of fossil fuel (diesel) by powering the APU and GPU at the airport. The system has also helped to run on-board systems and interior cooling before aircraft depart for their next flight.

The solar facility has generated 737,014.86kWh annually on average with a total power generation of 2,092,959.8 kWh as of December 2021. Thus, it has reduced on average 704.225 tonnes of CO₂ annually. In total, the amount of carbon dioxide emissions reduced equalled 1,932.422 tonnes as of December 2021. The airport gate equipment serves more than 1,497 flights per year, with both GPU & PCA consuming 75,816.96 kWh in 2021, therefore demonstrating a concrete solution to reduce aviation carbon dioxide emissions.

The Solar Pilot Project was implemented at Moi International Airport at a cost of 1,50132.22USD which was part of the € 6.5 million initiative, entitled “Capacity Building for

CO₂ Mitigation from International Aviation”. This initiative targeted 14 African and Caribbean states. Twelve States were from the African Region and two from the Caribbean Region. This project was implemented by the International Civil Aviation Organisation (ICAO), the Kenya Civil Aviation Authority (KCAA), and the Kenya Airport Authority (KAA). It was funded by the European Union and the Government of Kenya

KCAA and the Kenyan aviation industry stakeholders developed the Kenya’s Action Plan for the Reduction of Carbon Dioxide emissions from aviation in December 2015. This State Action Plan resulted into funding of the “solar-at-gate” projects in Mombasa, which was one of the mitigation measures selected. The project has further resulted into efficient operations at Moi International Airport, with savings of electricity charges at an average amount of 25,000 USD (Ksh 2.5 million) per month. Figure 5 shows the trend in power generation per month and annually.

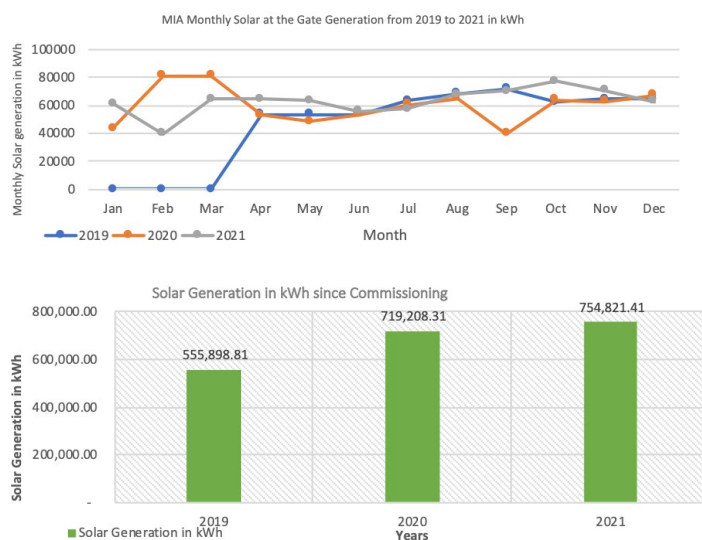


FIGURE 5: Trend in power generation per month and annually

Status on Achievements and Progress

- The project was relevant since there was a need to improve on power supply at the airport and reduce CO₂ emissions.
- The project was effective as the solar system is operational.

- The project was achieved within the contract period and budget, and the project met specified quality standards.
- The project improved on power stability at the airport.
- The system has led to the reduction of operational costs related to electricity bills and use of power generators.
- The system has reduced CO₂ emissions and noise due the clean energy use by parked aircraft and less usage of a generator.
- The project is sustainable as there are adequate measures in place to manage the system in terms of human resources, institutional arrangements, and budget.
- The formation of Project Implementation Teams was observed to have contributed enhanced the implementation of the project and reporting.

Recommendations

- There is need for further funding or provision of more financial resources to expand the solar system at Moi International Airport to provide for all the airport's power requirements, resulting in a 100% solar power during the day.
- There is need to implement similar solar projects in other airports and other installations serving the aviation industry, especially Jomo Kenyatta International Airport.
- Solar powered GPU and PCA systems should be implemented across all major international airports.



FIGURE 6: Solar Farm at Moi International Airport



FIGURE 7: Ground power unit (GPU)



FIGURE 8: Pre-conditioned air (PCA)

New airport infrastructure for clean energies

By Juliana Scavuzzi (ACI), Jonas van Dorp (Groningen Airport Eelde, Yukio Nakatani & Yuka Takeuchi (Kansai Airports)

Introduction

Following the call from the Intergovernmental Panel on Climate Change's (IPCC) to reach net zero carbon emissions by 2050, Airports Council International (ACI) World conducted a study on the feasibility of a long-term carbon goal (LTCG) for the airport industry. This LTCG study was carried out in 2019-2020 and engaged with ACI regions and airport leaders worldwide.

As a result, in June 2021, global ACI member airports committed to reach net zero carbon emissions by 2050, urging governments to provide the necessary support in this endeavour¹. The LTCG study also included some of the key actions that can help accelerate decarbonisation, such as encouraging renewable energy transitions, promoting the regional grid decarbonisation, deploying viable onsite renewable energy systems, implementing energy efficiency measures, and electrifying airport infrastructure.

Airports are embracing technology and innovation to eliminate their scope 1 and 2 emissions, from installing LED lighting, fixed electrical ground power, and electric charging stations to investing into photovoltaic systems, electric ground support equipment, vehicles running on renewable fuels, or energy microgrids. In this article, two airports describe some of the initiatives they are taking to integrate clean energy into their operations.

While airports do not have control over many of the sustainability, technical or safety aspects of clean energy sources that are different to conventional aviation

fuel, they can play a key role in their enablement by facilitating the availability of sustainable alternative sources of energy onsite, including addressing the challenges associated with new entrants to the aviation market and innovative propulsion methodologies. Understanding interdependencies and fostering collaboration through partnerships can help airports to be more resilient, and to promote a positive transformation of the aviation ecosystem and improve the services that they provide².

ACI Initiatives

To support its members in understanding the possible impacts and requirements that clean energies may have on infrastructure and operations, ACI World released a whitepaper on sustainable energy sources for aviation, from an airport perspective.

The document provides an overview of the most important considerations for airports in terms of supply chain, safety, storage, processes, infrastructure, and equipment requirements, for three types of alternative fuels:

1. Drop-in sustainable aviation fuels (SAF)
2. Hydrogen (H₂) aircraft (for combustion or for electricity generation through a fuel cell) and;
3. Electric battery-powered aircraft

Impacts of these clean fuels may include:

- Improvements in local air quality

¹ Net zero by 2050: ACI sets global long term carbon goal for airports, 8 June 2021. Online: <https://aci.aero/2021/06/08/net-zero-by-2050-aci-sets-global-long-term-carbon-goal-for-airports/>

² RESOLUTION #2 Sustainable development of the aviation ecosystem, 24 November 2021. Online: <https://aci.aero/wp-content/uploads/2021/11/ACI-Resolution-2-WAGA-2021.pdf>

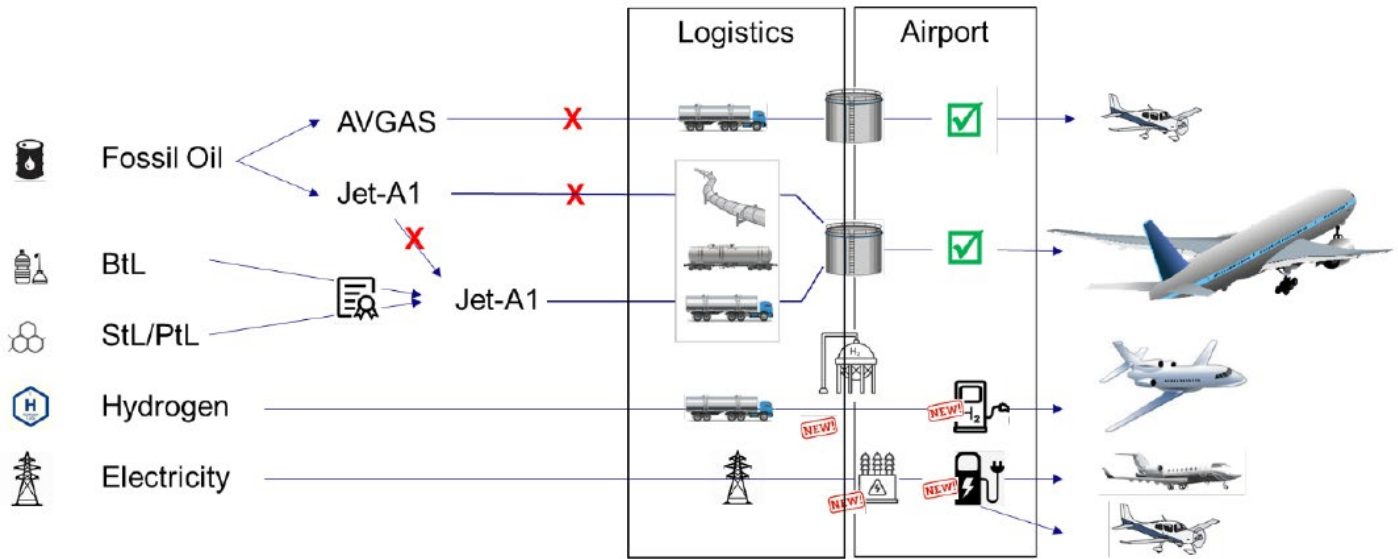


FIGURE 1: Energy options for civil aircraft propulsion. Courtesy of Zurich Airport.

- Changes in turnaround time
- Changes to equipment and procedures
- New infrastructure (buildings, ground, mobile, energy)
- Specialised training needs
- Changes in supply chains

- Other hazards related to hydrogen fuel at airports
- Aircraft/airport compatibility and ground operations
- Cost considerations
- Gaps identified
- Opportunities for airports and case studies

As is the case for any anticipated change, airports need to coordinate and engage with all stakeholders at an early stage, including with neighbouring communities. This will be essential to ensure a successful integration and the acceptance of the new technologies (Figure 1).

To increase awareness and understanding, ACI further looked at the integration of hydrogen aircraft into the air transport system, in partnership with the Aerospace Technology Institute (ATI). The study, which is from an airport's operations and infrastructure perspective, provides a comprehensive overview of the potential impacts that hydrogen aircraft could have. More specifically, it explores the following elements:

- The hydrogen supply chain (infrastructure to deliver hydrogen to the airport and to store it, and to transport it within the airport)
- Hazards and safety considerations
- Passenger perception
- Physical properties of LH2 vs Jet A-1 and hazards

Engaging early, addressing common questions, identifying knowledge gaps, challenges and opportunities, and sharing key learnings among the aviation industry, governments, and other stakeholders, are all essential steps to advance the development and potentially, the adoption of novel technologies such as hydrogen-powered aircraft.

Further research and analysis of all alternative sources of sustainable energy and their impact on airports operations and infrastructure (Figure 3) will continue as more data becomes available.

A publication on Sustainable Aviation Fuels (SAF) from an airport perspective is to be published in 2022.³

Groningen Airport Eelde

Groningen Airport Eelde (GRQ) is the international airport of the Northern-Netherlands, home of the KLM Flight Academy and Cirrus Sales, main European dealer of

³ <https://store.aci.aero/product-category/environment/>





Challenges		Advantages	
			
Ramp traffic and vehicle congestion	Infrastructure Costs	Less infrastructure	Boil-off recovery (up to 96%)
Truck emissions (GHG, AQ)	Maintenance Costs	Lower capital cost	Lower operating cost
Potential losses during transfer ⁴	Leak detection	Commercially available	Potentially safer
Heat source if truck has IC engine (ignition source)	Development timelines & permitting	Minimal permitting	Faster delivery

FIGURE 2: Challenges and advantages of truck and pipeline distribution inside the airport

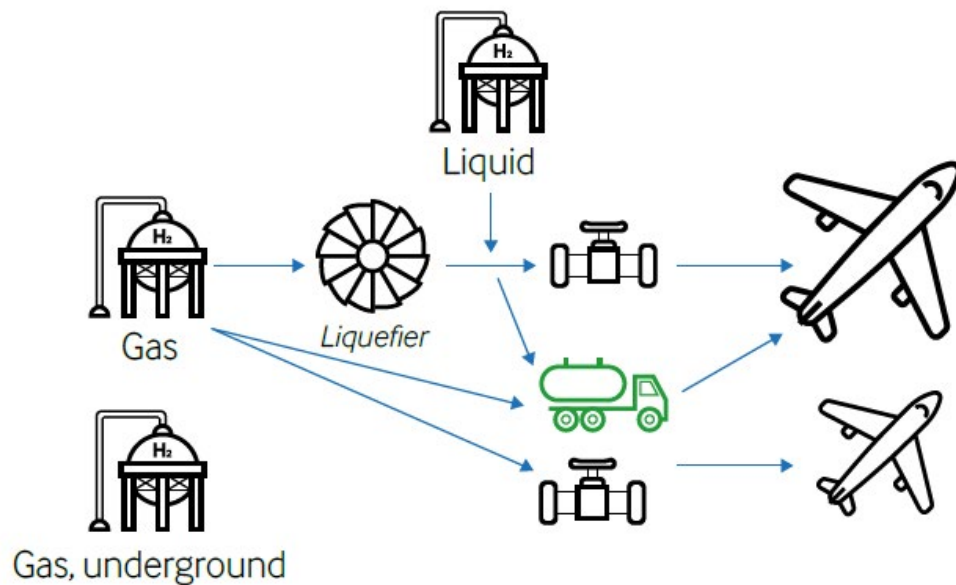


FIGURE 3: Hydrogen supply chain inside the airport



FIGURE 4: Groningen Airport Eelde

Cirrus Aircraft. GRQ is essential to the University Medical Center Groningen's organ transplant-flights and trauma-helicopter. GRQ is also a popular point of departure for holiday charters and business jet operators.

NXT Airport Initiative - GRQ has a strong focus on innovation, sustainability, and education. Its NXT Airport programme includes many projects focussing on electric flying (infrastructure) (Figure 5), eVTOL development, drones, solar-energy, hydrogen application, and education - over 300 students' study at GRQ.

Hydrogen Valley Airport - At GRQ, Europe's first 'Hydrogen Valley Airport' will be developed (Figure 6). The full-scale hydrogen ecosystem will involve production of green hydrogen, distribution, and utilisation. The starting point is its existing 22MW solar park, the largest airside solar field in operation at any operative commercial airport, with 63.000 solar panels. The airport is located in Europe's first Hydrogen Valley, which is being built by the Fuel Cells and



FIGURE 5: Projects on electric flying (infrastructure) at Groningen Airport Eelde

Hydrogen Joint Undertaking (FCH-JU) and is supported by the HEAVENN project of the New Energy Coalition and a €9 Billion Hydrogen regional Investment Agenda.

The four- to five-year project includes research, development and realisation of an electrolyser by utilising the solar park



FIGURE 6: Hydrogen Valley Airport

to produce green hydrogen onsite - a trailer-fill installation that enables filling of mobile storage. This will enable both the onsite and offsite distribution of green hydrogen, including a hydrogen refuelling station that serves both land- and airside vehicles. In this station, the Fuel Cell Electric Vehicles (FCEV) -and at a later stage airplane- can be fuelled, leading to emission-free ground handling operations.

The switch towards green hydrogen, in combination with the application of green electricity, will ensure the demonstration of full decarbonisation of airport operations.

To effectively use the regional zero-emission infrastructure, connections will be made to the regional hydrogen distribution system already in place, developed under various EU supported projects (TSO2020, DJEWELS). The interrelation with the HEAVENN project and the integrated production and green hydrogen therein can contribute to the robustness and operational excellence of the GRQ Hydrogen Valley Airport system, facilitating the ramp up and scale up of uptake of green hydrogen solutions.

Using the operational experiences of the zero-emission GRQ Hydrogen Valley Airport scalable ecosystem testbed will enable other airports to make no regret choices in the implementation of green hydrogen solutions and avoid unnecessary delays in reaching the ambition to zero emissions operation.

Kansai International Airport

Kansai Airports operates three airports in Japan: Kansai International Airport (KIX), Osaka International Airport (ITM), and Kobe Airport (UKB). In 2018, KIX was forced to close the airport for 17 days due to the severe damage caused by the high waves triggered by Typhoon Jebi. The rising sea level associated with climate change is a major risk for KIX, an artificial island surrounded by the sea, and we believe that responding to climate change is an urgent matter. Therefore, in March 2021, Kansai Airports declared to achieve zero greenhouse gas emissions by 2050 and is working on activities to reduce the burden on the environment together with the entire airport community. During such activities, the Level 4 (Transformation) of Airport Carbon Accreditation was acquired at three airports in November 2021.



FIGURE 7: Kansai International Airport

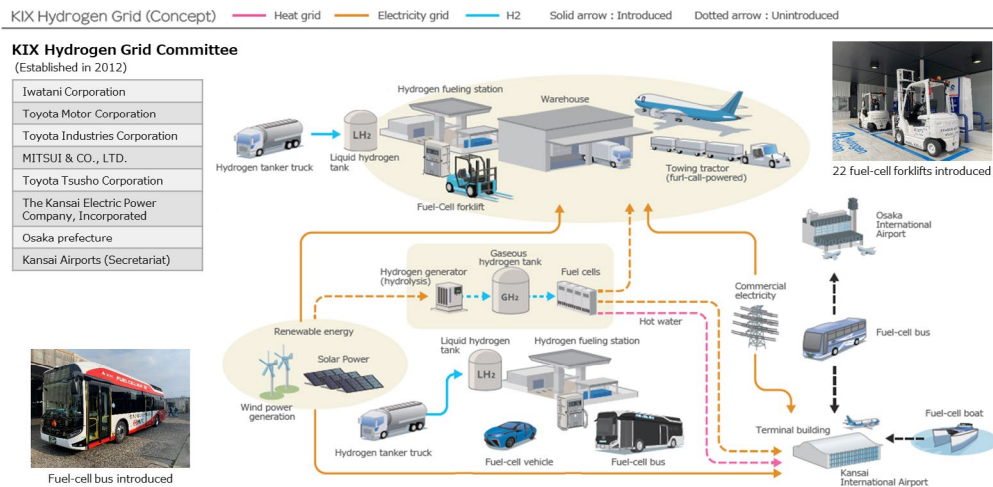


FIGURE 8: Hydrogen grid

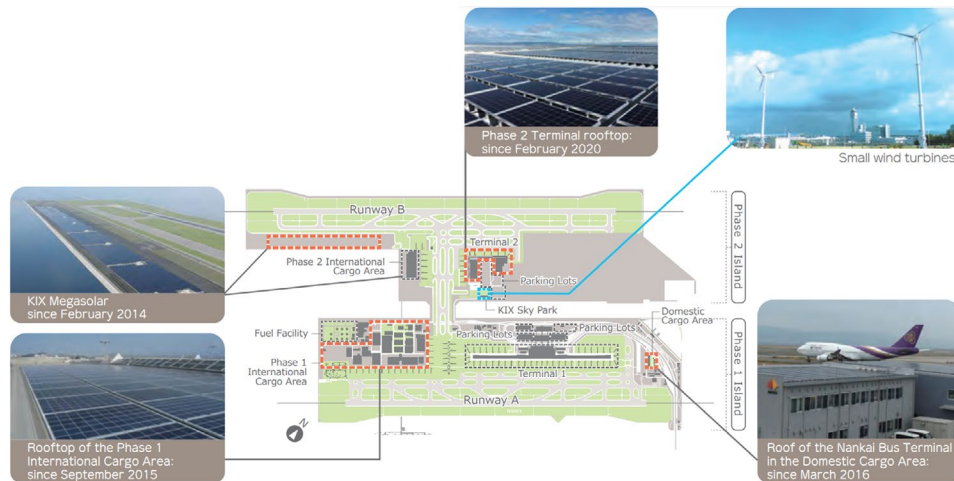


FIGURE 9: Solar power locations

Hydrogen energy - In anticipation of the advent of a hydrogen society, Kansai Airports is working with hydrogen providers, H₂ vehicle manufacturers and authorities to promote the utilisation of large-scale hydrogen energy into airport facilities and equipment. This initiative has already been implemented as a “Hydrogen Grid Project” since May 2014.

Currently, there are two hydrogen refueling facilities for vehicles in airside and landside. In addition, fuel cell vehicles (FCV), cargo-carrying Fuel Cell ForkLift (FCFL) and in-airport fuel cell buses (FC buses) are in operation (Figure 8). In particular, FCFL is low noise and exhaust gas-free, which not only reduces environmental impact but also leads to the improvement of the working environment. While expanding hydrogen vehicles, Kansai Airports will

work together with aircraft manufacturers, the Japanese government, and international organisations on hydrogen aircraft and necessary infrastructure facilities. In addition, the production and procurement of green hydrogen are major challenges Kansai Airports need to tackle to expand the utilisation of this technology.

Solar power generation - Since February 2014, solar panels have gradually been installed at KIX, which currently generate a total of 17,540MWh of electricity per year (Figure 9). We will introduce more solar power generation, mainly for self-consumption.

Accelerating efforts - Scope 3 CO₂ emissions at KIX account for three-quarters of the total CO₂ emissions, therefore joint-efforts with other airport stakeholders,

especially airlines, are extremely important (Figure 10). By expanding the above-mentioned use of hydrogen energy and solar power to airport stakeholders, it is aimed to reduce greenhouse gas emissions from three airports. The CO₂ emission reduction by airports is expected along with the promotion of decarbonisation by the Paris Agreement, COP26, and the Japanese government. In Osaka where KIX

is located, the World Exposition 2025 will be held under the slogan of “*Designing Future Society for Our Lives*” with the aim of contributing to the achievement of the SDGs and carbon neutrality. Therefore, Kansai Airports would like to accelerate its efforts for hydrogen energy and solar power generation at KIX, the gateway and first pavilion of the Exposition.

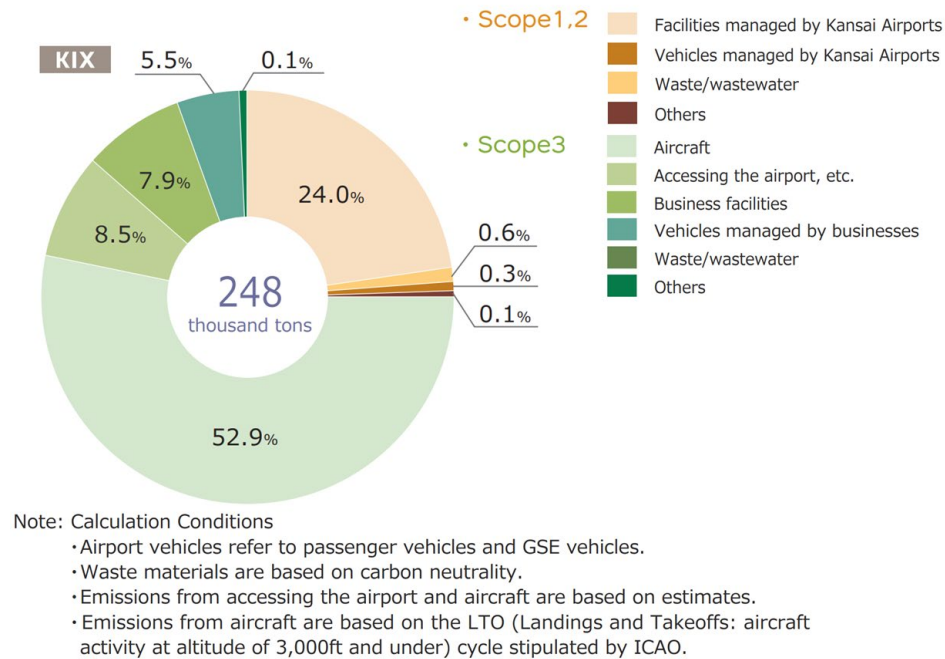


FIGURE 10: CO₂ emissions at airport as a whole (Fiscal year 2020)

Environmental Impact of Unmanned Operations at and Around Airports

By Monica Alcabin (ICCAIA – Boeing)¹

The International Civil Aviation Organization Committee on Aviation Environmental Protection (ICAO-CAEP) proposed the task of reviewing the current and future environmental impact of unmanned operations at airports globally. During the 3 year CAEP/12 cycle (2019-2022), the task group under Working Group 2- Airports and Operations conducted an extensive literature review, collected information through outreach to industry stakeholders. The task group quickly discovered that this topic was extremely dynamic, with new material on the subject emerging monthly, exacerbated by a wealth of new use cases appearing during the global COVID19 pandemic. Despite these challenges, the task group successfully delivered a State of Play report that will be published under the e-eco-airport toolkit as part of the CAEP/13 cycle.

For years, the primary use of Unmanned Aircraft (UA) was restricted to military purposes. However, over the past five years, the number of UA and their uses has grown exponentially and is expected to continue at that pace – not only for small UA (also referred to as drones), but also for unmanned aircraft that are being developed to transport passengers or cargo at lower altitudes within urban and suburban areas (referred to as Urban Air Mobility (UAM) or Advanced Air Mobility (AAM)).

AAM builds upon the UAM concept by incorporating cases not specific to operations in urban environments, such as commercial inter-city, cargo delivery, public services, and private/recreational vehicles. While many of the planned projects for UAM or AAM will start with a pilot onboard, the long-term vision is to have these aircraft either remotely piloted

or controlled through ground automation. Proposed concepts envision these UA operating between 400 ft–5,000 ft, while small UA are expected to operate below 500 ft.

The ICAO Remotely Piloted Aircraft Systems (RPAS) Panel is working on Standards and Recommended Practices (SARPS) on the technical aspects for certification and integration for international remotely piloted aircraft operating in an Instrument Flight Rules (IFR) environment flying in controlled airspace with no people onboard. However, currently there are no ICAO noise and emissions standards as there are for traditionally manned aircraft.

In October 2020, a National Aeronautics and Space Administration (NASA)-led UAM Noise Working Group released a paper identifying UAM noise needs and recommendations. The paper summarises current practices, gaps, and recommendations to close those gaps and highlights the need for noise measurement and prediction methodologies to support impact assessment, noise mitigation, and regulation. Anticipated UAM vehicles are likely to have novel and complex designs, operating modes, and operating environments for which acoustic data is currently lacking. Flight testing and measurement are critical to acquiring the necessary data to develop and validate modeling tools and noise reduction methods. Acoustic signature data is needed to understand the human response to this new noise, and to develop technologies and procedures that could help mitigate adverse impacts. Regulation and policy also require specific knowledge of noise source characteristics, both for certification and environmental reporting.

¹ Monica Alcabin is Lead of Working Group 2 Task Group “Environmental Impact of Unmanned Operations at and Around Airports” of the ICAO Council’s Committee on Aviation Environmental Protection (CAEP).



FIGURE 1: Cora, the UA from Wisk. Wisk is a joint venture of The Boeing Company.

The ICAO-CAEP Impact and Science Group (ISG) is developing a report on the state of knowledge on so-called non-acoustic factors. In addition, based on the experience with Chapter 13, CAEP Working Group 1 (Noise) will be gathering measurement data to recommend measurement procedures to define the noise footprint of these new vehicles in order to start laying the groundwork for a new standard. Research is needed to fully understand the unique acoustics effects of UA, how these will impact the public, and how they might be managed.

From an emissions perspective, small UA have the potential to provide a benefit where they can be used as a lower emission alternative for a mission typically carried out by a ground vehicle or traditional aircraft (e.g., runway inspections or calibration of navigational aids). On the other hand, the anticipated large number of larger UA that will be used for UAM/AAM operations raises issues on how these vehicles will be recharged and refueled between flights. While most UAM are expected to be electric, the carbon footprint of generating the additional electricity to charge/recharge these aircraft needs to be accounted for because, in some countries, electricity is still generated using fossil fuel.

eVTOL (Electric Vertical Take-off and Landing) operations are anticipated to operate at airports, for example, at the top of a parking garage or other building. eVTOL mobility may require additional infrastructure to accommodate the

additional loads on the electric grid that will be needed to charge/recharge these vehicles between flights. Assessment of the emissions of UA operations will need to be done on a life-cycle basis to account for the different power sources across the different types of UA.

The operations of these new entrants need to be sustainable and not impact the environmental performance of “traditional” aircraft. UAM/AAM may improve connectivity between cities and airports; however, the impact on airport operations, both landside and airside, must be understood and managed before deployment. The integration of manned and unmanned aircraft should support safe and efficient operations for all users of airspace. Any new operational requirements for UA should not have a negative impact on the environmental performance of conventional aviation nor limit conventional aviation’s access to airports and airspace.

Public and political opposition to UA operations pose a significant risk to the success and growth of this industry. Community annoyance to UA operations will differ from annoyance to traditional aircraft operations – UAs are unfamiliar in appearance and in noise characteristics; they are flown remotely at low altitudes and within close proximity to communities. This is not just a change, but an entirely new environment for residents that may be impacted by both traditional aircraft and UA operations. Just as new airport arrival and departure procedures can

introduce noise to neighborhoods that had not previously experienced that level of activity and raise opposition, airports have discovered that early and extensive community engagement is key to gaining public acceptance for any changes.

Community engagement around UA operations will be complex given that operations extend across municipalities, include airports, and co-exist with traditional aircraft operations. A harmonised approach to engagement is needed to properly convey the overall expectation around the airspace to community stakeholders.

In addition to addressing acoustic factors, a community engagement strategy should be developed that will focus on addressing non-acoustic factors such as fear around

safety, concern about intrusion, loss of privacy, sense of unfairness, anger around change in the overall environment, and degradation of nature. This will require transparency around the reasons for the change, how decisions are made, how the system works, safety rules and protocols, and an accurate prediction of impact.

It is also critical to include education on the environmental and economic benefits of UA operations as part of the strategy. Consultation should involve residents, elected officials, municipality representatives, and any other relevant community stakeholder group. For the CAEP/13 cycle, work will continue on a task to understand aviation stakeholder engagement needs for new entrants that will include UA. The goal will be to develop best practices for early community engagement.



| ICAO

CHAPTER SEVEN

Climate Change Mitigation: Sustainable Aviation Fuels

Progress of ICAO's work on SAF

By ICAO Secretariat

Sustainable Aviation Fuels (SAF) are renewable or waste-derived aviation fuels that meet sustainability criteria, as referenced in the ICAO Standards and Recommended Practices – Annex 16 Volume IV¹. They are one element of the ICAO basket of measures to reduce aviation emissions, which also includes technology and standards, operational improvements, and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

This article describes the progress of ICAO's work on SAF, included in four main workstreams: 1) development of globally-accepted **Standards** 2) Outreach of **Information**, 3) Establishment of **Policies and goals**, and 4) Supporting of **Capacity-building** in ICAO Member States.

Standards for sustainability and life cycle assessment of SAF, which represent the first global approaches to sustainability and life cycle assessment for an industry sector.

These Standards are developed by the Fuels Task Group of the ICAO Committee on Aviation Environmental Protection (CAEP). They are reflected into five ICAO documents that are referred to in Annex 16 Vol IV. Intensive work has been taken on these Standards on the last three years, in order to provide certainty to the nascent SAF and LCAF industries. This is reflected in the various amendments to these ICAO documents that have been approved by the ICAO Council in the last three years. More details on these developments are provided in Chapter 8.

Development of globally-accepted Standards

CORSIA allows aeroplane operators to reduce their offsetting requirements through the use of CORSIA Eligible Fuels, including Sustainable Aviation Fuels and Lower Carbon Aviation Fuels. To allow that, CORSIA includes

Outreach of information

The ICAO GFAAF (Global Framework for Aviation Alternative Fuels), established in 2009 after a recommendation of the ICAO CAAF/1, is a pioneering database for sharing information related to aviation alternative fuels. To



FIGURE 1: Techno-economic assessments for SAF conversion pathways

1 <https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx>

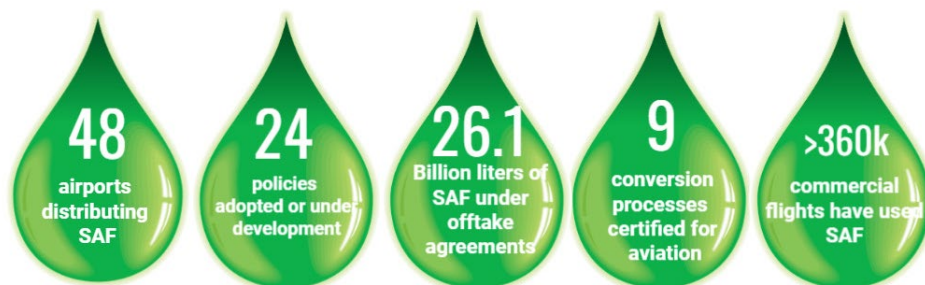


FIGURE 2: SAF tracking tools

supplement the GFAAF information, ICAO has launched a dedicated website with specific information on Sustainable Aviation Fuels², which builds upon the GFAAF information to provide includes a variety of information in support to a better understanding of SAF benefits and challenges.

SAF rules of thumb

As part of work on SAF projections, ICAO CAEP experts³ have developed a set of heuristics, or ‘Rules of Thumb’⁴ for SAF that could be utilised to make broad order of magnitude estimations related to SAF costs, investment needs and production potential. This would then inform policy makers and project developers. Techno-economic assessments have been made on the Gasification Fischer-Tropsch (GFT), Hydroprocessed Esters and Fatty Acid (HEFA) and Alcohol to Jet (ATJ) SAF conversion pathways, with details on feedstock, yield, scale, and total capital investments required.

SAF Tracking tools

The ICAO’s SAF webpage⁵ provides comprehensive documentation tracking SAF development. Its SAF tracking tools includes updates on latest news articles concerning SAF, ranging from airline offtake agreements, pilots, investments on SAF infrastructure and production, etc, as shown in Figure 2. As an example, the trackers includes details on the 26 billion litres of SAF in offtake agreements which have been documented under publicly available news sources.

A growing number of airports are also offering SAF, either continuously or in batches, as shown in the SAF airports tracker. A SAF facilities map has also been developed, providing information on facilities (existing and announced) around the world that could produce SAF (see Figure 3). The SAF tracking tools also include information on all the States that adopted or are developing SAF-related policies.

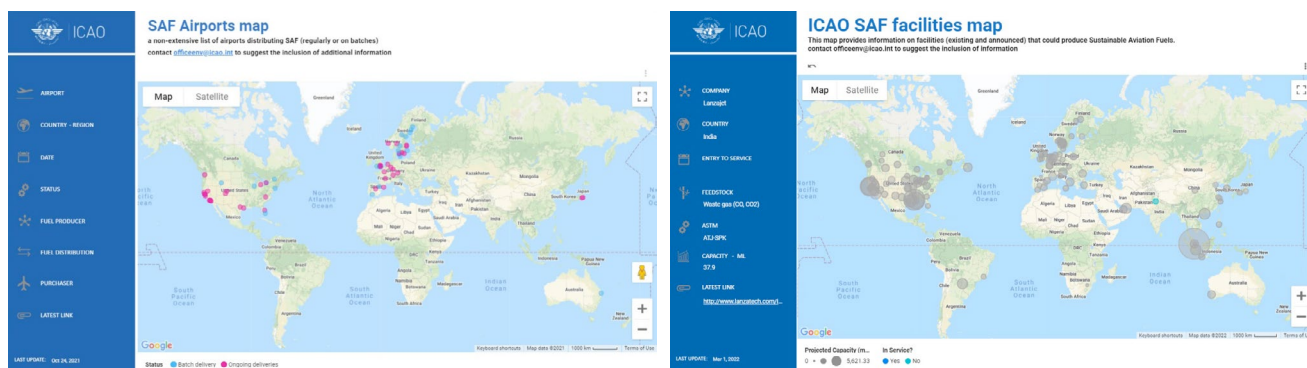


FIGURE 3: SAF airports and facilities map

² <https://www.icao.int/environmental-protection/pages/SAF.aspx>

³ From Washington State University, supported by experts from Hasselt University.

⁴ https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

⁵ <https://www.icao.int/environmental-protection/pages/SAF.aspx>

ICAO Stocktaking Process

Since 2019, the ICAO Stocktaking process is “taking stock” of global progress on the development and deployment of SAF. Building upon the success of the first ICAO Stocktaking Seminar toward the 2050 Vision for SAF held in 2019, the scope was expanded subsequently in 2020 and 2021 to encompass other possibilities for in-sector aviation CO₂ reductions in addition to SAF, to incorporate technology and operational innovations that could accelerate the realisation of sustainable aviation. The 2021 Stocktaking process also included ICAO Pre-Stocktaking webinars on synthetic fuels, hydrogen propulsion, and battery technologies, with the objective to provide a deeper understanding on these topics.

These seminars served as platforms for industry leaders, researchers and States to illustrate their concrete and ambitious plans for decarbonising international aviation. Many also took the opportunity to announce plans to support and accelerate the energy transition specific to SAF. All these Stocktaking Seminars are available to be streamed at the ICAO.TV platform.

Establishment of Policies and goals

ICAO is working to define quantified goals for SAF use. In that regard, the 2050 ICAO Vision for Sustainable Aviation Fuels calls for a significant proportion of SAF use by 2050, and a level-playing field with other sectors. The Vision also defines that a quantified long-term goal for SAF will be defined in the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3), to be held by 2025.

In addition, ICAO’s work on a long term global aspirational goal for international aviation (LTAG) also has an important fuel-related component, since the LTAG report shows that the largest CO₂ reductions for aviation by 2050 is expected to come from fuels. More details on these results are provided in the LTAG Supplement.

The contribution of SAF to the ICAO environmental goals is also reflected in ICAO’s Global Environmental Trends, which develops tools to regularly assesses the present and future impact of aircraft noise and engine emissions. This is integral to providing a robust reference to facilitate discussion and decision making in ICAO. The ICAO Environmental Trends are further elaborated in Chapter 1.

Supporting of Capacity-building in ICAO Member States.

Partnerships have also been established to promote the energy transition towards SAFs. Under the ICAO-UNDP-GEF assistance project ‘Transforming the Global Aviation Sector: Emissions Reductions from International Aviation’, a SAF Guide⁶ was developed to inform ICAO Member States on how SAF can be deployed to reduce CO₂ emissions from international aviation activities. Targeted feasibility studies on the use of SAF have also been developed as part of the ICAO-EU assistance project ‘Capacity Building for CO₂ mitigation from international aviation’.

ICAO regularly invites States and Organisations to indicate their interest in supporting or benefiting from potential future feasibility studies on SAF. In that regard, ICAO has recently launched the ACT-SAF Programme (Assistance, Capacity Building and Training for Sustainable Aviation Fuels), an ICAO initiative to facilitate the development and deployment of SAF. ACT-SAF will provide tailored support for States and facilitate cooperation under ICAO coordination. It will also develop a platform a Platform to facilitate knowledge sharing and progress monitoring. More information on this new Programme is provided in Chapter 11.

Conclusion

SAF is expected to contribute significantly to global efforts in reducing international aviation emissions. This article describes the various activities undertaken by ICAO to support the development and deployment of SAF, contributing to the 2050 Vision on SAF, and ICAO’s goal to limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

6 https://www.icao.int/environmental-protection/Documents/Sustainable%20Aviation%20Fuels%20Guide_100519.pdf

Key findings of IPCC sixth assessment cycle

The role of bio-based Sustainable Aviation Fuels in global climate mitigation pathways

By Joana Portugal-Pereira and Eduardo Müller-Casseres (Centre for Energy and Environmental Economics - CENERGIA, Federal University of Rio de Janeiro, Brazil)

IPCC mitigation scenarios

The recent UN Intergovernmental Panel on Climate Change (IPCC) Working Group III contribution to the Sixth Assessment Report (hereafter IPCC WG III AR6) reinforces that we are not on track to limiting global warming to 1.5°C by the end of the century. Although last decades marked significant advances in mitigation efforts and more than 20 countries have decoupled economic growth from greenhouse gas (GHG) emissions, a deep reduction of emissions requires major transformations at unprecedented scales in all sectors of the economy (Skea et al., 2022). This is particularly challenging for the aviation sector, as aircraft low-carbon technological strategies have not reached innovation maturity yet and efficiency improvements in air traffic operations present limited mitigation potential (Carvalho et al., 2019; Jaramillo et al., 2022).

According to the evaluation of the submitted and announced NDCs prior to COP26, annual GHG emissions will likely reach 50-53 [47-57] GtCO₂e by 2030, which exceeds 1.5°C during the 21st century and may lead to a median global warming of 2.8 [2.1 to 3.4]°C before 2100 (Skea et al., 2022). An emission gap of 6-16 and 16-26 GtCO₂e.yr⁻¹ needs to

be closed to stabilise warming to 2°C (>67% likelihood) and 1.5°C (>50% likelihood) levels, respectively (Lecocq et al., 2022). The next few years will therefore be crucial to decline emissions. Closing the 1.5° (>50%) warming gap with no or limited overshoot requires accomplishing three landmarks: (i) reach the peak of global GHG emissions as soon as possible and no later than 2025, (ii) reduce GHG emissions by 43% [34-60%] in the course of the next decade, and (iii) achieve nearly net CO₂ emissions by mid-century (Pathak et al., 2022; Skea, 2022). If we aim at closing the gap to achieve the 2°C (>67% likelihood) warming level, we have a bit more time to reduce CO₂ emissions to net zero by 2070's, but the task is still massive (Riahi et al., 2022).

A wide range of integrated assessment model (IAM) scenarios from the literature were assessed in the IPCC WG III AR6 and made available in the IPCC WG III AR6 scenario explorer and database¹ hosted by IIASA (Byers et al. 2022). More than 2,000 global mitigation scenarios² assessed by the report were classified into eight categories according to their degree of climate ambition ranging from narratives that reflect a limit warming to 1.5°C with no or limited overshoot or a warming of 4.0°C by the end of the century

1 An opensource database of quantitative scenarios with data on socio-economic development, greenhouse gas emissions, and sectoral transformations across energy, land use, transportation, buildings and industry is available at: <https://data.ene.iiasa.ac.at/ar6/#/downloads> (Byers et al 2022).

2 *Mitigation scenarios* are plausible descriptions of how the future may develop based on implementation of policies and measures to reduce GHG emissions consistent with assumptions about key driving forces (e.g., rate of technological change, prices). Scenarios are used to provide scientific sound information to policymakers on views of the implications of certain developments and actions, but by no mean shall be interpreted as predictions or forecasts (Guivarch et al 2022).

(Table 1). Among those, seven scenarios were selected to reflect the key findings of recent emission scenario literature (Figure 1). Two of these pathways are illustrative pathways (IPs) that reflect high (CurPol) and moderate (ModAct) emission trajectories. The CurPol scenario projects emissions based on policies implemented by the end of 2020, while ModAct depicts a pathway compatible with pledges of Paris Agreement NDCs. The five remaining scenarios, referred to as Illustrative Mitigation Pathways (IMPs), describe pathways with deep and rapid emissions reductions. They have a few common features but reflect different combinations of sectoral mitigation strategies. In all IMPs, global warming is limited to below 2°C over the whole century (with >67% likelihood). Furthermore, in IMPs with significant upfront emission reductions (Ren, LD, and SP), warming is limited to 1.5°C at the end of the century after a low overshoot (with >50% likelihood).

TABLE 1: Temperature categories and their relationship with the IMPs.

Categories	Description	IPs/IMPs
C1	Limit warming to 1.5°C with no or limited overshoot	LD, Ren, SP
C2	Return warming to 1.5°C after a high overshoot	Neg
C3	Limit peak warming to 2°C	GS
C4	Limit warming to 2°C	—
C5	Limit warming to 2.5°C	—
C6	Limit warming to 3.0°C	ModAct
C7	Limit warming to 4.0°C	CurPol
C8	Exceed warming of 4.0°C	—

Decarbonisation of the aviation sector

Among all IMPs, the aviation sector is considered a hard-to-abate sector given its dependency on fossil jet-A fuel and long timescale infrastructure turnovers. Figure 2 presents mitigation scenarios for travel demand and carbon dioxide emissions of the aviation sector up to 2100 under different

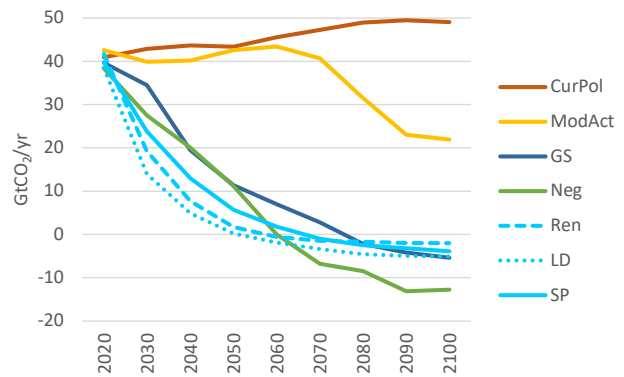


FIGURE 1: Net CO₂ emissions of modelled pathways. Source: Own elaboration based on Byers et al. (2022).

global warming assumption categories³. Although there is much uncertainty related to post-Covid19 pandemic recovery, scenarios without firm commitments to meet long-term temperature targets (C7) indicate a nearly six- and 12-folded increase in travel demand by 2050 and 2100, respectively, which suggests CO₂ emissions rise by a factor of six in 2050 and eight in 2100, over 2020 levels. In more stringent scenarios to limit warming to 2°C (>67% likelihood) (C3) and 1.5°C (50% likelihood) with no or limited overshooting (C1), aviation energy demand still rises, but in a lower level and travel demand peaks around 2080-90's. In terms of CO₂ emissions, the sector could reach net zero CO₂ emissions (C1) or stabilise emissions at 1470 MtCO₂ emissions yearly (C3), a 37% decline compared to a current policy scenario (C7).

To speed up mitigation strategies in the aviation sector, the IPCC WG III AR6 report highlights six major strategies to reduce emissions in the sector, namely: (i) Technology options for engine and airframe, (ii) Operational improvements for navigation, (iii) Bio-based, synthetic, and liquid hydrogen-based sustainable aviation fuels, (iv) Technological and operational trade-offs between CO₂ and non-CO₂ effects, (v) Market-based offsetting measures, and (vi) Modal shift to High-Speed Rail. Among these, bio-based sustainable aviation fuels (hereafter bio-SAF) present the highest potential and technology readiness level (TRL), varying from TRL5 for alcohol-to-jet (ATJ) routes and TRL9 for hydro-processed esters and fatty acids (HEFA) synthesis (Portugal-Pereira et al., n.d.). Bio-SAFs also have a high potential to support mitigation

³ Selected scenarios were based on IMAGE model results (Byers et al. 2022).

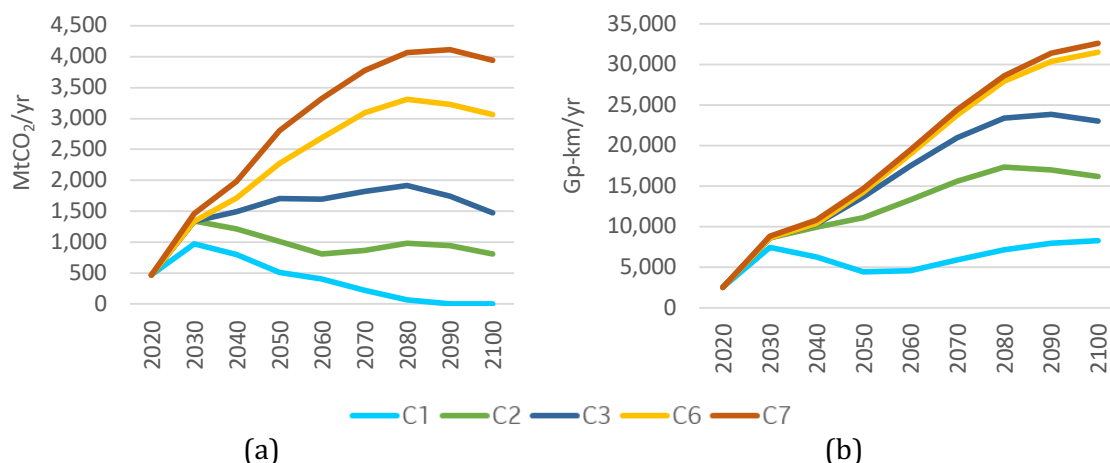


FIGURE 2: The aviation sector in selected mitigation scenarios from the IPCC WG III AR6: (a) CO₂ emissions (million tonnes per year) and (b) passenger aviation demand (billion passenger-kilometre per year).
Source: Own elaboration based on Byers et al. (2022).

scenarios in the short- and mid-term and to keep up with the projected growing demand for air traffic passengers and cargo. Further, bio-SAF conversion units may be coupled with carbon dioxide capture and storage (CCS) units, which could result in negative emission technologies. Thus, the IPCC WG III AR6 suggests that the deployment of bio-SAF is a leading strategy to coping with expected growing demand of aviation without increasing CO₂. As of October 2021, the American Society for Testing and Materials (ASTM) has certified nine conversion processes of bio-SAF with blends ranging between 5 and 50%.

Bio-SAF can be produced from a high range of biomass feedstocks, including cultivated sugar, starch, oily, and lignocellulosic feedstock crops, algae biomass, agricultural crop residues, municipal solid waste, waste fats, wood products and forestry residues (Carvalho et al., 2019). The production potential entails high uncertainty, but recent literature assessed in the IPCC Special Report on Climate Change and Land (hereafter IPCC SRCCL) consider that sustainable production of bioenergy could vary between 100 and 170 EJ (Calvin et al., 2021; Creutzig et al., 2015; Frank et al., 2021; Wu et al., 2019).

Benefits and potential adverse-side effects of bio-SAFs

While an important strategy in the mitigation of the aviation sector, the bio-SAF life cycle has variable carbon footprints due to various production methods, methodological approaches and associated land-use change. Estimations suggest that bio-SAF can reduce life cycle GHG emissions by 2-70% compared to conventional fossil jet-A under a wide range of scenarios (Jaramillo et al., 2022). However, large-scale production of bioenergy may result in significant land use changes and adverse side-effects for food security and terrestrial ecosystem services (de Coninck et al., 2018; Smith et al., 2019).

The magnitude of co-benefits and adverse side effects depends on a variety of factors, including the feedstock, management regime, climatic region, other demands for land, and scale of deployment (Calvin et al., 2021; Smith et al., 2019). Generally, the use of waste feedstocks and planting dedicated crops on degraded land result minimises competition for land and results in low GHG emissions, but land-related footprint increases when considering large-scale bioenergy supply scenarios.

The IPCC SRCCL draws attention to the potential adverse effects of bioenergy production on food security. The use of food crops for bioenergy, or cultivation of energy crops on high-quality arable land, can displace food production,

leading to increased food prices and land use changes to meet demand for displaced food crops (IPCC, 2019; Mbow et al., 2018; Smith et al., 2019). Moreover, the production of bioenergy may have negative impacts on water resources. Reporting of water impacts on ecosystems caused by the implementation of modern bioenergy systems varies significantly (Neary, 2018). While some assessments include only active human uses such as irrigation and water used in biofuels conversion processes, others include hydrologic processes such as evapotranspiration, infiltration, runoff, and baseflows, which are natural ecosystem processes influenced by human activity (Neary, 2013).

Finally, bioenergy production for bio-SAFs can affect wild and agricultural biodiversity in a positive way, if applied in restoration of degraded lands, but may also have negative impacts, for example when natural forestry landscapes are converted into energy cropland or peatlands are drained (IPBES, 2019; IPCC, 2019; Pathak et al., 2022). In general, wild biodiversity is threatened by loss of habitat when the area under crop production is expanded, whereas agricultural biodiversity is vulnerable in the case of large-scale monocropping, unsustainable fertilizer usage, and limited genetic variety.

In conclusion, IPCC WG III AR6 mitigation scenarios suggest that bio-SAFs are the most competitive strategy in the short- and mid-term to cope with stringent mitigation scenarios compatible with keeping global warming to 1.5°C and 2°C by the end of the century. However, large-scale deployment of bioenergy may compete for biomass and land, increasing pressure on terrestrial ecosystem services and other sustainable development dimensions beyond climate mitigation. The magnitude of adverse side effects and risks are local and context specific, but tend to be severe to food security, land tenure, water resources, soil quality and biodiversity, if institutions and weak governance fail in protecting natural ecosystem services and the most vulnerable people dependent on land-based activities.

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The role of renewables in decarbonising the aviation sector

**By Francisco Boshell, Seungwoo Kang, Ricardo Gorini and Maisarah Abdul Kadir
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Introduction

Globally, aviation produced 915 million tonnes of carbon dioxide (CO₂) in 2019. The sector's emission contributes about 2% of the world's CO₂ emissions and about 12% of all transport emissions. Non-CO₂ emissions from aviation also have a significant climate impact, contributing almost two-thirds of net radiative forcing¹. This is projected to double by 2050 in a business-as-usual scenario. Although the COVID-19 pandemic has affected the sector's emissions, the industry is likely to recover, reaching and exceeding pre-COVID emissions within a few years. The aviation sector consumed over 14 EJ in 2019, including civil aviation and non-commercial aviation (general, private and military use)², where international aviation accounts for 60% of the energy consumption, while remaining 40% for domestic aviation. Aircraft typically use jet kerosene, refined from crude oil. This counts to almost all (99.9%) the energy consumption for aviation, with aviation gasoline and sustainable aviation biofuels (SAFs) being the rest of the consumption.

Renewables provide options to decarbonise the aviation sector

Considering today's status with the added long-lasting impact of the pandemic, IRENA's 1.5°C Scenario foresees

that decarbonising the aviation sector requires major transitions in several components; such as the reduction of aviation demand and accelerated fuel efficiency improvements, a robust mixture of low-carbon fuels in the form of biojet fuels and synthetic kerosene, and the commercialisation of new electric and hydrogen aircraft. The fuel efficiency performance for airlines has improved on average 2% annually between 2009 and 2019³. This was largely the results of new generation aircraft and operational improvements. While improvement in fuel efficiency can curb carbon emissions in the short term, decarbonising the sector requires additional measures including new aircraft technologies (including electricity and hydrogen-powered aircraft), participation of sustainable aviation fuels (SAFs), the use of synthetic fuels supported by market-based measures, some of which was echoed by the International Civil Aviation Organization's (ICAO) commitment to address climate change⁴.

Several options powered by renewable energy can be discerned: electric batteries and green hydrogen (both for short-haul flights only); synthetic fuels produced from green hydrogen (made from splitting water molecules into hydrogen and oxygen using renewable electricity) — also known as electrofuels or e-fuels; and biofuels (IRENA, 2020⁵).

1 <https://www.sciencedirect.com/science/article/pii/S1352231009003574?via%3Dihub>

2 <https://www.iea.org/reports/world-energy-balances-overview>

3 <https://www.atag.org/component/factfigures>

4 <https://www.icao.int/environmental-protection/pages/climate-change.aspx>

5 <https://www.irena.org/publications/2020/Sep/Reaching-Zero-with-Renewables>

Renewables based Sustainable Aviation Fuel (SAF)

Airlines can only fly with fuels that have been approved by the industry under the auspices of US-based standards organisation ASTM International. So far, these have been limited to biofuels and e-fuels (also known as powerfuels). SAF production covers less than 1% of the global jet fuel demand with around 100 million litres of SAF produced in 2021⁶.

Sustainable aviation fuel, including biojet, has recently increased its production as more countries and airlines commit to reduce their CO₂ emission through use of SAFs. They are commonly used as drop-in fuels, blended with fossil fuel jet kerosene, up to a maximum of 50%. Majority of the SAFs produced today are HEFA-SPK⁷, while the other SAFs approved by ICAO have not yet reached commercialisation.

Developments in regional and national mandates — The European Union proposed in the ReFuelEU initiative fuel suppliers to include more SAF into jet fuel from 2030 to 2050⁸:

- 2% by 2025;
- 5% by 2030;
- 20% by 2035;
- 32% by 2040;
- 38% by 2045;
- 63% by 2050.

At country level, the USA has announced in September 2021 a goal of replacing all conventional jet fuel with SAF by 2050 — (projected at 130 billion liters per year), starting with SAF production of 12 billion liters annually by 2030 in co-ordination with Airlines for America. The UK has also announced a mandate to have at least 10% of their annual jetfuel production from SAF by 2030, and 75% by 2050⁹.

The expansion in other regions of similar initiatives may rapidly scale up the demand for SAF and bring economies of scale enhancing its competitiveness.

Biofuels — The use of biojet fuels would comprise of 47% of the total fuel consumption, or around 204 billion liters of biofuels produced annually in the IRENA's 1.5°C scenario¹⁰.

To date, nine pathways have received ASTM certification, which allows biojet fuel to be blended with petroleum-derived jet fuels or co-processed, but only one is said to be technically mature and commercialised — the process that uses vegetable oils, waste oils and fats (often used cooking oil) as its feedstock, known as HEFA-SPK (hydroprocessed esters and fatty acids synthetic paraffinic kerosene). More than 95% of biofuel flights to date have used HEFA-SPK fuel.

Global biofuels production totalled 150 billion litres in 2018, but just 17 million litres of advanced biofuels for aviation was produced, all from a single plant in California¹¹. Thus, rapid upscaling of biofuel for aviation is needed, and the share of aviation fuel in total biofuel must increase rapidly for a meaningful contribution. To significantly scale up production, alternative feedstocks such as lignocellulosic biomass, and technologies such as gasification with FischerTropsch (FT) and/or pyrolysis or hydrothermal liquefaction will be required.

IRENA surveyed leading advanced biofuel investors from Europe, Brazil, China and North America to obtain their perspectives on industry development and the main barriers for deployment¹². A high-level overview of the findings show that concerns about the stability of regulation are dominant, including the level of blending mandates and subsidies. However, economic concerns are also key, including feedstock cost, conversion efficiency and capital expenditure. Public perception, notably, does not represent a major concern.

6 <https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/>

7 Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)

8 https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3525

9 <https://www.nortonrosefulbright.com/de-de/wissen/publications/f81d3390/new-regulatory-initiatives-supporting-sustainable-aviation-fuel>

10 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_World_Energy_Transitions_Outlook_2021.pdf

11 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Sep/IRENA_Reaching_zero_2020.pdf

12 <https://www.irena.org/publications/2021/Jul/Reaching-Zero-with-Renewables-Biojet-Fuels>

E-fuels—According to IRENA, the use of synthetic kerosene will also be needed in a 1.5°C Paris Agreement aligned scenario, where they would comprise up to 23% of fuel use by 2050 with almost 100 billion liters of fuel required.¹³

Synthetic kerosene, also known as power-to-liquids (PtL), are drop-in fuels that, in theory, can provide very low-carbon-intensity transport fuels. The key process step is the utilisation of renewable energy sources (wind, hydro, solar) to electrolyse water and produce hydrogen. When the “green” hydrogen is combined with “green” or waste carbon sources, CO or CO₂, via processes such as FT synthesis, hydrocarbon fuels can be produced, including a jet fraction. The CO/CO₂ can also be obtained via direct air capture. Power-to-liquids are ASTM certified since 2009 for 50% blends. The ability to capture CO₂ at low cost is critical, as is the availability of low-cost renewable power to produce hydrogen.

Electric aircraft

The introduction of novel aircraft running on hydrogen and electricity (or hybrid) for regional short-haul flights is expected to take place by 2035.

Electrically assisted propulsion involves the use of electric motors to drive some or all of the propulsion on an aircraft. Typically, propulsion relies on electric energy storage (e.g. batteries), hybrid energy (e.g. a mix of electric and fuel-based propulsion) or turboelectric (e.g. fuel-based energy). Electric aircraft are already being assessed for their potential over short distances, such as vertical take-off and landing, for urban transport or for short distances over mountainous terrain. They can be fully carbon neutral if powered by 100% renewable electricity.

ICAO lists 27 electric planes currently in development by companies such as Boeing and Airbus, as well as five hybrid-electric models that would be partly propelled by electric motors. Given today’s batteries, this option is only feasible for small planes for short range flights (several hundred kilometers range).

Aircraft can use hydrogen either as a fuel for a jet engine or to supply a fuel cell that can provide electricity for propulsion¹⁴. When used as a fuel, hydrogen must be compressed or stored as a cryogenic liquid, with safe storage and refuelling recognised as critical steps. The main problem is that the hydrogen storage would take substantial space and the planes need to be redesigned for this. This is a process that would take decades. The world’s first four-seat passenger aircraft powered by a hydrogen fuel cell took off for the first time in 2016. The plan is to at least double the performance of the fuel cell over time, and to store hydrogen three times more efficiently. Airbus recently announced a target of enabling the “first climate-neutral, zero-emissions commercial airplanes up to cruising altitude within the next 15 years”. They suggest that two types of aircraft will be available by this time: a 200-passenger aircraft that can fly up to 3 700 km or 2 000 nautical miles, and a 100-passenger aircraft that can fly up to 1 850 km or 1 000 nautical miles¹⁵. In IRENA’s 1.5°C Scenario, both electric and hydrogen aircraft can potentially replace 35% of short haul flights of less than 1100 km.

Priority action areas

Decarbonising the aviation sector by 2050 is not possible without significant commitments from aircraft manufacturers, airlines and national governments to shift towards carbon-neutral technologies. While improvement in fuel efficiency can curb carbon emissions in the short term, decarbonising the sector requires additional measures including new aircraft technologies (including electricity and hydrogen-powered aircraft), participation of sustainable aviation fuels (SAFs), and the use of synthetic fuels.

Large investments into sustainable aviation fuel (SAFs) supply chain and production facilities around the world is clearly needed. Regions with strategic transport hubs, technological capacity, and abundant bioenergy potential could benefit as exporter and refueling hub for biojet fuels, as seen in future SAF production plants in USA, Brazil, Singapore and the Nordic Region. Regulatory

¹³ https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_World_Energy_Transitions_Outlook_2021.pdf

¹⁴ https://www.researchgate.net/publication/331430429_Comprehensive_investigation_on_hydrogen_and_fuel_cell_technology_in_the_aviation_and_aerospace_sectors

¹⁵ <https://www.emarketer.com/content/small-electric-aircrafts-making-inroads-tech-limitations-mean-long-flights-still-decades-away>

frameworks that assesses the fuel's sustainability should also be strengthened, as is currently being done under ICAO's Carbon Offsetting & Reduction Scheme for Aviation (CORSIA)¹⁶. The same applies to regions with abundant renewable electricity potential that could be used to produce green hydrogen and derive synthetic fuels from. With increased commitments and market-based measures such as in the EU (EASA, EEA, EUROCONTROL, 2019), biojet fuels and synthetic kerosene have the potential to be cost-competitive with jet kerosene by 2050.

For future aircraft propulsion technologies, more concentrated efforts in research and innovation is required before electricity and hydrogen powered aircraft can be fully commercialised in the short-haul segment by 2035. This is particularly pertinent for high-density battery technologies, where the battery storage limits the size and range of electric aircraft. Finally, airlines and governments should continue to support ICAO's CORSIA scheme and target of carbon neutral growth from 2021 (ICAO, 2020), while also taking the view that curbing the global appetite and demand for flying is the simplest yet necessary step towards decarbonisation.

16 <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

Decarbonising Aviation in the IEA's Net Zero Emissions by 2050 Scenario

By Praveen Bains, Hyeji Kim and Jacob Teter (International Energy Agency – IEA)

The roadmap for aviation in the Net Zero Emissions by 2050

The energy sector is the source of around three-quarters of greenhouse gas emissions today. In the International Energy Agency (IEA) Net Zero by 2050 Roadmap¹ (henceforth “NZE”), we have analysed a pathway where the global energy sector achieves net-zero CO₂ emissions by 2050 with no offsets from outside the energy sector, and with low reliance on negative emissions technologies. It is designed to maximise technical feasibility, cost-effectiveness and social acceptance while ensuring continued economic growth and secure energy supplies.

In the NZE, the aviation sector remains one of the net emitters by 2050, together with other sectors where emissions are hard to abate such as cement, iron and

steel, chemical, road freight and shipping (Figure 1). Despite rapid adoption of sustainable aviation fuels (SAFs) and alternative technology options using electricity and hydrogen, residual emissions from aviation total about 210 Mt (direct emissions from fossil fuel combustion) by 2050, or just over 10% of unabated CO₂ emissions from fossil fuels and industrial processes.

The aviation sector today is characterised by the low technology readiness level of zero or near zero emissions technology options, with over 90% of the future abatement potential lying in different technologies that are in prototype or demonstration phase today². These include both the most promising production pathways for expanding low-life cycle emissions SAFs, as well as new engine and aircraft designs (such as open rotor and blended-wing-body aircraft). Commercial aircraft taking advantage of

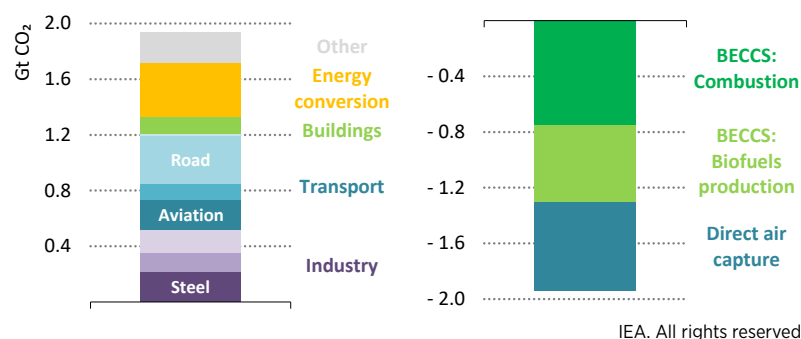


FIGURE 1: Residual CO₂ emissions by sector and of negative CO₂ emissions by carbon removal technology in the NZE, 2050
Note: BECCS = bioenergy with carbon capture and storage. Source: IEA (2021), Net Zero by 2050, IEA, Paris³

1 IEA (2021), Net Zero by 2050, IEA, Paris <https://www.iea.org/reports/net-zero-by-2050>. The IEA disclaims that the Roadmap describes one pathway but that is not the only pathway that can lead to net zero in 2050 depending on different variables and uncertainties, including significant uncertainties arising from the ongoing Covid-19 pandemic and the recent Russian invasion of Ukraine.
2 IEA (2021), ETP Clean Energy Technology Guide, IEA, Paris <https://www.iea.org/articles/etp-clean-energy-technology-guide>
3 <https://www.iea.org/reports/net-zero-by-2050>

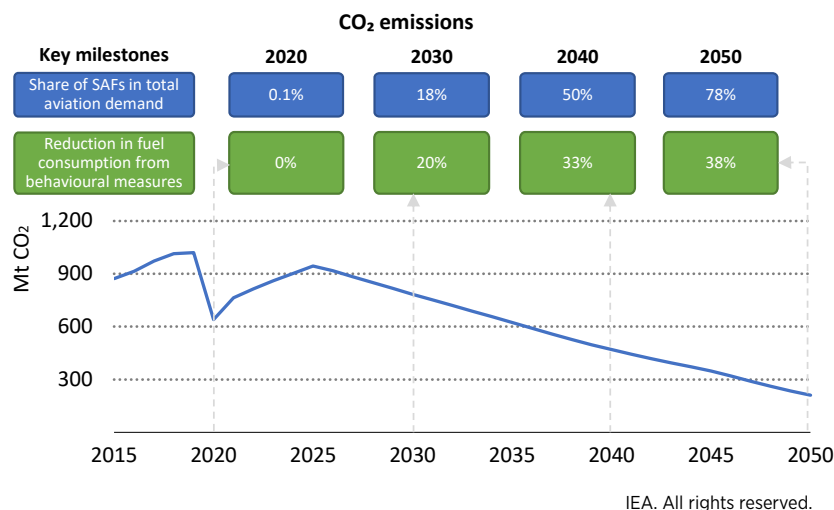


FIGURE 2: CO₂ emissions trajectory and key milestones for the aviation sector in the NZE, 2015-2050. Source: IEA (2021), Net Zero by 2050, IEA, Paris⁴

hybrid or even full electric propulsion, or running directly (whether via direct combustion or with fuel cells) on hydrogen, are likely to become commercial in the 2030s at the very earliest. In addition to accelerating innovation, the IEA analysis (Figure 2) emphasises the importance of reaching key milestones in improving energy efficiency, increasing adoption of sustainable aviation fuels and managing demand to meet the NZE trajectory.

The IEA pathway recognises the centrality of SAFs in reducing in-sector aviation emissions. In the IEA's NZE, SAFs, mostly bio-kerosene, represent already around 15% of aviation fuel demand in 2030, increasing to 80% in 2050. Direct use of hydrogen and electricity also plays a role in short-haul flights in the NZE, each contributing around 1% to final aviation demand.

The basis of the analysis in the NZE developed in 2021 is that passenger aviation demand grows more than threefold by 2050 in the absence of demand management. In the NZE, measures that require change of individual's behaviour – keeping air travel for business and long-haul flights for leisure at 2019 levels, plus modal shift from short-haul flights to high-speed rail – can lead to a 50% reduction in emissions while reducing the number of flights

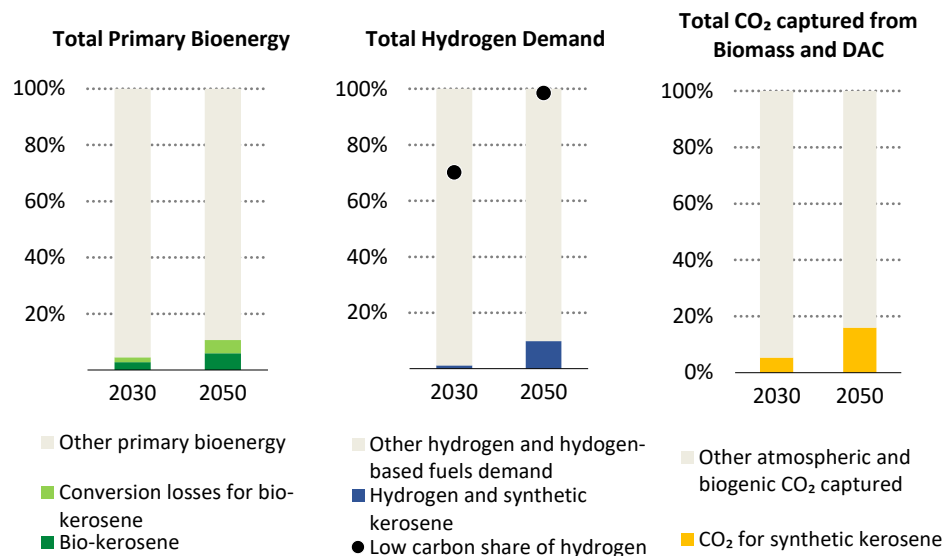
only by 12%. The IEA continues to assess the potential for measures to reduce overall demand such as limits on airport capacity expansion, frequent flier levies and supporting high-speed rail, as preferable to out-of-sector offsets in terms of providing wider societal benefits and having less risk of leakage, enforcement, or less complex verification.

Making energy supply fit for net zero aviation

Bio-kerosene production from advanced⁵ feedstocks is prioritised over other feedstocks in the NZE, even if in the short term certain conventional feedstocks are more economically competitive and readily scaled up. Bio-kerosene based on waste lipid feedstocks using the hydrogenated esters and fatty acids (HEFA) is already commercialised, and is the dominant SAF in the NZE in the near-term. However, HEFA bio-kerosene is limited by the supply of waste oils. Expanding bio-kerosene production to the volumes within the NZE hinges on commercialising technologies to convert woody biomass feedstocks into liquid biofuels (such as biomass gasification with Fischer-Tropsch and alcohol-to-jet). Additionally, these pathways can be paired with Carbon Capture Utilisation and Storage

⁴ <https://www.iea.org/reports/net-zero-by-2050>

⁵ Advanced feedstocks refer to waste and residues feedstocks as well as nonfood energy crops (e.g. miscanthus, poplar, jatropha) grown on marginal lands, minimizing impacts on food prices, land availability, biodiversity, soil health, and fresh water systems.



IEA. All rights reserved.

FIGURE 3: Share of aviation use in key metrics of energy and CO₂ supply in the NZE, 2030 and 2050. Note: DAC = direct air capture. Source: IEA (2021), Net Zero by 2050, IEA, Paris⁶

(CCUS) at relatively low costs.⁷ Production using advanced woody feedstocks is mostly under development today; projects currently in the pipeline are critical in ensuring bio-kerosene is ready to scale up by 2030. Improvements in collecting and sorting residue feedstocks (such as organic municipal solid waste, crop residues) and experience in cultivating nonfood energy crops on marginal lands are equally important to ensuring the sustainable scale up of bio-kerosene. While bio-kerosene could reach production costs of 110-140 USD/bbl by 2050 in the NZE (and potentially lower with a carbon price),⁸ costs are strongly dependent on highly uncertain biomass feedstock costs. In 2050, around 11 EJ of primary bioenergy⁹ is converted into 6 EJ of bio-kerosene for aviation.

Synthetic kerosene, produced from CO₂ and electrolytic hydrogen, is further away from commercialisation than bio-kerosene from woody feedstocks. In the NZE, synthetic

kerosene is produced at scale starting in 2040. While components of synthetic kerosene production are already commercialised today (such as synthesis¹⁰) full system integration including carbon-neutral CO₂ and renewable electrolytic hydrogen remains in the development phase. Additionally, production costs are very high today (300-700 USD/bbl), mostly driven by renewable electricity costs and inherently low conversion efficiencies. As the cost of renewable electricity as well as electrolyzers for hydrogen and direct air capture for CO₂ fall with greater deployment in the NZE, production costs could decline to 130-300 USD/bbl by 2050. The scale-up of synthetic kerosene is not limited by the same resource constraints as bio-kerosene, however, and use of biogenic carbon sources, and eventually direct air capture in concert with additional renewable energy may (Figure 3) lead to greater life-cycle CO₂ reduction potential than “pure” biomass-based production pathways without CCUS.

⁶ <https://www.iea.org/reports/net-zero-by-2050>

⁷ Both biomass gasification and Fischer-Tropsch as well as ethanol production produce relatively pure streams of CO₂ that can be captured and stored to produce negative emissions, or utilised, for example to produce synthetic kerosene.

⁸ For example, assuming a feedstock cost of 6 USD/GJ, a carbon price of 150 USD/t CO₂ in 2050 could lead to bio-kerosene production cost of 70 USD/bbl for the biomass gasification and Fischer-Tropsch route with carbon capture and storage, producing negative emissions.

⁹ In the NZE, around 100 EJ of sustainable primary bioenergy is considered to be available. For more information, please refer to: IEA (2021), What does net-zero emissions by 2050 mean for bioenergy and land use?, IEA, Paris <https://www.iea.org/articles/what-does-net-zero-emissions-by-2050-mean-for-bioenergy-and-land-use>

¹⁰ Synthesis refers to the process of converting syngas (consisting of CO, CO₂ and H₂) into hydrocarbons such as methane, diesel or kerosene.

Recommendations

Policy instruments will need to simultaneously provide certainty for a rapid technology development and scale up of SAF production while progressively prioritising those SAF production pathways that can demonstrate verifiable cost-competitive greenhouse gas emissions reductions on a life-cycle basis. Decisions will be needed by 2025 at the latest on how best to create markets for SAFs and close the cost gap between SAFs and fossil fuels, considering mechanisms such as low-carbon fuel standards, biofuel

mandates, CO₂ prices and CO₂ removal credits. Governments also need to define their strategies for low-carbon fuels in aviation by 2025, given the slow turnover rate of the fleets, after which they should rapidly implement them. International co-operation and collaboration will be crucial to success. Priority action should target the most heavily used airports so as to maximise the impact of initial investment.

New Sustainable Aviation Fuels (SAF) technology pathways under development

By Steve Csonka (CAAFI¹), Kristin C. Lewis (USA Volpe Center), Mark Rumizen (USA FAA)

Introduction

Since 2009, the aviation industry has qualified the use of seven pathways to produce synthesised (non-petroleum) jet fuel blending components. Details of these can be found in the body and annexes of specification ASTM² D7566, as well as in qualitative summaries by various industry practitioners (e.g. CAAFI). The industry has also qualified the co-processing of jet fuel in existing refineries via the use of two pathways defined in ASTM D1655, Annex A1. When these synthesised fuels are produced from wastes or renewable resources in accordance with sustainability criteria such as those required for CORSIA Eligible Fuels³, they are considered SAF. Over the next several years, based on ongoing evaluation and testing, the industry is expected to consider qualification from many additional pathways. The industry currently envisions that these new pathways also will be added to the two specifications above, using the guidelines of ASTM D4054.

Although sufficient fuel was produced for all seven approved pathways to enable initial pathway approvals, at present, SAF for regular civil aviation use has only been produced via two of the seven specifications, and by fewer than 10 refineries/biorefineries worldwide. This mismatch between the pursuit of SAF pathway qualification and actual SAF production can be driven by changing priorities of the technology developer or producer since qualification, additional technical discovery or changing market conditions that lessen interest in the pathway, and/or a reflection

of the difficulty (e.g., cost, effort, permitting, financing, acquiring offtake) of bringing such a production plant online to produce “economically viable” SAF.

Additional qualifications are typically being pursued to address these challenges through:

- Lowering the cost of production by introducing processes that have lower capital and operating expenses:
 - Utilising lower temperatures, lower pressures, lesser-cost materials;
 - Advancements in catalyst designs and separation technologies;
 - More selective conversion or retention of feedstock hydrocarbon structures.
- Utilising lower cost feedstocks, especially waste streams or those available on a continuous basis (24x7) to support continuous production, and avoid significant feedstock storage and handling:
 - Municipal solid waste, wet wastes, manures, food processing wastes, sanitary water treatment process waste, and similar feedstocks.
- Enabling the widest range of agricultural and silviculture feedstocks, targeting availability around the world.
- Addressing promising feedstocks that do not yet have effective conversion processes.
- Potentially producing a wider range of hydrocarbons that fully emulate petroleum-based jet fuel to lower or eliminate blending requirements (i.e. 100% SAF).

1 The Commercial Aviation Alternative Fuels Initiative, <https://www.caafi.org/default.aspx>

2 ASTM International – see Overview - <https://www.astm.org/about/overview.html>

3 <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

- Improving throughput, easing handling constraints, reducing feedstock pre-processing.
- Enabling higher total carbon utilisation, as well as lowering total carbon intensity of the process.
- Being more resistant to feedstock contamination or more accommodating to feedstock non-homogeneity/uniformity.
- Utilising refinery co-processing in order to leverage existing capital, as well as to enable blending and SAF delivery using existing infrastructure and at lower total cost.

Pathway development currently in-process

As of this writing (March 2022), several active ASTM Industry Task Forces are working toward the qualification (testing, evaluation, and industry approval) of new or derivative pathway specifications. These include:

- Five new active pathways targeted for ASTM D7566 (two additional pathway evaluations are currently on hiatus):
 - Virent SAK⁴ – use of aqueous phase reforming of sugars and catalytic processing;
 - Shell IH2⁵ – Integrated hydropyrolysis and hydroconversion of lignocellulosic materials;
 - Global Bioenergies⁶ – Alcohol-to-Jet (ATJ) derivative utilising biochemical production of isobutene;
 - Swedish Biofuel⁷ – ATJ derivative starting with the mixed alcohols;
 - Indian CSIR-IIP⁸ – Catalytic processing of lipids for more fully formulated SAF; and,
- Three co-processing Task Forces targeted for ASTM D1655 Annex A1 expansion:
 - The potential relaxation (increase) of the current 5% volume restrictions for existing co-processing definitions.
 - The evaluation of coprocessing of pyrolysis oil from recycled used tires.
 - The evaluation of coprocessing of hydroprocessed biomass and out-of-spec jet fuel batches containing SAF.

Beyond currently active pathway development

The aviation community recognises that researchers and practitioners are continuously developing and refining ways to create SAF and to produce it at lower cost and from a continuously broadening set of technologies and feedstocks. This is especially true given the consolidated messaging coming from industry and governments indicating that they will be focused on development and use of SAF as the primary means of aviation decarbonisation for the next several decades. As such, early interactions suggest emerging work is likely in the following areas (not all of which will necessarily require new pathways, but in some cases perhaps expansion of current pathway definitions):

- Coprocessing with a widening range of biocrudes leveraging hub-and-spoke feedstock energy supply chains with distributed, early energy-densification processes.
- Technologies targeting use of currently recalcitrant waste streams and circular-economy byproducts.
- Concepts around hybrid (bio- and thermo-chemical processes) or multi-technology conversions.
- Production of hydrocarbon fuels using renewable sources of gaseous hydrogen and carbon (which may or may not require new pathway definitions).

CAAFI expects to see quite a few more approaches from companies currently pursuing pyrolysis, hydrothermal liquefaction, and other hybrid biochemical and thermochemical concepts. Several additional exploratory approaches that are likely to result in near-term Task Force efforts include:

- REVO⁹ – Hydroprocessed Esters and Fatty Acids (HEFA) derivative that produces cycloalkane content.

4 <https://www.virent.com/products/jet-fuel/>

5 <https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/benefits-of-biofuels/ih2-technology.html>

6 <https://www.global-bioenergies.com/group/isobutene-vert/?lang=en>

7 <http://www.swedishbiofuels.se/>

8 <https://www.csir.res.in/readbook?bid=MTQ3ODcx&submit=view>

9 <https://www.e-revo.jp/english/>

- OMV Re-Oil¹⁰ – Pyrolysis of non-recyclable plastics.
- Green Lizard – Hybrid pyrolysis of mixed cellulosics.
- Forge LTH¹¹ – Pyrolysis of lipids.
- Enerkem¹² – Catalytic Hydroprocessing of lignocellulose fractionated to oligomers.
- Vertimass¹³ – ATJ derivative using consolidated catalytic conversion of ethanol.
- Alder Fuels¹⁴ – Upgrading of fractionation streams of fast pyrolysis of lignocellulose.

As inspection technologies continue to improve in capability, and we continue to learn more about the functionality and combustion of different hydrocarbon chemical species in aviation systems, we may see ourselves working in the direction of a compositional-based specification for jet fuel, providing much greater flexibility to the evaluation of future SAF pathways.

Background Definitions

Following are some definitions to help bridge the gap between the work being done in the technical community and terminology that is being used colloquially to discuss SAF and future pathway qualification efforts:

ASTM D1655: This is the conventional jet fuel specification that defines requirements for Jet A and Jet A-1 produced from petroleum. It has been used globally by the aviation industry since 1959 to ensure a safe and consistent jet fuel is available for all aircraft.

ASTM D4054: This ASTM standard practice defines the scope of fuel property, rig, and engine testing to be considered when evaluating a new synthetic jet fuel. It also describes the overall evaluation process and the prominent role of the engine and aircraft manufacturers to ensure the exemplary safety record of jet fuel is maintained with these new fuels.

ASTM D7566 Pathway: Per ASTM D4054, a pathway includes the definition of a synthetic jet fuel blending

component as defined by: its allowable feedstock(s); the conversion process and its attributes; and the final characteristics of the neat component. These are all detailed in both the body of D7655 and its Annexes. The pathway will also specify blending requirements. The blending component is not truly a viable jet fuel until after it is blended with petroleum-based jet fuel, and final specification tests are completed. At that point, the blended mixture is reclassified as ASTM D1655 jet fuel and becomes fully fungible with all other D1655 jet fuel. If certain sustainability requirements are met (as defined by different policy mechanism, e.g., CORSIA), then the fuel can be referred to as SAF. It is important that buyers understand the sustainability attributes of both the blending component as well as the final blended product, because aspects such as the carbon intensity of the blending component and blend percentage matter. Some people refer to the neat blending component as SAF (or neat SAF) too, but until the blending and final specification testing are done, it cannot be used as jet fuel.

ASTM Task Force: A voluntary group of interested parties who agree to work together on the development and approval of an ASTM committee proposal. Task Forces are formed and operate at the discretion of the committees; new Task Forces are formed by committee motions and consensus voting. New Pathway Task Forces are typically led by the entity who has developed the synthetic conversion technology, and/or an entity who wants to commercialise such technology.

Synthetic jet fuel blending component: The portion of synthetic jet fuel produced from non-petroleum sources. D7566 also defines the neat blending component itself, allowing it to be sold/purchased separately if desired, but it must be blended and certified as meeting all applicable D7566 criteria prior to use as a jet fuel.

Specification: Once a pathway is qualified by the industry, it is adopted as a specification (e.g. HEFA-SPK as defined by ASTM D7566 Annex A2). Any entity can subsequently produce synthetic jet fuel under the definitions in the

10 <https://www.omv.com/en/blog/reoil-getting-crude-oil-back-out-of-plastic>

11 <http://www.forgehc.com/home.html>

12 <https://enerkem.com/company/>

13 <https://www.vertimass.com/vertimass-technologies/>

14 <https://www.alderfuels.com/>

pathway, and subsequently certify that such fuel meets the specification, to allow commerce to take place between the producer and the buyer.

Certification: The process by which a producer or downstream handler of the fuel validates that the fuel being transacted meets the requirements of the specification under which the fuel is being purchased. Neither the industry nor the FAA “certifies” new pathways.

Qualification: The process by which the industry and government members of ASTM evaluate and issue a specification definition, i.e., an ASTM D7566 annex, for a new conversion pathway. This is what happens in the ASTM deliberation processes, summarised as follows.

It is important to note that ASTM International, as an entity, does not own or drive the process of developing or qualifying new SAF technologies, rather they create the framework, process, and repository under which individual industries create test methods, specifications, classifications, guides, and practices for their own needs. In the case of synthetic jet fuels, the work is accomplished by Committee D02 (Petroleum Products, Liquid Fuels, and Lubricants), and Subcommittees J0 (Aviation Fuels) and J0.06 (Synthetic Aviation Turbine Fuels). These groups are comprised of hundreds of volunteer aviation and petroleum experts, as well as many related industry practitioners (e.g., laboratories, testing devices, academia). Their role is to ensure that appropriate testing and evaluation has occurred to ensure that fuel components produced and blended to the specification detail are sufficiently controlled to perform in a consistently acceptable manner as drop-in fuels. Such work gets accomplished via the use of Task Forces, but the results of such work are reported and balloted for approval by the full subcommittee and committee. Any negative ballots are adjudicated before the specification change is adopted, resulting in more work being done to address technically persuasive concerns, or to dismiss technically non-persuasive objections.

Not all fuel qualification efforts are performed solely by ASTM committee or Task Force activities but are also augmented by related work that occurs within the petroleum and aviation industries, or related working groups (e.g., CRC Aviation Committee¹⁵, UK MOD Aviation Fuels Committee). In the U.S., the Federal Aviation Administration has funded multiple programs where supporting work is performed (e.g., CLEEN, ASCENT, and CAAFI).¹⁶

These committees and ASTM welcome and encourage participation of interested and informed parties from around the world. The aviation industry itself then encourages the adoption and harmonisation of ASTM specification changes with other specification bodies (e.g., DEF-STAN/MIL-DTL, and various countries with their own specification systems) in order to have a unified, world-wide approach.

Engagement with the evaluation of additional pathways

Entities interested in the evaluation or potential development of additional SAF pathways can contact the following for more information, or consider directly joining the overall efforts on SAF as a member of ASTM D02.J0:

- CAAFI and CAAFI Pre-screening activities
- Mark Rumizen (mark.rumizen@faa.gov)– Chair of ASTM D02.J0.06
- Steve Zabarnick (Steven.Zabarnick@udri.udayton.edu) – Manager of the FAA Clearinghouse efforts at UDRI
- Anna Oldani (Anna.L.Oldani@faa.gov) – FAA office of Energy and Environment, providing oversight of Clearinghouse efforts
- ASTM Committee D02, Petroleum Products, Liquid Fuels and Lubricants¹⁷

In closing, note that several additional governments are focusing on support for enabling higher throughput of efforts leading to more qualifications, through elements like R&D and new Clearinghouse efforts (EU and UK), and all such efforts are welcome.

¹⁵ <https://crao.org/events/>

¹⁶ CLEEN – Continuous Lower Energy, Emissions, and Noise, https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen#:~:text=The%20Continuous%20Lower%20Energy%2C%20Emissions%20and%20Noise%20%28CLEEN%29,the%20FAA%20is%20a%20cost-sharing%20partner%20with%20industry; ASCENT – the Aviation Sustainability Center, one of FAA's Centers of Excellence, <https://ascend.aero/>; CAAFI – the Commercial Aviation Alternative Fuels Initiative

¹⁷ <https://www.astm.org/get-involved/membership.html>

Incentives to Ramp-up Decentralised Production of Power to Liquid Sustainable Aviation Fuels

By **Sonia Rueda and Frank Mischler (PtX Hub, GIZ) and Ruth Barbosa (ProQR, Climate-neutral Alternative Fuels, GIZ Brazil)**

Introduction

The global aviation industry is responsible for 12% of carbon dioxide (CO₂) emissions from all transport sources and produces around 2.1% of all human-induced CO₂ emissions. In order to achieve the transition from fossil fuels to carbon-neutral alternatives, sustainable aviation fuels (SAF) are indispensable. Unfortunately, these fuels are currently available neither in sufficient quantities at all relevant locations, nor at competitive prices.

Germany is very committed to address this challenge, investing domestically and also promoting global and local initiatives. To create a vibrant market for Power to Liquid SAF (PtL SAF), many actors need to test and adapt technologies for their domestic needs. A good example is the Brazilian-German cooperation project *ProQR – Climate-neutral Alternative Fuels* that promotes small production plants of PtL SAF, located close to remote airports. The efforts of local producers may create even bigger impact if they were connected in a global system. Hence, the *Power-to-X-Hub*¹, a center of excellence for renewable hydrogen and Power-to-X (PtX) technologies, is exploring

opportunities for fostering a global book and claim system to pave the way for international PtL SAF ramp-up.

No doubt, PtX products are crucial to defossilise aviation; but they are not sustainable per se. Reliable sustainability standards are essential to unlock a truly sustainable PtX production. They can reinforce trust to develop regional and international markets and ensure financial support. These standards must also support ecosystem integrity, economic prosperity, social inclusion, decent work, as well as transparency and public acceptance. Establishing and enforcing international standards for PtX products and processes is thus an urgent but also a complex task.

PtX Sustainability

The PtX Hub has developed a framework aiming at capturing and understanding the different dimensions relevant for sustainability assessments at different levels and at every step of the value chain. The EESG framework covers four basic dimensions: Environmental, Economic, Social and Governance. For each dimension, sustainability concerns are identified and grouped together in four clusters, as illustrated in Figure 1.

¹ The PtX-Hub and ProQR are cooperation projects implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, commissioned on behalf of the German Ministry of the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and the Ministry for Economic Affairs and Climate Action (BMWK). They are part of the International Climate Initiative (IKI), supported by BMUV on the basis of a decision adopted by the German Bundestag.

PtX and Sustainability

– the EESG Framework

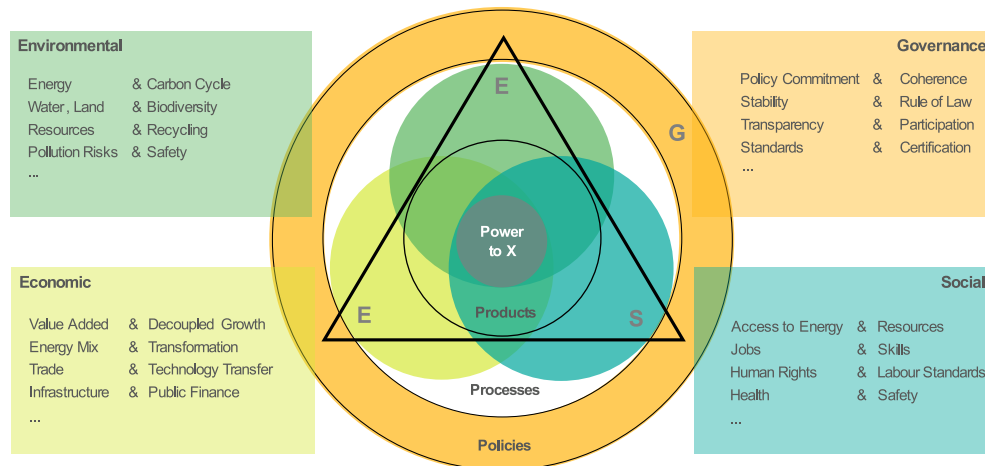


FIGURE 1: The Economic, Environmental, Social and Governance Reference Framework²; ©PtX-Hub

The relevance of each cluster within the framework should be screened in a risk based due diligence process. Whether for a PtX project, a product, a process or a policy, the weight of each cluster must be contextualised, and will be key for the development of transparent and reliable international and local PtX markets.

With regard to e-kerosene the origins of electricity, water and carbon matter. Electricity should be renewable. It should also be additional, ensuring that PtL production does not undermine countries' energy transformation. Water management should avoid increases in regional and local water stress. Carbon for PtL Synthesis should ideally stem from closed carbon cycles.

Book and Claim

The deployment of PtX technologies in developing countries and emerging economies presents substantial potential for the development of new sustainable value chains. It not only offers an economic opportunity but could develop into a cluster for social innovation, jobs creation and advance education. The local production of SAF would improve resilience against oil price volatility, currency exchange rate fluctuations and further delays associated with import logistics. It will contribute to the countries'

energy sovereignty and would enable new local markets. Several developing countries count on the best conditions to produce sustainable aviation fuels.

Now, beyond the potential for local markets, international commitments and ambitious targets are posing political pressure over the aviation industry, especially in industrialized countries. In this regard, a reliable market of sustainable products presents another opportunity for developing countries. A "Book and Claim" system would enable the market, overcoming the challenges posed by the different geographic locations of demand and supply sources.

SAF can be most cheaply produced in areas with high renewable energy potential, such as Australia, South Africa, the Gulf countries or Chile. But instead of transporting this fuel to airports worldwide, it'll be much better if it can be used as closely as possible to the production site. An airline that needs to fulfil a certain SAF-quote (as being proposed by the European Commission in the amendment of the ReFuelEU Aviation) or wishes to reduce its carbon footprint voluntarily could pay the price difference and then claim the CO₂ reduction. So, while the actual SAF may be filled into a tank of a different plane, the airline paying the premium-price still gets the credit. This would be possible if a registry, managed by a third party subject

² The EESG Reference Framework can be found on the PtX Hub website (<http://www.ptx-hub.org>)

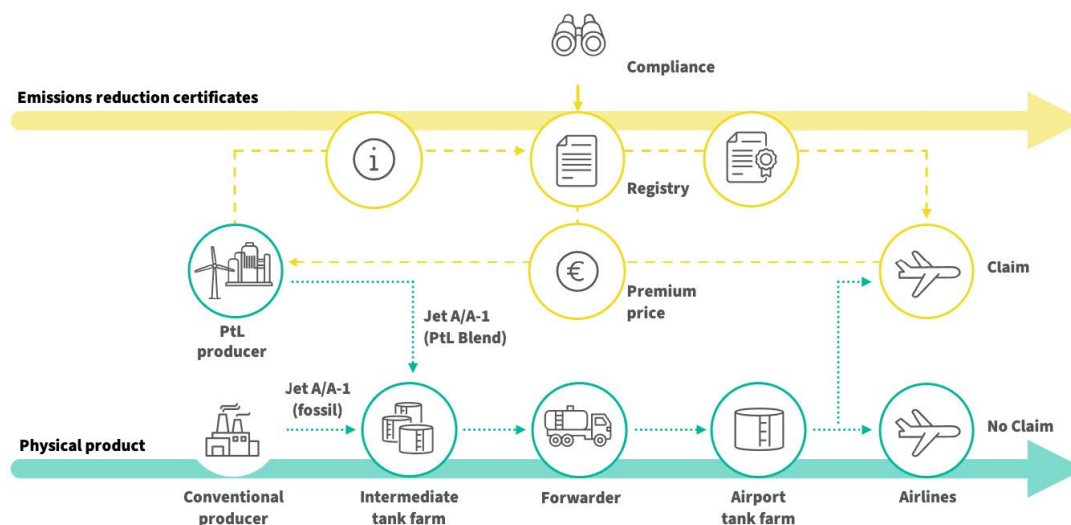


FIGURE 2: Schematic illustration of a book&claim system

to independent audits and checks, issues guarantees of origin (GoO) to SAF-producers. Those can be traded and monitored in a global system that avoids double counting of avoided emissions or double counting of green fuel usage as illustrated below.

Concretely, a SAF-supplier generates a sustainability certificate based on the physical environmental attributes of SAF and enters it into a SAF registry. An operator can purchase the sustainability certificate from the supplier, the transaction is recorded in the SAF registry while the physical delivery is separated (book&claim). The registry ensures transparency and prevents double claiming. Formalized and standardized documentation and tracking methods will ensure trust and auditability in the process.

Such a system has several advantages compared to a mass-balance system, a system still favoured by the European Commission. A mass-balance system implies that the SAF must be physically transported to all airports which involves transportation costs and additional greenhouse gas emissions. Either in an upstream step or at the airport, the SAF will be blended with fossil-based kerosene and then delivered to the various aircrafts. Attributing SAF to a single plane would imply running two separate fuel systems at the airport – a highly inefficient system.

The logistical challenge of providing SAF to various airports also gives undue advantage to large providers. Plants that may be able to produce only small quantities of SAF

and deliver it only to an airport in its vicinity would be disadvantaged. One may also lack harnessing the potential of investments in SAF worldwide, including in many developing and emerging countries. With the associated benefits to the local economy.

Lastly, under a book&claim system, an airline could sell the certificates to its business clients and customers. Companies that are committed to net-zero supply chains and private customers that want to fly with zero emissions attached, could shoulder the premium that can be associated to them (eg via calculating kerosene use per seat or weight). In other words, demand for SAF would not only arise from airlines fulfilling their obligatory quota but also from clients using the service of aviation.

This system works best if many suppliers participate. But producing bio-based kerosene or PtL aren't trivial. Therefore, GIZ fosters small and decentralized production plants to enter the market, such as in the case of Brazil.

Brazil's potential for decentralized SAF production

Brazil today has a promising future in the production of green hydrogen and SAF. Besides having 80% of its electricity matrix composed by renewable energy, the country presents an enormous availability of freshwater resources and a huge potential of solar and wind energy

production still little explored. Another important factor to be taken into consideration regarding the defossilization of aviation in Brazil is that GHG emissions do not only occur in air traffic, but also during fuel transportation to airports. Brazil is a country of continental proportions, and a large number of Brazilian airports are located in remote areas distant from fuel supply centers. Those locations are completely dependent on precarious highway or waterway transportation, or even airplanes to supply the kerosene.

In this context, the German-Brazilian technical cooperation project *ProQR – Climate-neutral Alternative Fuels* promotes the production of SAF in a local, decentralized and modular way: small production plants, located closely to the airports to produce the fuel where it's needed. The project favors the the Power-to-Liquid (PtL) approach, where the SAF synthesis process uses only renewable electricity, water and CO₂ captured directly from the atmospheric air (DAC) to produce the fuel. Studies have shown that such small-scale application is economically feasible in Brazil, taking into account the fuel transport cost to remote regions.

At the same time, other routes based on industrial waste or by-products have huge potential in the country. For example, in Brazil the ethanol fermentation standards produce almost pure CO₂, so that instead of DAC the carbon could be used from the ethanol sector. Also, the glycerine that is a by-product of Biodiesel production can be used to produce syngas, which is then to be converted into Crude and SAF. A research plant for this route is being installed at the SENAI Institute of Innovation (ISI-RE) in Natal with support of the GIZ project H2Brasil.

Brazilian decision makers have recognized those potentials during the past years when discussions about the production and use of green hydrogen and its derivatives became increasingly prominent to make the country's energy matrix cleaner. In 2021, the government instituted the Fuel of the Future programme, with a subcommittee specifically linked to the topic of SAF. Coordinated by the Brazilian Ministry of Mines and Energy (MME), the programme proposes the creation of public policies to boost the production and use of sustainable and low-carbon-intensity fuels. Also, in 2021, a law was signed to create the National Biokerosene Program; its main objective is to promote research and production of SAF.



FIGURE 3: Fueling at Brazilian Airport; ©GIZ Brazil / Soninha Vil

ProQR and its project partners in the Brazilian Ministry of Science, Technology and Innovations (MCTI) and the German Aerospace Center (DLR) accompany the process since the beginning with their expertise. Their studies serve as inputs for the working groups within the current political programmes. Also, teaching material and trainings are being offered to universities and key institutions in the aviation and fuel sector, to pave the way for a well-trained work force and decisionmakers in this innovative field. Furthermore, ProQR is facilitating a network of institutions that result in more pilot plant projects being in the pipeline.

The example of ProQR in Brazil is just one of many initiatives in developing, emerging and industrial countries that together have the potential to create a vibrant global market for SAF. With all adhering to the same industry standards and being governed under one global system, significant contribution can be made to make aviation more sustainable. Join GIZ and the PtX-Hub to push the boundaries and enter new territory!

New Policies for Sustainable Aviation Fuel (SAF) Development

By Andrei Mungiu (European Commission), Nate Brown (USA Federal Aviation Administration)

SAF and the need for policy

The availability and use of substantial quantities of sustainable aviation fuels (SAF) is of critical importance for global aviation to meet the sustainability goals being put forward by both governments and industry. However, the necessary expansion of commercial production of SAF to meet these goals, remains a significant challenge due to a number of factors. The greatest challenge at present is the significantly higher costs of production for SAF in comparison to conventional kerosene. This renders the final selling price of SAF uncompetitive with the more widespread and cheaper kerosene. Although the recent spike in oil prices increased markedly the price of kerosene, this may not be a long-lived phenomenon, and regulators cannot rely on an organic bridging of the price gap between kerosene and SAF.

There are also challenges associated with the development of SAF supply chains, reaching economies of scale, accelerating technology development to reduce costs and enhance environmental benefits, and overcoming investment risk. SAF production has only been initiated in limited locations where supporting policy frameworks are in place. Global market penetration is necessary in order to achieve solid emissions reductions through SAF. There are many States and regions with high production potential, and this potential needs to be tapped into. To achieve an expanded and sustained global SAF production industry, additional policies and supporting actions will be necessary.

There is no single path to successful SAF policy implementation. Due to different climates, feedstock supply systems, resources, economic factors, political dynamics, and regulatory structures, policy approaches may differ in each State and region. Rather, a considered and customised strategy is needed. Recently there has been a dramatic acceleration in SAF policy activity and thought put forward by both States and public/private coalitions. This article details two examples of SAF policy approaches. Considerable additional information on potential policies to support SAF are available in the “Guidance on potential policies and coordinated approaches for the deployment of SAF document”, available on the ICAO website¹.

RefuelEU Aviation

Part of the EU Green Deal package, which aims to make Europe a carbon-neutral continent by 2050, the European Commission brought forward the RefuelEU Aviation proposal, which transforms aviation, long seen as part of the problem into part of the solution to reach economy-wide decarbonisation.

Until the emergence of this proposal, the EU ETS was the only European policy tool addressing emissions from aviation, but that is a carbon-pricing policy, with potential side effects on connectivity.

Now, the EU proposes a mandate for suppliers to provide to all airports, bar the smallest or most remote ones, certain

¹ <https://www.icao.int/environmental-protection/pages/SAF.aspx>

quantities of SAF (Table 1). The EU's vision is that SAF should be available at all EU airports, and that blended fuels would become naturally the only products available at EU airports.

The definition of SAF in the EU relies on sustainability criteria, very similar to those recently adopted by ICAO in the CORSIA framework, but slightly more restrictive from the point of view of emissions reductions, where the EU requires a higher threshold of decrease on a life-cycle basis, which limits the eligibility of some types of fuel.

The gradual increase in the minimum share of SAF blended in kerosene ensures that the industry will be given sufficient time to set up. The long-term horizon, up to 2050, aims to provide regulatory certainty, de-risk investment, and allow producer, suppliers and member states to plan their strategies accordingly.

TABLE 1: Proposed EU ramp up of SAF production

Total shares in the fuel mix (in %)	2025	2030	2035	2040	2045	2050
SAF ramp up out of which:						
Specific sub-mandate on e-fuels	—	0.7	5	8	11	28

The EU proposal promotes the use of fuels with the greatest potential of decarbonisation, and this is why the ramp-up includes a sub-mandate for electro fuels (e-fuels) also known as power to liquid (PTL) fuels, which may be scaled up and from which massive economies of scale can be reaped. PTL fuels are a group of SAF-producing technologies where electricity is a main input to generate, extract, or purify (1) hydrogen; and/or (2) carbon-containing feedstocks from waste gases or the atmosphere, and therefore have the advantage of not competing with food sources, not relying on feedstocks which could be unreliable, and reaching very high life-cycle emissions reductions. Their prices, very high currently, may be decreased significantly through economies of scale.

Even if price predictions need to be revised in the light of the recent increases caused by a shifting geo-political situation, and the gaps might be smaller for a number of

years, forecasts show that a price difference will remain between kerosene and SAF for the foreseeable future (Figure 1). Therefore, in the absence of binding policy tools, combined with generous incentives, the economic case for SAF will continue to remain illusory.

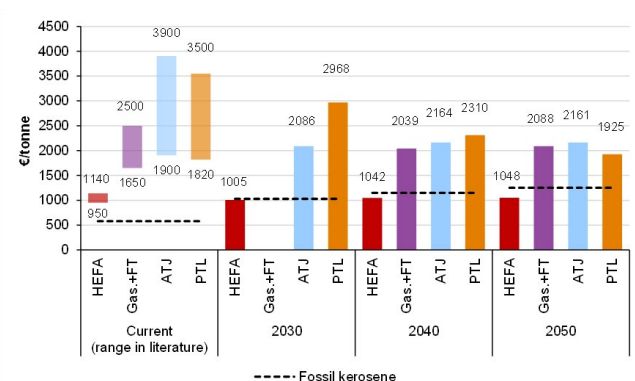


FIGURE 1: Forecast of prices of different fuel types in Europe²

The EU is bridging the gap through a number of pillars: firstly, the use of SAF on intra-European flights would exempt the emissions generated through combustion of SAF from the EU ETS. At current prices, the use of a tonne of SAF would reduce the ETS obligation by over 300 Euro. Secondly, any taxation of aviation fuel on intra-European flights would apply in a differentiated manner for kerosene and SAF. Thirdly, SAF used on CORSIA flights would benefit from reductions of offsetting requirements.

In order to facilitate overcoming obstacles in production of SAF and marketing it, the EU set up a Low Carbon Fuels Value Chain Alliance, involving stakeholders from production, supply, demand and regulatory side of the spectrum.

Especially in the flexibility period, it is likely that one side effect which will materialise is an excessive discrepancy between prices of fuel sold at different airports by suppliers. Some airports will not even have SAF at all.

In order to prevent that airlines circumvent the mandate by tanking at airports (in the EU or outside), where pure kerosene is available, and avoid tanking at airports where high blends are sold, the Commission proposes a clause whereby airlines must tank 90% of the necessary fuels for departing flights from each airport, on a yearly average basis.

² https://ec.europa.eu/info/sites/default/files/refueeu_aviation_-_sustainable_aviation_fuels.pdf

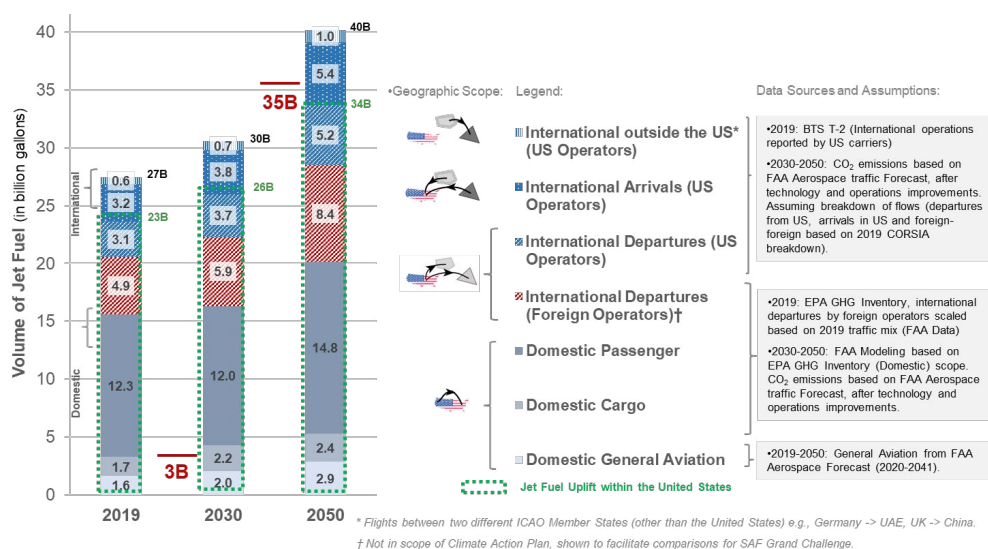


FIGURE 2: SAF Grand Challenge Goals Relative to Projected Jet Fuel Demand³

The Commission expects a very high compliance rate, and to ensure this, it proposes dissuasive, but proportional penalties for suppliers who do not market enough SAF.

USA SAF Grand Challenge

The United States 2021 Aviation Climate Action Plan⁴ was announced in November 2021 and sets an overarching framework and approach to achieving the U.S. aviation climate goal of net-zero greenhouse gas emissions from the U.S. aviation sector by 2050. Alongside advances in efficiency of operations and new aircraft and engine technology, dramatically expanded supplies of SAF are a critical pillar of this aviation decarbonisation approach.

Through the SAF Grand Challenge⁵, the U.S. government has committed to work with industry to rapidly scale up SAF production to meet the goals of at least 3 billion gallons per year of SAF by 2030 and meeting 100% of the fuel needs of all U.S. domestic and all international departures from the U.S. by 2050 (Figure 2). This approach emphasizes the role of U.S. executive branch agencies to take actions to support research, development, demonstration, deployment, and commercialisation of SAF. In addition, the approach recognises the need for well-designed economic incentives

that could be legislated by the U.S. Congress to help bridge the cost gap between SAF and petroleum jet fuel.

The SAF Grand challenge defines SAF as “drop-in” liquid hydrocarbon fuels with the same performance and safety as conventional jet fuels produced from petroleum and are fully fungible with the existing fuel supply and can be used in today’s infrastructure, engines, and aircraft. SAF can be created from either renewable or waste materials and must reduce life cycle GHG emissions by at least 50% relative to conventional petroleum jet fuel. This definition includes a range of biofuels as well as power to liquid (PTL) fuels. SAF are also recognised for their potential to reduce emissions that degrade air quality and contribute to the formation of contrails.

The SAF Grand Challenge is being led by the United States Departments of Transportation (DOT), Energy (DOE), and Agriculture (USDA). To meet the goals of the SAF Grand Challenge DOT, DOE, and USDA are implementing a government-wide effort to address barriers to expand SAF production through critical themes including reducing the cost, enhancing the sustainability, and expanding production and end use of SAF.

³ From 2021 U.S. Aviation Climate Action Plan, page 20 available at https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

⁴ https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

⁵ <https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge>

Reductions in the cost of SAF are possible through activities that drive down costs of production across the supply chain; expand the feedstock and conversion technology portfolio; leverage and repurpose existing production infrastructure; reduce risk to industry; and, provide economic support and incentives for production.

Enhancing sustainability of SAF can be accomplished by activities that include demonstrating sustainable feedstock production systems; developing and expanding low land-use change feedstock crops; reducing the carbon intensity of SAF supply chains; maximising the environmental co-benefits of production; ensuring robust standards that quantify and guarantee environmental integrity; and, enabling approvals of higher blend levels of SAF.

Expanding SAF supply and end use can be supported through activities including regional feedstock and fuel production development and demonstration; outreach, extension, and workforce development; direct infrastructure and commercialisation support; enabling approvals of diverse SAF pathways; and, continued outreach and coordination with military and industry end users.

In the near term the SAF Grand Challenge is developing a multi-agency roadmap to identify critical actions, agency roles and an implementation plan. This includes identification of existing SAF activities in research, development, demonstration, deployment, commercialisation support,

and policy and consideration of new efforts to accelerate additional research, development, demonstration, and deployment (RDD&D) of innovative solutions and technologies. Outreach to industry is being coordinated with support from the the Commercial Aviation Alternative Fuel Initiative (CAAFI). Finally, implementation of a supporting incentive framework will be critical to address the cost disadvantage faced by SAF. Actions under consideration include use of existing federal regulations (e.g., Renewable Fuel Standard), and implementation of new supporting policies (e.g., tax incentives) that could be enacted by the U.S. Congress. SAF support incentives and regulations at both the federal and U.S. state level are necessary to help cut costs and rapidly scale domestic production of SAF.

Conclusion

SAF are critical to meeting aviation's environmental goals and have additional co-benefits beyond greenhouse gas emissions and air quality improvements, including energy security and resiliency and economic development. Expansion of the global supply of SAF to meet the needs of aviation will require supporting programs, policies, and incentives. There are a broad range of approaches that can be pursued. This article shares two approaches being taken in the European Union and the United States that are both aimed at addressing fundamental dynamics to support expanded supply and availability of SAF.

Method for establishing lifecycle greenhouse gas emission factors for sustainable aviation fuels

By Robert Malina (USA), Matteo Prussi (Italy) and Farzad Taheripour (USA)¹

Introduction

Annex 16, Volume IV defines a “CORSIA eligible fuel” as a “CORSIA sustainable aviation fuel” (SAF) or a “CORSIA lower carbon aviation fuel” (LCAF), which an operator may use to reduce its carbon offsetting requirements. This article introduces the approved lifecycle emissions accounting approach that has been developed for SAF, as one core component of the overarching process by which operators can claim emissions reduction from the use of SAF.

The use of SAF can reduce greenhouse gas (GHG) emissions attributable to aviation. However, the potential to reduce GHG emissions can vary between different SAF pathways due to different factors, such as, for example, the specific feedstock used and its production location, the agricultural practices, the specific fuel conversion process, and the choice of utilities used in its conversion process.

There are two main reasons why the heterogeneity of emission factors between different SAF pathways within CORSIA has to be appropriately accounted for:

- First, sustainability criterion 1.1. of the ICAO document CORSIA “Sustainability Criteria for CORSIA Eligible Fuels” mandates that CORSIA eligible fuels such as SAFs need to achieve lifecycle greenhouse gas

emissions reductions of at least 10% compared to the baseline life-cycle emissions value for aviation fuel (e.g. conventional, petroleum-derived jet fuel). Therefore, for every type of SAF, it has to be established if it fulfils this criterion.

- Second, Section 3.3. of Annex 16, Volume IV establishes a crediting system for operators from the use of CORSIA-Eligible Fuels, such as SAF, in which the CO₂ offsetting requirements are reduced as a function of the mass of SAF used and the SAF-specific emission reduction compared to the use of conventional jet fuel. Therefore, for every type of SAF, its lifecycle greenhouse gas emission factor has to be defined.

CAEP tasked the Alternative Fuels Task Force and later the Fuels Task Group with developing an life cycle assessment (LCA)-based methodology for accounting for lifecycle greenhouse gas emission factors of different types of SAF, and for establishing appropriate emission factors. A wide system boundary was drawn for the lifecycle analysis in which both direct and indirect land use changes (summarized together by the term of “induced” land use change- ILUC) are included in the lifecycle. Emission types considered in the method are CO₂ for the SAF combustion step, and CO₂, CH₄, and N₂O for the other lifecycle steps, and they are added up using their 100-year Global Warming Potentials. Direct emissions occurring

¹ Robert Malina and Matteo Prussi are co-leads of the core Life Cycle Assessment (LCA) subgroup of the Fuel Task Group (FTG) of the ICAO Council’s Committee on Aviation Environmental Protection (CAEP). Farzad Taheripour is the lead of the Induced Land Use Change (ILUC) subgroup.

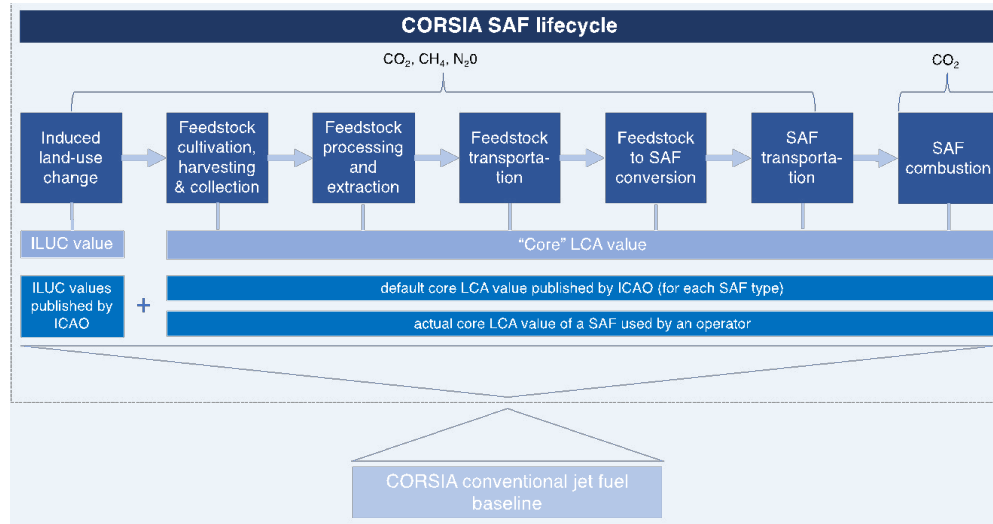


FIGURE 1: Lifecycle approach for SAF within CORSIA, including emissions scope by lifecycle step

from the full SAF production chain (e.g. CO₂ combustion emissions from the use of process fuels) are included, as well as indirect emissions associated with the production of feedstocks, utilities, chemicals and other inputs. One-time infrastructure-related emissions are not included, as their contribution to the lifecycle emission value of SAF is usually relatively small.

For ease of analysis, lifecycle emissions of SAF are first calculated separately for the ILUC emissions component of the lifecycle ("ILUC value"), and for the rest of the lifecycle ("core LCA"), and then summed up to yield the lifecycle emissions factor of a certain type of SAF, expressed in CO_{2e} per MJ (calculated on the lower heating value) of SAF used. Finally, results are compared to the lifecycle emissions of conventional, petroleum-derived jet fuel. Figure 1 summarizes the lifecycle approach for SAF under CORSIA.

Currently, two subgroups within the Fuels Task Group are responsible for conducting the work on SAF lifecycle values. The "Core LCA" subgroup developed the LCA methodologies for SAFs and continues to propose core LCA emission values for selected SAF pathways. The "ILUC" subgroup developed results in relevant modeling tools and continues to propose ILUC values for selected SAF pathways. Both subgroups closely interact so that parameters or assumptions are harmonized, where needed.

Method for establishing core LCA values

In the core LCA analysis, emissions from feedstock cultivation to SAF combustion are accounted for (see Figure 1), and are added up according to equation 1, where:

- e_{fe_c} denotes emissions from feedstock cultivation;
- e_{fe_hc} from feedstock harvesting and collection;
- e_{fe_p} from feedstock processing;
- e_{fe_t} from transportation of the feedstock to the processing and fuel production facilities;
- e_{fefu_p} from feedstock-to-fuel conversion processes;
- e_{fu_t} from fuel transportation and distribution;
- and e_{fu_c} denotes emissions from fuel combustion in an aircraft engine.

For purposes of reporting or accounting SAF emissions, the latter term (e_{fu_c}) is considered zero for SAF fractions produced from biogenic carbon. We also note that for waste, residue and by-product feedstocks, the system boundary only starts at the point of feedstock collection.

$$\text{Core LCA value [gCO}_2\text{e/MJ]} = e_{fe_c} + e_{fe_hc} + e_{fe_p} + e_{fe_t} + e_{fefu_p} + e_{fu_t} + e_{fu_c}$$

Equation (1)

In many SAF pathways, there are multiple co-products produced along the supply chain, and a decision has to be taken as to how to allocate emissions to the different co-products, including to SAF. For example, turning vegetable oils into SAF by means of the HEFA process also creates other liquid fuel products such as diesel or gasoline, as well as further upstream vegetable meal that can be used as animal feed. The CORSIA approach allocates emissions to the different co-products at the point of separation of production streams, based on the relative energy content of the different co-products.

An airplane operator has two options on how to apply the core LCA method (see Figure 1). It can either rely on a so called “default” core LCA value or it can use a so called “actual value”.

Default core values are pathway-specific emission factors agreed upon by ICAO and published in the ICAO document “CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels”. For the default core LCA values, several institutions (Argonne National Laboratory, European Commission - Joint Research Centre, Massachusetts Institute of Technology, University of Hasselt, University of Toronto, and Universidade Estadual de Campinas) contributed to the establishment of a life-cycle inventory for the different SAF pathways. Between the different modelling groups, core LCA results for a specific SAF pathway differ because of, inter alia, different type of data (e.g. industry versus simulation data; agricultural yield and practices assumptions, transportation distance and mode mix assumptions). Differences were assessed in detail and input assumptions reconciled, where judicious. In order to set a single default core LCA value for a SAF pathway, the CORSIA methodologies consider that a distinct SAF pathway is defined by a maximum variability in results of 8.9 gCO₂e/MJ (10% of the jet fuel baseline GHG intensity), and that the mid-point value of the highest and lowest core LCA value estimated by the different modeling institutions was taken as core LCA default value for this pathway. If differences remained outside of the 8.9g envelope even after reconciliation, then the data was split into two or more pathways and the mid-point value was used as default value for these separate pathways based on the remaining variability in the dataset. For

each SAF pathway, results were validated by a modeling institution not previously involved in the calculations for this specific pathway.

Alternatively, to the use of the proposed default core values, an operator can bring forward ‘actual core LCA’ values that replace the default core LCA value. In order to do so, it needs to select an ICAO-approved Sustainability Certification Scheme that certifies that the actual LCA analysis is in accordance with the CORSIA LCA methodology. In order to define the calculation and reporting requirements for the actual LCA value, a separate ICAO document was developed by the Fuels Task Group (“CORSIA Methodology for Calculating Actual Life Cycle Emissions Values”²).

Method to establish ILUC values

For the ILUC value, only values established by ICAO and published in the ICAO document “CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels” may be used. That is, irrespective of whether an operator brings forward an actual core LCA value for a specific amount of a certain type of SAF, the ILUC value established for this type of SAF has to be added to the core value in order to establish the lifecycle emissions factor for this specific amount of SAF.

In order to appropriately account for the inherent uncertainty with regard to ILUC emissions, two different economic models are employed, both of which are very well established in the domain. GTAP-BIO is a computable general equilibrium model developed at Purdue University. GLOBIOM is a partial equilibrium model developed at the International Institute for Applied Systems Analysis (IIASA).

The two original models have different structures, and use datasets and parameters from different sources, and are a priori expected to provide different results. Therefore, significant effort was devoted to understanding differences in initial modeling results, and to reconcile and harmonize data inputs wherever it was judicious to do so.

2 Available at <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

Differences between the results of the two economic models were assessed in detail and input assumptions reconciled, where judicious. In order to set a single default ILUC value for a SAF pathway, it was decided to follow the same recompilation approach applied to the Core LCA values.

Default life-cycle emission factors

The default lifecycle emissions values for SAF pathways are published in the ICAO document “CORSIA Default Life Cycle Emissions Values For CORSIA Eligible Fuels”. The Fuels Task Group is continuously establishing lifecycle emission factors for additional SAF pathways and brings them forward for CAEP and ICAO Council approval, after which the document is updated. As the time of writing, 81 distinct default values have been established, representing 22 different feedstocks, and 6 different conversion technologies. Figure 2 presents a graphical representation of the approved default values, specific for each feedstock-conversion technology combination, assessed, so far. Some feedstock-conversion technology

combinations have different ILUC values associated with them, and the resulting default lifecycle emission factors are represented by separate dots in the figure.

The Next Three Years

The ICAO document “CORSIA Default Life Cycle Emissions Values For CORSIA Eligible Fuels”³ will be updated when default LCA values have been established by the Fuels Task Group and agreed by CAEP. ICAO Member States, Observer Organizations, and ICAO-Approved SCSs can file a request for CAEP to consider a conversion process, feedstock, and/or region in this ICAO document. The process and required information is detailed in the CORSIA Supporting Document “LCA methodologies”, Part I². The Fuels Task Group will continue its work on establishing values for additional Sustainable Aviation Fuels, focusing on fuels that have reached high maturity in the ASTM-approval process, and therefore are likely to be used by the aviation sector in the future.

3 Available at <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

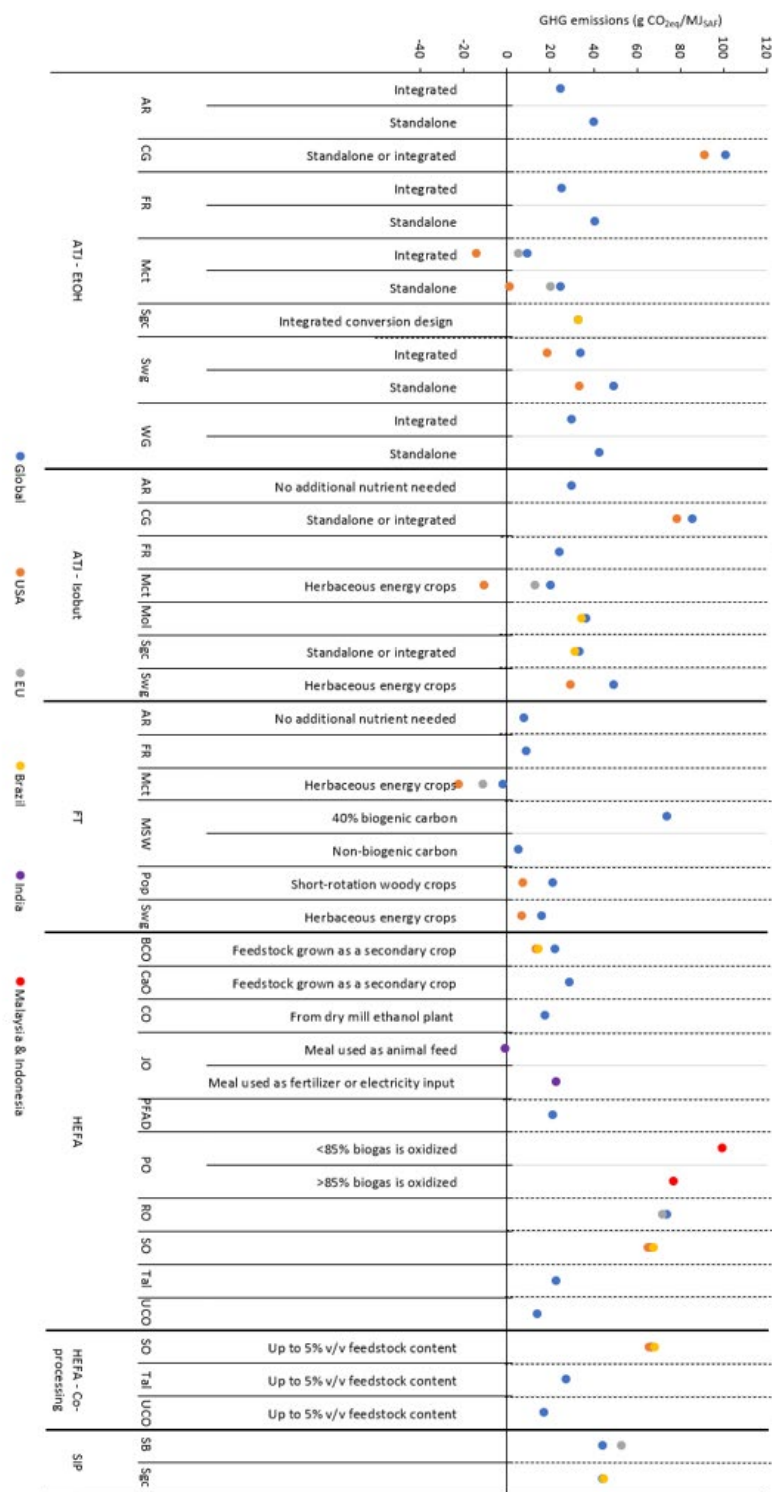


FIGURE 2: Default lifecycle greenhouse gas emission factors under CORSIA, shown by feedstock-conversion technology combination. Each dot in the figure denotes one distinct default value for a specific SAF pathway. For MSW, two values are shown, one for 40% biogenic carbon, and one for 100%. In the CORSIA method, an equation has been defined that links biogenic content for MSW to the default value. AR, Agricultural residues. CG, Corn grain. FR, Forestry residues. Mct, Miscanthus. Sgc, Sugarcane. Swg, Switchgrass. WG, Waste gases. Mol, Molasses. MSW, Municipal solid waste. Pop, Poplar. BCO, Brassica carinata oil. CaO, Camelina oil. CO, Corn Oil. JO, Jatropha oil. PFAD, Palm fatty acid distillate. PO, Palm oil. RO, Rapeseed oil. SO, Soybean oil. Tal, Tallow. UCO, Used cooking oil. SB, Sugar beet

High-integrity sustainable aviation fuels and the imperative of a net-zero climate impact by 2050

By Pedro Piris-Cabezas (Environmental Defense Fund)

Introduction

The pandemic has brought civil aviation to an inflection point. A precipitous drop in demand, continued reluctance of many leisure travelers to fly, and growing awareness among customers of the need to cut greenhouse gas (GHG) emissions, have all thrown a cloud over the future of passenger aviation. At the same time, new science underscores the larger scale of aviation's role in changing the climate due to non-CO₂ effects, which represent about two thirds of the sector's net climate impact.¹ These developments present an enormous challenge for the industry. But they also open an opportunity to chart a path forward for civil aviation to embrace the imperative of a net-zero climate impact by 2050.

One key step on that path is a dramatic acceleration of sustainable aviation fuel (SAF) use. SAF, which includes both biofuels and e-fuels, provides a distinct opportunity for aviation to decarbonise rapidly and permanently. However, deploying SAF only makes sense if the SAF actually significantly reduces emissions, meets a high standard of environmental integrity, and is transparently and accurately accounted for to avoid double counting emissions reductions.

SAF could potentially help fully decarbonise aviation by 2050, assuming e-fuels with zero life-cycle emissions become available and are deployed at scale (Figure 1). However, these potentials are theoretical and depend on supply constraints and large capital costs, and therefore need strong political support to materialise.

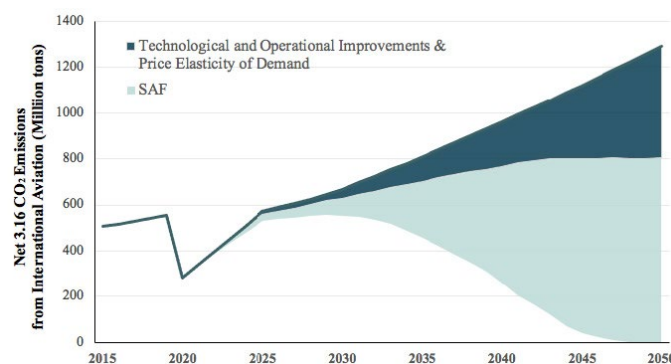


FIGURE 1: Reductions in atmospheric CO₂ from SAF use for international aviation. Based on ICAO 2019 forecasts, enhanced to reflect the notional impact of COVID19 and SAF deployment on price elastic demand and the adoption of technological and operational improvements. Source: The High-Integrity Sustainable Aviation Fuels Handbook.²

1 D.S. Lee et al, 2020, "[The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018](#)", Atmospheric Environment September 3, 2020.
2 Piris-Cabezas Pedro, 2022, "The High-Integrity Sustainable Aviation Fuels Handbook", Environmental Defense Fund.

SAF could also help reduce significantly the aromatic content³ in jet fuel and thereby contribute to cut air pollution around airports, benefitting the health of people who live and work nearby, and reduce the non-CO₂ climate effects from contrail cloudiness⁴.

In spite of all these co-benefits, SAF alone will not be able to completely eliminate aviation's net warming and public health effects. While SAF could represent a turning point in the aviation sector's journey to decarbonisation, complementary measures would be necessary to address the full spectrum of aviation's environmental impacts, including by balancing non-CO₂ climate effects with emissions reductions — and eventually net negative emissions — from other sectors.

A step in the right direction

The adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) by the International Civil Aviation Organization (ICAO) — operational as of January 1, 2021 — sets out a strong feedstock — and pathway-neutral framework for assessing emissions reductions from SAF use. Furthermore, the November 2021 decision by the ICAO Council to adopt an expanded set of sustainability criteria for SAF further strengthens this framework. This marks a major milestone for ICAO, as it is the first time a United Nations (UN) body has defined a clear standard for what constitutes sustainability for a mitigation action, and operationalised it with a full-fledged system of monitoring, reporting and verification.

However, in its current configuration, the CORSIA approach to SAF can only enable the production of truly beneficial SAF when paired with effective national policies that generate the needed economic incentives.

As countries engage in the design of national SAF policies, they should build on the rigorous, scientifically grounded work done by ICAO, but also ensure that:

1. Feedstocks used to produce SAF have low indirect land-use change (ILUC) emissions risk to avoid unintended consequences;
2. Resources are efficiently allocated to maximise emissions reductions rather than volumes; and,
3. Measures to avoid double counting given that Paris Agreement pledges are in place.

Based on these principles, only then could SAF be deployed with environmental integrity and contribute to the achievement of the UN Sustainable Development Goals.

1. Avoiding unintended consequences from feedstocks with ILUC risk

The state-of-the-art models used in ICAO for estimating default ILUC values incorporate three main market-mediated responses to meet a given additional feedstock demand for SAF production: (i) new agricultural land, (ii) yield increases, and (iii) reduced food and feed demand (including reduced food consumption).

In other words, the default ILUC values represent a theoretical estimation of the GHG emissions from new agricultural land — including from deforestation — that is needed to meet residual feedstock demand after considering: the amount of feedstock demand that would be satisfied by means of yield increases (e.g., from the introduction of cover crops or the restoration of degraded lands); and, the reduction in feedstock demand resulting from higher food and feed prices. While this approach is critical to identify feedstocks with ILUC risk, it does not account for unintended consequences such as biodiversity loss, food insecurity, and hunger/malnutrition that higher feedstocks prices could cause.

Therefore, countries should ensure that only feedstocks that can demonstrate low ILUC risk entitlements are eligible for financial support. This would be equivalent to focusing only on the feedstock produced with integrity by means of yield increases, while avoiding feedstock from new agricultural land or reduced food consumption.

³ Aromatics are hydrocarbons containing a benzene ring and range from benzene, the smallest aromatic compound to others such as toluene, xylene and naphthalene. Particulate matter emissions from aircraft turbine engines are a function of aromatic content.

⁴ C. Voigt et al., 2021, "[Cleaner burning aviation fuels can reduce contrail cloudiness](#)", Communications Earth & Environment.

The CORSIA SAF framework already includes innovative tools for demonstrating compliance with low ILUC risk.

2. Channeling resources efficiently with a focus on emissions reductions rather than volumes

Countries should also ensure that investments are channeled to SAF pathways with the highest emissions reduction potential, as these will deliver the most cost-effective way moving forward. Only SAF pathways that deliver large emissions reductions would make sense economically and environmentally, and represent viable production pathways.

While the SAF production costs are a relevant decision-making parameter, the main focus should be on the emissions reduction costs to establish the merit order in supporting SAF development. Figure 2 provides an overview of SAF production and emissions reduction costs for a number of SAF pathways. It builds on the production costs from ICAO's SAF Rule of Thumb⁵ complemented with the relevant default life-cycle values to derive emissions reduction costs. The pathways were then supplemented with e-fuels from renewable electricity, as it represents a potential source of zero life-cycle emissions SAF with no major biophysical constraints, and it is already among pathways certified by ASTM International⁶ as safe for use as a drop-in fuel.

While e-fuels are often considered a less mature SAF pathway, its deployment could happen earlier than anticipated if synergies from the decarbonisation of the power sector are fully exploited. The transition to renewables-based power generation systems – on which many countries have already embarked— means that the

production of e-fuels could generate valuable ancillary benefits through grid-balancing services.⁷ These benefits can significantly reduce the electricity cost for e-fuels production, altering the merit order of SAF pathways in favor of e-fuels, as illustrated in Figure 2. This should not only pave the road for a successful journey to net zero aviation but also beyond, including heavy land/sea transport, given the broad range of e-fuel co-products.

3. Avoiding double counting

ICAO has developed an innovative accounting approach for SAF: Rather than allowing air carriers to claim zero CO₂ combustion emissions from biogenic fuels under CORSIA (as most other GHG emissions reductions programs do), air carriers can only claim SAF emissions reductions for as long as these take place on a life-cycle basis.

Countries might find it challenging to reconcile this innovative approach with their GHG emissions inventories, leading to double counting of SAF emissions reductions, or more precisely double claiming.⁸ This is the case because there are potential time lags between SAF use and reporting,⁹ and countries have limited information publicly available in the CORSIA Central Registry.¹⁰

Several approaches exist to avoid double claiming, but the simplest approach involves countries reflecting SAF use as *international bunker* in their emissions inventories, meaning that countries need to rely on the timely information collected by the CORSIA-approved Sustainability Certification Schemes (SCS) to help identify SAF used for international aviation. In principle, SCS are already required to collect and report the necessary information,¹¹ but SCS

5 https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

6 ASTM International, formerly known as American Society for Testing and Materials, is a standards organization that develops and publishes technical standards for a wide range of products including SAF and jet fuel specification.

7 Once large wind or solar capacity is in place power production becomes intermittent, and the ability to manage the load becomes a critical feature for balancing the grid.

8 Double claiming is a type of double counting that occurs when the same emissions reductions are counted twice towards the climate change mitigation effort of both an air carrier and the host country of the emissions reduction activity.

9 CORSIA allows air carriers some flexibility on when they report the use of SAF, which can create a time lag of up to three years between SAF use and reporting.

10 The CORSIA Central Registry captures aggregate emissions from international aviation and compliance offsetting reports, but only limited information on SAF use claims under CORSIA.

11 See Requirement #12 in Table 1 with Requirements for SCS in ICAO Document Eligibility Framework and Requirements for Sustainability Certification Schemes (2019), available at: https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO_document_03_-_Eligibility_Framework_and_Requirements_for_SCS.pdf



FIGURE 2: Present and future SAF production and emissions reduction costs for biofuels (pioneer, and nth plant) and e-fuels (current, future-2035).^{12,13} Source: The High-Integrity Sustainable Aviation Fuels Handbook, Appendix B, (op. cit.)

12 Pathways considered: Gasification Fischer Tropsch using (1) municipal solid waste (MSW) with 70% biogenic content, (2) forest residues, and (3) agricultural residues; Alcohol-To-Jet using (1) ethanol from low ILUC risk corn grain as a feedstock, (2) isobutanol from agricultural residues (low and high estimates); Hydro-processed Esters and Fatty Acids - Synthetic Paraffinic Kerosene (HEFA-SPK) using (1) waste fats/oils/greases (FOGs), and (2) Vegetable oil from soybeans with low ILUC risk; e-fuels using (1) Proton-Exchange Membrane Electrolysis Cells (PEMFC) + Reverse Water-Gas Shift (RWGS) + Fischer-Tropsch (FT), and (2) Solid Oxide Electrolysis Cells (SOEC) + FT pathways, with varying feedstocks, technology choices and interactions with the power sector (resulting in varying electricity prices as a feedstock for e-fuels). Note: the “current” estimates for e-fuels consider economies of scale that might not be captured in the “pioneer” estimates for biofuels.

13 Same disclaimer as for the ICAO SAF “Rules of Thumb” apply here.

need guidance. To ensure a harmonised implementation, the ICAO Committee on Aviation Environmental Protection (CAEP) should develop such guidance during the next CAEP cycle.

An advantage is that this approach does not require any accounting adjustments or explicit authorisations by any country. The only adjustments and authorisations would apply to the optional removal and emissions credits embedded in the SAF life-cycle values. For such credits, a *letter of assurance and authorisation* –similar to those applicable to CORSIA offsets— would apply as countries would need to perform corresponding adjustments to prevent double claiming in accordance with the guidance on cooperative approaches of the Paris Agreement.¹⁴

Conclusion

The ICAO CORSIA framework holds enormous potential to enable the production of truly climate beneficial SAF –provided that national policies generate the needed economic incentives to channel resources towards high-integrity SAF with the highest emissions reduction potentials and implement measures to avoid double counting.

This is a pivotal moment for countries to embrace the imperative of a net-zero climate impact by 2050 and embark the aviation sector on its energy transition. If we successfully leverage all the critical opportunities ahead of us, we can put aviation on a new flightpath to reduce its climate impact and air pollution, while protecting ecosystems and communities.

14 The guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement guidance was adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at the 26th United Nations Climate Change Conference held in Glasgow in 2021. It provides the rationale that needs to inform how and when to perform corresponding adjustments for emissions reductions and removal credits. The guidance applies to mitigation outcomes authorized by a participating Party for use towards the achievement of either another Party's Nationally Determined Contribution or for use for other international mitigation purposes, including ICAO CORSIA. An advance unedited version of the guidance can be found here: https://unfccc.int/sites/default/files/resource/cma3_auv_12a_PA_6.2.pdf

Lower Carbon Aviation Fuels: contributing to the energy transition

By Jim Herbertson (Ipieca) and Derek Wheeler (ExxonMobil)

Introduction

Lower Carbon Aviation Fuel (LCAF) can serve as a complementary measure alongside Sustainable Aviation Fuel (SAF) in helping to reduce aviation greenhouse gas (GHG) lifecycle emissions. An LCAF may be certified as a CORSIA eligible fuel if it meets the CORSIA Sustainability Criteria, including a 10% reduction in lifecycle emissions compared to the conventional aviation fuel baseline of 89 g CO₂/MJ. During the energy transition and pursuit of pathways to a net zero future in aviation, all measures will be needed.

While the principal focus in CORSIA development has been on SAF as the longer-term fuel of choice, ICAO recognizes that LCAF can play a role. This is proven in the recent agreement for sustainability criteria and life cycle assessment methodologies for LCAF at the CAEP/12 Meeting, in February 2022.

SAF, LCAF and offsets are all included in the basket of measures supporting CORSIA. However, both SAF and LCAF have the benefit of enabling reductions associated with the physical fuel. SAF enables emissions reduction in the combustion phase of the fuel lifecycle. LCAF enables emissions reduction in the production phase of the fuel lifecycle. LCAF also offers near-term and scalable reductions in the GHG intensity of aviation fuels while SAF production expands over the coming years. For example, five billion liters of LCAF at 80 gCO₂/MJ could provide the equivalent GHG emissions reduction of about one billion liters of SAF at 45 gCO₂/MJ.

There are several means by which LCAF can reduce GHG emissions in the fuel production phase. These include measures such as application of best practices, implementation of technology, and use of newly developed crude oil with improved characteristics.

We outline some of these approaches below. Some of them relate to crude oil production (upstream) and others to crude refining to produce aviation kerosene and other products (downstream). Not all of the approaches will necessarily be implemented in LCAF production, and the degree to which they contribute to the overall lifecycle GHG emissions will vary. However, taken together, they can offer a significant reduction to the lifecycle carbon footprint of conventional aviation fuels.

Technology measures to reduce lifecycle carbon intensity of aviation kerosene

Energy Conservation

Among the most economical methods of reducing GHG emissions is to reduce energy consumed. Oil and gas companies can invest in new technologies and research including energy efficient design of plants, advanced computer controls, advanced modelling of reservoirs to increase production efficiencies, new extraction and processing methods, and improved technologies for monitoring the efficiency of equipment in the field.

Methane Emissions Reduction through Flare Management and Gas Recovery

Particular focus is called for with methane emissions. This is because methane is both the principal component of natural gas and a powerful GHG. Oil and gas companies can employ a range of actions to reduce methane emissions including replacing and upgrading field equipment, improving leak detection and employing new techniques for production.

There are also measures to reduce methane from flaring. Flaring can occur in the oil and gas industry for many reasons ranging from initial start-up and testing of a facility to unplanned equipment malfunctions, and in cases where the gas cannot be sold or re-injected into a well. A flare gas recovery system can be utilized to collect the gas, remove any liquids, and recycle the gas back to the process or into the refinery fuel gas system. The cost-effectiveness of flare gas recovery may vary widely between sites depending upon the nature and distribution of the sources of material going to flare.

Venting Control

Atmospheric process vents are generally pipes connected to vessels that emit process gases directly into the environment. The vents may be open to the atmosphere or controlled by a pressure relief valve that allows only occasional release of the process gases. The best control for these process vent emissions is to eliminate the need for discharge by altering the process operation or recycling the material. If this cannot be done, vapour controls such as recovery or destruction can be considered for application to the vent stream.

Storage, loading and unloading of oil in ships, shuttle tankers, storage tanks and terminals can also be sources of gas emissions to the atmosphere. These too can be mitigated with technologies like Vapor Recovery Units and practices like 'closed hatch' measurement and sampling.

Fugitive Emissions Detection

Refineries typically contain hundreds of thousands of piping components such as valves, connectors, flanges, pumps and compressors. Each of these has the potential for the process fluid to escape around the seal. While the

quantity of emissions from each individual component is usually very small, the large number of components in a refinery may make fugitive emissions the largest aggregate source of hydrocarbon emissions.

Emissions leaks are not usually visible. They have typically been found through the use of sensitive gas sampling devices to 'sniff' for parts-per-million (ppm) concentrations on the piping component. As the 'sniffer' has to be very close to the leak site this is a labour-intensive process. New optical gas imaging equipment and satellite imagery can visualize leaks and make detection simpler and much more cost-effective.

Carbon Capture and Storage

Carbon Capture and Storage (CCS) can use existing processes and technologies to collect and compress CO₂ generated by fossil fuel production, conversion and combustion. Compressed CO₂ is then permanently stored at depths beyond one kilometre below the earth's surface, within geological formations suitable for permanent storage. There are opportunities within refineries to capture CO₂ from processes such as catalytic cracking and hydrogen generation although further technology development will be key to bringing down costs.

Renewable Electricity

Electricity powers much of the equipment used in crude production and refining, such as the pumps used for extraction and flow throughout process units. Some oil and gas facilities are able to leverage renewable power, either through their own production or via purchase from providers. Facilities may be able to supply their own renewable power through technology like solar panel arrays. Or they may be able purchase it from a utility through renewable power purchase agreements. For offshore oil production platforms there may be an opportunity to connect by cable to shore-side electricity to replace energy produced on the platform by natural gas compressors or to make use of offshore wind energy.

Blue and Green Hydrogen

Hydrogen is used in refining processes to remove undesirable elements like sulphur from products. It is

most commonly produced by the steam reforming of natural gas (methane) into hydrogen and carbon dioxide. A lower carbon intensity hydrogen can be produced by capturing and storing the carbon emissions, often referred to as 'blue hydrogen'. Hydrogen can also be produced by using renewable electricity to split water into hydrogen and oxygen, often referred to as 'green hydrogen'. These alternative hydrogen sources can be applied in fossil fuel production to further lower GHG emissions.

New Development and crude oil selection

GHG emissions during fuel production can also be reduced through facility and operational changes enabled by newly developed crude. Lifecycle GHG emissions associated with the processing of a particular crude into fuel can vary according to factors such as the characteristics of the crude. For example, crude with a lower gas to oil ratio generally requires less gas compression, which can be an energy-intensive process. Crude with lower sulphur generally requires less hydro-processing to remove the sulphur, which in turn requires less energy and can result in lower emissions. A newly developed crude may have such characteristics to a greater extent than crude currently being produced and processed.

As new crude is called for to replace what is consumed, it presents an opportunity for crude oil producers to locate, develop and supply crude with improved characteristics. It also provides fuel producers (refiners) an opportunity to use such crudes to the extent that their refinery configuration and product demand allow.

SAF produced by co-processing of biological molecules in refineries

One additional approach that supplements SAF and LCAF is "co-processing", which is the simultaneous processing of bio-based material, such as fats, oils and other feedstocks, with fossil-based feeds using refinery infrastructure and economies of scale efficiencies. SAF produced through co-processing and that meets CORSIA criteria is recognized under CORSIA as an eligible fuel.

Using an existing refinery can offer benefits in terms of cost savings and carbon intensity reduction as it removes the need to build dedicated processing units. The potential volume of SAF that a refinery can produce through co-processing is currently limited by ASTM D1655. The standard currently only permits co-processing of 5% vegetable oils or waste oils and fats, and Fischer-Tropsch synthetic liquids for SAF production. Although 5% may seem like a small amount, it could still be considerable if the scale of refinery operations is considered. For example, if a refinery unit is processing 10,000 barrels per day (bpd) of aviation kerosene, then 5% amounts to about 500 bpd (nearly 30 million liters per year) of SAF.

Co-processing can increase the supply of sustainably certified SAF in the short-term at current co-processing limits and could become more significant if these limits are increased and other feedstocks are certified. Using existing refinery infrastructure allows for more rapid production of SAF as construction of new facilities proceeds.

Looking ahead

Two-thirds of the Ipieca member companies have now communicated net zero aims by 2050 at time of publication. To achieve these targets, they will need to: firstly, substantially reduce operational emissions which is key to enabling production of lower carbon intensity fuel such as LCAF and secondly, bring new lower carbon intensity transport fuels to the market such as SAF from biofuels, waste, and synthetic or e-fuels. All of these options are among those being actively pursued today by the oil industry through manufacturing in modified facilities, new build joint venture plants, and pilot and demonstration facilities.

Renewable Hydrogen for Aviation

By Xavier Vigor, Mélanie Petitjean, Dyane Hertogs, Delphine Roma and Pierre Crespi
(Air Liquide)

Introduction

Aviation is responsible for 2% of carbon dioxide (CO₂) emissions¹ and is at the heart of environmental challenges. Whilst existing technologies will keep improving, the development of radical new technologies is required in order to reach the industry's goal of Net-Zero Carbon Emissions by 2050². Hydrogen with a potential to drastically reduce aviation's carbon footprint needs to be assessed in the years to come. Present across the entire hydrogen value chain and with an expertise spanning more than 50 years in the aerospace industry, Air Liquide is using its technical and industrial expertise in hydrogen to help decarbonise aviation from the ground to the air.

This article details the potential of hydrogen as well as the challenges to tackle along the value chain.

Hydrogen production

With the climate challenges we are facing today, the supply of fossil-based hydrogen needs to be gradually replaced with renewable and low-carbon hydrogen in order to have a positive impact on the carbon footprint. Hydrogen is the most abundant element in the universe, but reacts easily with other elements to form, among others, carbon chains and water. Since it is very seldom available in a pure form, it needs to be extracted, using mainly two major pathways: steam methane reforming and water electrolysis.

Currently, steam methane reforming is the most common pathway to produce hydrogen, but its carbon footprint must be drastically reduced. For this, it's possible to replace methane by biomethane (from biomass), and the CO₂ produced can then be considered as biogenic. To reduce the carbon impact of steam methane reforming, it is also possible to capture carbon dioxide produced during the process and store or valorise it (an example being carbonated drinks). Carbon capture is the only short-term realistic solution to decarbonise quickly and at a large scale. It is also possible to reduce even further the impact of a steam methane reformer by combining the use of biomethane and carbon capture.

Hydrogen can also be produced using water electrolysis. This pathway is now mature and the most virtuous, provided that the energy source is renewable or low-carbon. We are currently witnessing an increase in the number of large-scale projects on all continents, as well as a rapid evolution of electrolysis technologies, whether for alkaline, Proton Exchange Membranes (PEM) or emerging technologies such as Anion Exchange Membranes (AEM) or even high-temperature electrolysis. The most promising technology to produce large quantities at a controlled cost is currently PEM, as shown by numerous projects worldwide. This is the feat that has been achieved by Air Liquide in Canada, with the world's largest PEM electrolyser (20 megawatts), inaugurated in January 2021³. Scaling up is key. Walking the talk, Air Liquide has since launched several new projects at an even larger scale: 30 MW in Germany, 200 MW in France through Air Liquide Normand'Hy to create the first low-carbon

1 <https://www.icao.int/environmental-protection/Pages/scientific-understanding.aspx>

2 RESOLUTION The 77th IATA Annual General Meeting

3 <https://www.airliquide.com/stories/industry/inauguration-worlds-largest-pem-electrolyzer-produce-decarbonized-hydrogen>

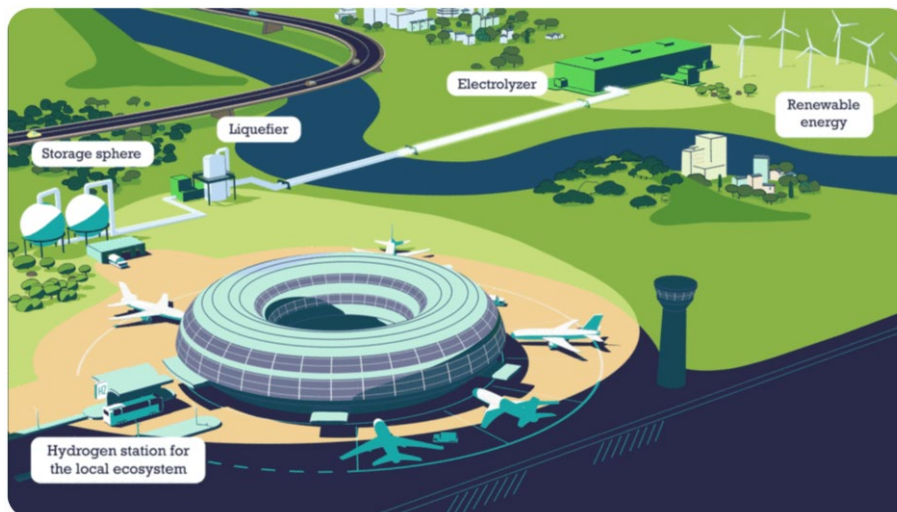


FIGURE 1: Producing, conditioning and distributing renewable and low-carbon hydrogen for airport ecosystems

hydrogen network in the world, capable of supplying all industrial customers in Normandy, as well as hydrogen refuelling stations for mobility (Figure 1).

The airport ecosystem

Low-carbon hydrogen is produced in gaseous form. Due to intensive usage, airports need large quantities which can be better suited by liquid hydrogen due to its high energy mass density⁴. It then has to be transported to the usage location by a pipeline network and dedicated fleets of trailers. Once it is transferred to storage containers, it can be used for many purposes, including ground logistics: baggage tractors, forklifts, pods, super tugs, shuttle buses, etc. On top of internal uses, the deployment of hydrogen-based mobility solutions can benefit external uses such as bus, taxi and all other ground mobilities. **The complementarity of uses in the ecosystems is a major lever for making low-carbon hydrogen accessible and creating early sources of demand. This is important because it will prepare the infrastructure and airport ecosystem for the arrival of hydrogen aircraft.**

With a well established presence in many strategic basins in North America, Asia and Europe, Air Liquide is ideally positioned to develop synergies between mobility applications.

In 2021, Air Liquide entered into partnerships with key players in the aeronautical sector in order to facilitate the development of airport infrastructure and be prepared for the arrival hydrogen-powered commercial aircraft by 2035:

- Air Liquide has partnered with Seoul International Airport (Incheon) to build two high-capacity hydrogen stations for airport vehicle fleets with filling times of under five minutes. The environmental impact of these vehicles fleets is considerably reduced by using hydrogen to power them.
- In June, one of the Air Liquide Group's projects was the winner of the AMI "H2 Hub Airport" organised by Groupe Aéroport de Paris, Air France-KLM, Airbus, Île-de-France Region to adapt existing liquid hydrogen trailers for aviation applications.
- In June and September, Air Liquide signed two Memorandum of Understanding with 1)Airbus and Groupe Aéroport de Paris and 2)Airbus, Groupe Vinci, Lyon Airport.

These partnerships will leverage the respective expertise of the stakeholders to support the decarbonisation of the aviation industry and to define the concrete needs: technological bricks, regulatory framework, and investments.

⁴ 120 MJ/kg



FIGURE 2: Hydrogen usage to decarbonise airports

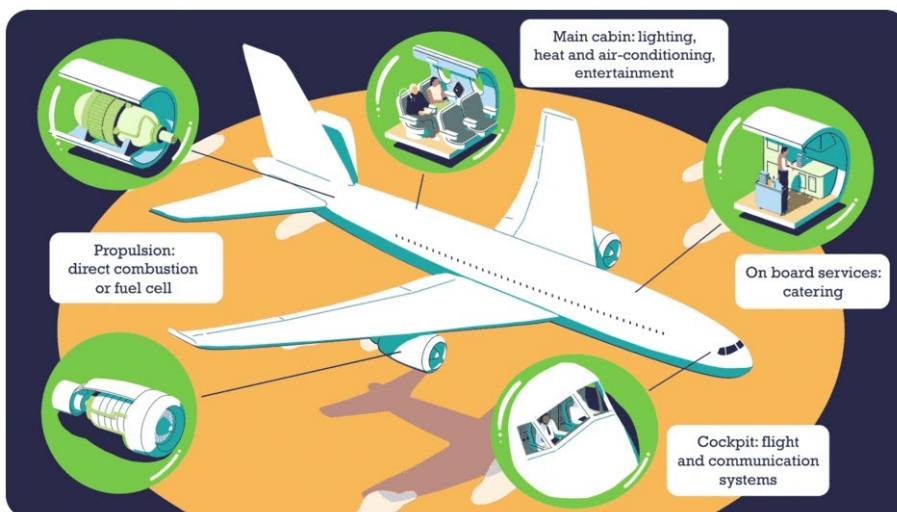


FIGURE 3: The different uses of hydrogen aboard the aircraft

Aboard the aircraft

Aboard the aircraft, hydrogen can produce electricity that will be used to power all the flight and communication systems in the cockpit as well as all on-board services. But in the future, it could be used for propulsion, either by direct combustion or by powering a fuel cell. Hydrogen significantly reduces emissions because its direct consumption in a turbine or using a fuel cell doesn't emit any CO₂ and substantially reduces nitrogen oxide (NO_x) particles. By the end of the 2000s, Air Liquide started to explore the potential of Hydrogen for aviation, with

various paper studies and ground or flight demonstrators that has demonstrated that a hydrogen storage under high pressure (350 or 700 bar) is too heavy when storing more than a few kilograms of gas. The ongoing High Power Density FC System for Aerial Passenger Vehicle Fueled by Liquid Hydrogen (HEAVEN)⁵ project should fly by late 2023, aboard a small 4-passengers aircraft to demonstrate for the first time the compatibility of a fuel cell system powered by a liquid hydrogen tank for aircraft propulsion. Air Liquide is responsible for the design, manufacture and testing of the tank and the ground filling station. The project aims to show that a liquid hydrogen tank suitable

5 HEAVEN project: financed by the Fuel Cell Hydrogen-Joint Undertaking of the European Commission

for flight is at least five times lighter and much smaller than a high pressure one, making it a viable solution for regional aircraft.

The development of key hydrogen technologies such as cryogenic hydrogen storage, distribution system, pump, cryogenic valves shall be supported by ambitious technological roadmaps while taking care of the safety issues: risk management, specific skills, etc.

In the short to medium term, the aviation sector is moving towards an energy mix in which synthetic fuels will be indispensable, since long-haul aircraft will not be able to fly entirely on hydrogen, mainly because of the mass/volume constraints and the necessary technological development

lying ahead. Similar to hydrogen for propulsion, innovations in the field of synthetic fuels are to come and could also contribute to the decarbonisation of aeronautics. In particular, synthetic fuels will have to be produced from low-carbon hydrogen and captured CO₂ (See “Hydrogen production” Section) to have a positive environmental impact.

Key partnerships will be necessary to develop on board technologies, deploy the supply chain and organise the appropriate regulatory framework for commercial aircrafts to fly using hydrogen. Indeed urgency for energy transition and its investment potential shall cause regulations to come. But it should be noted that hydrogen for aviation will benefit from synergies with ground mobility.



| ICAO

CHAPTER EIGHT

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIIA)

Introduction to CORSIA

By ICAO Secretariat

Introduction

In 2010, ICAO Member States adopted two global aspirational goals for the international aviation sector: an annual average fuel efficiency improvement of 2 per cent; and keeping the global net carbon emissions from 2020 at the same level (also referred to as carbon neutral growth from 2020, or CNG2020).

To contribute to the achievement of these goals, ICAO Member States have since then developed and submitted their State Action Plans, whereby they establish their strategy on climate change for the international aviation sector, selecting appropriate emissions mitigation measures from ICAO's basket of measures to reduce CO₂ emissions from international aviation. Such measures include aircraft technologies, operational improvements, and the use of sustainable fuels. As of mid-June 2022, 129 ICAO Member States have submitted their State Action Plans. More information on State Action Plans can be found in *Chapter 11* and in the ICAO website¹.

As a complement to these aviation in-sector CO₂ reduction measures aimed at ensuring the achievement of the carbon neutral growth goal, ICAO Member States adopted, at the 39th Session of the ICAO Assembly in 2016, a global market-based measure scheme for international aviation, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Thus, CORSIA became the first global market-based measure for any industry sector.

At the 40th Session of the ICAO Assembly in 2019, ICAO Member States reiterated the two global aspirational goals for the international aviation sector, welcomed the progress made on CORSIA implementation since 2016, and emphasized the strong support of ICAO Member States for a global solution for the international aviation industry,

as opposed to a possible patchwork of duplicative State or regional market-based measures.

Establishment of the CORSIA implementation framework

Following the historic agreement at the 39th Session of the ICAO Assembly, the ICAO Council initiated its work on a series of actions required to make CORSIA implementation possible, as per a timeline that highlighted two key dates:

- 1 January 2019, the starting date for the monitoring, reporting and verification (MRV) of CO₂ emissions under CORSIA; and
- 1 January 2021, the starting date of CORSIA's pilot phase (2021-2023).

Key milestones prior to 1 January 2019

Ahead of the start of the CORSIA MRV system on 1 January 2019, the focus of Council's work, with the technical contribution of the Council's Committee on Aviation Environmental Protection (CAEP), was on the development of the Standards and Recommended Practices (SARPs) for CORSIA implementation. The CORSIA SARPs determine the required actions by States, aeroplane operators and third-party verification bodies to implement CORSIA (i.e. the "who", "what" and "when"). The CORSIA SARPs were compiled in Volume IV of Annex 16 (*Environmental Protection*) to the Convention on International Civil Aviation, whose first edition was adopted by the Council in June 2018 and became applicable on 1 January 2019².

In order to support the implementation of the CORSIA SARPs, technical guidance on CORSIA implementation (i.e. the "how") was developed by CAEP and compiled in

1 https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

2 <https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx>

Volume IV of the *Environmental Technical Manual* (Doc 9501). The first edition of ETM, Volume IV was published in August 2018.

When reaching agreement on CORSIA in 2016, ICAO Member States requested the Council to develop simplified MRV procedures, with the purpose of preventing small operators from bearing an undue burden when implementing the MRV provisions in CORSIA. In response to this request, CAEP developed the ICAO CORSIA CO₂ Estimation and Reporting Tool (CERT). The first version of the tool, published in July 2018, could be used by operators for various purposes, namely: to assess whether CORSIA MRV requirements were applicable to them; and if so, whether they were eligible to use the ICAO CORSIA CERT to estimate their CO₂ emissions from international flights from 2019 onwards.

Aware of the fact that a number of States needed assistance to prepare themselves for the implementation of the CORSIA MRV system from 1 January 2019, the Council endorsed, in July 2018, the ICAO ACT-CORSIA (Assistance, Capacity-building and Training for CORSIA) programme as part of the *No Country Left Behind* initiative. The programme, whose scope and timeline have spanned beyond its original purpose of “bringing States up to speed”, has become an invaluable support for States in their implementation of CORSIA. The ICAO Assembly, at its 40th Session in 2019, highlighted this programme, and emphasized the importance of a coordinated approach under the umbrella of ICAO. More information on the ACT-CORSIA programme can be found in Chapter 11 and in the ICAO CORSIA website³.

Key milestones prior to 1 January 2021

With CORSIA implementation under way from 1 January 2019, work continued ahead of the start of CORSIA’s pilot phase on 1 January 2021. A second edition of the ETM, Volume IV, containing additional guidance developed by CAEP on CORSIA implementation, was published in September 2019⁴.

Council’s work focused on the development of the five CORSIA Implementation Elements, with contributions from CAEP and the Council’s Technical Advisory Body (TAB). This work translated into the production and maintenance of a series of related ICAO documents which contain materials that are essential for the implementation of CORSIA and are directly referenced in Annex 16, Volume IV. These documents, which are approved by the Council for publication on the ICAO CORSIA website⁵, are the following:

- The ICAO document *CORSIA States for Chapter 3 State Pairs*, listing the States that participate in CORSIA in a given year from 2021; this document is updated on an annual basis since its first edition published in July 2020.
- The previously-mentioned ICAO CORSIA CERT, updated on an annual basis since its first (2018) version, in order to incorporate additional functionalities and update the tool’s background information to allow aeroplane operators to apply MRV simplified procedures. More information can be found in the dedicated article in Chapter 8.
- The five ICAO documents related to CORSIA Eligible Fuels, whose respective first editions were completed prior to the start of CORSIA’s pilot phase. Since then, further updates have been published for some of these ICAO documents. More information can be found in the dedicated article in Chapter 8.
- The two ICAO documents related to CORSIA Eligible Emissions Units, including the ICAO document *CORSIA Emissions Unit Eligibility Criteria*, whose first edition was approved by the Council in March 2019; and the ICAO document *CORSIA Eligible Emissions Units*, which is regularly updated on the basis of TAB recommendations since its first edition in March 2020. More information on the work of TAB can be found in the dedicated article in Chapter 8.

³ <https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx>

⁴ <https://www.icao.int/environmental-protection/CORSIA/Pages/ETM-V-IV.aspx>

⁵ <https://www.icao.int/environmental-protection/CORSIA/Pages/implementation-elements.aspx>

ICAO completes all essential components for CORSIA implementation package

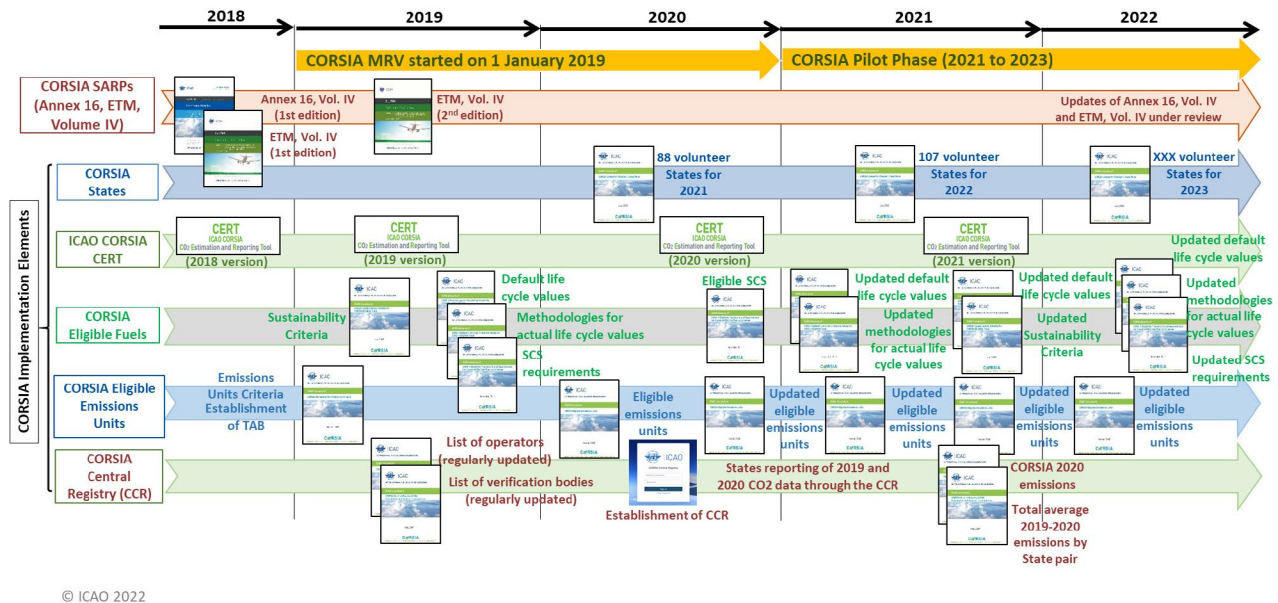


FIGURE 1: Development of the CORSIA Implementation Package (2018 – 2022)

- The ICAO documents containing information derived from States' reporting through the CORSIA Central Registry (CCR), which was launched in May 2020, ahead of the deadline of 31 August 2020 for State reporting of 2019 CO₂ emissions under CORSIA. Information contained in these documents include, *inter alia*: a list of aeroplane operators attributed to States and a list of accredited verification bodies (regularly updated since they were first published in May 2019); total 2020 CO₂ emissions to determine the first year in which a new entrant will be subject to offsetting requirements in CORSIA (published in November 2021); or total average CO₂ emissions for 2019 and 2020 aggregated for all aeroplane operators on each State pair route (published in December 2021). Upon the start of CORSIA's pilot phase in 2021, data collected through the CCR allows for the calculation of CORSIA annual Sector's Growth Factor. More information on the CCR can be found in the dedicated article in Chapter 8.

Figure 1 reflects the timeline for the development of the three pillars of CORSIA implementation (Annex 16, Volume IV; ETM, Volume IV; and the five CORSIA Implementation Elements).

States and operators' participation in CORSIA

Under CORSIA, all operators conducting international flights are required to monitor and verify the CO₂ emissions from these flights, and to report the related information to their State of registration. Consequently, all States with operators conducting international flights have a CORSIA MRV system in place since 1 January 2019, which allows the States to compile the information from operators, aggregate such information, and report to ICAO through the CCR. More information on the status of State reporting through the CCR can be found in the dedicated article in Chapter 8.

Upon the start of CORSIA's pilot phase, the monitoring, reporting and verification of CO₂ emissions from all international flights is complemented with the calculation of offsetting requirements associated to the emissions from those international routes connecting States participating in CORSIA. During the pilot and first phases of CORSIA (2021-2023 and 2024-2026, respectively), State participation in CORSIA is determined on a voluntary basis.

For 2021, 88 States volunteered to participate in CORSIA's pilot phase. For 2022, the number of volunteer States increased to 107. The number of volunteer States for 2023 will be determined after the deadline of 30 June 2022 for the notifications from States, and reflected in the third edition of the ICAO document *CORSIA States for Chapter 3 State Pairs*. As of mid-June 2022, five more States had already announced their voluntary participation in CORSIA in 2023, increasing the number of volunteer States to 112.

Mechanisms for possible adjustments in CORSIA: the safeguards provision and the periodic review

When reaching agreement on CORSIA in 2016, and as recalled by the 40th Session of the ICAO Assembly in 2019, ICAO Member States established two mechanisms for the consideration of possible adjustments to CORSIA throughout its implementation, namely:

- The CORSIA safeguards provision, which aims at ensuring that CORSIA contributes to the sustainable development of the international aviation sector and does not lead to an inappropriate economic burden on the sector; and
- The provision for a CORSIA periodic review, to be conducted by the Council every three years from 2022. The CORSIA periodic review serves as an important basis for the Council to consider whether it is necessary to make adjustments to the subsequent phase or compliance cycle and, as appropriate, to recommend such adjustments to the ICAO Assembly for its decision.

While the CORSIA periodic review is a mechanism subject to a pre-defined schedule (every three years from 2022, with a special review by the end of 2032), the CORSIA safeguards provision provides a means for the Council to react to unexpected circumstances that may have a significant impact on CORSIA.

The COVID-19 pandemic and its impact on CORSIA triggered the application of the CORSIA safeguards provision and also affected the process concerning the 2022 CORSIA periodic review.

Application of the safeguards provision in response to the impact of the COVID-19 pandemic

Following the outset of the COVID-19 pandemic in early 2020, the Council initiated work with the aim of assessing the related impact on CORSIA. The Council was supported in this task by the technical inputs provided by CAEP on the impact of COVID-19 on the 2019-2020 average CO₂ emissions (the so-called "CORSIA baseline") and on CORSIA's offsetting requirements.

After consideration of all inputs, the Council decided, in June 2020, to apply the CORSIA safeguards provision. In so doing, the Council agreed that, in order to safeguard against inappropriate economic burden on aeroplane operators, 2020 emissions should not be used for three CORSIA design features (the CORSIA baseline; the reference year for calculating offsetting requirements for the pilot phase; and the new entrant threshold). In this regard, the Council decided that during the pilot phase, 2019 emissions shall be used for 2020 emissions and published in all relevant ICAO documents referenced in Annex 16, Volume IV.

The decision made by the Council did not imply a disruption in the CORSIA MRV requirements, so that States and operators were still required, as per Annex 16, Volume IV, to do the monitoring, reporting and verification of CO₂ emissions from international flights performed in 2020. The 2020 CO₂ emissions data may still be required after CORSIA's pilot phase, on account to the fact that the Council's decision was applicable only to CORSIA's pilot phase (2021-2023).

The definition of the CORSIA baseline after the scheme's pilot phase will be considered by the ICAO Assembly on the basis of the outcome of the 2022 CORSIA periodic review conducted by the Council.

2022 CORSIA periodic review

In March 2021, the Council approved the Terms of Reference for the 2022 CORSIA periodic review, thus initiating its work on the topic, with the objective of reporting to the 41st Session of the ICAO Assembly (27 September – 7 October 2022).

Council's work on the 2022 CORSIA periodic review has been supported by CAEP and TAB, on the basis of a series of requests whose scope and related timelines were also determined by the Council in March 2021. An important element of CAEP's technical inputs was the committee's analysis of the impact of COVID-19 on CORSIA, with updates provided at various Council sessions. More information on the CAEP analysis of COVID-19 impacts on CORSIA can be found in the dedicated article in Chapter 8.

The Council's consideration of technical inputs from CAEP and TAB was supported by the Council's Climate and Environment Committee (CEC). More information on the work of the Council on the 2022 CORSIA periodic review can be found in the dedicated article in Chapter 8.

Final remarks

Despite the impact of the COVID-19 pandemic on aviation in general, and on CORSIA in particular, States and operators have been implementing CORSIA as per the established

timeline, and the number of CORSIA volunteer States increases on an annual basis. Both aspects are a reflection of the commitment by ICAO Member States and operators alike to CORSIA implementation.

CORSIA implementation being on track is testimony of a joint vision for the international aviation sector where CORSIA plays a complementary, albeit fundamental, role to the aviation in-sector CO₂ reduction measures already being applied by States and all relevant stakeholders to ensure the achievement of the ICAO carbon neutral growth goal.

The ICAO Assembly will consider, at its 41st Session, the outcome of the work undertaken by the ICAO Council on the 2022 CORSIA periodic review. The robustness of the process and its reliability on robust technical inputs should provide Member States with the confidence to make decisions on the basis of the review's outcome, with the purpose of ensuring that CORSIA contributes to the achievement of the carbon neutral growth goal in the context of a sustainable international aviation sector.

Monitoring, Reporting and Verification Implementation – States' Reporting through the CORSIA Central Registry

By ICAO Secretariat

Introduction

The successful implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) requires the establishment of a robust and transparent Monitoring, Reporting and Verification (MRV) system to track annual CO₂ emissions from international aviation. This information is used to determine offsetting requirements in accordance with the provisions of Assembly Resolution A40-19.

To achieve this, in 2018, the ICAO Council adopted the First Edition of Annex 16, Volume IV, which contains Standards and Recommended Practices (SARPs) that address the implementation of CORSIA. The CORSIA SARPs became applicable on 1 January 2019 for all States with aeroplane operators with international flights.

The CORSIA Central Registry (CCR)

The CORSIA Central Registry (CCR) is one of the five Implementation Elements of the scheme, as identified by the ICAO Council at the time of the adoption of Annex 16, Volume IV.¹ The CCR facilitates the reporting of CORSIA-related information and data from States to ICAO, while enabling ICAO to consolidate this information and make it publicly available on the ICAO website.²

The CCR is administered by the ICAO Secretariat and has been implemented as a secure web interface (web platform) supported by a database and a workflow engine. It comprises of the following four components (see Figure 1):

- A. Web application with pre-defined forms and automated checks;
- B. Data transfer and storage;
- C. Administrative console to perform internal checks and manage data and users;
- D. ICAO website for the publication of information.

Each State has one account on the CCR. Access to this account is granted to authorized users, who are nominated by each State. Each CCR user has unique login details (username and password) and given access to certain functions of the CCR based on a pre-defined list of permissions (see Table 1). It is important to note that, for the purposes of the CCR, only one CCR user per State is assigned the role of the CORSIA Focal Point (CFP), and the CFP is the only CCR user who can initiate the reporting process and submit data to ICAO. More than one State User can be nominated by a State.

¹ More information on the CORSIA Implementation Elements can be found in the ICAO CORSIA website (<https://www.icao.int/environmental-protection/CORSIA/Pages/implementation-elements.aspx>)

² <https://www.icao.int/corsia>

CORSIA Central Registry

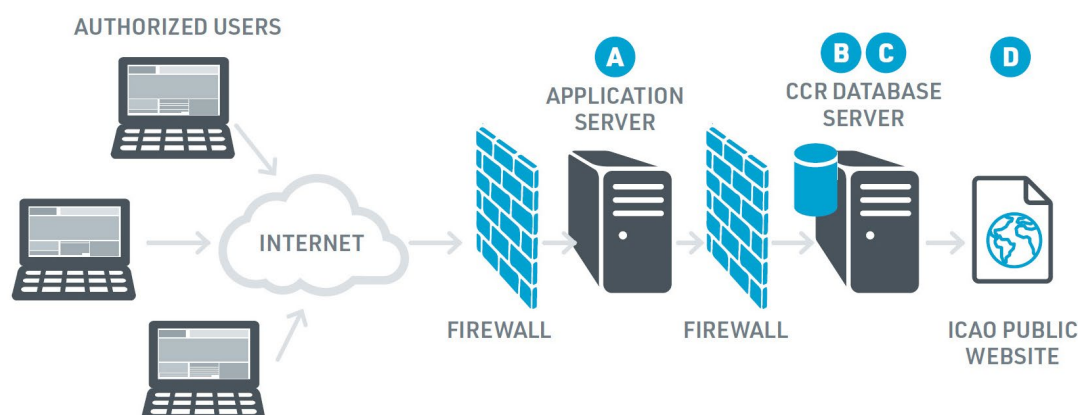


FIGURE 1: Main Components of the CCR

TABLE 1: Examples of Permissions to Main CCR Functions for each User Group

User Group	Main Functions for CCR Users		
	Start the Reporting Process	Add, Edit, Delete Data	Submit Data to ICAO
CORSIA Focal Point	Yes	Yes	Yes
State User	No	Yes	No

All CCR users can provide new information and/or update previously submitted information, while their actions are time-stamped and recorded (including the electronic signature of the user who initiated an action) to ensure traceability and data integrity. If previously submitted information needs to be modified, the previous version of the data is not deleted, but is archived for future reference.

Information and data are uploaded on the CCR and submitted to ICAO using pre-defined online forms. These forms facilitate entering information incorporating, where possible, dropdown lists (for example, list of ICAO States, attribution options, feedstock used for CORSIA eligible fuels etc.) to minimize typing errors. Business rules have been created to check information and data before submitting to ICAO; for example, numerical data cannot contain letters or symbols, emissions data cannot be negative numbers.

The CORSIA MRV System

Under CORSIA, aeroplane operators with international flights are subject to MRV requirements. As of 1 January 2019, operators are required to monitor their annual CO₂ emissions from international flights, have them verified through a third-party verification process, and submit them to the States to which they are attributed (as depicted in Figure 2). States collect emissions data from all their operators and submit consolidated information to ICAO through the CCR.

Starting with the reporting year 2021, States with operators that wish to claim CO₂ emissions reductions from the use of CORSIA eligible fuels are required to submit information and data on such fuels in accordance with the provisions of Appendix 5 to Annex 16, Volume IV. Information on CORSIA eligible fuels must also be verified prior to its submission to the State of attribution.

In addition to CO₂ emissions, States are required to submit to ICAO information on aeroplane operators attributed to them, and on verification bodies accredited in them. The lists of aeroplane operators and verification bodies as submitted by States can be found in the latest editions of the ICAO document “*CORSIA Aeroplane Operator to State Attributions*” and in Part I of the ICAO document “*CORSIA Central Registry (CCR): Information and Data for Transparency*”, respectively (more details of ICAO CORSIA documents can be found later in this article).

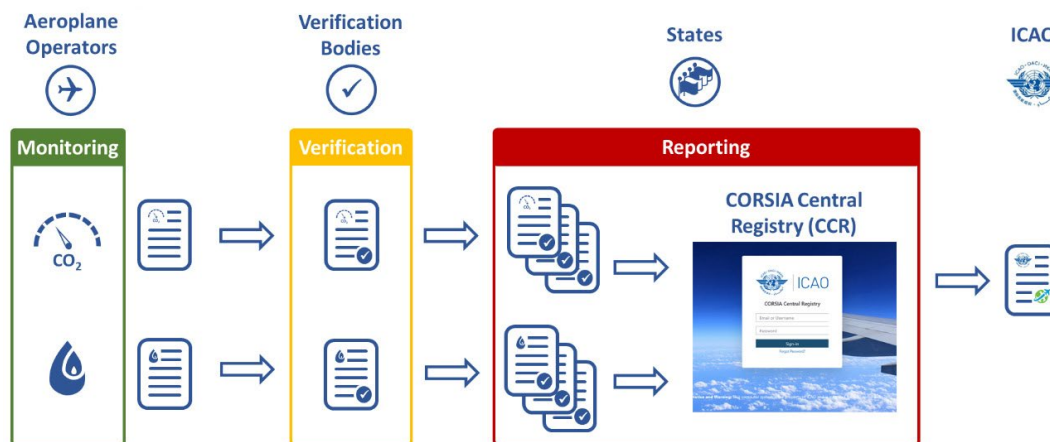


FIGURE 2: Sequence of actions under the CORSIA Monitoring, Reporting and Verification (MRV) system for CO₂ emissions and CORSIA eligible fuels

TABLE 2: Summary of CORSIA-relevant Information to be Reported by States to ICAO (in italics the deadlines for reporting in accordance with Appendix 1 to Annex 16, Volume IV)

Information type	Baseline		Pilot Phase			First Phase		
	2019	2020	2021	2022	2023	2024	2025	2026
Aeroplane Operators	<i>30 Apr</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>
Verification Bodies	<i>30 Apr</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>	<i>30 Nov</i>
CO ₂ Emissions		<i>31 Aug</i>	<i>31 Aug</i>	<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>
CORSIA Eligible Fuels*				<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>	<i>31 Jul</i>
Cancelled Emissions Units							<i>31 Jul</i>	

*Information can be reported annually or once at the end of each three-year compliance cycle depending on the frequency of reporting by the operator(s) attributed to the State.

In accordance with Appendix 1 to Annex 16, Volume IV, there are different deadlines for States to submit CORSIA-specific information and data for a particular year (see Table 2). For example, for year 2021, information and data on aeroplane operators and verification bodies were due by 30 November 2021, while CO₂ emissions and data on CORSIA eligible fuels are to be submitted by 31 July 2022, and information on cancelled emissions units for the pilot phase (2021 to 2023) are due by 31 July 2025.

Publishing CCR-related ICAO CORSIA Documents

The information and data uploaded in the CCR are used to produce five ICAO CORSIA documents that are referenced in Annex 16, Volume IV. Specifically:

1. ICAO Document “*CORSIA Central Registry (CCR): Information and Data for the Implementation of CORSIA*” is an umbrella document that contains:
2. ICAO Document “*CORSIA Aeroplane Operator to State Attributions*” contains a list of aeroplane operators and the State to which they are attributed
 - Availability: Sixth edition published in December 2021 (*updated regularly*)
3. ICAO Document “*CORSIA 2020 Emissions*” contains the total 2020 CO₂ emissions to determine the first year in which a new entrant has offsetting requirements
 - Availability: First edition published in November 2021
4. ICAO Document “*CORSIA Annual Sector’s Growth Factor*”
 - Expected availability: by 31 October 2022 (to be updated annually)

5. ICAO Document “*CORSIA Central Registry (CCR): Information and Data for Transparency*” contains:

- Part I: List of verification bodies accredited in each State
- Part II: Total average CO₂ emissions for 2019 and 2020 aggregated for all aeroplane operators on each State pair route
- Part III: Total annual CO₂ emissions aggregated for all aeroplane operators on each State pair (with identification of State pairs subject to offsetting requirements)
- Part IV: Information and data for each aeroplane operator
- Part V: Information and data on CORSIA eligible fuels claimed
- Part VI: Offsetting requirements and emissions units cancelled (at State and global aggregate level for a specific compliance period)
 - Availability: Ninth edition of Part I published in December 2021 (updated regularly)
 - First edition of Part II published in December 2021

All five ICAO CORSIA documents are published on the ICAO CORSIA website³, following their approval by the ICAO Council.

Status of States’ Reporting Through the CCR

ICAO Member States started using the CCR in June 2020. As of the first quarter of 2022, 176 States had access to their CCR accounts, with ICAO having created 176 CORSIA Focal Points accounts and an additional 80 State User accounts (total 256 CCR users) on the CCR (see Figure 3 and Table 1 for permissions of CCR users). States have used the CCR to report the following:

- List of aeroplane operators attributed to each State for the years 2019⁴, 2020, and 2021;
- List of the verification bodies accredited in each State for the years 2019⁴, 2020, and 2021;
- CO₂ emissions on each State pair for the years 2019 and 2020 (see Table 3).

Using the information submitted by States and, where necessary, data provided by ICAO for States that did not submit their aggregated Emissions Report in accordance with the timeline as defined in Appendix 1 to Annex 16, Volume IV, ICAO calculated the CORSIA baseline CO₂ emissions (2019-2020) for international aviation. Specifically, ICAO published two datasets for average CO₂ emissions on each State pair:

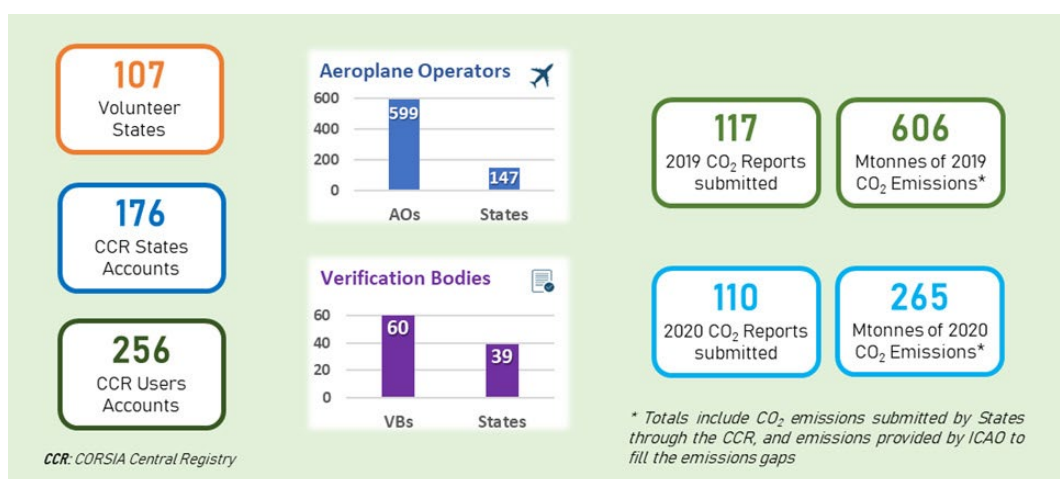


FIGURE 3: Status of reporting through the CCR

³ <https://www.icao.int/environmental-protection/CORSIA/Pages/CCR.aspx>

⁴ Given that the CCR came online in June 2020, ICAO made available an online spreadsheet for States to submit information on aeroplane operators and verification bodies for 2019. All 2019 reported information and data was transferred to the CCR in May 2020.

- Average emissions that apply to the CORSIA pilot phase (2021-2023), taking into account the ICAO Council decision in June 2020 that during the pilot phase, 2019 emissions shall be used for 2020 emissions; and
- Average emissions based on data for both 2019 emissions and 2020 emissions.

The fact that more than 97% of the total CO₂ emissions have been reported through the CCR for both year 2019 (606 million tonnes of CO₂ in total) and year 2020 (265 million tonnes of CO₂ in total) is testament of the determination of both States and aeroplane operators to ensure the successful implementation of CORSIA.

TABLE 3: Status of CO₂ emissions submissions for 2019 and 2020⁵

	2019	2020
Number of States that submitted data	117	110
Number of States for which ICAO provided data*	22	22
Number of States with no reporting requirement**	54	61
Total aggregated CO ₂ emissions (in Mtonnes)	606	265

* In accordance with Annex 16, Volume IV, Part II, Chapter 2, 2.5.2.2. The methodology for ICAO-level gap filling can be found on the ICAO website.⁶

** States without operators, and States with operators with international flights that emit less than 10 000 tonnes of CO₂ per year.

The CORSIA baseline CO₂ emissions were subject to the impact of COVID-19, with CO₂ emissions for year 2020 being 56% lower compared to those of 2019; such an impact can be observed for all ICAO regions (see Figure 4).

From 2022 onwards, ICAO will determine the Sector's Growth Factor (SGF) for the previous year (based on the appropriate average baseline CO₂ emissions) and report back to States. States will use the SGF to determine the CO₂ offsetting requirements for each of their aeroplane operators. Using this information, aeroplane operators will purchase CORSIA eligible emission units and cancel them to fulfill their CO₂ offsetting requirements. Information on such cancellations will be submitted by States through the CCR starting with the pilot phase (due by 31 July 2025 as shown in Table 3).

Final Remarks

The CCR is a vital part of the CORSIA MRV system assisting

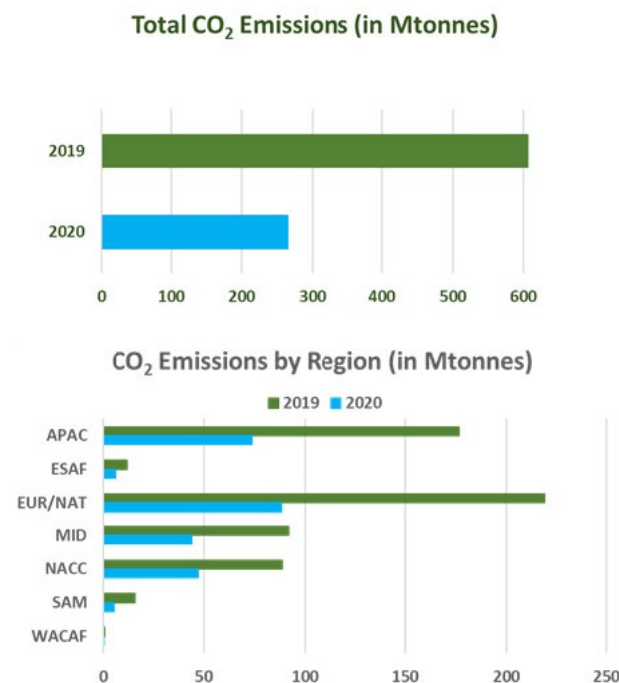


FIGURE 4: CORSIA baseline CO₂ Emissions⁷

States to meet their reporting requirements under CORSIA. In the first few years of its operation, it has proved to be an extremely user-friendly tool and has been used by the majority of States to submit their CORSIA-specific information and data.

The CCR will remain in operation for the duration of the Scheme. In accordance with the timeline in Appendix 1 to Annex 16, Volume IV, it has to be in place at least until 31 July 2037, when the last piece of information is to be submitted by States for the year 2035. Over the coming years, ICAO will continue to maintain and, if necessary, improve the CCR to ensure that it continues to serve the needs of all States in the spirit of ICAO's *No Country Left Behind* initiative.

⁵ CORSIA Newsletter – December 2021. Available at <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIANEWSLETTERS.aspx>

⁶ <https://www.icao.int/environmental-protection/CORSIA/Pages/CCR.aspx>

⁷ CORSIA Newsletter – December 2021. Available at <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIANEWSLETTERS.aspx>

ICAO CORSIA CO₂ Estimation and Reporting Tool (CERT)

By ICAO Secretariat

Introduction

The ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) CO₂ Estimation and Reporting Tool (CERT), referenced in Annex 16, Volume IV, Appendix 3, is one of the five implementation elements of CORSIA used to facilitate the implementation of simplified monitoring and reporting requirements in accordance with the Standards and Recommended Practices relating to CORSIA.

The ICAO CORSIA CERT supports an aeroplane operator to:

- Assess whether it is within the applicability scope of the Monitoring, Reporting and Verification (MRV) requirements (see next section);
- Assess its eligibility to use the ICAO CORSIA CERT as its CO₂ estimation method in support of its Emissions Monitoring Plan (see next section);
- Fill any CO₂ emissions data gaps; and
- Fulfill its monitoring and reporting requirements by filling-in the standardized Emissions Monitoring Plan and Emissions Report templates.

ICAO States can use the ICAO CORSIA CERT to fill-in the CO₂ emissions gap in case an operator is not able to submit emissions estimates.

The ICAO Council's Committee on Aviation Environmental Protection (CAEP) develops updates to the ICAO CORSIA CERT on an annual basis and makes recommendations to the ICAO Council. Following approval by the ICAO Council, updated versions of the ICAO CORSIA CERT, together with the accompanying documentation, are published on

the ICAO CORSIA website¹. As of mid-2022, four versions (2018, 2019, 2020 and 2021)² of the ICAO CORSIA CERT had been published, while the 2022 version of the tool is expected to be finalized and published by the end of 2022.

Aeroplane operators eligible to use the ICAO CORSIA CERT (2021-2035)

As shown in Figure 1, the use of the ICAO CORSIA CERT depends on the level of emissions of an aeroplane operator. All aeroplane operators can use the tool with no restrictions for a preliminary CO₂ assessment. This summary assessment indicates if the aeroplane operator is under the scope of applicability of CORSIA (i.e. if its annual international CO₂ emissions are greater than 10,000 tonnes). For reporting year 2021 and beyond, an aeroplane operator can use the ICAO CORSIA CERT, as its monitoring method, on the condition that its annual international CO₂ emissions subject to offsetting requirements are less than 50,000 tonnes.

Aeroplane Operators Eligibility for CERT (2021 – 2035)			
Offsetting Threshold on State pairs in "CORSIA States for Chapter 3 State Pairs"	≤ 10K CO ₂	< 50K CO ₂	≥ 50K CO ₂
Preliminary CO ₂ Assessment	✓	✓	✓
CO ₂ Estimation & Reporting	No CORSIA requirement	✓	Not Eligible to use CERT
Filling Data Gaps	No CORSIA requirement	✓	✓

FIGURE 1: Aeroplane operator eligibility for ICAO CORSIA CERT (2021 – 2035)

¹ <https://www.icao.int/environmental-protection/CORSIA/Pages/CERT.aspx>

² Each version of the tool is only valid for the specific reporting year (i.e., 2019, 2020 etc.).

How the ICAO CORSIA CERT Works

Using the ICAO CORSIA CERT involves a three-step approach as shown in Figure 2:

- (1) Entering aeroplane operator's information (to meet the requirements of the Emissions Report template as per the Environmental Technical Manual (Doc 9501), Volume IV);
- (2) Entering flight data (manually or through a file upload) to estimate CO₂ emissions based on:
 - a. The Great Circle Distance (GCD) method (inputs needed: aircraft type, aerodrome designator for origin-destination based on ICAO Doc 7910 – Location Indicators; or
 - b. The Block Time method (inputs needed: aircraft type, flight operating time);
- (3) Generating the Emissions Report.

The method that underlines the ICAO CORSIA CERT is a statistical method that is referred to as the ICAO CO₂ Estimation Models (CEMs). The ICAO CEMs make use of actual historic fuel burn data, provided by aeroplane operators, to convert the user's input (i.e., aircraft type, aerodromes of origin and destination, Block Time, if available) into estimated CO₂ emissions. More information on the ICAO CORSIA CERT and the ICAO CEMs is available on the ICAO website.³

The 2021 version of the ICAO CORSIA CERT

The 2021 version of the ICAO CORSIA CERT is based on Microsoft Excel 2013 and Windows 7 as the operating system and can be used for the estimation of CO₂ emissions for the reporting year 2021. In accordance with Annex 16, Volume IV, from 2021 onwards, emissions that are subject to offsetting requirements must be reported separately from emissions not subject to offsetting requirements. To meet this reporting requirement, the 2021 version uses the list of 88 ICAO States that volunteered to participate in CORSIA in 2021 as listed in the ICAO document “*CORSIA States for Chapter 3 State Pairs*” that is available on the ICAO website⁴ to determine which State pairs are subject to CORSIA offsetting requirements and which are not.

Future developments

To facilitate the aeroplane operator's accessibility, ICAO has been working towards developing a version of the ICAO CORSIA CERT in the form of a user-friendly and downloadable application that can be used locally on a user's computer. Future users of the tool will be able to upload data according to the corporate flight plan for emissions estimation, and to generate an Emissions Monitoring Plan and annual Emissions Reports that can be submitted to their respective State authorities in fulfillment of the operators' reporting requirements under CORSIA.

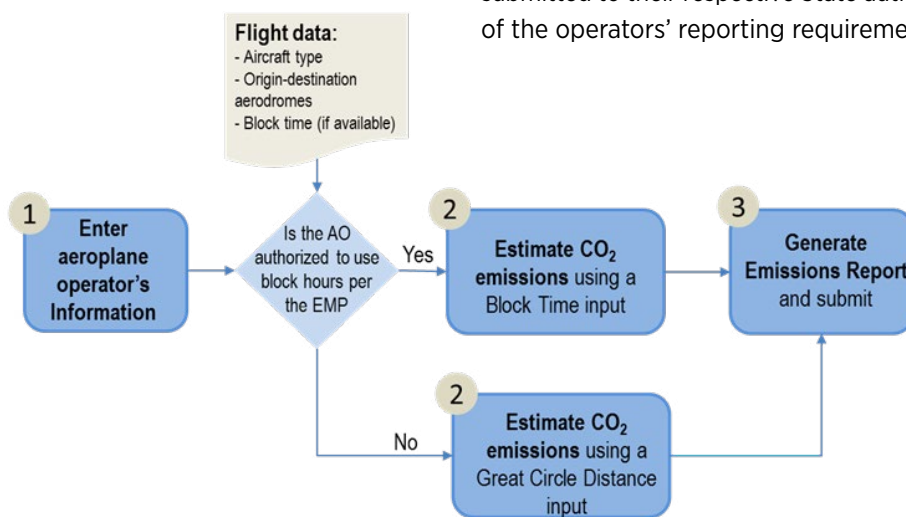


FIGURE 2: Overview of the high-level functions of the ICAO CORSIA CERT

³ <https://www.icao.int/environmental-protection/CORSIA/Pages/CERT.aspx>

⁴ <https://www.icao.int/environmental-protection/CORSIA/Pages/state-pairs.aspx>

Developments in CORSIA Eligible Fuel

By James Hileman (USA FAA), Kristin Lewis (USA Volpe Center), Daniel Rivas Brousse and Juan Hermira (SENASA Spain)¹

Introduction

As defined in Annex 16 Volume IV, CORSIA allows aeroplane operators to reduce their offsetting requirements through the use of CORSIA Eligible Fuels (CEF), which comprises CORSIA sustainable aviation fuels (SAF) and CORSIA lower carbon aviation fuels (LCAF).

Annex 16 Volume IV also lists a series of ICAO documents that are essential to the implementation of the CORSIA. Five of these documents are related to CEF. They provide the necessary technical elements that allow claiming the benefits of CEF under the scheme.

Based on the work from the CAEP Fuels Task Group (FTG) and CAEP Sustainability Certification Schemes Evaluation Group (SCSEG), extensive progress was reached on the development and approval of these documents over the last three years. This article describes these milestones, and the future work to keep these documents up to date with the developments of the SAF and LCAF industries.

CORSIA Eligible Fuel (CEF) definitions

Annex 16, Volume IV provides the following definitions regarding CEF:

- *CORSIA eligible fuel*. A CORSIA sustainable aviation fuel or a CORSIA lower carbon aviation fuel, which

an operator may use to reduce their offsetting requirements.

- *CORSIA lower carbon aviation fuel*. A fossil-based aviation fuel that meets the CORSIA Sustainability Criteria under this Volume.
- *CORSIA sustainable aviation fuel*. A renewable or waste-derived aviation fuel that meets the CORSIA Sustainability Criteria under this volume.

CORSIA Implementation Element for CORSIA Eligible Fuel (CEF)

The procedures and requirements for a CEF to be considered under CORSIA are defined under five ICAO documents referenced in Annex 16, Volume IV. These documents are described in further detail below:

1. ICAO Document - CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (SCS)².

This ICAO document, approved in November 2019 and kept updated thereafter, sets out the framework and eligibility requirements that SCS need to comply with, which also includes SCS' requirements on economic operators (i.e., feedstock producers, processing facilities, and traders) and certification bodies.

The approval of SCSs is carried out by the ICAO Council, with the technical contribution of CAEP, which will assess the compliance of the SCS with the

¹ James Hileman and Daniel Rivas Brousse are Co-Rapporteurs of the Fuels Task Group (FTG) of the ICAO Council's Committee on Aviation Environmental Protection (CAEP). Kristin Lewis and Juan Hermira are Co-Rapporteurs of the Sustainability Certification Schemes Evaluation Group (SCSEG).

² <https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2003%20-%20Eligibility%20Framework%20and%20Requirements%20for%20SCS.pdf>

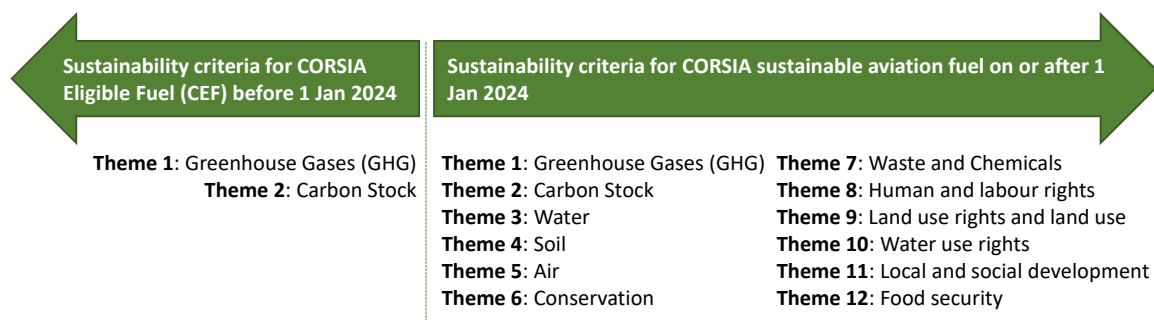


FIGURE 1: CORSIA sustainability criteria for CORSIA Eligible Fuel

framework and eligibility requirements listed. Only the SCS that fulfills all the framework and eligibility requirements are included in the list of approved SCS.

2. ICAO Document - CORSIA Approved Sustainability Certification Schemes (SCS)³.

This ICAO document, approved in Nov 2020, provides the list of SCS that are approved by the ICAO Council as meeting the framework and eligibility requirements set out in ICAO document. They are eligible to certify fuel producers for compliance with the applicable CORSIA requirements. As of March 2022, two SCSs have been approved:

- International Sustainability and Carbon Certification (ISCC); and,
- Roundtable of Sustainable Biomaterials (RSB).

Applications by new SCSs will be reviewed on an ongoing basis. In that regard, SCSs around the world are invited to apply for approval by following the process contained in the ICAO public website⁴.

3. ICAO Document - CORSIA Sustainability Criteria for CORSIA Eligible Fuels (CEF)⁵

This ICAO document, first approved in Jun 2019, sets out a list of sustainability themes, and associated principles and criteria, that applies to CEF until 31 Dec 2023 (end of the CORSIA pilot phase). The 2nd Edition was subsequently approved in November 2021 setting

out the expanded sustainability criteria for CORSIA sustainable aviation fuel that apply on or after 1 Jan 2024. Compliance with the sustainability criteria will be ensured by an approved SCS as reflected in the ICAO document. Aeroplane operators that intend to claim emissions reductions from the use of CEF will be required to provide evidence of the SCS' certification in their emissions reports in accordance with Annex 16, Vol IV.

The sustainability themes and their applicability timeframe can be found in Figure 1.

The supporting document '*Guidance to Sustainability Certification Schemes (SCS) for application of CORSIA Sustainability Criteria, Themes 3 to 7, for CORSIA Sustainable Aviation Fuel produced on or after 1 January 2024*⁶', approved in November 2021, provides guidance to SCSs to support the globally uniform application of the sustainability criteria, including potentially applicable parameters to support the certification of CORSIA sustainable aviation fuel.

As a recent development, the CAEP/12 meeting, in February 2022, agreed to recommend amendments to this document, in order to include the sustainability criteria for CORSIA lower carbon aviation fuels (LCAF) that apply on or after 1 Jan 2024. These will be published following Council approval.

³ <https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2004%20-%20Approved%20SCSs.pdf>

⁴ <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-SCS-evaluation.aspx>

⁵ <https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202021.pdf>

⁶ <https://www.icao.int/environmental-protection/CORSIA/Documents/Guidance%20on%20Sustainability%20Themes%203-7.pdf>

4. ICAO Document - CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels (CEF)⁷

This ICAO document, first approved in November 2019, provides a list of CORSIA default life cycle emissions values (incorporating core life cycle assessment (LCA) and induced land use change (ILUC) values) that may be used by an aeroplane operator to claim emissions reductions from the use of CEF. More details on the methodologies used to obtain these default values are provided in Chapter 7.

The 2nd and 3rd Editions were subsequently approved in March and November 2021 respectively, which included new default life cycle emissions values and specifications for additional CORSIA sustainable aviation fuel conversion pathways and feedstock. Currently, these default life cycle emissions values are sorted into various fuel conversion pathways, feedstocks and production regions, as listed in Table 1. The supporting document '*CORSIA Eligible Fuels – Life Cycle Assessment Methodology*⁸ provides technical information and describes ICAO processes to manage and maintain this ICAO document. The latest editions of this supporting document included documentation on the calculation of new default core LCA and ILUC values, as well as details on the process to add new default life cycle emissions values and related guidance for submission of LCA data to ICAO.

TABLE 1: Feedstocks, conversion processes, and regions with default LCA values

Feedstocks	Conversion processes	Regions
Agricultural Residues*	Fischer-Tropsch	Global*
Forestry Residues*	Hydroprocessed Esters and Fatty Acids (HEFA)	Brazil
Municipal Solid Waste (MSW)*	Alcohol (isobutanol) to jet (ATJ)	USA
Poplar	Alcohol (ethanol) to jet (ETJ)	Malaysia and Indonesia
Miscanthus	Synthesized iso-paraffins (SIP)	European Union
Switchgrass	Coprocessed HEFA at petroleum refineries	
Tallow*		
Used Cooking Oil*		
Palm Fatty Acid Distillate (PFAD)*		
Corn Oil		
Soybean Oil		
Rapeseed Oil		
Palm Oil		
Brassica Carinata		
Sugarcane		
Corn Grain		
Waste gases*		
Sugar beet		

*global values are only applicable to feedstocks defined as wastes, residues, or by-products. The CAEP/12 meeting, in February 2022, agreed to recommend a set of global values that encompass most of the other feedstocks in this list; these will be published following Council approval.

5. ICAO Document - CORSIA Methodology for Calculating Actual Life Cycle Emissions Values⁹

This ICAO document, first approved in November 2019, explains the methodology and processes whereby a CEF producer can demonstrate lower actual core life cycle emissions than the default core life cycle emissions values as reflected in ICAO document. It also allows obtaining life cycle emission values for pathways that do not yet have a default life cycle emissions value. The LCA values obtained with these methodologies should be certified by an approved

SCS before being claimed in CORSIA, to ensure that the methodology has been applied correctly.

The 2nd Edition of the document, approved in March 2021, provided clarifications to consider possible direct land use change emissions associated with the conversion of high carbon stock ecosystems, as well as amendments that allow feedstocks produced with low land use change (LUC) risk practices to be considered in CORSIA without the inclusion of a specific ILUC value in the ICAO document.

7 <https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20November%202021.pdf>

8 https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V3.pdf

9 <https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2007%20-%20Methodology%20for%20Actual%20Life%20Cycle%20Emissions%20-%20March%202021.pdf>

As a recent development, the CAEP/12 meeting, in February 2022, agreed to recommend amendments to this document, in order to include life cycle assessment methodologies for CORSIA lower carbon aviation fuels (LCAF). These will be published following Council approval.

Conclusion

The developments described in the article highlight the extensive progress made on CEF consideration under CORSIA implementation, with globally harmonized sustainability criteria and life cycle emissions methodologies that allow CEF to reduce airlines' offsetting requirements in CORSIA.

The ICAO documents on CEF will be updated regularly. For example, CAEP/12 meeting in February 2022 agreed to recommend further amendments to four of these ICAO documents, including landmark agreements on the LCA methodologies and Sustainability Criteria for CORSIA lower carbon aviation fuels. These will be incorporated into future editions of the ICAO documents, following approval by the ICAO Council. Work will continue in ICAO to further progress CEF developments, in support of ICAO's goals on climate change.

Recent developments on CORSIA Eligible Emissions Units

By Grégoire Baribeau (Canada) and Rachid Rahim (Qatar)¹

Introduction

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is a way to manage emissions from the international aviation industry, as part of the International Civil Aviation Organization's (ICAO)'s basket of measures for working towards carbon neutral growth for international aviation from 2020 onwards. Since the adoption of the CORSIA by the ICAO Assembly in October 2016, officials from the Member States, the Secretariat, aeroplane operators, and emissions unit programmes, have all been working diligently on its implementation.

The CORSIA requires participating aeroplane operators need to meet their CO₂ offsetting requirements by cancelling CORSIA eligible emissions units that meet the CORSIA Emissions Units Criteria (EUC).² In 2019, the ICAO Council approved the EUC and established the Technical Advisory Body (TAB) and its process of work. TAB is mandated to assess emissions unit programmes against the EUCs and make recommendations to Council on the programmes whose emissions units should be eligible for use toward compliance with the CORSIA.

TAB's 19 members are technical experts nominated by their respective member States and approved by the Council. TAB launched the first call for applications in June 2019 and delivered its first recommendations to Council in

early 2020. To date, TAB has processed 25 applications for assessment against the EUC and 15 notifications of material changes to previously assessed programmes. TAB continues to undertake assessments on an annual basis and recently launched its fourth assessment cycle earlier this year.

On the basis of these assessments, TAB has made a series of recommendations to Council, which in turn has approved eight CORSIA eligible emissions unit programmes³ for the 2021–2023 pilot phase:

1. American Carbon Registry
2. Architecture for REDD+ Transactions
3. China GHG Voluntary Emission Reduction Program
4. Clean Development Mechanism
5. Climate Action Reserve
6. Global Carbon Council
7. The Gold Standard
8. Verified Carbon Standard

For most of these programmes, the emissions units eligible for the pilot phase are issued to activities that started their first crediting periods in January 2016 or later, and in respect of greenhouse gas (GHG) mitigation (emission reductions or removals) that occurred from 2016 to 2020. Council has further approved two programmes⁴ to also supply emissions units issued that represent 'post-2020' mitigation, namely with unit dates from 2021 to 2023. Going forward,

¹ Grégoire Baribeau is Chairperson of the Technical Advisory Body (TAB) of the ICAO Council. Rachid Rahim is Vice-Chairperson.

² See Assembly Resolution and CORSIA-related SARPs (Annex 16, Volume IV) adopted by the ICAO Council in June 2018

³ Not all units from these programmes are eligible for use in CORSIA. Certain emissions units from these programmes are not eligible (see each programme's *Scope of Eligibility* in the ICAO document *CORSIA Eligible Emissions Units*)

⁴ American Carbon Registry (ACR) and Architecture for REDD+ Transactions (ART).

TAB will continue to make further recommendations on eligible emissions units based on the ongoing and future assessments.

CORSIA Eligible Emissions Units and TAB assessment

TAB's work has been fundamental to the progress achieved to date in implementing the EUCs and determining CORSIA Eligible Emission Units. ICAO follows a step-by-step approach to ensure that the TAB's technical assessment and related recommendations are robust, and evidence based. Each annual assessment cycle contains five main steps: A) application by emission unit programmes; B) assessment by TAB; C) recommendation by TAB to the ICAO Council; D) decision by ICAO Council; and finally, E) publication of CORSIA eligible emissions units in the ICAO document⁵.

The Emissions Unit Criteria (EUC), published on the ICAO website⁶, address a variety of concepts that have been broadly applied across both regulatory and voluntary offset credit programs to address environmental and social integrity. The EUC cover programme-level design elements, procedures and other provisions which, when taken together, serve to ensure the integrity of eligible units issued by each programme. Key issues include but are not limited to: programme governance; quantification; additionality; baseline-setting; permanence and carbon leakage; validation and verification; monitoring and reporting; issuance, tracking and retirement; legal and property aspects; transparency and public participation; sustainable development; environmental and social safeguards; and the avoidance of double-counting. TAB's application of the EUC is further informed by Guidelines for Criteria Interpretation, which outline detailed expectations for some criteria.

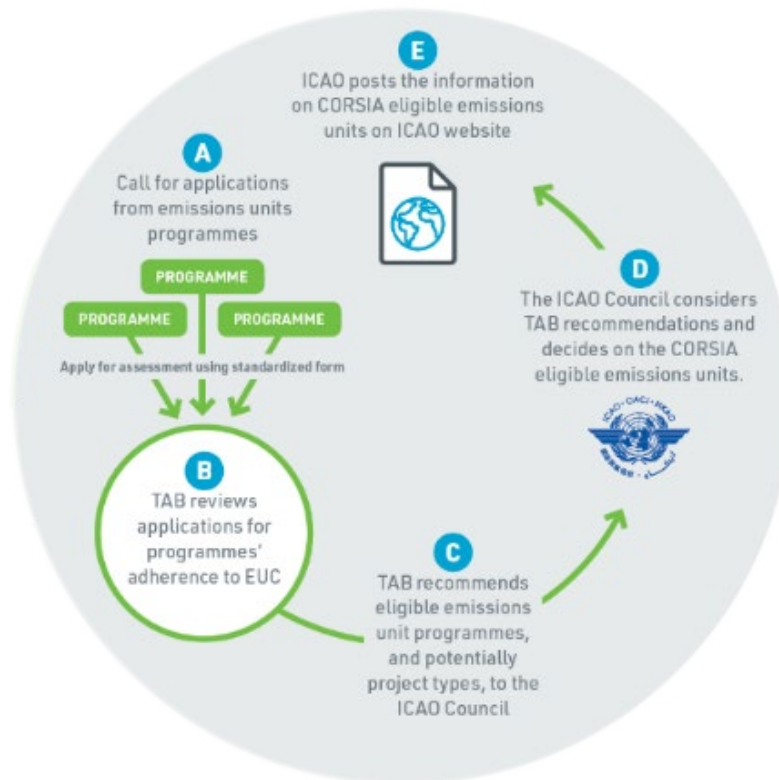


FIGURE 1: Process to determine CORSIA Eligible Emissions Units

⁵ https://www.icao.int/environmental-protection/CORSIA/Documents/TAB/ICAO%20Document%2008%20_%20CORSIA%20Eligible%20Emissions%20Units_November%202021.pdf

⁶ https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO_Document_09.pdf

Each TAB assessment cycle demands considerable expertise and time commitment from TAB members. The TAB typically holds three formal meetings per year, interspersed by teleconferences that bring together all members or smaller ‘sub-groups’ focused on specific technical topics. Each TAB member also undertakes extensive desk work, processing many hundreds of pages of programme applications, supporting documentation and public comments every year. The TAB’s annual work programme is scheduled to align with the Council’s annual meeting cycle, in order to deliver timely recommendations at the relevant Council sessions.

In early 2022, in addition to the annual call for new applications, the TAB initiated a re-assessment of currently eligible emissions unit programmes to consider recommendations on their eligibility beyond the pilot phase (i.e., from 2024 onwards). While potentially offering more clarity to the market looking forward, this re-assessment of CORSIA-eligible programmes is not intended to revoke the eligibility status of emissions units that the ICAO Council has already approved for use during the CORSIA’s pilot phase (from 2021 to 2023).

Transparency and public participation are key to the TAB’s success. After each call for applications or notification of material changes submitted by an emissions unit programme, the TAB posts the application packages on the ICAO website for a 30-day public comment period.

TAB members are grateful for the many helpful comments they have received since 2019, which are also published for transparency following each assessment cycle. The TAB also conducts public webinars at the start of each new assessment cycle, as well as periodic public events, to engage stakeholders and introduce potential applicants to the CORSIA, the EUC, the TAB’s procedures and the application processes.

To follow the TAB’s work, a dedicated page on the ICAO website⁷ contains up-to-date information, including governance-related documents (membership, Terms of Reference and Procedures); annual work programmes; application forms and materials; registry attestations of eligible programmes; recommendation to ICAO Council; outcomes of the Council decisions; public comments; and Frequent Asked Questions (FAQs) reflecting recurring inquiries submitted by programmes and the public.

Supply of CORSIA Eligible Emissions Units

CORSIA Eligible Emissions Units serve to offset the greenhouse gas footprint of international civil aviation by undertaking different activities that reduce or avoid GHG emissions. While there are dozens of different activity types and many methodologies to quantify them, most emissions

CORSIA Eligible Emissions Units: Projected volume by region and activity type, 2016-2020 vintages

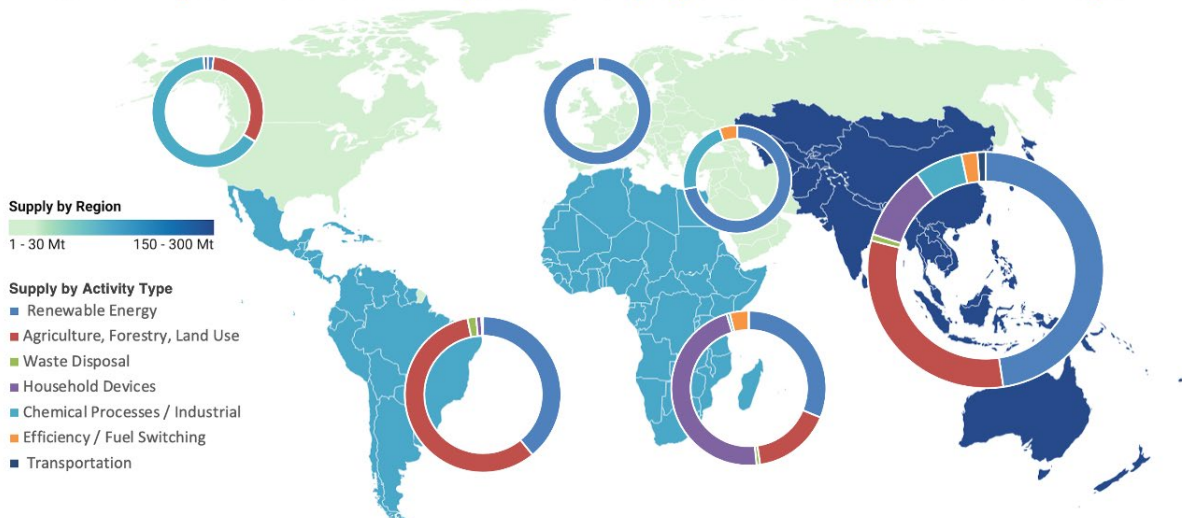


FIGURE 2: Regional distribution of CORSIA eligible emissions units

7 <https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx>

unit activities can be sorted into six broad categories: (1) renewable energy; (2) agriculture, forestry and land use (AFOLU); (3) waste disposal; (4) household devices; (5) chemical processes and industrial manufacturing; (6) energy efficiency and fuel switching; and (6) transportation.

In 2021, at the request of ICAO Council, TAB conducted an analysis of the supply of CORSIA Eligible Emissions Units, including with respect to the sectoral and geographic distribution of programme activities. Based on the data collected in a survey of Eligible Emissions Unit programmes, TAB estimated that these programmes are likely to issue around 300 to 350 million units representing GHG mitigation that occurred between 2016 and 2020. Each of these units would currently be eligible for use toward CORSIA offsetting requirements in the 2021-2023 pilot phase, or alternatively, could be used in other voluntary and compliance offset markets, where applicable. The analysis also indicated that, given the extension of Eligible Unit Dates through 2023 for two programmes, another 150 to 180 million units could be issued for GHG mitigation that occurs in 2021-2023. However, it is not currently known how many of these units would obtain authorization by the host country attesting to their intention and steps taken to avoid double-claiming against national greenhouse gas targets (see next section).

Figure 2 below shows the projected volume of CORSIA eligible emissions units by region and activity type. Based on 2021 data, eligible emissions units are mainly from activities relating to renewable energy (90 – 210 million units), AFOLU (110 – 140 million units) and household devices (25 – 60 million units). The leading region generating CORSIA eligible emissions units is Asia-Pacific (140 – 270 million units), followed by Latin America & the Caribbean (60 – 100 million units), Africa (30 – 65 million units), North America (14 – 15 million units), Europe (2.5 – 5.5 million units) and Middle East (0.6 – 1.5 million units).

Future of CORSIA Eligible Emissions Units and TAB assessment

At the Glasgow Climate Conference (COP26) in November 2021, Parties to the Paris Agreement adopted substantive

outcomes relating to its article 6, including accounting guidance for internationally transferred mitigation outcomes (ITMOs) and rules, modalities and procedures for a new international offset programme (“the Article 6.4 mechanism”). To prevent double claiming, the new guidance requires Parties to adjust to their reported emissions levels to account for any ITMOs they have authorized and transferred for use toward another country’s national target (“NDC”), or towards other international mitigation purposes such as CORSIA. It also contains new expectations relating to additionality, tracking, and reporting, including on social and environmental safeguards, among others. Some programmes may update their procedures in light of COP26, particularly as they pertain to post-2020 mitigation. TAB will also consider possible implications of the relevant Article 6 outcomes in its ongoing (re-)assessments as well as in future assessments going forward.

Due to COVID-19 pandemic, the international aviation sector had a major reduction in air traffic, resulting in lower sectoral CO₂ emissions than anticipated at the time CORSIA was adopted. As a result, aeroplane operators have so far not needed to purchase many eligible emissions units in order to comply with their offsetting obligations for the CORSIA pilot phase. Nevertheless, the EUCs and the TAB have exerted a positive influence on international carbon markets more broadly. The EUCs have helped sensitize market actors and stakeholders to key features of high-integrity carbon offset programmes, while the TAB assessment process has further clarified how emissions unit programmes can apply these concepts in practice. This experience has helped raise the bar for quality in international offset markets, while also reducing information barriers for new market entrants.

Together with the new policy clarity achieved at COP26, the CORSIA is helping to build a robust foundation for high-integrity international carbon markets in this critical decade for climate action. As the international airline industry continues to recover from the pandemic, driving new growth in the demand for Eligible Emissions Units, we expect the CORSIA to continue to play an important role in scaling up international carbon markets going forward.

Impacts of COVID-19 on CORSIA implementation

By Kerri Henry (Canada), Stephen Arrowsmith (EU EASA), Philippe Bonnefoy (USA) and Stefano Mancini (EU EUROCONTROL)¹

Introduction

The outbreak of the COVID-19 pandemic in the initial months of 2020 had a deep and immediate impact on the aviation sector, with lasting effects still noticeable as of 2022. As with any other aspect of international aviation activity, the implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) has also been impacted by the pandemic. A clear understanding of the extent of such impact thus far, and of future scenarios as CORSIA implementation progresses in coexistence with COVID-19, is of paramount importance to ensure that CORSIA contributes to the environmental integrity and the sustainability of international aviation.

In April 2020, the ICAO Council requested its Committee on Aviation Environmental Protection (CAEP) to assess the impact of the COVID-19 outbreak on the average of annual CO₂ emissions in 2019 and 2020 (the so-called “CORSIA baseline”), as well as the related impact on the CORSIA offsetting requirements. Since then, CAEP has provided regular updates to the Council on this matter in support of the 2022 CORSIA periodic review. The assessment update², presented to the Council in March 2022, is the subject of this article.

CAEP’s assessment of the impacts of COVID-19 on CORSIA implementation has involved a large number of experts engaged in various CAEP subgroups, namely: the Forecasting and Economic Analysis Support Group (FESG);

the Modelling and Databases Group (MDG); the Fuels Task Group (FTG); and Working Group 4 (WG4). The work of FESG, MDG, and FTG has served as a fundamental input to WG4, tasked with considering all relevant inputs and conducting the analysis yielding the impact assessment.

Assessment of the CO₂ emissions drop and development of recovery scenarios

An immediate impact of the COVID-19 pandemic was a sharp drop of international aviation activity and hence its related CO₂ emissions in 2020. Based on the latest assessment conducted by CAEP, CO₂ emissions from the international aviation sector dropped by approximately 59% from 2019 to 2020.

In conjunction with the drop in CO₂ emissions witnessed in 2020, CAEP developed three recovery scenarios on the basis of air traffic forecasts, in consultation with ICAO’s Aviation Data and Analysis Panel (ADAP). These three scenarios consider different rates of recovery to 2019 levels of CO₂ emissions from international aviation. The latest version of these recovery scenarios was developed in November 2021, which served as the basis for the information provided to the Council in March 2022 (see Figure 1).

Figure 1 also shows the CO₂ emissions trends as reported in the ICAO 2016 Environmental Report³, also referred

¹ Kerri Henry and Stephen Arrowsmith are Co-Rapporteurs of Working Group 4 of the ICAO Council’s Committee on Aviation Environmental Protection (CAEP). Philippe Bonnefoy and Stefano Mancini are Co-Leads of Working Group 4 CORSIA Tools and Analysis Group.

² ICAO, “COVID-19 impacts and 2022 CORSIA periodic review”, available at: <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx>, last retrieved: May 4th, 2022.

³ ICAO, “2016 Environmental Report, Chapter 1: Aviation and Environmental Outlook, Environmental Trends in Aviation to 2050”, available at: <https://www.icao.int/environmental-protection/pages/env2016.aspx>, last retrieved: May 4, 2022.

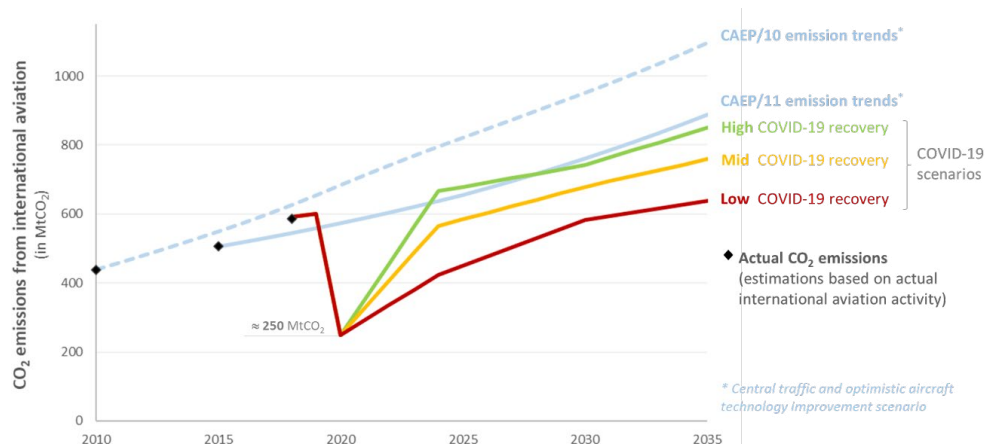


FIGURE 1: CO₂ emissions trends used in CORSIA Analyses including scenarios that reflect drop in CO₂ emissions in 2020 and recovery from COVID-19

to as the “CAEP/10 trend”. These trends used actual CO₂ emissions in 2010 as a reference forecast year and were also used in the CAEP analysis that supported the decision by the 39th Session of the ICAO Assembly (2016) to implement CORSIA. CAEP subsequently developed its “CAEP/11 emissions trends”⁴, for which the reference point was actual CO₂ emissions in 2015. As shown in Figure 1, long-term projections of CO₂ emissions in the CAEP/11 trend were lower than in the CAEP/10 trends, mostly due to lower international aviation traffic forecasts. The latest version of the COVID-19 recovery scenarios is based on the “CAEP/12 trends”, using 2018 as a reference forecast year.

Potential return to 2019 levels of CO₂ emissions and resulting non-emitted CO₂ emissions

The development of the three COVID-19 recovery scenarios allowed CAEP to estimate the range of years when international aviation may reach pre-COVID-19 levels in CO₂ emissions terms. As shown in Figure 2, each of the three scenarios provides a different year of return to 2019 levels of activity, ranging from 2024 under the high recovery scenario to 2032 under the low recovery scenario.

The CAEP analysis also provides, for each COVID-19 recovery scenario, an estimate of the amount of CO₂ emissions that, due to the drop of emissions in 2020 and subsequent pattern of recovery, will in fact not be emitted up to the year of return to 2019 levels of activity. As shown in Figure 2, these “non-emitted emissions” range from 780 Mt of CO₂ under the high recovery scenario to 1,800 Mt of CO₂ under the low recovery scenario. These data show that the impact of COVID-19 on international aviation activity could lead to the non-emission of a significant portion of the emissions and hence to a significant lower call for CORSIA offsetting requirements, which were estimated to be approximately 2,500 Mt CO₂ at the time when CORSIA was agreed upon in 2016.

To avoid inappropriate economic burden on the aviation industry and as the safeguard in light of paragraph 16 of Resolution A40-19, the Council decided in June 2020 to amend the CORSIA baseline to a 2019 level (only) during the pilot phase from 2021 to 2023⁵.

4 ICAO, “2019 Environmental Report, Chapter 1: Aviation and Environmental Outlook, Environmental Trends in Aviation to 2050”, available at: <https://www.icao.int/environmental-protection/pages/envrep2019.aspx>

5 ICAO, “ICAO Council agrees to the safeguard adjustment for CORSIA in light of COVID-19 pandemic”, available at: <https://www.icao.int/Newsroom/Pages/ICAO-Council-agrees-to-the-safeguard-adjustment-for-CORSIA-in-light-of-COVID19-pandemic.aspx>, last retrieved: May 4, 2022.

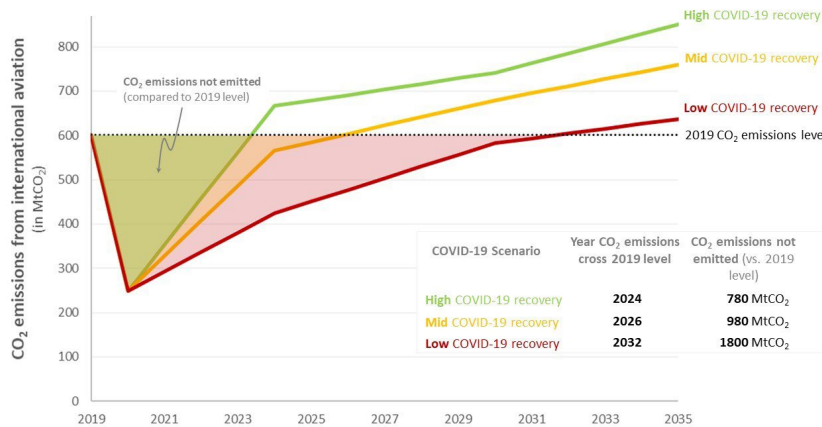


FIGURE 2: Year of return to 2019 levels of activity and related non-emitted CO₂ emissions

Impact on CORSIA offsetting requirements

In the context of CAEP's assessment of the impacts of COVID-19 on CORSIA, one of the aspects considered was the impact on the volume of CORSIA offsetting requirements. In this regard, three factors were identified as relevant.

- The drop of CO₂ emissions from 2019 to 2020;
- The path of recovery of the sector towards pre-COVID-19 levels of activity; and
- The definition of the CORSIA baseline after the scheme's pilot phase (i.e., from 2024 to 2035).

As it has been shown above, the drop of CO₂ emissions from 2019 to 2020 has been estimated by CAEP, whereas the path of recovery of the sector has been modeled through

three COVID-19 recovery scenarios (see Figure 1). Regarding the definition of the CORSIA baseline from 2024 to 2035, it is important to note that this is yet to be determined by the ICAO Assembly and the Council. Mindful of this, CAEP considered two possible options within its analysis:

- Average of annual CO₂ emissions in years 2019 and 2020; or
- CO₂ emissions in 2019 (i.e., continuation through 2035 of the amended CORSIA baseline during the pilot phase 2021-2023).

Figure 3 shows the impacts of the CORSIA Baseline on offsetting requirements for the mid COVID-19 recovery scenario. The figure on the left illustrates a scenario where the CORSIA baseline is set to an average of actual 2019 and 2020 emissions. This results in a drop in the baseline

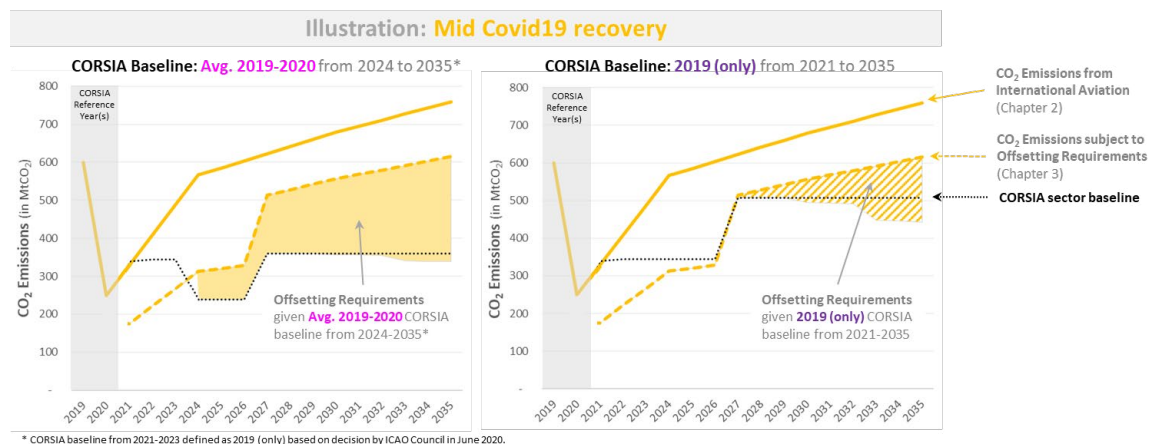


FIGURE 3: Impact of the CORSIA Baseline on offsetting requirements through 2035

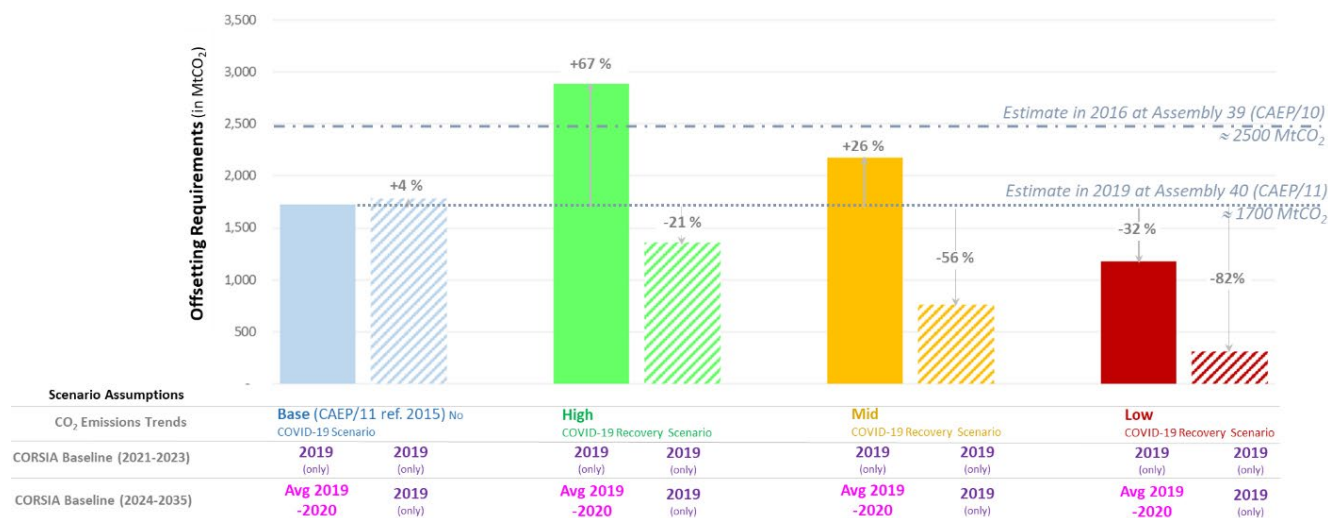


FIGURE 4: Estimation of CORSIA offsetting requirements under Avg. 2019-2020 and 2019 (only) CORSIA baseline from 2024 to 2035

in 2024 (start of First Phase). The increase in the baseline value in 2027 is driven by the phased implementation of additional States joining CORSIA. The colored wedge between CO₂ emissions subject to offsetting requirements and the CORSIA sector baseline represents offsetting requirements. As shown on the above figure, increasing the CORSIA baseline to a 2019 (only) level reduces the amount of offsetting requirements through 2035.

When considering an average 2019-2020 baseline from 2024 to 2035, the CAEP analysis shows that estimated offsetting requirements could range from 1,200 Mt CO₂ under the low recovery scenario to 2,900 Mt CO₂ under the high recovery scenario. Figure 4 shows how these values vary from the estimated value at the time of the 40th Session of the ICAO Assembly in 2019 (1,700 Mt CO₂), and the estimate at the time when CORSIA was agreed upon in 2016 (2,500 Mt CO₂).

When considering a 2019 baseline from 2024 to 2035, the CAEP analysis shows that offsetting requirements could range from 310 Mt CO₂ under the low recovery scenario to 1,400 Mt CO₂ under the high recovery scenario (see Figure 4).

Regional breakdown

The ICAO Council requested CAEP to assess the regional breakdown of the impacts of COVID-19 on international aviation to determine whether such impacts differed among regions.

In order to undertake this part of the analysis, WG4 used forecasts of CO₂ emissions on 40 international route groups, coupled with State pair level information, to develop operator and State pair specific projections. The CAEP analysis estimated that the reduction in 2020 CO₂ emissions from international aviation compared to 2019 ranged from -24% to -68% across the route groups. Route groups also illustrated different behaviour when estimating their recovery to pre-COVID-19 levels of activity. While some route groups returned to 2019 levels of activity as early as in 2023, a few routes may not recover to 2019 levels of activity within the timeframe of the analysis. In connection with this, the analysis showed that CO₂ emissions from international aviation could grow by a factor of 0.95 to 2.5 across the route groups by 2035 (relative to 2019 levels).

When considering the regional component in terms of the impact of COVID-19 on the volumes of CORSIA offsetting requirements, CAEP considered the “ICAO Statistical Regions” as shown in Figure 5.

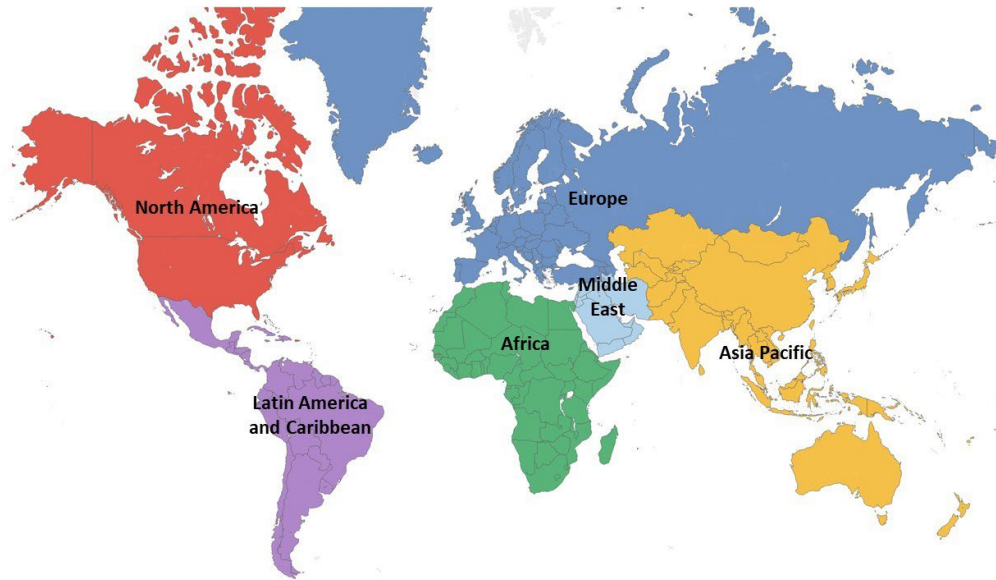


FIGURE 5: Definition of regions as considered by CAEP for the regional breakdown of its analysis

It is important to highlight that, prior to the outbreak of the COVID-19 pandemic, different regions were expected to have different volumes of CORSIA offsetting requirements on account of variations in factors such as traffic volumes or the number of States participating in CORSIA (Chapter 3 states) at any given point throughout the implementation of the scheme. Therefore, the scenarios analyses of the impact of COVID-19 among the various regions, and the identification of possible variations in the degree of such impact among regions, would necessarily need to take into account that the starting point (i.e., the “pre-COVID-19 scenario”) differs for each region.

The result of the CAEP scenarios analyses concluded that all regions show similar relative changes to the related volumes of CORSIA offsetting requirements compared to the “pre-COVID-19 scenario”, so that all regions are expected to be affected by COVID-19 in a similar manner.

Final remarks

As the world recovers from the severe consequences of the COVID-19 pandemic and adjusts to a new normality conditioned by the lasting presence and decreasing impact of the pandemic, so does the international aviation sector moving forward.

Despite these difficulties, CORSIA is being successfully implemented with a growing number of participating (Chapter 3) States. CAEP and its subgroups, including Working Group 4, remain ready to support the ICAO Council in the provision of technical inputs, especially in the continued monitoring of the impact of COVID-19 on the implementation of the scheme.

The 2022 CORSIA periodic review

By ICAO Secretariat

Introduction

At the 39th Session of the ICAO Assembly in 2016, ICAO Member States reached a historic agreement when they decided to adopt a global market-based measure scheme for international aviation, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

One of the key points that facilitated the agreement of CORSIA was the inclusion of a periodic review mechanism that, every three years from 2022, would serve as an important basis to determine the need to make adjustments to CORSIA in future phases of the scheme.

In March 2021, the ICAO Council agreed on the Terms of Reference that would guide its work throughout the 2022 CORSIA periodic review, in order to address the ICAO Assembly's request. Prior to that, the Council had to apply CORSIA's safeguards provision in response to the impact of the COVID-19 pandemic on the scheme.

Application of CORSIA's safeguards provision in response to the impact of COVID-19

In June 2020, after careful consideration of various technical inputs provided by CAEP on the impact of the COVID-19 pandemic on CORSIA, the Council agreed to apply the CORSIA safeguards provision, enshrined in CORSIA in response to circumstances that may prevent CORSIA implementation from contributing its fair share to the sustainable development of the international aviation sector. With this in mind, the Council decided that 2020 emissions should not be used during CORSIA's pilot phase (2021-2023) to define the scheme's baseline.

It is important to note that this important decision, affecting CORSIA implementation during the pilot phase, was not part of the 2022 CORSIA periodic review *per se*. However, it anticipated the prominence that the assessment of the impact of the COVID-19 pandemic on CORSIA implementation would have during the review.

Operationalizing the 2022 CORSIA periodic review

As a starting point, the Council requested a series of inputs that would help define the way forward to conduct the 2022 CORSIA periodic review. These inputs, to be delivered by the ICAO Secretariat, included a proposal for a review structure, process and methodology, including a work programme to determine the contributions to the process from the Council's Committee on Aviation Environmental Protection (CAEP).

In March 2021, the ICAO Council agreed on the process and methodology for the 2022 CORSIA periodic review, and on the framework for the consideration of various inputs; this was reflected in the related Terms of Reference that would guide the Council's work throughout the process.

Governance

As requested by the ICAO Assembly, the responsibility of undertaking the 2022 CORSIA periodic review lies on the ICAO Council. In the initial steps of the process, the Council counted with the support of its Advisory Group on CORSIA (AGC), established in 2017 with the purpose of discussing any CORSIA-related items prior to their consideration by the Council. Shortly after the start of the process, the AGC was discontinued as a result of the

establishment of the Council's Climate and Environment Committee (CEC), whose role was expanded from that of its predecessor to cover all environmental matters.

Needless to say, the Council and the CEC have not conducted the review in isolation; ICAO Member States have played a fundamental role *during* the review through the provision of inputs regarding their experiences with CORSIA implementation. Moreover, ICAO Member States will also play a key role *after* the review when, in the context of the 41st Session of the ICAO Assembly (27 September – 7 October 2022), they will be presented with the Council's conclusions and recommendations stemming from the review.

Two Council subsidiary bodies have featured prominently through the provision of technical inputs to the Council and the CEC: CAEP and the Technical Advisory Body (TAB).

ICAO Secretariat also took part in the review process, through its support to the Council, CEC, CAEP and TAB, as appropriate.

States' inputs

In order to collect inputs from States on their experiences regarding CORSIA implementation, the Council requested the Secretariat to conduct a consultation process. To that effect, a detailed questionnaire was prepared and, upon approval by the Council, submitted through a State letter, which is one of the official means of correspondence between ICAO and its Member States. The State letter, issued on 7 May 2021, provided a three-month period for States to reply, so that sufficient time was given to States to provide their inputs.

As many as 106 States provided responses to the State letter, allowing for the compilation of a wealth of information that was considered by the Council in November 2021. The Council acknowledged that the high response rate to the State letter was a sign of States' positive interest and engagement in the 2022 CORSIA periodic review.

As per the structure of the questionnaire, States provided their inputs on four overarching topics, namely: views on CORSIA capacity building activities; experience in CORSIA implementation; views on the application of the provision for safeguards in CORSIA implementation; and expectations on the outcome of the 2022 CORSIA periodic review.

After consideration of the received inputs by CEC, and subsequently by the Council, the latter concluded that those inputs related to States' experience in CORSIA implementation should be incorporated in CAEP's work in support of the 2022 CORSIA periodic review. Moreover, received inputs on CORSIA capacity building activities are extremely helpful for the ICAO Secretariat to identify ways and related required resources to enhance these activities. Regarding States' inputs on views on the application of the CORSIA safeguards provision, and expectations on the outcome of the 2022 CORSIA periodic review, these have been taken on board by the Council as part of its work towards completion of the review, and will serve as inputs in the definition of modalities of CORSIA safeguards.

CAEP and TAB' inputs

When, in March 2021, the Council approved the Terms of Reference that would guide its work throughout the 2022 CORSIA periodic review, it also agreed on a series of requests for specific technical inputs to be provided by CAEP and TAB for consideration in subsequent Council sessions. These requests and related timing are detailed in the corresponding Summary of Decisions, available in the ICAO website¹.

The main focus of TAB's technical inputs was an analysis of the supply of CORSIA Eligible Emissions Units, including with respect to their sectoral and geographic distribution. More information on the result of TAB's analysis can be found in Chapter 8 of this report. TAB also provided initial observations and suggestions for improvements of its work. TAB's inputs were considered by the Council in November 2021.

1 C-DEC 222/12, available at https://www.icao.int/about-icao/Council/Pages/council_sessions_222.aspx

CAEP's technical inputs throughout the process can be grouped as follows:

- Regular updates on the analysis on the impact of COVID-19 on CORSIA;
- Analysis of costs of CORSIA implementation for the various relevant stakeholders (namely States and aeroplane operators);
- Consideration of possible market distortions stemming from CORSIA implementation; and
- Initial suggestions on the improvement of CORSIA.

Since June 2021, CAEP's inputs to the Council, including key takeaway messages, have been made available in the ICAO CORSIA website, with the latest information having been provided to the Council in March 2022². More information on CAEP's assessment of the impact of COVID-19 on CORSIA can be found in Chapter 8 of this report.

In March 2022, the Council acknowledged that CAEP had provided technical inputs and analyses on all the requests of the Council in support of the 2022 CORSIA periodic review within the established timeline and with due consideration of the data available at the time.

The way forward

At the time of writing this article, the Council continues its work on the 2022 CORSIA periodic review. Based on all inputs received, the Council will produce a report that will be presented to 41st Session of the ICAO Assembly (27 September – 7 October 2022); the report will set

out the Council's conclusions and recommendations for consideration by the Assembly.

Among the decisions expected to be made by the ICAO Assembly, the definition of the CORSIA baseline beyond CORSIA's pilot phase (2021-2023) remains an outstanding one. The outbreak of the COVID-19 pandemic, the application of the CORSIA safeguards provision and related amendment of the CORSIA baseline for the pilot phase, and the expected recovery of the international aviation sector in the near future, are inter-related factors that will be considered in the Council's conclusions on this matter.

Based on the agreement reached at the ICAO Assembly, the Council will consider adjustments, if any, to the Standards and Recommended Practices (SARPs) for CORSIA implementation, as contained in Volume IV of Annex 16 (*Environmental Protection*) to the Convention on International Civil Aviation. Similarly, possible necessary adjustments to the five CORSIA Implementation Elements and related ICAO documents will also be considered³.

With the final steps of the 2022 CORSIA periodic review under way, the Council and its Climate and Environment Committee remain committed to the timely delivery of the Council's conclusions and recommendations. In completing this first CORSIA periodic review, the Council is fully aware of the need to start planning ahead for future reviews. It is in this context that the Council recognizes the need for a regular and systematic assessment of CORSIA, supported by the technical contributions of CAEP and TAB as needed.

² <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx>

³ <https://www.icao.int/environmental-protection/CORSIA/Pages/implementation-elements.aspx>

CORSIA Implementation: aeroplane operator perspectives

By International Air Transport Association (IATA)

Introduction

Since news of the coronavirus disease (COVID-19) first emerged in early 2020, people, businesses and governments around the world have been trying their best to manage and contain the pandemic while adjusting to a new way of life. Aviation, as one of the primary sectors providing connectivity for our global community, was hard hit. Travel restrictions and public health measures saw levels of international aviation activity drop to levels not seen since the 1980s. Despite the unprecedented crisis facing airlines, their commitment to address the industry's impact on the environment and transition toward a more sustainable future continued to strengthen.

Support for CORSIA

In October 2021, IATA's Member Airlines committed to increasing their long-term environmental ambition from previous goals established in 2009 to achieving net-zero emissions by 2050 and reinforced their strong support for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). In parallel, the International Civil Aviation Organization (ICAO) Member States continued to volunteer for the pilot phase of CORSIA, bringing global coverage of the scheme to its highest levels yet. This sustained and even increasing support for CORSIA can in many ways be attributed to the effective governance and flexibility of the ICAO Council in managing the implementation of CORSIA and reacting to a crisis so severe that it could not have been foreseen when the design elements of CORSIA were first agreed.

CORSIA implementation

Since the 39th Session of the ICAO Assembly in 2016, IATA has been working closely with its member airlines to prepare for the start of CORSIA. These capacity-building initiatives, often directly supported by authorities in ICAO Member States, focused at first on ensuring that airlines were ready for the monitoring, reporting and verification (MRV) of emissions. With airline readiness varying between and within regions, airlines collaborated to build up knowledge and skills using the practical experiences of airlines already familiar with fuel monitoring procedures, fuel efficiency systems and third-party verification of data. This collaborative spirit, among what would otherwise often be close competitors, exemplifies the industry unity in support of CORSIA as the best means of achieving immediate progress towards our climate commitments through a multilateral and global approach.

These discussions among airlines often raised new questions and highlighted areas where additional guidance would be helpful. The IATA Secretariat and airline experts relayed this information back to the experts of the Committee on Aviation Environmental Protection (CAEP) whenever relevant. IATA would like to commend and thank the CAEP, and the ICAO Secretariat, for their expertise, dedication, and hard work to address the numerous requests for clarification to ensure airlines understood precisely how to comply with their MRV obligations under CORSIA. ICAO's ability to address emerging issues in a timely manner and issue new or revised standards, recommended practices, and guidance to clarify compliance for airlines has been essential to the successful implementation of CORSIA. The COVID-19 crisis reinforced the importance of CAEP and its

expertise in responding to significant issues ranging from the implications for the CORSIA baseline of a collapse in international traffic in 2020, to the use of remote verification procedures in exceptional circumstances when verifiers are unable to travel for on-site visits. In all cases, CAEP responded with the careful consideration and deep expertise that characterizes its work to inform decision-makers in the ICAO Council – and did so all while meeting virtually.

ICAO's recognition of the important role of simplified compliance procedures and the ability of CAEP to deliver the tools and guidance needed to support them, has also been key success factor in ensuring the successful implementation of CORSIA. On this note, IATA would like to congratulate the members and organizations that have supported the CORSIA CERT Group (CCG) under Working Group 4 on the consistent delivery of the CORSIA Estimation and Reporting Tool (CERT) each year. It has made the lives of both small and large airlines much easier.

Conclusion

As the industry emerges from the COVID-19 crisis, IATA will continue its capacity-building activities to support airlines as they return to a more normal rhythm of business activities and are able to begin preparing for future offsetting obligations. IATA welcomes the continued support of, and collaboration with ICAO Member States, the ICAO Secretariat and CAEP to ensure the airline community is prepared to continue on the trajectory of successful implementation for the world's first global market-based measure to address emissions from international aviation.

Delivering the first ever CORSIA-certified Sustainable Aviation Fuel to American Airlines

By Chris Cooper and Jorrian Dorlandt (Neste)¹

Introduction

CORSIA, or ‘Carbon Offsetting and Reduction Scheme for International Aviation’, allows airlines to reduce their offsetting requirements through the use of “CORSIA eligible fuels²” But until now, no airline across the world has actually used CORSIA-certified fuel. Neste’s recent ISCC CORSIA certified pilot delivery of sustainable aviation fuel (SAF) to American Airlines makes this a first in aviation history.

This article shares the learnings and experiences of Neste and American Airlines, working together in this pilot supported by ISCC. Or as Tom Opderbeck, Senior Sustainability Manager at American summarized: *“SAF is the key component of the aviation industry’s decarbonization strategy so we are very interested in promoting efforts that help accelerate its use.”*

What is Sustainable Aviation Fuel

Sustainable aviation fuel has been recognized as one of the key elements in helping the aviation industry to achieve the ambitious emissions reduction goals. SAF is the main term used by the aviation industry to describe an aviation fuel not made from fossil sources.

In general, SAF is produced from renewable resources (plant or animal material) and there are currently seven approved pathways for SAF. HEFA-SPK is currently the commercially most viable pathway for SAF, and it is the one being used by Neste, the world’s leading producer of SAF.

Neste has been producing SAF since 2011 and uses sustainably sourced 100% renewable waste and residue raw materials, like used cooking oil and animal fat waste. The main advantage of Neste MY Sustainable Aviation Fuel™ is that it reduces greenhouse gas emissions (GHG) by up to 80% in neat form and over the life cycle compared to conventional fossil-based jet fuel. This calculation is based on the CORSIA methodology. As these are life cycle based calculations, similar SAF produced by different companies from different raw materials, or other types of SAF produced with different technologies might provide different GHG savings.

SAF has been used in more than 370,000 flights since 2016 according to IATA, and that number is rapidly increasing. Currently SAF can only be blended with fossil-based jet fuel up to 50% based on ASTM standards, but in reality this percentage is rarely achieved. SAF is a drop-in fuel which

¹ Neste is the world’s leading producer of renewable diesel and sustainable aviation fuel. Neste’s currently produces 100,00 tons of SAF per annum at its Porvoo, Finland refinery. With the ongoing expansion of Neste’s Singapore refinery and modification to its existing Rotterdam, the Netherlands refinery, Neste will have an annual SAF production capacity of 1.5 million tons by the end of 2023. In the past two years, Neste has been opening up SAF supply to the aviation sector with multiple cooperations and partnerships within commercial, business and general aviation, including working together with fuel providers, airports, and regulators.

Chris Cooper is Vice President North America Renewable Aviation at Neste. Jorrian Dorlandt is Communication Manager Renewable Aviation at Neste. The authors would like to thank Tom Opderbeck (American Airlines) and Thomas Bock (ISCC) for their contribution.

² <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

means that once blended, it can be supplied via existing infrastructure and uplifted without aircraft modifications, removing any logistical or technical barriers to its use.

The airline perspective – American Airlines

CORSIA covers all aircraft operators performing international flights. These operators, mostly commercial airlines, will either have to buy emission reduction offsets from other sectors to compensate for any emissions obligations or use sustainable aviation fuel in their own operations.

American Airlines (American) is one of the largest airlines in the world, offering an average of nearly 6,700 flights daily to 350 destinations in 50 countries. As such, CORSIA is also applicable to American. It has an ambitious strategy to reach net-zero carbon emissions by 2050 and a clear plan to get there. This includes a goal to replace 10% of the jet fuel it uses with sustainable aviation fuel by 2030. For this, American also works together with Neste supplying its Neste MY Sustainable Aviation Fuel™ to American at San Francisco International Airport (SFO).

Like many airlines, American is supportive of CORSIA and endorses the goals it aims to achieve. Emission reductions by using SAF will play a growing role in American's own strategy, although carbon offsets will also continue to play a role for the foreseeable future. But like many other airlines across the world, experience with CORSIA-certified SAF has been limited.

Tom Opderbeck describes it as follows: *“Until this pilot, our understanding of the CORSIA certification process was limited. Participating in this pilot project with Neste served as a perfect opportunity to see how it works and learn.”*

The ISCC CORSIA pilot

Until recently, no airline across the world had actually made use of CORSIA-certified SAF to mitigate emissions. While several companies had already received CORSIA certificates, CORSIA certified SAF had not been delivered and used.

Neste and American have a long-standing relationship, based on which the companies started discussions to see what the possibilities are to use CORSIA-certified SAF to mitigate the emissions of international flights. The companies decided to set up a pilot project as part of the voluntary CORSIA pilot phase.

What needed to be done

Although the aviation industry has extensive experience in using SAF, getting the SAF to be CORSIA-certified was a complicated task. Compliance to the CORSIA sustainability criteria is granted on the basis of independent attestation by ICAO-approved Sustainability Certification Schemes (SCS). This applies to both the fuel producer as well as the batches of fuel produced by the producer. For Neste, that meant a complete new certification needed to be implemented.

Currently, two certification schemes are approved by the ICAO Council as meeting the requirements. These are the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). For this project, the decision was made to pursue an ISCC certification as Neste had worked with ISCC on similar certifications (like ISCC EU).

The perspective of the sustainability certification scheme – ISCC

The ISCC (International Sustainability and Carbon Certification) system is a leading global sustainability certification system for renewable products and their supply chains. Today, almost 6,000 companies in more than 100 countries use the ISCC system to demonstrate sustainability and credible greenhouse gas emissions reductions along their supply chains. ISCC is widely applied for the certification of alternative fuels, including SAF, with most major producers and suppliers part of the ISCC system.

In addition to providing SAF certification solutions for a wide variety of raw materials and pathways, as well as for important aviation markets (e.g. CORSIA, EU RED II, EU ETS), ISCC intends to play a major role by leveraging

its vast stakeholder network to support the sustainability transition of the aviation sector.

A general task for certification systems lies in taking sustainability regulations and helping to interpret them to guide practical application on the ground. *“One of the main questions we deal with is: How can we take the relevant parts from the regulation and effectively and efficiently apply them along global and often complex supply chains, while taking into account the realities ‘on the ground’ that companies work in,”* says Thomas Bock, Sustainability Certification Expert at ISCC.

For ISCC, this pilot proved to be a valuable opportunity to test the relatively new ISCC CORSIA audit procedures in practice, ensuring both the integrity and practicability of the certification approach. Or to put it into the words of Thomas Bock: *“ISCC puts great focus on doing pilot projects to ensure that certification approaches are practical and can actually realistically be applied. One of our goals here was to show that ensuring sustainable SAF supply chains is not only possible, it can also be practical and realized with relatively little additional cost.”*

CORSIA certification scope

The CORSIA certification scope covers the entire supply chain for the specific batch of SAF, from the raw materials through each supply chain step to the fuel producer. Ensuring the supply chain meets the strict sustainability criteria requires, for example, thorough processes, auditing, and a clear chain-of-custody through every step of the process.

This means a certification process is quite complex, especially for a producer like Neste, which sources feedstocks globally from many different suppliers, has multiple production facilities in different parts of the world, as well as systems and procedures to produce high quality renewable fuel and other renewable products meeting not only sustainability criteria, but also all the strict safety standards and guidelines for aviation use.

For this pilot, it was therefore decided that a CORSIA certification would be done for only one feedstock supplier, limiting the costs while maximizing the experience to be gained.

The delivery to American Airlines

Neste has ample experience in delivering SAF to airlines and airports. Neste has, for example, been delivering SAF to the fuel system at San Francisco International Airport since 2020.

Arranging for a specific batch of ISCC CORSIA certified SAF to be delivered at San Francisco International Airport was completed as part of normal procedures but with some additional work. As the integrity of the batch of ISCC CORSIA certified SAF needed to be certified separately, special transport and administrative arrangements were made, for example, to deliver the specific batch separately from the normal continuous SAF deliveries.

The ISCC CORSIA certified batch of SAF was delivered to American Airlines at San Francisco in May this year.

The results and conclusions

A successful pilot

The pilot project achieved what it was set out to do: deliver the first CORSIA-certified batch of sustainable aviation fuel to American Airlines, proving its feasibility. Along the way, quite a bit of “trailblazing” had to be done but we gained useful insights into setting up the process and the challenges we need to overcome to enable CORSIA certified SAF to be actually delivered and used going forward.

Challenges remain

Sustainable aviation fuel is the only viable alternative to significantly reduce the dependency on fossil jet fuel in the near term. But current price levels for SAF are generally 3–5 times higher than for its fossil counterpart, depending on where the fossil prices are at any time, hampering the wider adoption of SAF. Both Neste and American are committed to helping promote the use of SAF and make it more cost-competitive. Incentive or mandate schemes can play a major role in this process but it is currently unclear if different schemes can be combined (‘stacked’), which would help addressing part of the pricing issue.

Accelerating demand for CORSIA-certified SAF

CORSIA is an extra tool to scale SAF production and use. But until this pilot project, no CORSIA certified SAF had been actually delivered to an airline. The certification can be done but today there is not enough demand for CORSIA-certified SAF. One of the reasons is that the economic incentive for CORSIA is less competitive compared to other schemes, like the EU RED or the Renewable Fuel Standard (RFS) in the United States. Competition between different incentive and mandate schemes will draw the supply of SAF to the most economically-attractive schemes. ICAO can play an important role in getting clarity about incentives and setting up the appropriate supporting policies.

Harmonizing certification schemes

Certification for the SAF to be CORSIA eligible required certification to another sustainability standard than the standards used until now. As certification can only be done against one standard, for this pilot Neste had one raw material supplier specifically certified for the production of the CORSIA certified batch of SAF. With

global and complex sourcing, certifying a value chain against multiple similar certification schemes not only creates extra costs but can potentially create a similar situation as with incentives. Uniform certification standards will help simplify this process, keep the costs down as well as the administrative and reporting burdens for all stakeholders involved, resulting in a faster adoption of CORSIA.

Cooperation is key to succeed

This pilot project shows that cooperation and alignment within the whole value chain was essential to succeed. Just as cooperation within the aviation industry will be crucial to make CORSIA work. Both Neste and American see a great willingness of stakeholders to cooperate and facilitate, including ICAO. ISCC shares similar experiences. And we should also not forget the role that businesses and the individual traveler can play. Challenges remain and the goals set out are ambitious, but we see encouraging developments and actions unfolding, helping to achieve a sustainable future for aviation.



| ICAO

CHAPTER NINE

Climate Change Adaptation & Resilience

Towards a more resilient aviation sector

By ICAO Secretariat

Introduction

The aviation industry is at the center of international trade and globalization, and once it is exposed to the risk of climate change impacts, any disruption in one part of the network can incur multiple delays and even collapse others. Therefore, there has been a growing awareness of climate change impacts and the specific challenges they may bring to the aviation industry, whether related to en route or ground impacts to airports, air navigation service providers (ANSPs), airlines, and other aviation infrastructure.

In this context, mitigation and adaptation measures should be strategically combined for sustainable development, considering their synergies to enable a more effectively climate-resilient aviation future. Climate adaptation in aviation involves adapting, changing, or enhancing aircraft operations and infrastructure to prepare for expected climate changes and keep the adverse impacts to acceptable levels. In turn, aviation climate resilience is the ability of aircraft operations and infrastructure to be able to withstand and recover from external perturbation resulting from the impacts of climate change.

The outbreak of the COVID-19 pandemic in early 2020 severely affected the aviation sector, with border closures, travel restrictions and quarantine measures imposed by States. In addition, risk composition between the COVID-19 pandemic and climate change has also negatively affected the broad adaptive capacity of communities, governments and societies. Apart from their impacts, a related similarity shared by climate change and the pandemic is the need for a holistic and systemic approach that requires global, national, and local coordinated responses.

Regarding this systemic approach, facing the pandemic offered a unique chance to reexamine worldwide transportation and considering the chance of building back better. The pandemic has shown how important it is to take early action to address an impending crisis, and how severe events can affect people and the economy. As a result, it has been realized by all parties that there are numerous opportunities for developing future transportation and mobility concepts that are not only climate and pandemic-proof, but also sustainable and potentially less vulnerable to the negative consequences of globalization, such as environmental degradation, economic over-exploration, and overcrowding.

Another important takeaway from the pandemic for the aviation industry is the need for preparedness in order that the industry network could respond in a more resilient manner to future pandemics, reducing impacts such as the cancellation of flights and airports closure.

Scientific understanding

Adaptation and resilience are at the core of the latest report from the UN's Intergovernmental Panel on Climate Change (IPCC), which is the second part of the WG2 Sixth Assessment Report *Climate Change 2022: Impacts, Adaptation and Vulnerability*¹, published in February 2022.

Although development and adaptation efforts have reduced vulnerability, the report states “rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their

1 IPCC WG2 Sixth Assessment Report *Climate Change 2022: Impacts, Adaptation and Vulnerability* (2022) Available at: <https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii>

From climate risk to climate resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems

(a) Main interactions and trends

(b) Options to reduce climate risks and establish resilience

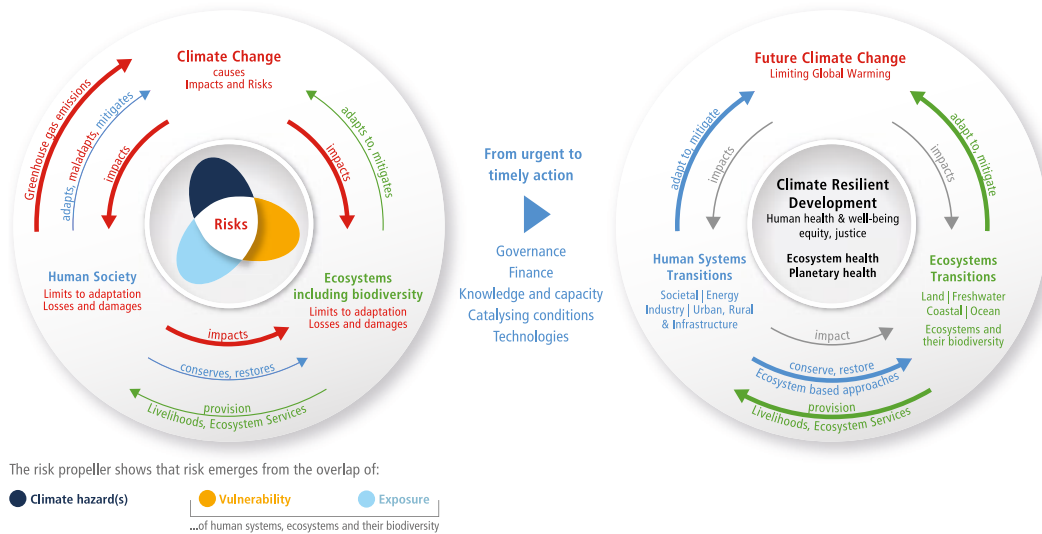


FIGURE 1: Interdependence of climate, ecosystems and biodiversity, and human societies (IPCC, 2022)

ability to adapt”. In addition, it highlights that “evidence of observed impacts, projected risks, levels and trends in vulnerability, and adaptation limits demonstrate that worldwide climate resilient development action is more urgent than previously assessed.”

The work of the International Civil Aviation Organization (ICAO) on adaptation and resilience is also in line with one of the report’s main points, which reinforces that “political commitment, institutional frameworks, policies and instruments with clear goals and priorities are key enabling conditions for implementing, accelerating and sustaining adaptation in human systems and ecosystems”.

Chapter 6: Cities, Settlements and Key Infrastructure of the IPCC report provides information on aviation by stating, “many airports are in the low elevation coastal zone making them especially vulnerable to flooding and sea level rise”. Under a 2°C scenario the report suggests that “the number of airports at risk of storm surge flooding increases from 269 to 338 or as many as 572 in an RCP8.5 scenario and that these airports are disproportionately busy and account for up to 20% of the world’s passenger routes”.

A few examples are also provided on climate related impacts at airports in different regions. This includes the vulnerability of European airports to inundation from sea level rise and storm surges that may double between 2030

and 2080 without adaptation, and the weight restrictions for large aircraft due to reduced lift caused by rising temperatures. There is also the issue of the exposure to climate-induced extreme events, in particular coastal airports in Asia.

Overview of ICAO work on Climate Adaptation

Over the last decade, ICAO has been disseminating best practices and guidance aligned with the scientific understanding to ensure adaptation and resilience of the international aviation system. Member States and stakeholder organizations are expressing increasing concerns about the potential impacts of climate change for their aviation infrastructure, operations and business.

Following successive Assembly Resolutions calling for the adaptation and resilience of aviation to climate change, guidance documents have been continuously released over the years. The latest request was through the Assembly Resolution A40-18: *Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change*. This Resolution requested the Council to identify the potential impacts of climate change on international aviation operations and related infrastructure, to identify adaptation measures to address

the potential climate change impacts, and, to develop guidance on climate change risk assessment for international aviation in cooperation with other relevant international organizations and the industry.

Therefore, key guidance and best practices documents has been developed by ICAO regarding adaptation and resilience, through the collaboration of hundreds of experts and the Committee on Aviation Environmental Protection (CAEP). Particularly noteworthy are some documents, such as:

ICAO Doc 9184, Airport Planning Manual – Part 2, Land Use and Environmental Management primarily focuses on identifying environmental and climate-related impacts, and enabling their consideration at a very early stage of planning for new and redeveloping infrastructure. Important to highlight that city and infrastructure planning approaches that integrate adaptation into everyday decision-making are supported by the 2030 Agenda (the Paris Agreement, the Sustainable Development Goals, the New 22 Urban Agenda and the Sendai Framework for Disaster Risk Reduction).

ICAO Climate Adaptation Synthesis Report captures existing information on the range of projected climate impacts in the aviation sector to better understand risks to airports, air navigation services providers (ANSPs), airlines and other aviation infrastructure. It also identified potential climate effects on the aviation sector for eight climate impact categories through both a literature review and a survey designed and sent to all ICAO Member States.

Climate Risk Assessment, Adaptation and Resilience Report provides guidance on steps for aviation organizations to conduct climate change risk assessments and adaptation planning and to identify key vulnerabilities. This guidance document will be further detailed in a following article of this Chapter.

Another example of guidance material and tools are the Eco-Airport Toolkit e-publication on Climate Resilient Airports, which provides a high-level overview of the issues climate change may bring for airports as well as some strategies on how to anticipate and prepare for contingencies with concrete examples of action.

Next Steps

ICAO's role and commitment in supporting 193 Member States on climate change adaptation topic with referring to SDGs (Sustainable Development Goals) will continue to be a key cornerstone of ICAO's work. It will be reinforced as adaptation and mitigation actions need to scale up due to more frequently or intense climate impacts foresighted for the years and decades to come.

Further work planned on adaptation and resilience topics will include the update of the ICAO Climate Adaptation Synthesis, including a new comprehensive survey with aviation stakeholders to support further guidance. It also includes the continue monitoring of adaptation progression in the aviation sector and the tracking of a variety of information on initiatives related to adaptation measures implemented by airports, aircraft operators, air navigation service providers (ANSP) and other aviation stakeholders.

Climate Change Risk Assessment, Vulnerabilities, and Adaptation Measures

By Rachel Burbidge (EUROCONTROL) and Andrea Deitz (USA FAA)¹

Introduction

Despite efforts and advancements in science and technology to reduce greenhouse gas emissions, some impacts of climate change are unavoidable. Higher temperatures are already contributing to more frequent storms, and sea level rise has caused unprecedented storm-surge impacts. The aviation community is not immune to these impacts. As part of the process to begin identifying and investigating the specific effects of climate change on civil aviation, in 2020, ICAO (International Civil Aviation Organization) published the first-ever Climate Adaptation Synthesis Report.² The following years as part of the ICAO Committee on Aviation Environmental Protection (CAEP)/12 cycle (2019-2022), following the Assembly Resolution A40-18 that requested the Council “to develop guidance on climate change risk assessment for international aviation”, the Working Group 2 produced guidance material on climate change risk assessment, identifying vulnerabilities, and adaptation measures, that will be published on the ICAO website in the second half of 2022. The guidance provides support on performing a climate change risk assessment and on developing and implementing a climate change adaptation plan. There is an overview of key climate change vulnerabilities which a State or organisation may be at risk from and a menu of potential adaptation options which can be considered to reduce those impacts. It is intended for use by airports, aircraft operators and air navigation service providers (ANSP) across the global aviation network, and can also be used at the National

level by States that are engaging in climate change risk assessment of their aviation sector either as an aviation-specific assessment or as part of a wider national or transportation sector assessment.

Significance of Climate Change Adaptation for Aviation

Aviation is vital for the mobility of people and cargo. Therefore disruption to the sector due to climate change impacts will cause ripple effects across the global economy. As aviation is often an important part of disaster recovery, airports and air traffic control operations must continue to be reliable even as storms intensify and become more frequent. Aviation climate resilience is the ability for aircraft operations and infrastructure to be able to withstand and recover from external perturbation resulting from the impacts of climate change. Climate change adaptation to strength resilience to actual or projected climate and its effects, specifically tailored to aviation, is critical.

Benefits of Risk Assessment and Adaptation Planning

To adapt to climate change impacts, aviation stakeholders must be able to determine risks and identify priorities for planning. Identifying and prioritizing risks and possible adaptation measures is critical since it is not possible

¹ Rachel Burbidge and Andrea Deitz are Co-Leads of the climate adaptation work of Working Group 2 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

² <https://www.icao.int/environmental-protection/Pages/Climate-Adaptation.aspx>

to plan for all possible scenarios. The guidance on Risk Assessment and Adaptation Planning sets out a step-by-step process divided by two stages, “Risk Assessment” and “Adaptation Planning”, to carry out a climate change risk assessment and develop and implement a climate change adaptation plan. This process can be scaled and utilized by States and organisations of any size or structure. There are six key steps in the risk assessment stage (Figure 1).

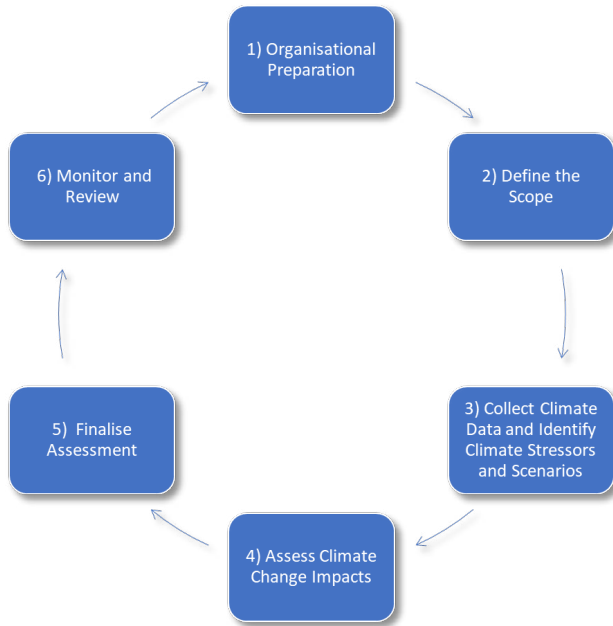


FIGURE 1: Six key steps in climate change risk assessment

The first step is to get the buy-in, or commitment, of senior leadership within the state or organisation so that they understand why the risk assessment is necessary. The next step is to define the scope of the assessment. During this stage, consideration should also be given to all the different stakeholders that should be involved in the risk assessment. For example, if the risk assessment was being scoped for an airport, different parts of an airport may be managed by different entities, and it will be important to make sure that all critical entities are represented. Another key component of defining the scope is to identify the timeline your Risk Assessment will consider.

The third step in the Risk Assessment process is to identify and collect data on climate stressors and any scenarios that will be used. During this step, it may be helpful to work with local MET providers to get climate data on what the key climate change impacts might be, how local

conditions might change. Once the climate stressors and projections have been identified, step four is to assess what the consequences of those impacts might be for the organisation’s infrastructure and operations and what the likelihood of those impacts happening might be. It may also be important to consider cumulative impacts, for example how might a combination of sea level rise and higher wind speeds impact storm surges?

The guidance also includes an overview Key Climate Change Vulnerabilities for Aviation Organisations for the four climate change impacts categories which respondents to the 2018 ICAO Climate Adaptation Synthesis Report stakeholder survey identified as the climate impacts categories they expect to be most affected by. These are: Higher Average and Extreme Temperatures, Changing Precipitation, Increased Intensity of Storms, and Sea Level Rise. For each organisation type (airports, air navigation service providers (ANSPs), aircraft operators), the section presents a breakdown of potential effects by impact category. This overview may be helpful for States and organisations as they are assessing potential climate change impacts. While this overview is detailed and provides specific effects on the different organization types, it is not meant to be comprehensive of all potential effects and should be used as a starting point for consideration during stage four. Figure 2 gives an example of what this overview looks like.

CAEP WG2 CLIMATE RISK ASSESSMENT, ADAPTATION AND RESILIENCE: KEY CLIMATE CHANGE VULNERABILITIES FOR AVIATION ORGANISATIONS		
Potential effects from four main climate impacts to aviation risk categories		
Airports		
Climate Impact	Risk Category	Potential Effect
Higher Average and Extreme Temperatures	Operations	Runway length: <ul style="list-style-type: none"> Limits to operations due to reduced climb performance: higher temperatures reduce thrust and lift of aircraft during take-off, reducing take-off performance and requiring more fuel, or a reduction in overall weight. Reduced ability of certain airports to take certain aircraft due to runway length limitations and reduced climb performance.

FIGURE 2: Six key steps in climate change risk assessment

Step five is the preparation of a final assessment document. Once this has been done then it is time to use the Risk Assessment as the basis for adaptation planning. However, since the impacts from climate change will continue to evolve and the information on climate change projections continue to be refined, it will be important to monitor and review the assessment periodically and update the risk assessment as appropriate, which is the sixth and final step. Any updates to the risk assessment should go through a similar six-stage process as the initial assessment.

There are four consecutive steps to the adaptation planning and implementation stage (Figure 3). The first step is to identify the most critical elements that should be protected. It may not be feasible to adapt to all potential impacts so it is important to identify where the biggest potential vulnerabilities are.

The second step is to identify potential adaptation and resilience measures, and decide which are most suitable, according to the level of risk and the resources available. The guidance includes a menu of potential adaptation options with a range of potential measures for different impacts and diverse types of organisations which States and organisations can consider and select from to adapt to and build resilience against the vulnerabilities identified (Figure 4). Small Island Developing States (SIDS) can face specific climate change vulnerabilities, especially due to storms and sea level rise, which make adaptation measures particularly important. In the Menu adaptation options which may be critical for SIDS are indicated with a “SIDS” marker

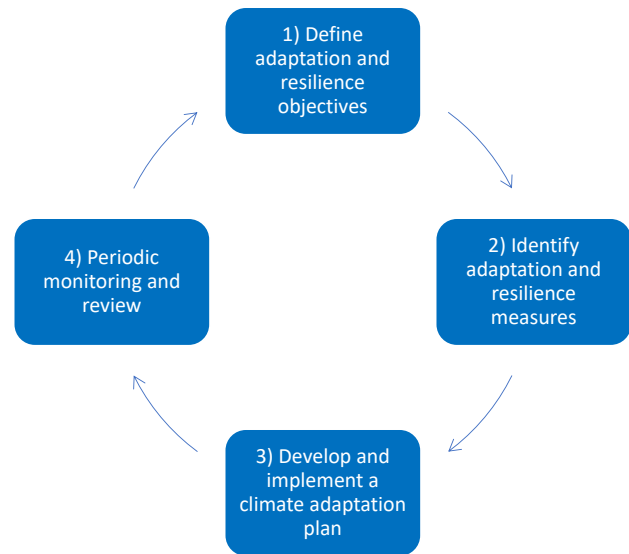


FIGURE 3: Four key steps in adaptation planning

As with the list of potential impacts on organizations from climate change impacts, this menu of adaptation options is detailed but not comprehensive of all possibilities. States and organizations should use this list as the starting point for adaptation planning. The third step is to define a plan to implement those measures, giving priority to the most critical elements.

And finally, as with the risk assessment stage, the fourth and final step is to monitor and review the measures the plan to make sure that the measures are achieving what is required and make any changes if necessary.

CAEP WG2 CLIMATE RISK ASSESSMENT, ADAPTATION AND RESILIENCE: MENU OF ADAPTATION OPTIONS	
Adapting Airports	
Higher Average and Extreme Temperatures	
Operations	
<input type="checkbox"/> Increase cooling capability in buildings <input type="checkbox"/> Increase external air conditioning to match demand (e.g., air conditioning pumping cold air outdoors, or supply of pre-conditioned air to aircraft) <input type="checkbox"/> Implement program to promote safety in the heat for ground staff – potentially extending to aircraft operator and ground handling staff <input type="checkbox"/> Implement or update wildlife management plans to account for changes in wildlife impacts	<i>Adelaide Airport in Australia is in a trial of irrigating the airport buffer, which may result in lowering airport surface temperatures and improving human thermal comfort.</i>
Infrastructure	
<input type="checkbox"/> Extend runway length <input type="checkbox"/> Move obstacles at the end of the runway (to adjust for reduced take-off performance due to reduced thrust and lift)	

FIGURE 4: Example from the Menu of Adaptation Options

Scalability and Tailored Strategies

In addition to identifying risks and priorities, it will be critical to scale adaptation appropriately to the level of risk and tailor adaptation strategies depending on operational goals and infrastructure lifecycles. Not all adaptation options will apply to every scenario, and in some cases, the most important adaptation measures may have low or no cost to resources (e.g., moving electrical equipment to higher locations within buildings). The “Menu of Adaptation Options” is a list of possibilities that each aviation organization may take into consideration, but must tailor as appropriate for their resources and goals. Simply going through the list and selecting a few options may not result in desired adaptation outcomes.

The Next Three Years – and Beyond

The 2018 Climate Adaptation Synthesis³ is a key resource for ICAO States and aviation organisations to prepare for the impacts of climate change. Therefore, it is important to ensure the information in the Synthesis stays current and incorporates the latest scientific information, such as information from the recently released Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report⁴. During the CAEP/13 cycle (2022-2025), Working Group 2 will review and update each section of the Synthesis to ensure that the information is as current as possible.

The 2018 Climate Adaptation Synthesis also included the results of a survey of global aviation sector stakeholders. The survey results captured an overview of the status of climate adaptation action in the global aviation sector at that time, the impacts that stakeholders were most concerned by, the actions they were already taking, and the measures that they thought needed to be taken. As five years have now passed since the survey was sent out to ICAO members and observers, Working Group 2 will also re-run a version of the survey as part of update to the Adaptation Synthesis during the CAEP/13 cycle to see to what extent further adaptation action has been taken and whether stakeholder concerns have evolved.

Conclusion

Climate change already has impacts on aviation, and despite significant advances in greenhouse gas mitigation measures, climate change will continue to have disproportional impacts around the world, particularly to SIDS. Freely-accessible ICAO guidance on climate adaptation that can be scaled to and applied by any state or aviation organisation will be critical to ensuring continued global connectivity and efficiencies.

³ <https://www.icao.int/environmental-protection/Pages/Climate-Adaptation.aspx>

⁴ <https://www.ipcc.ch/assessment-report/ar6/>

Climate change impacts on airports and measures – case of Schiphol Airport

By Nanco Dolman (Royal HaskoningDHV) and Vivekanandhan Sindhamani (NACO/InterVISTAS)

Introduction

Climate change risk is a growing concern in aviation, considering the effects of sea-level rise, storm surges, increase of extreme rainfall, changes in wind patterns, increase of average and maximum temperatures, increase in the number of extreme weather events and the increase in lightning strikes. In its 2016 Environmental Report¹, the International Civil Aviation Organization warned that rising temperatures caused by greenhouse gas emissions will increasingly affect the ability of aircraft to take off.

Climate change will likely lead to more extreme weather events, exacerbating the effect on airports that are already affected and putting at risk those that have not yet experienced climate-related adverse effects.

Given the significant value of the asset base at a typical medium to large scale airport which can run into the billions, combined with the complexity and interdependency of the various airport systems and supply networks, this situation is undesirable.

TABLE 1: Five incremental key actions to enhance resiliency of airports

Nr.	Key action	Climate stressors (Climate Adaptation Synthesis Report, ICAO, 2018)
Climate adaptation	1 Flood protection	sea level rise
	2 Dealing with weather extremes	increased intensity of storms, changing precipitation, temperature change, changing icing conditions, changing wind,
	3 Achieving a good water quality and a healthy eco system	desertification, changes in biodiversity
Sustainable	4 Adaptive airport city planning	enhancing airport use and passenger convenience
	5 Greening' airport operations	sustainable solutions and innovations to improve local climate and energy management)

¹ ICAO, International Civil Aviation Organization (2017), 'Annual Report of the Council – 2016', Montréal, Canada.

² Dolman N. (2016), 'Creating water sensitive airports in times of climate change', 5th Singapore International Water Week (SIWW), Singapore.

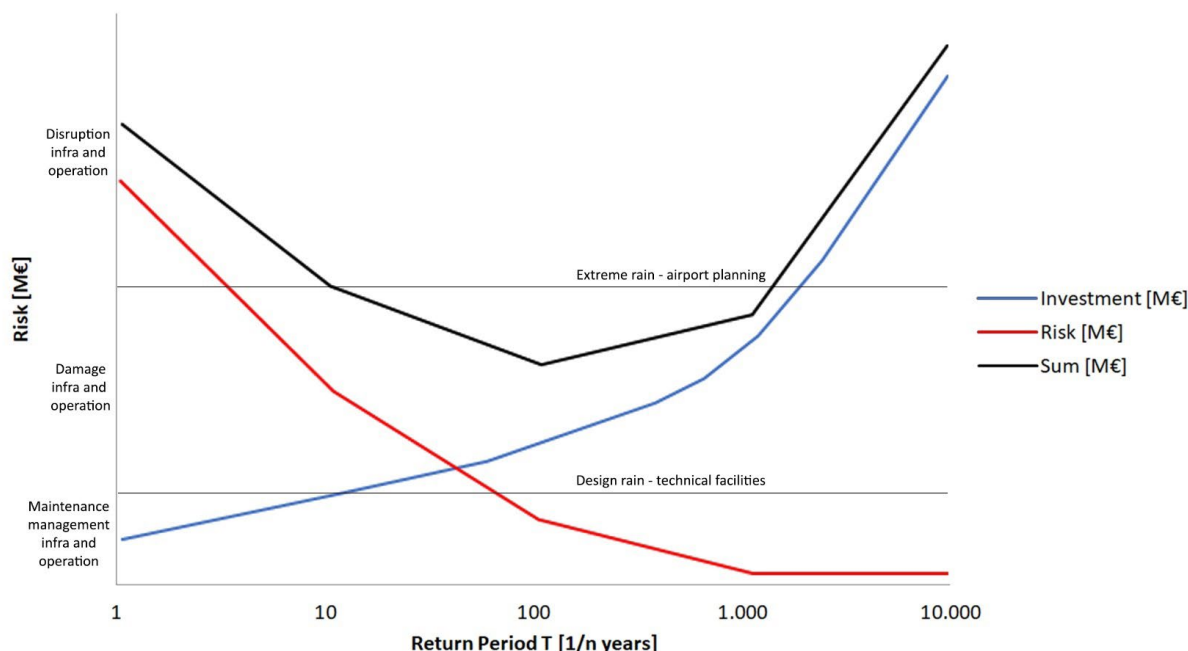


FIGURE 1: Schiphol pluvial flood risk evaluation, based on Rijkswaterstaat smarter investment strategy to reduce flood risk (adjusted for this article, Amsterdam Airport Schiphol, 2017)

One airport which is seizing the opportunity to build resilience to climate change into its airport planning is Amsterdam Airport Schiphol, the Netherlands, a low-lying airport built on reclaimed land in the Polder Haarlemmermeer, which faces water challenges daily. Schiphol's situation is extreme; Europe's most preferred airport is situated approximately 4.5 meters below sea level.

Five actions for Climate Resilient Airports

In 2015 Amsterdam Airport Schiphol presented its Water Vision 2030 that has been considered as Schiphol's climate adaptation strategy. This strategy sets out the ambition to cope with the risks of climate change, airport planning and water management activities to 2030 and beyond. Following experience from practice in the Schiphol Water Vision 2030 a set of five incremental key actions to enhance climate resiliency have been developed (Table 1), also known as the Climate Resilient Airports (CRA) framework.

The CRA framework helps airports to develop their climate change adaptation pathway to achieve long-term goals and ambitions. In the short- and medium-term, first steps are needed, preferably in line with the 2018 Airport Council

International (ACI World) resolution and policy brief on 'Airports' Resilience and Adaptation to a Changing Climate', and the ISO 14090 'Adaptation to climate change - Principles, requirements and guidelines'.

Flood impact assessment

Making Schiphol Airport less vulnerable to weather extremes and (pluvial) flood risk means additional investment. At the same time Schiphol will benefit in avoided damages and disruption of operation. Based on a comprehensive pluvial flood stress test (2017) and the judgement of Schiphol's airside experts, a flood impact assessment was adapted. The flood impact assessment illustrates the chance (frequency) and extent of pluvial flood risk to expected damages and disruption of operation, translated to (direct & indirect) cost. Figure 1 shows an optimal protection level of an extreme rainfall event close to once per 100 year (T100). This level of protection implies stricter requirements than current design standards.

Extreme weather effects and floods can result in delay of flight operation or even in a (temporary) shutdown. In general, most stakeholders of the airport are financially affected when a shutdown occurs. In 2010 some airports in

Europe experienced the largest air-traffic shut-down since the 2nd World War, in response to concerns that volcanic ash ejected during the 2010 eruptions of Eyjafjallajökull in Iceland would damage aircraft engines. The controlled airspace of many European countries was closed to instrument flight rules traffic. Amsterdam Airport Schiphol in the Netherlands estimated a loss of €25 million of having no air transport for one day³.

Water robust Schiphol and Strategic Investment Plan

Following the flood impact assessment, Schiphol's management team decided on a T100 pluvial flood adaptation pathway and initiated the "Flood resilient Schiphol" program. The goal of this program is to adapt existing infrastructure and mitigate flood risk effects on operations. Although an estimate was given on the required budget, a more detailed roadmap with strategic (annual) investments was needed. In 2020 a more detailed financial risk evaluation was done, which resulted in the Strategic Water Investment Plan 2020-2030. This plan consists of a blue masterplan, water storage assignment per sub-area and developments, as well as the strategic investment costs and planning.

A distinction has been made between (already planned) projects and additional measures required to meet the "flood resilient Schiphol" ambition. A geo-based management tool was developed, to benchmark and report on climate risks and airport developments. Concrete measures consist of realizing extra water retention and robust water connections, besides "sponges" (e.g. green roofs and rainwater collection for toilet flushing) and alternative water storage under parking lots and along runways. In response to the disruption caused by COVID-19, Schiphol announced in 2021 that it is adjusting its construction schedule. Schiphol has found itself in the same position as other organizations where it needs to cut costs and achieve an optimal balance between short-term investments and the need for capacity in the future. Based on the new "flight plan" of airports developments and projects the Strategic Water & Climate Investment Plan is recalibrated and updated accordingly.

3 Dolman N., Sindhamani V., Vorage P. (2021) Keeping Airports Open in Times of Climatic Extremes: Planning for Climate-Resilient Airports. In: Brears R.C. (eds) The Palgrave Handbook of Climate Resilient Societies. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-42462-6_8

Adapting to climate change: an ANSP perspective

By Jarlath Molloy, Beatrice Turrini and Trevor Smith (NATS)



FIGURE 1: Impact of the storm at the Great Dun Fell radar

Introduction

Fuelled by climate change, extreme weather events are becoming more frequent. Severe weather brings specific challenges for air traffic management, and it is increasingly important for air navigation services providers (ANSPs) like NATS¹ to prepare for acute and chronic climate change impacts.

Climate hazards

During Storm Arwen in November 2021, a power failure at the Great Dun Fell radar and radio station in England's Pennines, East Cumbria, – situated 848 metres above sea level – posed a particular challenge. The site lost main power during the storm but was running on its standby

generator until that suddenly stopped, leaving the site with just its battery back-up.

NATS has specialist engineers based around the country who form part of 24/7 teams, are ready to respond as and when required. These are some of the very best in the business, but even they found the conditions caused by Arwen challenging.

Getting to the site was extremely difficult. Snow had blocked the main road and the team was forced to gain access via an off-road alternative route using a tracked vehicle (Figure 1). Once on site, the cause of the generator failure was evident, as the electrical supply and the generator fuel pumps were covered in snow, which had to be cleared before repairs could be made.

¹ NATS is the primary Air Navigation Service Provider (ANSP) in the UK. It provides Air Traffic Control (ATC), engineering and other services to aircraft flying in UK domestic airspace and the eastern part of the North Atlantic Ocean (Shanwick) and at 20 civil & military airfields in the UK plus Gibraltar.

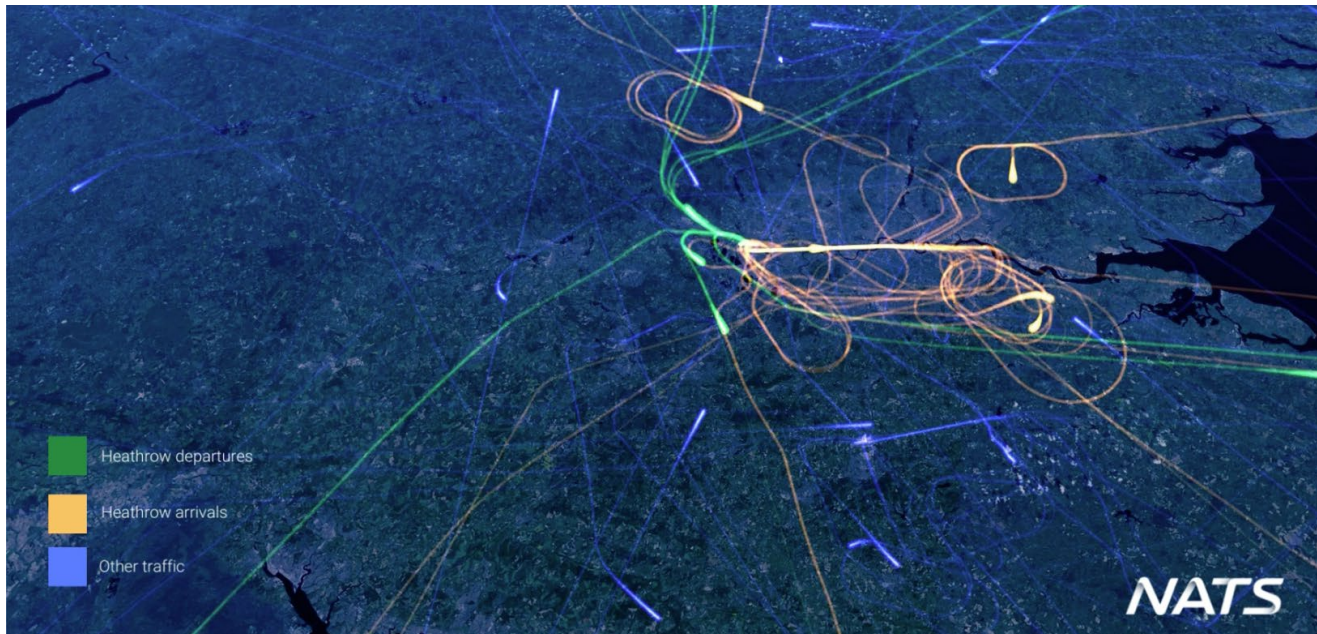


FIGURE 2: Visualisation snapshot of the day Storm Eunice hit the UK with strong winds forcing multiple go-arounds.

The Great Dun Fell team also supported the local power company to reach their own sites nearby, highlighting the interdependencies between operators of critical national infrastructure.

A few months later, the UK was heavily impacted by strong winds, snow, heavy rain and flooding from three consecutive storms in a week – Dudley, Eunice and Franklin. NATS teams did their best to tackle all the challenges to keep the people safe and the operation running effectively. It included pre-positioning people to respond more quickly and implementing proactive shutdowns of equipment where the forecast wind was above tolerances, helping avoid significant damage to the equipment and ensuring that NATS were able to return to service quickly when the weather improved.

But it is not just at NATS' sites and infrastructure that adaptation to the impacts of severe weather is needed. Storm Eunice resulted in significantly more diversions than usual. At Heathrow Airport in London, England there were a total of 40 missed approaches, compared to one a day on average, with some pilots having to make three attempts to land.

Strong winds can cause multiple challenges, ranging from larger gaps being needed between landing aircraft, to wind shear which can cause unstable approaches. If an aircraft cannot make a stable approach due to wind like seen with Storm Eunice, the pilot may decide to 'go-around' where they will climb to a safe altitude and, in most cases, attempt another approach and landing, which adds to the workload of NATS' controllers².

In airspace that is already busy with other aircraft queuing to land, it is NATS' job to make sure the pilot can do that safely. When bad weather is forecast, NATS 'regulate' – effectively putting a cap on the amount of traffic in the airspace, to ensure there is more room to safely manoeuvre and to keep the workload manageable for its controllers.

Adaptation measures

As climate change continues to make its presence felt, and extreme weather events become more regular and severe, NATS is in need to embed climate resilience into its facilities and operations. NATS' adaptation to climate change report, submitted to the UK Government before Storm Eunice hit, summarises the progress towards identifying and assessing

2 Video Storm Eunice go-arounds at Heathrow <https://www.youtube.com/watch?v=8nE62WX-x80&t=3s>

climate risks to the critical national infrastructure under NATS' management, and what is planned to do now and into the future to increase resilience to severe weather events.

NATS has identified nine physical climate risks based on the latest climate scenarios pointing to increased warmer, wetter winters, and hotter, drier summers along with an increase in the frequency and intensity of extreme weather events. The report provides the main physical hazards from an air traffic perspective and provides an assessment of the risks faced in the transition to a low-carbon economy. The NATS 2021 Climate Risks and Adaptation Progress Report is available online³.

In order to prepare for some of these risks, since 2016, NATS has had a UK Met Office team embedded at the Control Centre in Swanwick, Hampshire, England, allowing for proactive forecasting on adverse weather that could affect the operation. They are providing invaluable data for NATS' operation and engineers.

NATS continuously maintains and improves both proactive and reactive controls across the operation and its estate. More recently, NATS has been working closely with partners to develop and prioritise a comprehensive list of controls and actions to mitigate risks and incorporate these into NATS' business and planning, as part of a new climate change resilience strategy. This work is set to continue in the coming years and inform investment decisions and NATS' approach to adapting to the impact of climate change on its business.

³ <https://www.nats.aero/wp-content/uploads/2022/01/NATS-2021-Climate-risk-and-adaptation-progress-report-FINAL.pdf>



| ICAO

CHAPTER TEN

Biodiversity

The crucial importance of biodiversity

By the Convention of Biological Diversity (CBD)

The term ‘Biodiversity’ derived from “biological diversity,” refers to the diversity of life on Earth at all scales, from genes to ecosystems, and can include the ecological, evolutionary, and cultural processes that support life. The systems that sustain all life on Earth, including humans, depend on biodiversity. We cannot have the healthy ecosystems that we depend on to give us the air we breathe and the food we consume without a diverse variety of animals, plants, and microorganisms.

Like many different sectors impacting biodiversity, the aviation sector can have adverse effects on biodiversity in a number of ways, including habitat loss when airports and airfields grow, the dispersal or management of wildlife for practical purposes, and the effects of light and noise pollution on particular species. The impacts of aviation on biodiversity many times are addressed in the context of airport planning and thus it is important that the environmental assessments put more effort in identifying sensitive habitats, relevant risks and appropriate climate change mitigation (i.e. aircraft technologies, operational improvements, relocation/re-creation of habitats elsewhere to provide home for flora and fauna upon expansion, etc.)

In the context of pollution from aviation; fish, mammals, reptiles, amphibians, and invertebrates can all be extremely susceptible to light and noise pollution. According to a study (Brumm et al, 2019)¹, even very low levels of human noise disruption can have a negative effect on an animal’s capacity to communicate and reproduce. By interfering with natural day-night rhythms and nighttime behaviours, light pollution affects biodiversity by interfering with many different animal species’ reproductive, feeding, and migratory cycles. Artificial lights can make migratory birds

confused, deplete their energy supplies, and undermine their chances of survival. Light pollution can increase the amount of time daytime feeders spend seeking, which can over-prey on some nocturnal species. When combined, noise and light pollution from traffic, shipping, urban development, and aviation can seriously disrupt the life of animal populations.

To cover all aspects of biological diversity across different sectors, including the aviation sector, the Convention of Biological Diversity (CBD) is a global agreement to conserve biodiversity with an overall objective of encouraging actions which will lead to a sustainable future. The convention has three main goals: the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of benefits arising from the use of genetic resources.

The consequences of the aviation section on biodiversity can be further extrapolated with actions showcasing transformative actions from all stakeholders from this sector to help with climate change mitigation and adaption and protection of biodiversity. As such, the Sharm El-Sheikh to Kunming Action Agenda for Nature and People (Action Agenda) is spearheaded by the Governments of China and Egypt, with support of the Secretariat of the Convention on Biological Diversity. It was created to foster engagement with non-state actors to inform, inspire and showcase voluntary commitments for biodiversity. The Action Agenda works with non-state actors to raise awareness on the urgency, ambition and concrete actions, across different sectors that can reduce the drivers of biodiversity loss and enable the needed shifts to halt and reverse biodiversity loss aligning to the post-2020 global biodiversity framework.

¹ <https://books.google.ca/books?hl=en&lr=&id=O5lnDwAAQBAJ&oi=fnd&pg=PA254&dq=noise+pollution+and+conservation,+encyclopedia+of+animal+behavior&ots=nOVeVkyDzU&sig=N0TAoQsBdQaOa7RHeGXiJosHlMO#v=onepage&q=noise%20pollution%20and%20conservation%2C%20encyclopedia%20of%20animal%20behavior&f=false>

There is an urgent need for international partners come together to halt and reverse the alarming loss of biodiversity. Hence, the 15th Conference of the Parties (COP15) meeting of the Convention on Biological Diversity (CBD) aims to bring together the world's governments to agree a new deal on halting the loss of animals, plants and habitats globally by 2030. This pivotal global biodiversity summit is set to be held in Montreal, Canada, in December 2022. On this road to COP 15, it is of an utmost importance to have joint collaboration between CBD, ICAO and all relevant partners and showcase to become part of this exciting opportunity

to adopt the global agreement that will kickstart the much needed transformation to halt and reserve biodiversity loss and taking actions to ensure minimal loss of biodiversity is affected by the aviation industry.

References:

Brumm, Henrik, and Andrew G. Horn. "Noise pollution and conservation." *Encyclopedia of animal behavior*, 2nd 1 (2019): 254-259.

Aviation Taking Action Against Wildlife Trafficking

By Crawford Allan (TRAFFIC), Cori MacFarland (WWF), and Juliana Scavuzzi (ACI World)

The Wildlife Trafficking Threat

Wildlife trafficking is a global problem. It includes the importing and exporting of protected species of wild animals and plants, derivatives or products thereof in contravention to international and/or domestic law. Depending on the jurisdiction, it can also include smuggling, poaching, and illegal capture or collection.¹

Wildlife trafficking (including illegal timber and fisheries products) is estimated to be the fourth largest illegal trade following drugs, counterfeit goods, and human trafficking.² Traffickers frequently use air transport as a fast, relatively low-risk, high-profit means of illegally transporting wildlife from source to consumer. While interception and arrest of wildlife traffickers are the responsibility of law enforcement; with the proper means, the many thousands of air transport staff operating along the supply chain (e.g., cabin crew, baggage screeners, and others) are uniquely placed to support law enforcement by identifying and reporting any wildlife trafficking suspicions.

In addition, the SARS-CoV-2 pandemic has created a new awareness of zoonotic diseases and the need to understand its risks.³ The illegal wildlife trade has been identified as a factor that can increase the emergence and spread of

zoonotic diseases.⁴ Proper sanitary controls and quarantine requirements are also at risk of being disregarded by wildlife traffickers.

The ROUTES Initiative

In October 2015, the USAID Reducing Opportunities for Unlawful Transport of Endangered Species (ROUTES) Partnership was established, bringing together transport and logistic companies, government, industry agencies, development groups, law enforcement, and conservation organizations to disrupt wildlife trafficking from legal air transport supply chains. The goal of ROUTES was to help aviation stakeholders counter wildlife trafficking within their respective roles and to support law enforcement, not act as law enforcement.

Convened by USAID and led by the NGO TRAFFIC⁵, ROUTES core team included several US government agencies, industry associations IATA and ACI, and NGOs WWF and C4ADS with respective roles and functions (Figure 1). There was a wider international group of collaborators across the industry, conservation, and governments that worked together, including Freeland Foundation that was a core partner for the first few years.



FIGURE 1: ROUTES partnership.

1 UNODC. Criminalization of wildlife trafficking (2019)

2 UNEP-INTERPOL. The Rise of Environmental Crime (2016).

3 Ibid. World Bank Group, UNEP, UNDP & others Analysis of International Funding to Tackle Illegal Wildlife Trade (2016).

4 WHO. WHO-convened global study of origins of SARS-CoV-2: China Part. (2021) and Statement on the seventh meeting of the International Health Regulations (2005) Emergency Committee regarding the coronavirus disease (COVID-19) pandemic. (2021).

5 <https://www.traffic.org/about-us/illegal-wildlife-trade/>

Since its inception, ROUTES has engaged with a diverse range of stakeholders across the air transport supply chain, including airlines, airports, ground handling companies, and industry associations, focusing on those with operations along known wildlife trafficking routes within and between Africa, Asia, Europe, Latin America, and the Middle East.

With the support of its partners, and nearly \$10 million invested by USAID, ROUTES has developed targeted materials, including e-module training, policy guidance, and communication materials, to increase the aviation industry's attention on wildlife trafficking, and to make it as easy as possible for aviation stakeholders to take action against wildlife trafficking. These materials remain readily accessible beyond the lifespan of the Partnership.

ROUTES evolved from the recognition of a surging threat to wildlife from wildlife trafficking, which was being carried out through exploitation of the transport sector, in addition to increasing operational and reputational risk to transport companies. This conservation crisis was caused by growing demand for wildlife as fashion, food, medicine, and pets.

ROUTES and associated initiatives like the United for Wildlife (UfW) Buckingham Palace Declaration determined that transport leaders can help to champion such solutions by integrating wildlife trafficking prevention into policies, strategies, and practices for long-term action against wildlife trafficking.

ROUTES defined a goal and objectives to help the aviation industry with integrating the approaches and solutions shown in the graphic here:



FIGURE 2: ROUTES objectives.

Evidence

Before ROUTES, very little analysis existed on wildlife trafficking in air transport. The Partnership published extensive research on various aspects, such as the scale of trafficking, types of wildlife and products commonly trafficked, smuggling methods, and routes involved in wildlife trafficking. These resources informed the industry and helped prioritize their responses to wildlife trafficking. Much of the data gathered was presented in an online ROUTES Dashboard⁶ created by C4ADS. The ROUTES Dashboard allows open access to an interactive map-based visualization (Figure 3) system that generated detailed analysis, including identifying high-risk routes for wildlife trafficking.



FIGURE 3: A map produced by the ROUTES Dashboard showing the flight routes for all wildlife seizures recorded in the C4ADS Air Seizure Database between January 2009 and July 2021.

6 <http://www.routesdashboard.org>

ROUTES Activities

ROUTES' engagement with the aviation industry grew from three stakeholders in the first year to 45 by the last year. Stakeholders included airlines, airports, industry associations, and more (see Figure 4 for annual breakdown).



FIGURE 4: ROUTES aviation sector partners annual breakdown.

The first critical step in engagement was to illustrate how the issue of wildlife trafficking was material to each company's operations, how wildlife trafficking exploited security gaps in supply chains, and how trafficked wildlife posed health and safety risks to passengers and employees. Once the pertinence of the issue was established, with the support of ROUTES, stakeholders determined the appropriate next steps. In some cases, that was meeting with other stakeholders to commit to joint actions; for others, it was setting up training for employees in strategic positions or updating reporting protocols. Each company was able to address wildlife trafficking to fit its unique needs best. The ROUTES materials were available to support them and were developed to be customizable to the needs of each company/organization. The ROUTES materials are free to download and use by the aviation sector via the ROUTES website⁷.

ROUTES also hosted two regional partnership workshops in South Africa and Latin America. In South Africa, ROUTES partnered with UfW to bring together transport companies, customs and security, government, and conservation stakeholders to establish a Southern Africa Transport Task Force. By bringing these stakeholders together, they could build new relationships and identify how they can collaborate to address wildlife trafficking. In Latin America, ROUTES hosted a virtual workshop (due to COVID) that brought transport companies, government, law enforcement, and conservation organizations together, primarily from Colombia, Ecuador, Brazil, and Mexico. ROUTES partners supported these stakeholders by concentrating on this region as they developed country-specific action plans to address wildlife trafficking. These workshops were a launchpad for continued collaborative efforts beyond the ROUTES Partnership.

Recognition and engagement of the aviation sector

ACI developed guidance to help airports meet the UfW Buckingham Palace Declaration commitments⁸, a handbook⁹ and an e-module¹⁰ specifically for airports containing possible actions, references to relevant materials and case studies. ACI has also developed a virtual assessment of Wildlife Trafficking prevention measures for airports under the umbrella of the Airport Excellence (APEX) program. IATA has developed guidance and amended protocols and procedures including the Live Animal Regulations¹¹ that lowers the risk of exploitation and has launched a wildlife certification scheme that provides independent assurance that an airline is delivering on its wildlife commitments. Many airports and airlines have joined the fight against wildlife trafficking. IATA and ACI have adopted Resolutions to counter wildlife trafficking, including:

- ACI World's commitment to the UfW Buckingham Palace Declaration and support to the ROUTES Partnership was re-affirmed in a Resolution against

⁷ routespartnership.org

⁸ <https://store.aci.aero/form/buckingham-palace-declaration-guidance-document-on-potential-interpretations-for-airports/>

⁹ <https://aci.aero/2021/06/28/industry-partnership-delivers-support-for-airports-in-fighting-wildlife-trafficking/>

¹⁰ <https://olc.aero/product/combating-wildlife-trafficking/>

¹¹ <https://www.iata.org/en/publications/store/live-animals-regulations/>

wildlife trafficking adopted by the Twenty-sixth ACI World General Assembly¹².

- In June 2016, IATA's 72nd Annual General Meeting adopted a Resolution on the Illegal Trade in Wildlife¹³ which provides a clear and unequivocal statement of the airlines' position on wildlife trafficking.
- In 2020 at the Thirtieth ACI World General Assembly, a Resolution encouraging airports to support the protection of biodiversity, and thereby also help averting future pandemics was adopted¹⁴.

The issue of wildlife trafficking has been raised several times in ICAO Assemblies and Panels, in particular thanks to papers presented by ACI and IATA.

In July 2021, the ICAO Facilitation Panel unanimously endorsed a proposal by ACI and IATA to adopt the following recommended practice under the UN Convention on International Civil Aviation, Annex 9¹⁵:

“Contracting States should ensure that procedures are in place to combat wildlife trafficking, including clear reporting systems and relevant competent authorities’ points of contact for airport and airline operators.”

The ICAO Council approved the recommended practice in March 2020, effective as of 18 July 2022. The recommended practice establishes some of ROUTES’ critical recommendations and paves the way for widespread and long-term uptake of the ROUTES-supported reporting app. This represents one of ROUTES’ greatest achievement and assurances of long-term action against wildlife trafficking.

Impact

Policy guidance and influence was a critical part of ROUTES’ approach. Both IATA and ACI developed specific guidance documents and recommended practices supporting their respective members to institutionalize wildlife trafficking

prevention. Both industry associations also established accompanying assessment programs for guiding, monitoring, and demonstrating their efforts – critical for incentivizing long-term and continual improvement in wildlife trafficking prevention practices. There were many initiatives to help the aviation sector provide a lasting impact. ROUTES and Crime Stoppers International (CSI) jointly developed a novel mobile reporting app, Wildlife Sentinel¹⁶, to empower air transport staff to report suspicions of wildlife trafficking to law enforcement anonymously. The app is available in English, Spanish, and Portuguese on Android and iOS mobile platforms. Over 120 reports were submitted to CSI via the app within the first two months.

ROUTES also catalyzed industry and enforcement responses that resulted in the interdiction of illegal wildlife smuggled by air. For example, in September 2021, 3,493 shark fins and 117 kilograms of fish swim bladders were seized at El Dorado International Airport, Colombia, following a report from a transport company. The airport staff had recently attended the ROUTES stakeholder workshop, and the airport had made ROUTES training compulsory for any transport staff coming into the airport. This example was one of several seizures following ROUTES airport training.

The Next Three Years

The ROUTES partnership generated a wealth of resources, learning, and best practices that will be sustained into the future. With the e-learning programs, aviation sector policy changes (e.g., ICAO Annex 9), sensitization of the industry, reporting tools, and global/regional transport sector wildlife taskforces, many elements will help to scale efforts.

One ROUTES innovation with lasting promise involved supporting and coordinating the development of an automated algorithm to detect priority wildlife products in security screening x-ray systems at airports by analyzing

12 <https://aci.aero/2016/09/28/airports-council-international-expressed-the-commitment-of-airports-to-join-the-effort-to-stop-the-transportation-of-illegal-wildlife-products/>

13 <https://www.iata.org/contentassets/e79883665f7142818a1b73f0f3d52dc6/resolution-agm-2016-wildlife.pdf>

14 <https://aci.aero/2020/11/16/aci-world-annual-general-assembly-urges-global-climate-change-effort/>

15 https://www.icao.int/Meetings/FALP/Documents/FALP12-2021/WP/revised%20WP25/WP25_Collaborative%20Approach%20in%20the%20Fight%20Against%20Wildlife%20Trafficking%20-%20REVISION%201.pdf

16 <https://routespartnership.org/news-room/new-mobile-reporting-app-helping-combat-corruption-and-wildlife-trafficking>

the x-ray data generated for aviation security. The algorithm development by Sandia National Laboratories, USA, with funding by USAID, achieved excellent accuracy rates in detecting target wildlife products. It has proven successful through repeat testing in practice. This technology has the potential for expansion to detect a broader range of smuggled wildlife products and other illicit goods without impacting aviation security. The US Department of State has invested nearly \$1.5 million (2021-2023) to implement the algorithm with the ROUTES team in selected airports in Africa to establish a new tool in the fight against wildlife trafficking by air.

And finally, ROUTES focused on learning, with an emphasis on making public-private partnerships effective. Some recommendations for consideration in leveraging change when working with public/private aviation sector stakeholders are mentioned here:

- Use tailored evidence to show how wildlife trafficking affects each particular stakeholder
- Understand the motivations of the stakeholder and that every stakeholder is different
- Seek industry leaders to help influence stakeholders from within their sector
- Provide simple solutions for action with accompanying guidance, resources, and support
- Support stakeholders to gain recognition for their efforts
- Exploit aviation technology and systems to provide digital intelligence on wildlife trafficking

ROUTES has shown that with expert help, resources and leadership, the aviation industry can make a significant and lasting difference in supporting important environmental, social, and governance goals. The benefits of helping protect wildlife will resonate and favor the industry, society, and the planet.

Biodiversity Conservation Initiatives at Airport's Level

By Anastasios Anagnostopoulos (Athens International Airport S.A.), Nick Gabriel (Gatwick Airport), Melina Santos Vanderlinder (Aeropuertos Dominicanos - AERODOM), and Wendy Avis (Vancouver International Airport)

Introduction

Although the presence of wildlife at an airport surrounding and within its operational areas is a safety hazard and a well-known risk, airports are facing a growing challenge which is the balance between their construction and operation with the safeguard of natural ecosystems and biodiversity conservation under pressure by their activities.

Efforts to conserve biodiversity are essential to maintaining the “ecosystems services” as a foundation of all civilization, ensuring health, food, sustainable economies, and an adequate environmental quality for all living beings.

Growing demand for transport infrastructures such as airports are putting pressure into biodiversity in a number of ways, most commonly causing loss or degradation of natural habitats due to expansion and operation of such infrastructures. In addition, there are strong links between climate change, biodiversity loss and economic prosperity, which leads to changing business approaches in order to increase protection of natural capital, including the ecosystems as a provider of essential goods and services.

In this context, airports worldwide are finding ways to prevent biodiversity loss as a major sustainability challenge and incorporating such challenges into their business strategy, leading to stronger policies and enhanced projects that take into account biodiversity conservation. As such, this article provides examples of initiatives on airport-related biodiversity projects around the globe, indicating worldwide commitment to continuously support the biodiversity conservation in aviation.

Wetlands Conservation at Athens International Airport

In cooperation with the Hellenic Ornithological Society (HOS) and local authorities, Athens International Airport (AIA), located at the Mesogeia Plain, E. Attiki, has undertaken a project for the Preservation and Promotion of the Wetland of Vravrona (Site of Community Importance of the NATURA 2000 Network) since 2008, and the Wetland “Alikí” of Artemis (Priority A' Wetland for Conservation according to Regional Planning) since 2015. Both wetlands are located east of the Airport along the coastline of the South Evoikos Gulf, part of an important bird migration route, at distances of 3.3 km and 4.7 km for Vravrona and Artemis, respectively.

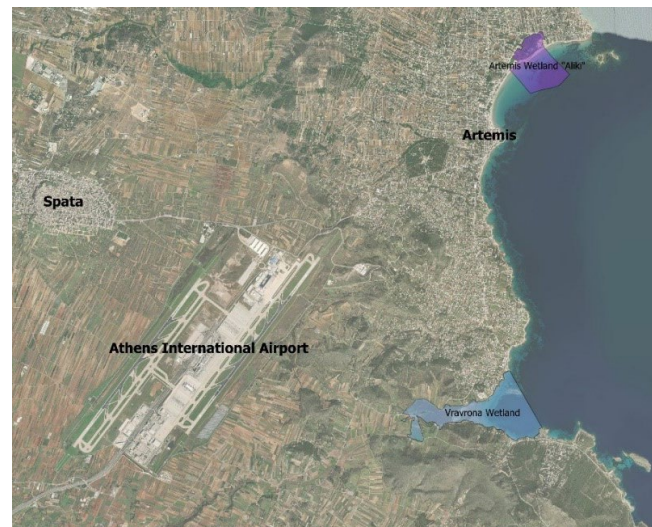


FIGURE 1: Athens International Airport and the adjacent wetlands


FIGURE 2: Wetland of Vravrona

FIGURE 3: Wetland “Aliki” of Artemis

The actions undertaken, mainly include:

- Removal of waste and other inert material and management of the aquatic vegetation to restore the proper function of the habitats;
- The construction and maintenance of walking paths, informative signs, and fences to facilitate year-round visits of the Wetlands;
- Guided tours for students of all ages, complemented by Environmental Educational presentations, and tours for the public, performed by HOS staff. Special events are also organized in honour of International Days celebrating the Environment, Biodiversity and Birds; and
- Monitoring bird populations and their activities at the wetlands.

These initiatives are aligned with AIA’s strategy focusing on environmental sustainability, while also promoting aviation safety. The strategy includes, among others, the following pillars:

- Preservation of Biodiversity and Ecosystem Services;
- Mitigation of the impacts of Climate Change;
- Sustainable Wildlife Hazard Management for the mitigation of Wildlife Strike Risks to Aircraft; and
- Social Responsibility.

Further to the benefits mentioned above, Athens International Airport intends to continue its project to Preserve and Promote the Wetlands of Vravrona and Artemis, adjusting and improving the actions planned in order to address future challenges.

From Biodiversity Benchmark to Protecting Woodlands and Attenuating Floods: the Gatwick Airport Experience

In 2012 Gatwick Airport launched its Biodiversity Action Plan (BAP). The BAP was prepared to drive the protection and enhancement of 75 hectares of Gatwick’s non-operational landholdings (Figure 4). These areas are collectively called Gatwick’s biodiversity areas and are dedicated to wildlife conservation and the local community. A range of habitats are located in the biodiversity areas including ancient woodland, rivers, floodplain meadows, old hedgerows, scrub mosaic and wildlife ponds, and therefore provide habitat for a wide range of species including rare and threatened flora and fauna.


FIGURE 4: Gatwick Airports biodiversity areas

The BAP was initiated by Gatwick’s Environmental Health and Safety Team in partnership with the grounds maintenance team and the Gatwick Greenspace Partnership (GGP). It provides a framework for managing our biodiversity areas to enhance their condition through



FIGURE 5: Invertebrate surveying in the North West Zone.

setting improvement targets, scheduling actions and monitoring performance through a robust ecological monitoring programme. The BAP and its delivery are also aligned to The Wildlife Trusts Biodiversity Benchmark Standard which is designed to complement ISO 14001 and achieve continual biodiversity enhancement and protection. Gatwick Airport is proud to have retained this award for 8 consecutive years.

A critical element of the BAP is the biodiversity monitoring programme delivered by our Biodiversity Advisor, technical specialists, and community volunteers (Figure 5). In 2021 the monitoring programme involved 22 different survey methodologies, including bat, reptile, bird, invertebrate, mammal, fungi, and botanical surveys. The results of these surveys are fundamental to improving our understanding of the biodiversity areas and the species that rely on them. To date Gatwick has 35,570 biological records, comprising of 2,490 different species across our landholdings. This includes 74 rare, declining or protect species, including



FIGURE 6: Nationally scarce Long-horned Bee on Gatwick's road verges.

Great Crested Newt, several bat species, and the nationally scarce Long-horned Bee (Figure 6).

Community involvement in our biodiversity areas is another crucial element of our approach to biodiversity, ensuring the project is raising awareness about biodiversity with our staff (Figure 7) and with local community members (Figure 8). Educational events involve introducing local schools and colleges to wildlife conservation practices and visits from university students to witness conservation in action. In 2021 Gatwick held 58 volunteering and 15 educational events on our sites.

Surrounded by three main rivers including the River Mole, Crawters Brook and Gatwick Stream, Gatwick's biodiversity areas play a key role in safeguarding our airport operations by reducing flood risk potential through provision of flood storage capacity. Our Land East Zone flood attenuation field provides 186m³ of storage capacity and our Northwest Zone provides floodplain meadows providing both biodiversity



FIGURE 7: Gatwick security staff volunteering in the woodlands



FIGURE 8: Community volunteers installing Dormouse boxes

benefit and reducing flood risk potential downstream of the airport.

Gatwick Airport is committed to protecting and enhancing biodiversity and has robust plans for building on our efforts thus far. In the short-term we are focused on progressing a wildflower road verge scheme to improve the connectivity and wildlife potential of our existing greenspaces. Further, we are also trialling biodiversity net gain methodologies enabling us to quantify the biodiversity performance of habitats while keeping in line with latest standards.

Biomonitoring with Bees and Reducing Pesticides at Aerodom

Aeropuertos Dominicanos Siglo XXI (Aerodom) has been part of the global airport platform VINCI Airports since April 2016. Aerodom manages and operates six airports in the Dominican Republic, under a concession contract granted by the State, which runs until 2030, and handles an annual average of 5 million passengers, with 76,610 aircraft movements. Through its airport network, 49 airlines connect the Dominican Republic with 63 cities in the world. One of the pillars of VINCI's global environmental policy is *Preserving Natural Environments*, which means that throughout the operations, the airports must have as little impact as possible on natural environments and must develop solutions to conserve freshwater resources and restore ecological balance.

In 2019, all Aerodom's airports eliminated the use of glyphosate-based herbicides which are known to affect honeybees and other beneficial insects' survival, honey production, brood survival, and development, thus impacting the pollination of nearly three quarters of the plants that produce 90% of the world's food.

Biomonitoring with bees

Biomonitoring is an environmental assessment technique that determines the impact of pollution on the living part of the environment, unlike traditional methods that only assess the abiotic part of it (air, water, soil). This application on beekeeping has its first antecedents in the

1970s¹ and until now there have been many professionals who have investigated the subject. Bees are 1,000 times more sensitive to pollutants than other insects on their average travel of a 3km radius, and they accumulate air pollutants by electrostatics and with the help of their body hairs. These pollutants can be particles, pesticides, heavy metals, volatile organic compounds, among others, and help determine if these contaminants are attributed to the airport's operation or not, and how effective are the environmental management plans implemented.



FIGURE 9: Bees at Aerodom



FIGURE 10: Environmental quality biomonitoring project of with bees at Aerodom

1 Tong et al, 1975. "Elemental analysis of honey as an indicator of pollution."

The management of hives intended for environmental monitoring allow a better observation of the bees' behavior and biological activity and the collection of data from samples of the wax, honey, pollen, propolis and the bee itself. At Aerodom, two biomonitoring stations with three beehives each were installed on Las Américas International Airport and La Isabela International Airport. Observations and data collection have been carried out at both stations and compared to the data on a "model hive," far from the airport sampling locations.

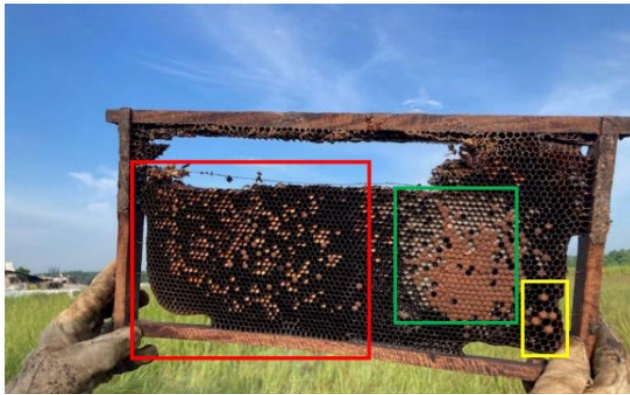


FIGURE 11: Monitored bee-hive at La Isabela Airport.

Quantitative/qualitative benefits

The monitoring of the urban and industrial environment requires increasingly expensive and complex techniques. Biomonitoring with bees is the only tool that allows the collection of qualitative and quantitative data on: (i) type of plant species present and their deficiency and impact on the whole ecosystem (biodiversity measurement tool) and (ii) the type, concentration, and impact of industrial pollution (pollution measurement tool). This is done over large areas, at a relatively low cost. Additionally, social programs can be implemented with local beekeepers for bee production and commercialization.

AERODOM's goal is to be able to spread this biomonitoring program on all its airports, as it is already part of the National Observatory of Air Quality and provide valuable information on the environmental health of the ecosystems and allow targeted action to be taken, if necessary, by collaborating or communicating with the local community and evaluating the impact of the measures taken, with scientific indicators and figures.

Vancouver International Airport: A Salmon Safe Airport

Vancouver International Airport (YVR) is located on Sea Island, 25 square kilometres of low-lying land at the mouth of the Fraser River, and on the traditional, ancestral and unceded territory of the Musqueam people in Richmond, British Columbia, Canada.



In 2016, YVR became the first airport in the world to achieve Salmon-Safe certification. This certification acknowledges the ongoing efforts and commitment to transform land and water management practices in order to protect Fraser River water quality and enhance habitat so that Pacific salmon continue to thrive.

YVR's Environmental Management Plan sets out four strategic priorities; improve ecosystem health, achieve net zero carbon emissions by 2030, reduce potable water and increase the diversion of waste. While Salmon-Safe is focused on improving ecosystem health, it affects nearly all aspects of development and operation at YVR through improvements in environmental management and innovation.

To certify YVR, a team of independent Salmon-Safe experts conducted an assessment looking into stormwater management, water quality protection, landscaping practices, construction practices, chemical containment, and wildlife and pest management.

Key commitments include:

- Ensuring all development activities at YVR meet rigorous standards, including a commitment to zero sediment run-off from construction sites into waterways
- Conducting a comprehensive water quality monitoring program and operating a centralized and contained de-icing facility to protect water quality
- Undertaking a significant habitat restoration project on Sea Island in collaboration with the Musqueam Indian Band
- Managing over 530 hectares of land airside with use of minimal herbicides and pesticides through a zoned



FIGURE 12: Aerial view from Vancouver International Airport (YVR) and the Salmon-Safe certification.



FIGURE 13: View of water filtering bioswale at YVR.

approach and innovative grass management strategies to manage pests and control wildlife. Landscape management practices groundsides include onsite nutrient cycling of organic matter through leaf recycling and sparse irrigation or use of fertilizer

- Building a public demonstration project to showcase the role of green infrastructure in stormwater management
- Reducing potable water consumption by using drought tolerant species as well rainwater harvesting for equipment washing.
- Supporting public education efforts that increase knowledge and understanding of the cultural, environmental, and economic importance of salmon to British Columbians, and the tangible connection between land-use, water quality and salmon health.

In 2021, YVR underwent an assessment of its Salmon-Safe program and successfully re-certified for the next five-year period. In recognition of the importance of indigenous ways of knowing, the Musqueam Indian Band was asked to review the salmon-safe standards prior to the evaluation and Salmon-Safe BC invited an Indigenous Assessor from

Musqueam to be part of the Assessment Team, a first for a recertification process. Including indigenous knowledge in the assessment helped to inform the workplan for the next five years, strengthening our relationship with the Musqueam people and our commitment to reconciliation.

Over this next recertification period, YVR will continue to evolve our program specifically looking to complete our habitat restoration project, which was put on pause due to the impacts of the COVID 19 pandemic, exploring green stormwater infrastructure and green flood management while encouraging our tenants to do the same, continuously improving our water quality and water conservation programs, ensuring native plants are chosen carefully to align with Musqueam historical use and knowledge that is site-specific and showcasing our environmental stewardship story within our Terminals.

Achieving and maintaining YVR's Salmon-Safe certification enables YVR to maintain the highest standards of conservation and stewardship on Sea Island while operating a world class sustainable hub airport.

Aerial Wildfire Fighting: Russian Experience and a Look at the Future

By Artur Mirzoyan (Central Institute of Aviation Motors, Russia) and Konstantin Gongalsky (A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Russia)

Introduction

One of the key solutions to reduce the global CO₂ emission is to increase both the absorption capacity of forests and to reduce emissions from wildfires.

According to the latest information from the Global Emission Database¹, the average gross carbon emissions from global wildfires were 7.7 Gt in CO₂ equivalent annually from 1997 to 2017. It represents almost 25% of the total annual CO₂ emission from burning fossil fuels².

Every year, millions of hectares of forest are affected by wildfires, populations are threatened, and flora and fauna are destroyed. In addition, the economic damage caused by global wildfires is estimated to cost billions of dollars, e.g. in Russia in 2016, the wildfire destroyed forests worth about 15 billion rubles.

Greenhouse House Gas (GHG) capture by Russian forests is central in the Climate Doctrine of the Russian Federation³. The Russian Federation, as a party to the Paris Climate Agreement, has established several voluntary commitments to reduce GHG emissions, which are set out in a document

called the Intended Nationally Determined Contribution (INDC) of the Russian Federation. It states that “the long-term goal of limiting anthropogenic GHG emissions in the Russian Federation may be 70-75% of 1990 emissions by 2030, under condition that *the absorption capacity of forests is taken into account as much as possible*”⁴.

A significant increase of the effectiveness of implementing such key solutions may be achieved through integrated wildfire management, including planning, prevention, early detection, firefighting, and the reduction of the negative consequences of fires. Today, the most important element of such an integrated approach is the rational use of modern aviation capabilities.

Aviation, Wildfires and Biodiversity

It is well known that wildfires have serious consequences for biodiversity and biogeochemical cycles. While on a global scale, they cause carbon dioxide emissions, on a local scale, they cause significant changes in biodiversity⁵. This includes the loss of nutrients and carbon from the soil through smoke and subsequent leaching of compounds

1 Global Fire Emissions Database, Version 4.1 GFEDv4. www.globalfiredata.org
<https://catalog.data.gov/dataset/global-fire-emissions-database-version-4-1-gfedv4>

2 Le Quéré, Corinne, et al. “Global carbon budget 2017.” Earth System Science Data Discussions (2017).
http://gci.org.uk/Documents/le_Quere_et_al_Global_Carbon_Budget_2017.pdf

3 Climate Doctrine of the Russian Federation December 2009 (validating Presidential Resolution No. 861-rp), Unofficial translation.
<https://policy.asiapacificenergy.org/sites/default/files/Climate%20Doctrine%20of%20the%20Russian%20Federation%20%28EN%29.pdf>

4 Paris Agreement, UNFCCC, 2015. https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

5 Kelly, L. T., Bennett, A. F., Clarke, M. F., & McCarthy, M. A. (2015). Optimal fire histories for biodiversity conservation. Conservation Biology, 29, 473-481. <https://doi.org/10.1111/cobi.12384>

contained in ash⁶. Figure 1 illustrates only 1 fact of the huge damage that global wildfires cause to biodiversity (animals, plants), and soil properties⁷. It shows the 80-year time required to restore the number of soil animals after fires in the Karelia Taiga Forests in the north of Russia.

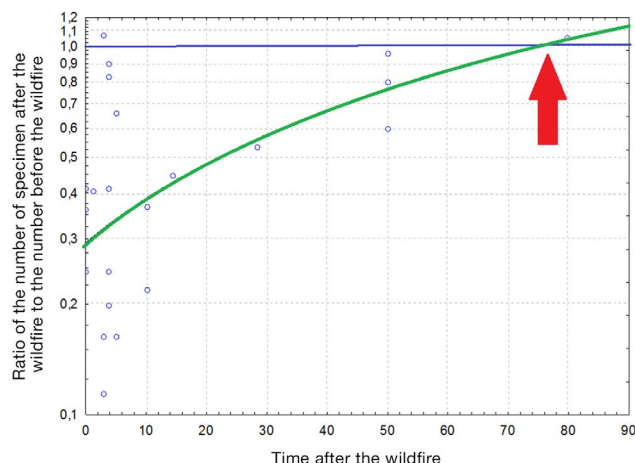


FIGURE 1: Recovery of soil animals after fires in the boreal forests of Karelia.

Given the projected increase in the frequency of wildfires over the next century, it is likely that wildfires will pose a major threat to forest ecosystems around the world⁸.

The effective use of aviation in wildfire management may significantly reduce their CO₂ emissions and contribute to the conservation of biodiversity. This will be accomplished through earlier detection of fires, use of high-tech aviation monitoring tools (including unmanned aerial systems of various dimensions, global satellite monitoring), ensuring higher efficiency of delivery of the necessary volumes of firefighting agents, the early start of fighting operations, and the ability to manage wildfires regardless of the actual availability and condition of local land access roads.

Russian Experience

Forests make up almost half of Russia's land area (46%), 99.0% of them are Boreal (Taiga) forests, which are most susceptible to fires. The centers of ignition in the forests are commonly located far from settlements and roads. It is for this reason that the use of aerial firefighting in such remote forests is the only effective solution in the field of wildfire management.

Currently Russia has one the strongest, most diverse, and well-equipped firefighting air fleet in the world. Among them, the most widely used multi-purpose aircraft: the An – 2/3 aircraft (load capacity is up to 2 tons), the Be – 200ChS amphibious aircraft (12 tons), and the Ilyushin – 76 transport aircraft (42 tons). The helicopter fleet includes the following: Mil – 8 (4 tons) and the Ka – 32A (3 tons) universal helicopters as well as the Mil – 26T1 heavy multi-purpose transport helicopter (20 tons) (Figure 2)⁹.



FIGURE 2: Russian aviation fleet for firefighting.

They are successfully used not only in Russia, but also abroad (e.g. in Turkey, Indonesia, Balkan Peninsula, Israel, Portugal, Chile, Serbia, Armenia, Abkhazia and many other countries).

6 Moody, J. A., Shakesby, R. A., Robichaud, P. R., Cannon, S. H., & Martin, D. A. (2013). Current research issues related to post-wildfire runoff and erosion processes. *Earth-Science Reviews*, 122, 10-37. <https://doi.org/10.1016/j.earscirev.2013.03.004>

7 M. Gordin, V. Rozhnov, N.Kopylov, A. Mirzoyan. Aviation and Forest Fire Fighting. ICAO Aviation Green Recovery Seminar. 23-24 November 2020. <https://www.icao.int/Meetings/GreenRecoverySeminar/Documents/3.8%20ICAO%20AGR%20-%20Aviation%20and%20forest%20fire%20fighting.pdf>

8 Bowman, D. M. J. S., Perry, G. L. W., Higgins, S. I., Johnson, C. N., Fuhlendorf, S. D., & Murphy, B. P. (2016). Pyrodiversity is the coupling of biodiversity and fire regimes in food webs. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371. <https://doi.org/10.1098/rstb.2015.0169>

9 <https://en.mchs.gov.ru/>



FIGURE 3: Regions of Russia with the highest level of biodiversity and having unique ecosystems inhabited by endangered species of animals.

In addition to the threat to the life of population and direct economic losses, wildfires cause enormous damage to biodiversity and habitats of valuable and rare species of animals and plants. Figure 3 shows the regions of Russia with the highest level of biodiversity and having unique ecosystems inhabited by endangered species of animals¹⁰.

ICAO and International Cooperation in Aerial Firefighting

It is quite reasonable to talk about the globalization of the impact of wildfires in the world due to the transboundary nature of their consequences, the lack of local resources, and finally, the global impact on the ecosphere, climate change, and biodiversity.

Currently, there are a large number of United Nations and other international organizations that have organized international cooperation in the field of disaster management, aerial firefighting, and global fire monitoring.

These include the Global Fire Monitoring Center (GFMC), the Forest Fire Advisory Group of United Nations International Strategy for Disaster Reduction (UN-ISDR), the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), the International Working Group on Fire Aviation (IFAWG) and others.

At the same time, aerial firefighting has a significant potential to increase the efficiency of using aviation in managing global wildfires and preserving biodiversity. This potential is primarily related to the legal issues of timely participation of aviation of some countries in firefighting in other countries, difficulties in international recognition and appropriate certification of aviation fire equipment, advanced methods and systems for supporting aerial firefighting, ensuring increased flight safety of aerial firefighting, as examples. ICAO could be most successful in addressing these issues.

ICAO could ensure the development of international standards taking into account national law and order,

¹⁰ WWF Russia position on wildfire. <https://wwf.ru/regions/>

the formation of legal bases for the use of international aviation in the wildfires management.

Under the auspices of ICAO, the I4F initiative¹¹ has already initiated a discussion and dialogue on international cooperation to improve the use of aviation in the management of world wildfires.

Conclusion

In conclusion, it is appropriate to recall a quote from President Franklin Roosevelt's address to the famous Chicago Conference: "Full recognition of the sovereignty and judicial equality of all nations, let us work together so that the air may be used by humanity to serve humanity."

With the planned recovery of the aviation sector after the pandemic, ICAO can assist the forest sector, to which humanity owes a great debt, to become more resilient to wildfires, to remain, as before, the main accumulator of CO₂, and thereby affect global CO₂ emission and biodiversity conservation.

Key recommendations for wildfire management include the following:

- Improving the efficiency of wildfire management through the use of aviation has become relevant for reducing global CO₂ emission, taking into account the increased absorption capacity of forests and reducing emission from fires themselves.
- Given the increasingly serious impacts of wildfires on the conservation of biodiversity and biogeochemical cycles, aviation has a special and unique role to play in reducing these impacts.
- Taking into account the extensive successful experience of using the Russian fleet of aerial firefighting vehicles both in our country and abroad, Russia actively supports the ICAO initiative I4F to organize an international dialogue in the field of aerial firefighting.
- The development of the ICAO I4F initiative with the involvement of interested States in broad international cooperation in the field of aerial wildfire management will make it possible in the future to significantly reduce the impact of global wildfires on global CO₂ emission and biodiversity conservation.

11 ICAO Flying Forest Fire Fighting Dialogue (I4F). <https://www.icao.int/Meetings/I4F/Pages/default.aspx>

ICAO Flying Forest Fire Fighting Dialogue

By ICAO Secretariat

Introduction

Forests cover approximately 30% of the Earth's land surface, are the second largest carbon sink and carbon storage, next to the Earth's oceans. Forests are also home to 80% of the world's terrestrial biodiversity. They supply oxygen, protect soils and watersheds. They also provide food, fuel, medicines, and building materials for human activity. They inspire wonder, and provide places for recreation and relaxation.

Yet the Earth's forests are under threat. As outlined in the Intergovernmental panel on Climate change (IPCC) Assessment Report 6 on Climate Change 2021, widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred due to human influence. Climate change is already affecting every inhabited region across the globe, and every year large areas of forest are affected by fires. The number of fires and their size varies from

year to year, but the risk of fire is increasing globally due to extreme temperatures (Figure 1). Forest fires devastate ecosystems, threaten the safety of global citizens, and can result into environmental and human disasters.

With increasing awareness of the importance of safeguarding forests, the rapidly growing problem of forest fires has risen over the past years to the forefront of political and public awareness. The 2020 United Nations Summit on Biodiversity highlighted the crisis facing humanity from the degradation of biodiversity and the urgent need to accelerate action on biodiversity for sustainable development. It emphasized biodiversity conservation as a necessary condition for the achievements of Agenda 2030 for Sustainable Development and the fight against climate change.

Emergency responses to forest fire fighting involves both ground and air intervention forces. Although ground forces remain the principal lever of action and

Type of observed change in hot extremes

- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution to the observed change

- High
- Medium
- Low due to limited agreement
- Low due to limited evidence

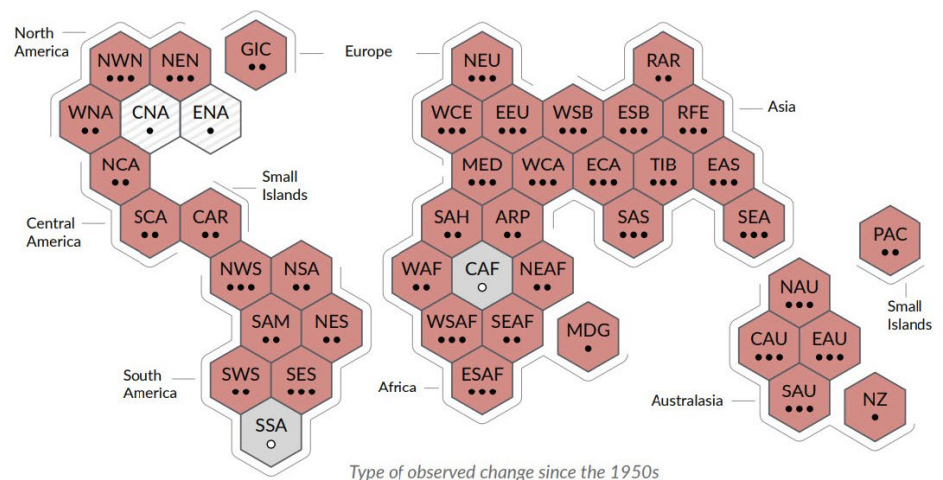


FIGURE 1: The observed change in hot extremes and confidence in human contribution to the observed changes in the world's regions (IPCC Assessment Report 6, Climate Change 2021: The Physical Science Basis).

the coordinator of the overall response, aircraft play a crucial complementary role to control the escalation of fires at the early stages. The aerial response to fires has improved over time, and contributing to this has been the continuous improvements of monitoring tools and early warning systems. However, there are always opportunities for further improvements.

During the Aviation Green Recovery Seminar in 2020, the International Civil Aviation Organization (ICAO) announced the launch of the ICAO Flying Forest Fire Fighting (I4F) Dialogue. It has a goal of exchanging information on existing activities, technologies, arrangements, and facilitating the cooperation on aviation forest fire fighting activities among States and other relevant stakeholders. This will be accomplished through sharing knowledge, experience, and resources, as well as discussing possible areas of improvements and cooperation under the auspices of ICAO.

I4F Dialogue

The ICAO Flying Forest Fire Fighting Dialogue was held on 22 November 2021¹ as an online event, and served as a platform to exchange best practices, initiatives, and by strengthening international cooperation for aerial firefighting action. The first session was dedicated to the scientific background, presented by Ms. Valerie Masson-Delmotte, Co-Chair of the Working Group I of the Intergovernmental Panel on Climate Change.

The second session was focused on an overview of the United Nations (UN) and international action². The participants from the Global Fire Monitoring Center (GFMC), International Fire Aviation Working Group (IFAWG), and Joint United Nations Environment/Office for the Coordination of Humanitarian Affairs (UNEP/OCHA) Environment Unit highlighted the importance of ICAO's role. It also highlighted the need for an informal multi-stakeholder working group with other relevant United Nations bodies and international organizations (Figure 2).



FIGURE 2: Proposal for coordination made by Ms. Charlotta Benedek, Head of UNEP/OCHA Joint Environment Unit.

The third session covered perspectives of Member States on aerial firefighting, international cooperation, and best practices. The fourth session focused on the recent technological solutions, innovations, and partnerships in aerial firefighting. The participants underscored the importance of identifying focal points across ICAO Member States in order to increase awareness and gain support for forest fire fighting efforts. The need for more outreach, certification work, awareness and innovations on fire fighting, forecasting, mitigation and prevention were also highlighted. Specific proposals were made on coordination towards facilitating new international aviation regulations and harmonization across States.

During the discussion session, it was acknowledged that the alarming trends in increasing number of wildfires across the globe are accelerating. The participants and online viewers received extensive information on international firefighting practices, and on aviation solutions, expressing support to these crucial actions worldwide (the recording of the I4F Dialogue is available on ICAO.tv platform³).

1 I4F Dialogue Programme: https://www.icao.int/Meetings/I4F/Documents/I4F%20Programme%20v_2021-11-21.pdf

2 I4F Dialogue Speakers : <https://www.icao.int/Meetings/I4F/Pages/speakers.aspx>

3 Recording of I4F Dialogue on ICAO.tv: <https://www.icao.tv/videos/flying-forest-fire-fighting-dialogue>

I4F Next Steps

ICAO will engage, through an informal multi-stakeholder working group, with GFMC: International Search and Rescue Advisory Group (INSARAG) and Joint UNEP/OCHA Environment Unit for facilitating international cooperation while also identifying focal points across ICAO Member States. It will also be important to advance in investigating new areas for global cooperation, supporting outreach, certification, and innovations on firefighting. Other parameters will include forecasting, mitigation, and prevention, including coordination on new international aviation regulations, such as facilitating Remotely Piloted Aircraft System (RPAS) regulations to ensure safe and secure RPAS application and integration.



| ICAO

CHAPTER ELEVEN

State Action Plan & Capacity Building

The ICAO State Action Plan Initiative

By ICAO Secretariat

A Long-Term Collective Engagement

The International Civil Aviation Organization (ICAO) and the 193 Member States have a longstanding history of cooperation in the field of environmental protection. While ICAO has exercised continuous leadership to international civil aviation in limiting and reducing CO₂ emissions through the development of policies and standards, the Member States have demonstrated active engagement and cooperation. The cooperation between ICAO and the States has been marked by a common understanding that addressing environmental issues requires a dynamic and multi-stakeholder approach of collaboration.

Since its creation in 2010, the State Action Plans on CO₂ Emissions Reduction has been one of the most successful programmes with ICAO Member States. It is a voluntary initiative and a means to provide States with the capacity and tools to develop and implement a State Action Plan for

CO₂ emissions reduction. At its beginning, the programme was created with a view of leaving “No Country Left Behind” ensuring that all States have the human, technical and financial capacity to develop and implement a State Action Plan. Today ICAO is proud to count 133 State Action Plans received as of July 2022, totaling more than 98% of global Revenue Tonne-kilometres (RTK)¹. This is reflective of ICAO’s continual progress.

The ICAO State Action Plan is a living document to be updated every three years as per Resolution A37-19 and a medium-long term climate change strategy at the national level involving all interest parties to reduce greenhouse gas emissions. As a first step in developing or updating a State Action Plan, is the creation of an integrated team working together to plan, develop and implement a State Action Plan. The team, comprising Headquarter, Regional, and State representatives will work together with all interested parties to define a quantified baseline, select appropriate



FIGURE 1: Map of the State Action Plans submitted to ICAO as of July 2022

¹ https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

mitigation measures from ICAO's basket of measures, quantifying emissions reduction derived from each of the selected measures, and quantifying expected results from the implementation of these mitigation measures in terms of CO₂ emissions reduction.

The State Action Plan is also a monitoring and communication tool. It enables ICAO, through the compilation of quantified data from States, both for baseline and expected results, to measure the progress towards the achievement of ICAO's global aspirational environmental goals for international aviation. This represents the annual improvement in energy efficiency of 2% until 2050 and neutral growth in carbon from 2020, as established at the 37th Assembly in 2010. The information gathered by ICAO through the State Action Plans also serves as a gap analysis in terms of capacity building requirements at the State level. ICAO is continuously assessing the needs of States to ensure continual delivery of excellent assistance and support.

ICAO's assistance and support to its 193 Member States with the development and implementation of their State Action Plan takes various forms. ICAO has created a series of guidance documents and quantification tools. Guidance on the Development of States' Action Plan on CO₂ Emissions Reduction Activities (Doc 9988), provides a detailed step-by-step approach to enable States to develop their State Action Plan and meet the basic requirements. The Third Edition of Doc 9988 was published in 2019 and ICAO is preparing the Fourth Edition for publication.

Due to the current COVID-19 outbreak, face-to-face meetings were replaced by virtual teleconferences. Since March 2020, ICAO has organized multiple online events including the 2020 and 2021 Stocktaking Seminars, an important event in the field of sustainable aviation. Additionally, ICAO Regional webinars were organized between July 2020 and August 2020 to provide additional information for the State Action Plan development process, and ICAO's updated activities and supporting tools. Success stories and examples were also provided to support and inspire States.

Moreover, in 2020, ICAO celebrated the 10th Anniversary of the implementation of the Programme created by the adoption of Assembly Resolution A37-19 on October 9, 2010, at its 30th Session. To celebrate all that has been achieved so far, each ICAO Regional Offices organized celebratory

meetings together with States National Focal Points. It was been an opportunity to discuss further successes, challenges and potential solutions as well as the next steps.

In 2021, as the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment was released which included recent scientific findings and their implications for aviation, ICAO continued its work on the feasibility of establishing a long-term aspirational goal for international aviation as reached during the ICAO 40th Assembly session in 2019, when the Assembly requested its Council to continue to explore the feasibility of adopting a long-term global aspirational goal in light of the 2 °C and 1.5 °C temperature goals of the 2015 Paris Agreement.

ICAO assessed the feasibility of a global long-term aspirational goal, including possible implementation roadmaps for reducing international aviation CO₂ emissions. Through a robust process involving more than 600 experts from States, and the main stakeholders inside and outside of the aviation industry, ICAO conducted detailed studies assessing the attainability and impacts of any goals proposed. It is important that the impact on growth as well as costs in all countries, especially developing countries, be presented the 41st Session of the ICAO Assembly in 2022. This assessment of long-term goals will include information from States on their experiences working towards the medium-term goal.

Capacity Building and Green Funding for Aviation Emissions Reduction

As stated in the latest IPCC Assessment Report, the limitation of global warming to 1.5 degrees Celsius requires breakthrough technologies. In that regard, ICAO continues to support States in the implementation of forward-looking mitigation measures for CO₂ emissions reduction. The new and updated State Action Plans should include innovative mitigation measures based on the latest scientific knowledge such as disruptive new aircraft technologies, sustainable aviation fuels, and renewable energy.

Today, States are indeed developing mitigation measures based on current and future methods and ideas that can be qualified as innovative. Some States have also independently set themselves net zero targets for aviation by 2050.

PARTNERS		STATUS OF ACTION PLAN		
State Providing support	State receiving support	Under development	Submitted to ICAO	Posted on the ICAO website
Bulgaria	North Macedonia			
Spain	Ukraine			
Namibia	Zambia			
Kenya	Botswana			
Dominican Republic	Panama			
Namibia	Gambia			
Italy	Madagascar			
Brazil	Mozambique			
Spain	Bolivia (Plurinational State of)			

FIGURE 2: List of State Action Plan Buddy Partnerships

Therefore, it is evident that infrastructure will require enhancement and funding to meet these goals and objectives. Therefore, ICAO continues to work on the identification of potential impacts of climate change on international aviation. Infrastructure and investment related needs, as well as incentives to encourage the deployment of clean and renewable energies sources for aviation such as sustainable aviation fuels at a decreased and more accessible cost.

ICAO is also taking into consideration the different circumstances among States in their capacity to respond to the challenges associated with climate change and the need to provide further support in particular to developing countries and States having particular requirements. Specific measures have been put in place over the years by ICAO to facilitate access to financial support, technology transfer and capacity building to these States. These measures included partnerships among States and other international organizations.

For the States who have not yet submitted a State Action Plan or are in process of updating their State Action Plan, ICAO offers the possibility of being matched with another State and serves as an intermediary for the establishment of a Buddy Partnership. This capacity building partnership provides access to financial resources, technology transfer, and capacity and assistance in bridging gaps among ICAO

Member States of terms of capability of developing and implementing a State Action Plan.

ICAO in partnership with the European Union has offered capacity building assistance to its member states for the development of their action plans within the framework of the project: ICAO Assistance Project with the European Union Funding. These projects consists of two phases: the first phase of the Assistance Project which supported 14 States from Africa and the Caribbean, and the second phase includes the implementation of State Action Plans in 10 African States. In the first phase, all expected results were achieved, and the second phase, currently in progress, is demonstrating promising results.

Another funding project in partnership with the United Nations Development Program (UNDP) was created in 2015 to facilitate the sustainable development of the aviation sector. This project was funded by the Global Environment Facility (GEF) and was directed to developing States and Small Island Developing States (SIDS) in their efforts to reduce CO₂ emissions from international aviation.

ICAO is working on the publication of a Fourth Edition of the Guidance on the Development of States' Action Plan on CO₂ Emissions Reduction Activities (Doc 9988) which will provide further guidance on how to further assess environmental and social benefits of innovative mitigation measures versus costs, with a view to submit

an application for funding. As the State Action Plan is a platform to showcase States environmental benefits, it can be used to access green funding. It will form the basis for justification for the funding application.

As more and more States are setting targets for international aviation, green funding will secure the achievement of these targets and the State Action Plan will serve as a climate change plan and roadmap.

Conclusion

Today, we are at a cornerstone in the field of sustainable aviation, and the continual implementation and updating of the State Action Plan initiative is very important. Greater accessibility to scientific knowledge, and additional commitments in international aviation, will require additional green finance to achieve global common environmental goals for CO₂ emissions reduction. The International Civil Aviation Organization together with its Member States will continue to deepen their collaboration which have proven to be a key factor of success.

Acting now – Qatar's Efforts Towards Sustainable Aviation Fuels

By Rachid Rahim (Qatar Civil Aviation Authority)

Introduction

In 2021, the State of Qatar has launched its National Climate Change Action Plan (NCCAP) that aimed at achieving a 25% reduction in greenhouse gas emissions by 2030. Under this umbrella, in the civil aviation sector, Qatar Civil Aviation Authority (QCAA) is working closely with all the stakeholders in the aviation industry to fully do its part in achieving the State's NCCAP objective, and to abide by Qatar's National Vision 2030 (QNV 2030) which contains four pillars, namely: Human, Social, Economic and Environmental Development. Specifically, QNV 2030 indicates that:

“Economic development and protection of the environment are two demands neither of which should be sacrificed for the sake of the other”; and

“Environment Development: management of the environment such that there is harmony between economic growth, social development and environmental protection”

Among the initiatives that were taken, recently, to tackle climate change in the National Aviation Industry, we can mention:

Improve Hamad International Airport's carbon efficiency per passenger by 30% by 2030 against a 2015 baseline; and

Commitment, by the national carrier, to net zero carbon emissions by 2050.

The State of Qatar is pursuing the implementation of ICAO (International Civil Aviation Organization) comprehensive strategy to progress all elements of the “basket of measures”,

namely: Aircraft-related modern technology; Improved Air Traffic Management; More efficient operations - Infrastructure improvements; Market-based measures; and CORSIA Eligible Fuels (CEF) including the Sustainable Aviation Fuels (SAFs) and the Lower Carbon Aviation fuels (LCAF).

One especially essential element of the stated above basket of measures, is SAF which, according to recent analysis, is aimed to enable the global civil aviation industry to reach the goal of net zero carbon emission. The State of Qatar as per its strategy, continues to support research, development, and demonstration of CORSIA Eligible Fuels in collaboration with different Stakeholders. This includes the discussion of the potential for, benefits of, and barriers to CEFs production and use in Qatar. With regards to SAFs, the main object of the joint synergies in Qatar is to find alternative sources of feedstock to produce biomass to liquid (BTL) fuels. In the following paragraphs, two projects are presented as examples.

1. Algal Technologies Program: Towards Sustainable Aviation Fuel

An example of Qatar's efforts is the Qatar University Biofuel Project which is taking advantage of Qatar's resources and climatic conditions for growing marine microalgae as feedstock. Specifically, lipid-rich marine microalgae that could be grown using seawater on non-arable land. Qatar's abundant sunlight throughout the year, easy access to vast non-arable lands, and seawater, make Qatar a suitable location for producing lipid-rich marine microalgae as a potential feedstock to commercially produce SAFs.



FIGURE 1: Lipid rich marine microalgae cultivated in 25,000 L outdoor open raceway ponds

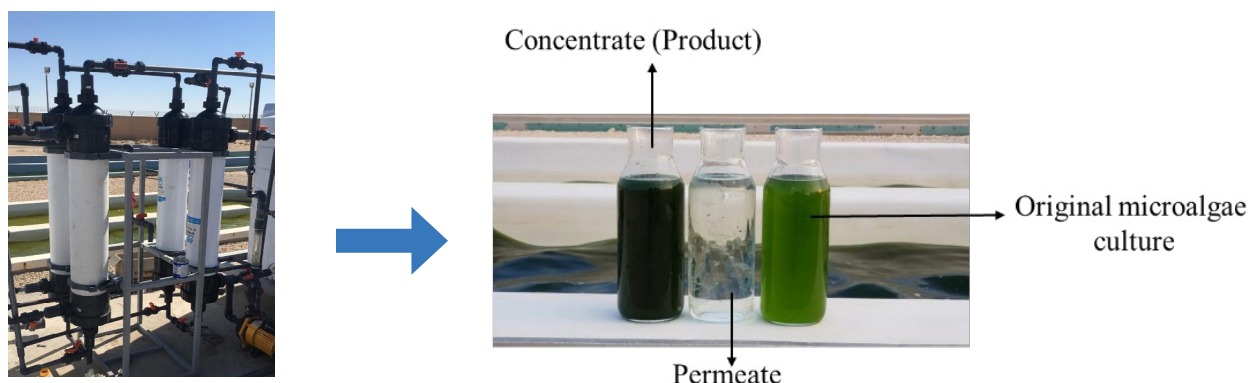


FIGURE 2: Tangential flow filtration system developed by algal technologies program (ATP)-Qatar University

Presently, the Algal Technologies Program (ATP) research group at Qatar University has successfully cultivated lipid-rich marine microalgae in 25 m³ – 100 m³ outdoor open raceway ponds, as shown below. The research group has also developed a tangential flow filtration system for harvesting microalgae – capable of processing 1300 L/hr microalgae culture at 0.2 – 0.3 kWh/m³. The filtration unit can concentrate marine microalgae cultures to biomass densities ranging from 25 to 30 g/L as shown below.

For this project, researchers used a high-pressure Parr reactor for producing biocrude oil from microalgae; the hydrothermal liquefaction (HTL) reactions were conducted at temperatures ranging from 275 – 400 °C and 200 bar pressure. A similar reactor setup will be used for the hydroprocessing of marine microalgae lipids to SAFs or bio-jet fuels. ATP is working on biocrude oil production from various marine microalgae strains.

A biorefinery process was developed to extract pigment and lipid efficiently at a large scale. More than 40 % lipid has been successfully extracted from sundried marine microalgae by using a pilot-scale soxhlet extractor.

Future steps for the ATPs biofuel project would focus on the scale-up of microalgae production facility. Additionally, the hydroprocessing reaction parameters will be optimized for obtaining higher SAF yields from marine microalgae lipids. The results from optimization studies would then assist in developing continuous SAF production systems.

2. Sustainable Solar-Driven Biofuel Generation from Industrial Wastewaters without External Bias

Hydrogen is considered by many experts, a promising alternative fuel. It is characterized by easy storage, high energy density, and a clean combustion process which produces water. Hydrogen can be generated from various sources such as reforming fossil fuels such as coal and natural gas, water electrolysis, biological sources such as dark fermentation process, and solar-driven methods such as photo-electrochemical.

Qatar University, in collaboration with the Environmental and Municipal Studies Center at the Ministry of Environment,

Korea Maritime, and Ocean University, is working on a project that can be considered as an added value for converting industrial wastewater into hydrogen. This project can break the limitations of traditional Microbial Electrolysis Cell (MEC) and rely on coupling of solar energy with bioenergy. The project design, photo-assisted microbial electrolysis cell (PA-MEC), can deliver sustainable hydrogen fuel together with efficient degradation of organic contaminants without the use of external power as shown below.

The project work has reached an advanced level, where researchers will calculate the amount of the produced Hydrogen and then evaluate the process performance in terms of system design and materials used, cost, and efficiency to pave the way for commercialization of PA-MEC technology as a practical alternative approach for biofuel production in the State of Qatar. The State of Qatar is making huge efforts in enabling diversification of renewable energy resources and in the heart of it the sustainable aviation fuels a major element of the ICAO basket of measures in the coming decades.

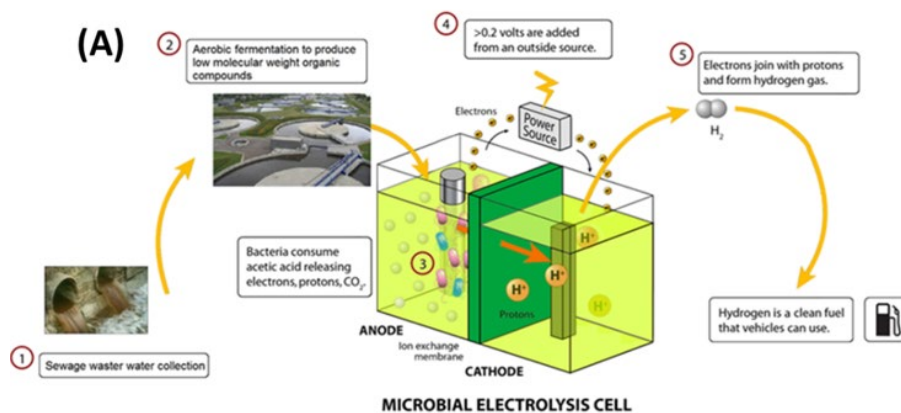


FIGURE 3: Schematic diagram for the microbial electrolysis cell

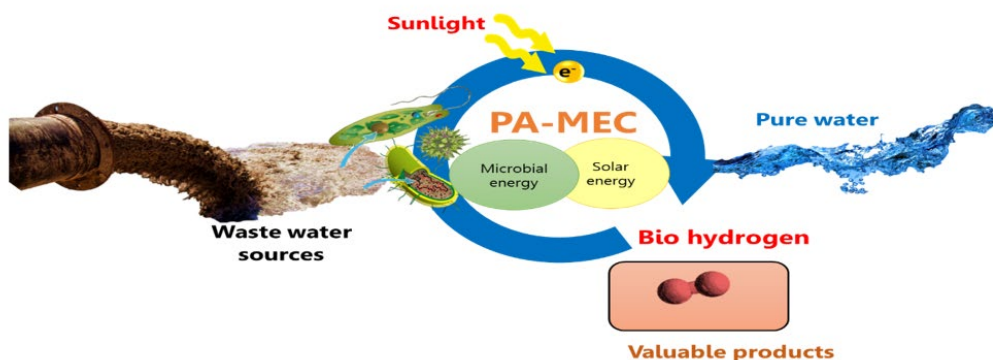


FIGURE 4: Schematic diagram of (PA-MEC) hybrid system coupling solar energy with bioenergy

Acting now – The Implementation of Performance Based Navigation (PBN) in Nigeria

By Oyetoun Foluwake Adegbesan (Nigerian Civil Aviation Authority)

Introduction

The Government of Nigeria has implemented various measures for the mitigation of CO₂ emissions in its efforts to contribute to the global targets set by ICAO. These measures and initiatives, which include improvement of airport operations and infrastructure, air navigation facilities and air traffic management system, and the acquisition of more fuel-efficient aircraft by Nigerian operators, etc. are all detailed in the State Action Plan.

One of the significant projects embarked upon to improve the air navigation facilities and air traffic management systems aimed at reducing flight times, terminal delays, fuel consumption, and distance flown within the Nigerian airspace, is the implementation of the Performance Based Navigation (PBN) by the Nigerian Airspace Management Agency (NAMA).

The PBN Project

In accordance with the AFI PBN Roadmap, the implementation of the PBN Project started with the conduct of World Geodetic System (WGS) 84 surveys of 24 airports in Nigeria. This included PBN approaches with Lateral Guidance (LNAV), as well as approaches with Vertical Guidance (BARO VNAV) for some specific airports. These were in addition to the Standard Instrument Departure Routes (SIDs) and the Standard Terminal Arrival Routes (STARs) for five (5) airports. The primary purpose of the project is to provide the required capacity for the global migration from ground-based system of navigation, to satellite-based navigation as contained in the National Performance Based Navigation Implementation Plan.

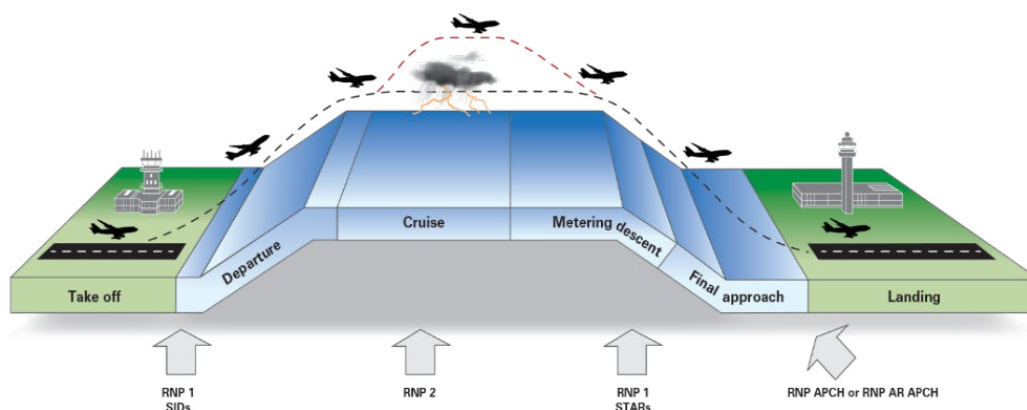


FIGURE 1: Application of PBN in the Nigerian Airspace

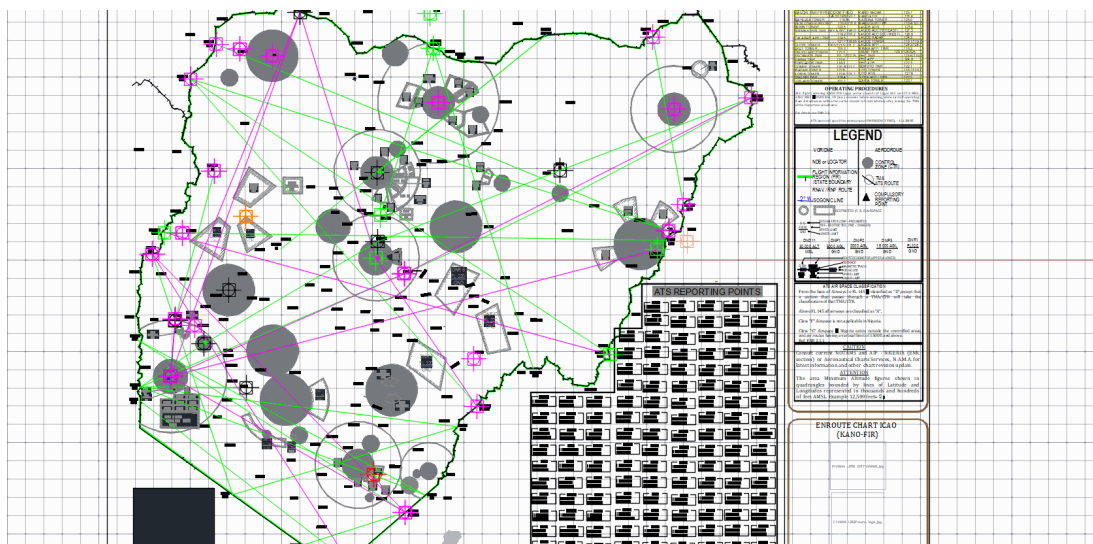


FIGURE 2: FRA implementation in Kano FIR – (Published and yet-to-be published direct route segments)

By April 2020, in collaboration with the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), nine (9) PBN Area Navigation Regional Routes (RNAV10 Routes) have been implemented to enhance regional connectivity, reduce flight distance, flight time, fuel consumption, CO₂ emissions, cost of operations, pilot workload, and an increase the capacity of the airspace. These new routes, which connect cities in Nigeria to regional destinations, were in addition to other PBN Routes earlier established. The new routes include UQ300 connecting Lagos to the Central African Republic; UY604 linking Abuja and Port Harcourt to Southern Africa; UQ181 connecting East and Central Africa to Europe through Nigerian airspace; and UQ400 connecting Southern Africa to North Africa through Nigeria to Europe.

In addition to the new routes, the Free Route Airspace (FRA) concept was implemented in 2021 in the Kano Flight Information Region. The FRA concept is associated with the ICAO Aviation System Block Upgrade (ASBU) modules B1-FRTO on free routing in defined airspace, where the flight plan is not defined as segments of a published route network or a track system to facilitate adherence to the user preferred profile. The benefits of the FRA concepts include fuel savings per route leg as much as 289.21kg per user, multiplied by the number of users per day. This could translate to estimated CO₂ savings per route leg of 942.35kg per user, multiplied by number of users per day.

Impact of the PBN Project

The implementation of PBN has:

- led to the reduction of flight delays and diversions attributable to holding for weather improvements and outright air returns. The PBN implementation has complemented the Total Radar Coverage of the Nigerian Airspace and has resulted in the review of the mandatory Minimum State Weather Conditions;
- brought about further reduction of flight delays attributable to use of conventional navigational facilities, which has inherent limitations of accuracy, reliability, integrity and availability. This has led to increase in flight efficiency and reduction in fuel burn and CO₂ emissions as stated in Table 1;
- enhanced flight safety through continuous decent procedures that reduce the risk of controlled flight into terrain and loss of control;
- allowed for more efficient use of the airspace and reduced the need to maintain senior-specific routes and procedures, with their associated cost; and
- resulted in the need to avoid the development of senior-specific operations with each new evolution of navigation systems, which could be cost-prohibitive.

TABLE 1: New PBN RNAV10 Routes with Savings in Distance, Fuel and Emissions

S/No	Route Designator	Type of Route	Routing	FIRs Involved	Distance Savings (nm)	Fuel Savings (kgs)	CO ₂ Savings (kgs)
1	UQ300	New Route RNAV10 IATA Request	KOKAM – NLY – ILBAS – EDGOT	Brazzaville, Kano	29	179	566
2	UY604	RNAV10 New, Nigerian Request	POT-BIPIV	Kano, Brazzaville	30	193	610
3	UQ181	New Route RNAV10 IATA Request	BIPIV - TENTU	Brazzaville, Kano, Accra	44	550	1750
4	UQ400	New Route RNAV10 IATA	BIPIV – NANOS	Brazzaville, Kano, Niamey	30	179	566
5	UQ324	New Route RNAV10 IATA Request	NY-GULEN-KELAK	Niamey, Kano, Ndjamena, Khartoum	50	618	1953
6	UY333	RNAV10 New, Nigerian request	KIGRA-OPDOL-UBEVA	Kano, Niamey, Algiers Tunis	44	550	1730
7	UY87	New Route RNAV10	TYE-KIDKI	Kano, Accra, Abidjan	15	91	287
8	UY57	New Route RNAV10 ACCRA Request	LIREX-SESIG	Kano, Accra, Abidjan	7	39	123
9	UQ200	New Route RNAV10 IATA Request	ADDIS – LAGOS (GWZ – GADUV	Addis, Khartoum, Ndjamena, Brazzaville, Kano	95	950	3002
10	UY87	New Route RNAV10	TYE-KIDKI	Kano, Accra, Abidjan	15	91	287

The Future Work on the PBN Project

With the resultant effects of implementing the PBN project, NAMA intends to consolidate the positive gains by taking more pragmatic actions on the project in the next three years including:

- reviewing the PBN roadmap and the WGS 84 survey of all airports;
- developing a national Satellite Based Augmentation System (SBAS) and Ground Based Augmentation System (GBAS) plan, and conduct a cost benefit analysis for their implementation, amongst others; and
- intensifying the training and retraining of all relevant personnel on the project.

Update of Dominican Republic State Action Plan Progress on Emissions Mitigation

By Judit De Leon (Instituto Dominicano de Aviación Civil, IDAC)

Introduction

The International Civil Aviation Organization (ICAO) Document 9988 - “Guidance on the Development of States Action Plan- CO₂ Emissions Reduction Activities, was a particularly important tool guide for updating the 4th Edition of the State Action Plan for the Dominican Republic (PARE-CO₂).

This update process represented a great challenge as many members of the working group were new. Thus, to develop capacities, virtual meetings and workshops were held.

Update of the Dominican Republic State Action Plan – 2021–2023

As a result of the border closures at the beginning of the COVID-19 pandemic in 2020, and the paralysis of tourist activity during the period of January–November 2020, the country only received 2.1 million non-residents, which represented a drop of 64.7% compared to the same period in the previous year. The effects on air operations for 2020 were also significant, representing a reduction of approximately 43% flight traffic compared to 2019. However, the work teams of the Dominican Republic (DRWG) maintained the implementation of the mitigation measures and are reflected in the plan of action.

For PARE-CO₂ 2021–2023, a working group was added, titled “DRWG 7 Market-based Economic Measures” This group is currently comprising government institutions such as the Dominican Accreditation Organization (ODAC). IDAC signed a collaboration agreement in July of 2021



FIGURE 1: Cover of the 4th edition of the action plan



FIGURE 2: Photo of the signing of the IDAC-ODAC Agreement, represented by Román Caamaño director of IDAC and Ángel Taveras director of ODAC

with the aim of complying with the provisions of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

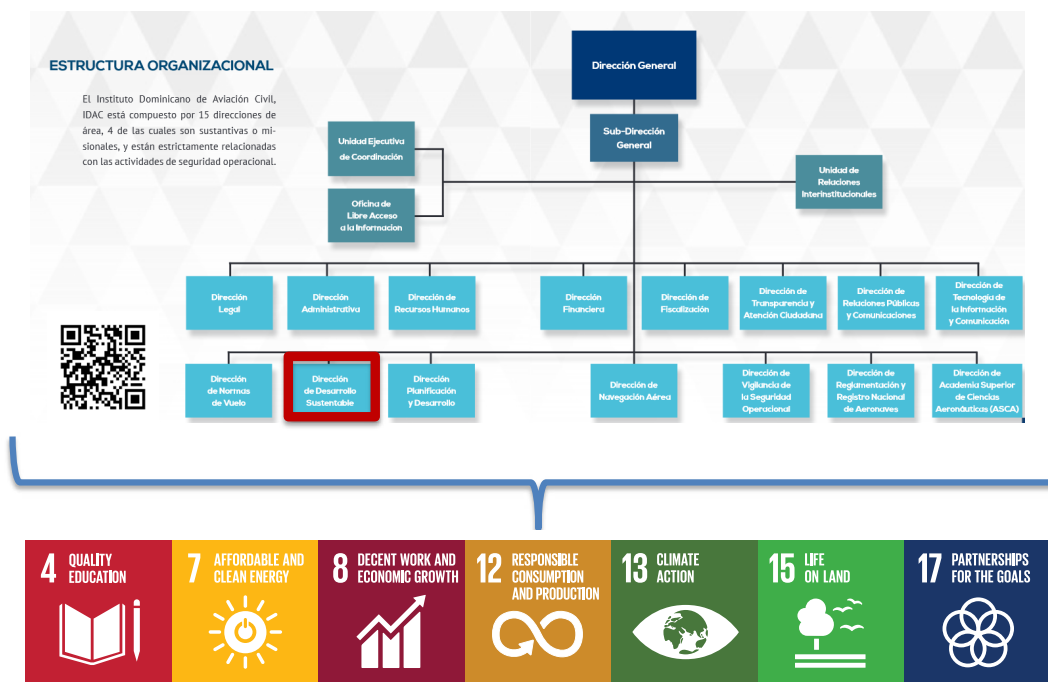


FIGURE 3: IDAC Organizational Structure supporting UN SDGs

The IDAC published a regulatory framework with the objective of ensuring the neutral growth of CO₂ emissions. Included in the Institutional Strategic Plan¹ is the objective of protecting the environment and a modified Structure of the Department to the Directorate of Sustainable Development, to monitor compliance with the goals of the UN SDGs (Sustainable Development Goals) by its Member States in Dominican aviation.

aviation sector personnel, and members of aeronautical authorities from other States such as Panama and the Bahamas.

Under the ACT-CORSIA Framework, we held virtual working meetings in 2020 with the United States, Panama, and Ecuador to share best practices on the verification Body and National Accreditation Body scheme. This was of great value to the national team.

Participation In CORSIA

The Dominican Republic communicated in 2018 that it was voluntarily participating in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), with the aim of continuing the efforts it had been making in terms of protecting the aviation environment. By July 2019, it modified the regulatory framework through the Dominican aeronautical regulations for the implementation of CORSIA.

In March 2020, the CORSIA MRV COURSE was given at the Superior Academy of Aeronautical Sciences (ASCA), where it was attended by national verification entities,



FIGURE 4: CORSIA MRV Course at the Superior Academy of Aeronautical Sciences (ASCA), March 2020

¹ <https://www.idac.gob.do/plan-estrategico-institucional-2021-2024/>



FIGURE 5: Virtual meeting CORSIA capacity building for CO₂ mitigation from international aviation - Africa and Caribbean, April 2021.

I. CORSIA² Capacity Building For CO₂ Mitigation From International Aviation Africa and Caribbean

The Dominican Republic is one of the 45 States that is participating in the capacity building project for the implementation of CORSIA that commenced in 2021. This Project is linked to the Working Group (DRWG) No. 7 of the action plan.

Training was given through virtual seminars to government institutions such as national accreditation bodies, verification bodies, air operators, environment and climate change agencies.

II. Airport Improvements³

The Airports Council International (ACI) granted the Cibao International Airport (AIC), and the six airports managed by Aeropuertos Dominicanos Siglo XXI (AERODOM), the accreditation in the Optimization and Reduction Levels respectively of the Airport Carbon Accreditation (ACA) Program. This included the standard implemented for the reduction of carbon emissions. The strategy is to be able to obtain Level 3+ (Neutrality) until 2024 where 6 international airports are accredited and a domestic aerodrome.



FIGURE 6: Map of solar panels in the airports of the Dominican Republic



FIGURE 7: Inauguration of electric chargers for vehicles in the Norge Botello aeronautical complex

The mitigation measures implemented include the use of renewable energy sources through solar panels, implementation of chargers for electric vehicles, and other measures such as waste management. It represents an estimated reduction of 9,594 tons of CO₂ per year.

III. Creation of the National MRV

Through decree 541-20 issued on October 9, 2020, the President of the Dominican Republic, Luis Abinader, created the national system for measuring, reporting and verifying greenhouse gases in the Dominican Republic (MRV). This system includes the objective of accounting for greenhouse gas emissions and executing mitigation actions aimed at promoting climate actions.

² <https://www.eu-corsia-af-c.org/>

³ <https://www.airportcarbonaccreditation.org/participants/latin-america-caribbean.html>



FIGURE 8: Launch of the 4th edition of the action plan accompanied by Héctor Porcella Deputy General Director of IDAC, Miguel Mejía, Director of Sustainable Development, Román Caamaño Director of IDAC, Max Puig President of the Council of Climate Change and Clean Development Mechanism, Mónica Infante General of Aeropuertos Dominicanos Siglo XXI, SA (Aerodom).

The ICAO/European Union (EU) project that concluded in 2018, allowed the establishment of a CO₂ emissions monitoring system, through the Aviation Environmental System Software (AES), which has contributed to the generation of reports of CO₂ emissions resulting from aviation.

Lessons Learned

We understand that the implementation of the capacity building project sponsored by the ICAO-EU from 2015 to 2018, was of great benefit to the Dominican Republic. It developed the important capacity within the working groups, despite the change in government and the pandemic of the COVID-19. As a result, mitigation measures have been maintained through their implementation.

We can point out:

- Cooperation agreements between States are an excellent tool for capacity development, because they can share the barriers that may arise for the implementation of measures and options as implemented by other States;
- The creation of working groups contributes to public-private partnerships that make it possible to achieve the implementation of mitigation measures;

- Capacity building and assistance programs are key to successful implementation in developing countries, such as:

- Project of the International Civil Aviation Organization (ICAO) and the European Union (EU) On Capacity Building For Mitigation Of CO₂ Emissions Resulting From International Aviation;
- ACT-CORSIA; and,
- CORSIA Capacity Building for CO₂ Mitigation from International Aviation Africa and Caribbean.

The Next Three Years

The Dominican Republic will face great challenges in the next 3 years. As such, these challenges have been implemented in the State Action Plan. The most relevant include:

- Capacity building on CORSIA, carbon market financing, offsetting, carbon neutrality projects;
- Technical and economic assistance to implement a pilot project for alternative fuels for medium plane aviation.

Ukraine's initiatives to reduce the environmental impact of aviation

By Iryna Kustovska (Ukraine)

Aviation noise pollution

Aviation noise is considered to be one of the most damaging factors for people living and working in the airport area and directly in the area of residential development located near the airport. The State Aviation Administration of Ukraine has developed regulation for establishing the principles of air noise management in airports - "Requirements to the aerodrome operator in terms of space zoning the territory around the airport under the conditions of aviation noise impact" (order of the State Aviation Administration of Ukraine № 381 adopted on March 26, 2019), which is based on the principles of the Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise.

According to the above-mentioned Regulation, the results of aviation noise measurements should be periodically published on the official websites of the airport (aerodrome). Aircraft noise contours are an informational basis for summarizing statistical information about the characteristics of aircraft noise at the airport (aerodrome) and in the area around it. At the same time, it is a tool for informing people, state and local authorities about the noise characteristics. Clarification of the actual zones experiencing permanent aircraft noise near the airport (aerodrome) is important to consider while arranging the prospects of development of the residential areas.

To make data on noise contours more accessible and understandable, the State Aviation Administration of Ukraine developed an online system for collecting information about

noise from the aviation infrastructure (using geospatial information) with a visualization (interactive map of Ukraine) – NOMOS¹ (Noise monitoring system).

This is an interactive tool to inform users about the level of air traffic noise near Ukrainian airports and about the conditions and restrictions of construction near the airport area with regard to the impact of air traffic noise. The NOMOS project was implemented by the State Aviation Administration of Ukraine with the support of the "Advisory Fund for EU Association of Ukraine" and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit).

The NOMOS portal displays:

- equivalent and maximum noise levels for each airport, measured over different time periods (day, night, 24 hours, week, month, etc.);
- noise contour for different time period (day, night).

Currently, the portal includes information about noise contours from 10 Ukrainian airports: Lviv, Kyiv Antonov, Odessa, Dnipro, Mykolaiv, Boryspil, Zaporizhzhia, Sumy, Poltava and Kharkiv.

Energy Efficiency

Two Ukrainian airports have already been certified under the ISO 14001 system: Boryspil International Airport and Mykolaiv International Airport. Other airports are actively implementing environmental management systems that can reduce costs, increase efficiency and

¹ <https://nomos.avia.gov.ua/>

lower the anthropogenic impact on the environment. As a result, the environmental information became publicly available. In particular, information about the environmental intentions of companies to reduce the negative impact on the environment became accessible to the public on the websites of airports.

State Aviation Administration of Ukraine with the support of the “Advisory Fund for EU Association of Ukraine” and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) has developed the “Fly Green” training course (MOOC), with free access to everyone. This course contributes to the implementation of the sustainable development, particularly in the field of energy efficiency. It contains structured material of environmental management, especially regarding ISO environmental management, green mobility, adaptation to climatic changes, use of clean energy, energy efficiency, review of financial instruments, as well as practical guidelines for the implementation of “green” technology with a description of the benefits of implementation by the world’s leading airports.

The course:

- Provides practical tools for the implementation of “green” technologies in airports, understanding how to reduce the negative impact of airports on the environment, as well as recommendations for the management of financial and natural resources;
- Provides practical information from the experts and engineers of several Ukrainian airports: Boryspil, Lviv, Mykolaiv, Odessa, Zaporizhzhia;
- Is designed for a wide range of stakeholders who want to make the operation of the airports as eco-friendly as possible;
- After the training each participant receives a certificate.

The educational course “Fly Green: The Path to Greening the Aviation” is available on the State Diia.Digital Education portal².

The improvement of energy efficiency will remain our main strategy for the reduction of emissions from civil aviation. Increased awareness, strengthened regulation, capacity building will help Ukraine to achieve these goals.

Emission reduction

In the framework of CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), State Aviation Administration of Ukraine has developed the Regulation № 1001 “Technical requirements and administrative procedures for monitoring emissions by operators of civil aircrafts” which allowed to start the process of monitoring, reporting and verification of CO₂ emissions.

Currently, 8 Ukrainian operators are monitoring and verifying CO₂ emission. They annually submit to the State aviation Administration of Ukraine consolidated State Reports on emissions.

The next step should be the implementation of the rest building blocks of market-based scheme of emission reduction, particularly CO₂ offsets related to international flights and emission reductions using CORSIA eligible fuels.

Another method of developing a long-term climate change strategy for the international aviation sector is the National Action Plan for reducing aviation CO₂ emissions (Action Plan). It allows to show the specific voluntary actions that Ukraine intends to take to reduce CO₂ emissions and to contribute to the goals set by the ICAO (International Civil Aviation Organization) Assembly.

With this in mind, the State Aviation Administration of Ukraine in 2012 developed the Plan with the involvement of all stakeholders and included the following measures:

- Development of technologies associated with aviation manufacturing;
- Use of alternative fuels;
- Improvement of the operating efficiency;
- Economical / market measures (CORSIA).
- Others.

The goal of the Ukrainian action plan is to calculate and forecast emissions of CO₂ and to take appropriate measures to reduce and prevent pollution, in particular to optimize and improve the management of air traffic and infrastructure.

In 2021, the State Aviation Administration of Ukraine updated the Plan.

² <https://osvita.diia.gov.ua/courses/flygreen>

ICAO Assistance Project with the European Union Funding Phase II

Capacity Building for CO₂ Mitigation from International Aviation

By Magnus Gislev (EU) and ICAO Secretariat

Introduction

With the goal of assisting States in their efforts to mitigate CO₂ emissions from international aviation, and to ensure that all States have the capacity required to develop States Action Plans and implement their mitigation measures, ICAO launched in 2013 the first phase of the Assistance Project Capacity Building for CO₂ Mitigation from International Aviation, in partnership with the European Union (EU). The project successfully supported 14 States in Africa and the Caribbean, and met all its expected results, exceeding some of the initial targets by its completion in 2019. A full description of the project and the final project report can be accessed on the ICAO's website.¹

Building on this successful partnership, ICAO and the EU initiated the Second Phase of the ICAO Project-Capacity Building for CO₂ Mitigation from International Aviation-Development of ICAO States' Action Plans for 10 States. Funded by the European Union under the Development Cooperation Instrument (DCI), and subject to the provisions of the Financial and Administrative Framework Agreement (FAFA) between the EU and the United Nations, the second phase has a total cost of EUR 1.5 million. Ten beneficiary States, which include five from the WACAF (Benin, Cabo Verde Cote d'Ivoire Mali, Senegal) and five from the ESAF

(Botswana, Madagascar, Rwanda, Seychelles and Zimbabwe) Region are supported under this project as part of the ICAO's No Country Left Behind initiative. The project, which started on 1 January 2020, had an initial duration of 36 months. However, due to Covid-19, ICAO and the EU agreed on a no-cost extension of 10 months, with an end date of October 31, 2023².

How does the Project contribute to the reduction of the environmental footprint of aviation?

The overall objective of the ICAO Assistance Project with the European Union Funding Phase II is to contribute to the mitigation of CO₂ emissions from international civil aviation in the selected States by implementing capacity building activities that will support the development of low carbon air transport and environmental sustainability.

This overall objective is to support the following specific objectives:

- Improved national capacity of the beneficiary States to develop/update and implement an Action Plan on CO₂ emissions reduction from international aviation in accordance with ICAO recommendations (SO1);

1 ICAO Assistance Project with the EU Funding Phase I. https://www.icao.int/environmental-protection/Pages/ICAO_EU.aspx
Project Phase I Final Report. https://www.icao.int/environmental-protection/Documents/ICAO-EU_Project_FinalReport.pdf

2 ICAO Assistance Project with the EU Funding Phase II. https://www.icao.int/environmental-protection/Pages/ICAO_EU_II.aspx

- State Action Plans on emissions reduction are developed by the beneficiary States (SO2);
- Mitigation measures selected by the beneficiary States are assessed and their feasibility is evaluated (SO3).
- To achieve the objectives, the project centers around the following expected results:
- (R1): National Action Plan Teams (NAPT) are established in the beneficiary States with the participation of relevant stakeholders from the aviation sector.
- (R2): At least 2 members of staff in the aviation sector or related authority trained to develop and implement Action Plans in each selected State.
- (R3): State Action Plans on emissions reductions developed by beneficiary States fully complying with ICAO Guidance on the Development of States' Action Plans on CO₂ Emissions Reduction Activities (Doc 9988).
- (R4): An Aviation Environmental System (AES) installed in the selected Member States for collection of historical data for the preparation of the baseline scenario and expected results.
- (R5): A total of three feasibility studies on the implementation of selected mitigation measures are conducted in certain selected beneficiary States.

The implementation of the Action is undertaken through several activities including the following:

- Creation of National Action Plan Teams
- Capacity building meetings
- On-site missions
- Regional Seminars
- Briefings to Directors General of the Beneficiary States
- Feasibility studies.
- Installation of the Aviation Environmental System (AES)
- UNITAR online training course for Focal Points

The UNITAR Online Training Course: A successful tool for capacity building on Action Plan Development

Developed under the first phase of the ICAO Assistance Project with the EU funding phase II, the ICAO training course *International Aviation CO₂ Emissions Reduction : States' Action Plans*³ hosted on the United Nations Institute for Training and Research (UNITAR) / UNCC: e-Learn platform allows all Focal Points of the beneficiary States to access the most up-to-date training on Action Plan development. The first module of the course is accessible free of charge to all users whereas States' Focal Points have access to the full course. This self-paced course offers the flexibility to Focal Points to get the training on their own schedules and complements the in-person activities undertaken in the scope of the project.

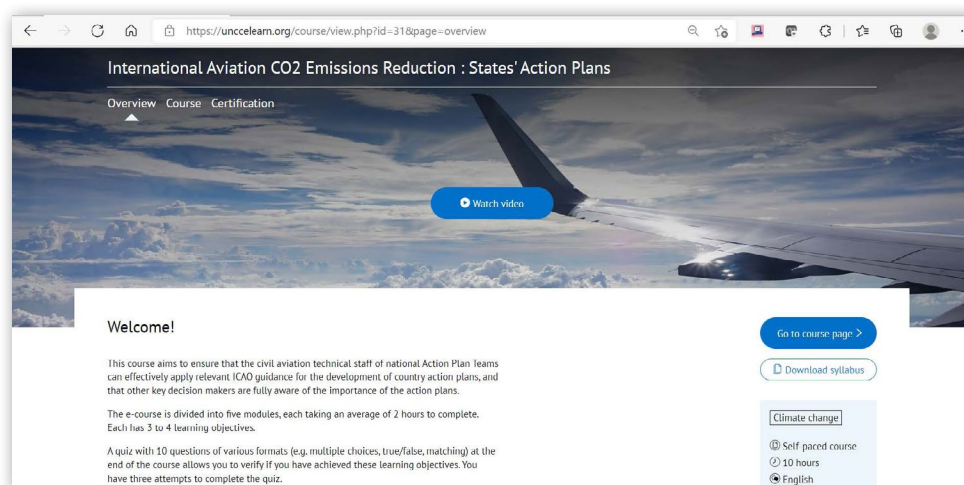


FIGURE 1: Training course: International Aviation CO₂ Emissions Reduction: States' Action Plans

3 Available at <https://uncclearn.org/course/view.php?id=26&page=overview>

What are the associated quantitative/qualitative benefits?

Participation in this Project comes with several benefits and co-benefits for the beneficiary States. Through the Project, participating States strengthen their local capacity for State Action Plan development. States are further supported for the selection and quantification of their mitigation measures to reduce CO₂ emissions. Feasibility studies are also conducted in a few States to assess the potential for Sustainable Aviation Fuels and other innovative measures for the sustainability of international aviation. The Aviation Environmental System is installed in all beneficiary States to monitor the implementation of the mitigation measures in the Action Plans.

The Next Years

The second Phase of the ICAO Assistance Project with the EU Funding will conclude in October 2023. In light of the success of both phases of the Project, several States have expressed their interests in benefiting from similar capacity building assistance to mitigate CO₂ emissions from international aviation.



FIGURE 2: Certificate of Completion: International Aviation CO₂ Emissions Reduction: States' Action Plans

ACT-CORSIA Programme: Capacity-Building and Assistance to States in Times of the Pandemic

By ICAO Secretariat

Introduction

From its initial launch in July 2018, the ICAO ACT-CORSIA (Assistance, Capacity-building and Training for Carbon Offsetting and Reduction Scheme for International Aviation) Programme has been the cornerstone of ICAO and its Member States' continuous commitment to capacity building vis-à-vis the implementation of Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The importance of taking all necessary actions in providing capacity building activities by ICAO and its Member States, through the Programme's coordinated approach under the umbrella of ICAO, was particularly highlighted at the 40th session of the ICAO Assembly in 2019.

Despite the challenges posed from the global COVID-19 pandemic, in particular to the international aviation sector, significant progress and adjustments to cater to the challenges of the pandemic have been made on various elements of the Programme, in particular on the ACT-CORSIA Buddy Partnerships, Frequently Asked Questions, brochures and leaflets, videos, CORSIA seminars' and workshops' materials and recordings, and online tutorials.

A complete list of information about the Programme and progress made is available on the ICAO CORSIA public website¹.

Progress made on the ACT-CORSIA Buddy Partnerships

At the center of the ACT-CORSIA Programme is the Buddy Partnerships, where bilateral or multilateral partnerships among the ICAO Member States are formed in the coordination with the ICAO Secretariat. Through these partnerships, Member States help each other to prepare for CORSIA implementation, with 'supporting States' providing CORSIA technical experts to work together with the CORSIA focal points of 'requesting States' (hence, Buddies) on the preparation and implementation of the requesting States' CORSIA CO₂ Monitoring, Reporting and Verification (MRV) system, in a coordinated yet tailored manner to the needs of the requesting States. Typically, the assistance is in the form of on-site training delivered by the CORSIA-technical experts of supporting States, and additional follow-ups with the requesting States as needed, in close coordination with the ICAO Secretariat.

Building on the successful implementation of Phase 1 and Phase 2 of the Buddy Partnership, which focused on the preparation of Emissions Monitoring Plans and CORSIA regulatory framework, and the reporting and verification of CORSIA baseline year emissions, the Phase 3 of the Buddy Partnerships was launched at the beginning of 2020. The focus of Phase 3 was supporting the State's readiness to proceed with reporting to ICAO aggregated 2019 CO₂ emissions and other relevant information through

1 ICAO CORSIA website – <https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx>

the CORSIA Central Registry (CCR), as 2020 was the very first year for States to report such data to ICAO.

However, shortly after the initiation of the Phase 3, the challenges posed by the global COVID-19 pandemic required rapid adjustment of the Buddy Partnerships from on-site training, to virtual remote training to cater to various mobility restrictions. States nonetheless strove to continue the Buddy Partnerships bearing in mind of the challenges, in particular, in view of the relevant deadlines in Annex 16, Volume IV, Appendix 1 and ICAO Council's decision to allow more flexibility to accommodate Member States facing difficulty in meeting the deadlines.

ACT >>> CORSIA Phase III Assistance, Capacity-building and Training on CORSIA	
AUSTRALIA 1. BRUNEI DARUSSALAM 2. INDONESIA 3. NAURU 4. PAPUA NEW GUINEA 5. SRI LANKA 6. THAILAND	KENYA 1. RWANDA 2. SEYCHELLES 3. SOUTH SUDAN 4. UGANDA
BRAZIL 1. ANGOLA 2. CABO VERDE 3. MOZAMBIQUE 4. SAO TOME AND PRINCIPE	NEW ZEALAND 1. FIJI 2. SAMOA 3. SOLOMON ISLANDS 4. VANUATU
CANADA (Facilitated by CASSOS) 1. ANTIGUA AND BARBUDA 2. BARBADOS 3. GUYANA 4. HAITI 5. JAMAICA 6. SURINAME 7. TRINIDAD AND TOBAGO	NIGERIA 1. GAMBIA 2. GHANA 3. LIBERIA 4. SIERRA LEONE 5. SUDAN
CANADA / FRANCE 1. BENIN 2. BURKINA FASO 3. BURUNDI 4. CAMEROON 5. CENTRAL AFRICAN REPUBLIC 6. CHAD 7. COMOROS 8. CONGO 9. DJIBOUTI 10. D. R. OF CONGO 11. GABON 12. GUINEA 13. MADAGASCAR 14. MALI 15. MAURITANIA 16. MAURITIUS 17. NIGER 18. SENEGAL 19. TOGO	REPUBLIC OF KOREA 1. LAO PEOPLE'S D. R. 2. MONGOLIA 3. PAKISTAN 4. PHILIPPINES 5. VIETNAM
FRANCE (* Facilitated by ACAO) 1. ALGERIA * 2. COTE D'IVOIRE 3. MOROCCO * 4. SAUDI ARABIA * 5. TUNISIA *	QATAR 1. BARBAIN 2. IRAN 3. IRAQ 4. KUWAIT 5. LIBYA 6. OMAN
GERMANY 1. ALBANIA 2. ARMENIA 3. AZERBAIJAN 4. BELARUS 5. GEORGIA 6. KAZAKHSTAN 7. NORTH MACEDONIA 8. REPUBLIC OF MOLDOVA 9. SERBIA 10. TAJIKISTAN 11. TURKMENISTAN	SINGAPORE 1. COOK ISLANDS 2. KIRIBATI 3. MARSHALL ISLANDS 4. PALAU 5. TONGA 6. TUVALU
ITALY 1. BAHAMAS 2. COLOMBIA 3. ERITREA 4. ETHIOPIA 5. PARAGUAY 6. SOMALIA 7. UNITED REPUBLIC OF TANZANIA	SOUTH AFRICA 1. BOTSWANA 2. ESUATINI 3. LESOTHO 4. MALAWI 5. NAMIBIA 6. ZAMBIA 7. ZIMBABWE
JAPAN 1. AFGHANISTAN 2. BANGLADESH 3. BHUTAN 4. CAMBODIA 5. MALAYSIA 6. MYANMAR	SPAIN (* Facilitated by COCESNA) 1. BELIZE * 2. BOLIVIA 3. COSTA RICA * 4. CUBA 5. EL SALVADOR * 6. EQUATORIAL GUINEA 7. GUATEMALA * 8. HONDURAS * 9. MEXICO 10. NICARAGUA * 11. PERU 12. URUGUAY
	USA 1. ARGENTINA 2. DOMINICAN REPUBLIC 3. ECUADOR 4. PANAMA
16 SUPPORTING STATES 118 REQUESTING STATES	

FIGURE 1: List of Member States participating in the Phase 3 of Buddy Partnerships

Such efforts were well received by the Member States, as exemplified by the increase in the number of Member States' participating in the Buddy Partnerships, from 113 States (15 supporting States and 98 requesting States) at the start of the Buddy Partnerships to 134 States (16 supporting States and 118 requesting States) in Phase 3 (as of March 2022). Furthermore, the training provided has contributed to the high level of CORSIA implementation globally, as demonstrated by the fact that 97% of total CO₂ emissions for 2019 and 2020 were submitted to ICAO through the CCR.

Phase 3 of the Buddy Partnerships has progressed further in 2022, with additional material and information covered to consider differing reporting requirements reflected in Annex 16, Volume IV for the baseline years (2019 and 2020) and the pilot phase of the CORSIA (2021-2023).

The list of Member States participating in the Phase 3 of the Buddy Partnerships are available on Figure 1, and further information on Buddy Partnerships can be found on the ACT-CORSIA Buddy Partnership webpage².

Seminars, Workshops, and Training

With the spread of COVID-19 and the associated mobility restrictions, it became difficult for ICAO to support its Member States in conventional, face-to-face settings. Hence, a number of web-based capacity building events and activities has been organized by the ICAO Secretariat. in particular:

- In April 2020, five online pre-Seminar training³ for all ICAO regions were conducted to help CORSIA Focal Points of each Member States familiarize themselves with the main functionalities of the CCR and, in particular, on the ways to report 2019 CO₂ emissions by the deadlines contained in the Annex 16, Volume IV. The training was conducted prior to the official launch of the CCR in June 2020, to allow smooth operationalization and use of the CCR. The trainings on the CCR were also complemented by the initiation of the Phase 3 of the ACT-CORSIA Buddy Partnerships.

² ACT-CORSIA Buddy Partnership webpage - <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Buddy-Partnerships.aspx>

³ 2020 Pre-Seminar Remote Training on the CCR - <https://www.icao.int/environmental-protection/CORSIA/Pages/VRS2020.aspx>

- Mobility restrictions caused by the COVID-19 pandemic brought about some concerns from Member States and aeroplane operators in terms of their requirements for third-party verification under CORSIA. Particularly, aeroplane operators in some Member States were having difficulty with the verification of their Emissions Report as the site visits were not feasible due to travel restrictions, and social distancing measures imposed in several Member States. To address the concerns, an online verification webinar⁴ was conducted in May 2020 and clarified relevant provisions of CORSIA SARPs (Standards and Recommended Practices) and guidance, in particular with respect to site visits. In this regard, the webinar was conducted to shed light on the CORSIA guidance material stating that while site visits are recommended, it is not a requirement under the CORSIA SARPs. The webinar also provided an opportunity for Member States to receive answers to their questions on verification under CORSIA.
- The 2021 CORSIA Forum⁵ was held as a virtual and open event, from 6 to 7 October 2021, with an overview of the “state of play” in CORSIA implementation, focusing on milestones successfully reached thus far. It served as a platform for several ICAO Member States, in particular those actively participating in the ACT-CORSIA Buddy Partnerships, to share success stories and lessons learned regarding CORSIA implementation.

The event also provided information on the process and progress made regarding the 2022 CORSIA periodic review that the ICAO Council embarked on as requested by the ICAO Assembly, along with the analysis of the impact of COVID-19 on CORSIA and recovery scenarios.

Navigating CORSIA on ICAO TV

Benefiting from the launch of ICAO TV in 2020 – the video hosting platform of ICAO that streams live and on-demand videos from ICAO and civil aviation partners – the Secretariat unveiled “Navigating CORSIA – a guide to the scheme’s design and implementation”⁶ in November 2020. It includes a package of videos on CORSIA, prepared for an audience interested in CORSIA, but not fully conversant with the scheme’s design and implementation features. The available videos are as follows:

- Introduction to Navigating CORSIA
- CORSIA Overview
- CORSIA’s Monitoring, Reporting, and Verification system and related tools
- CORSIA Eligible Fuels
- CORSIA Eligible Emissions Units

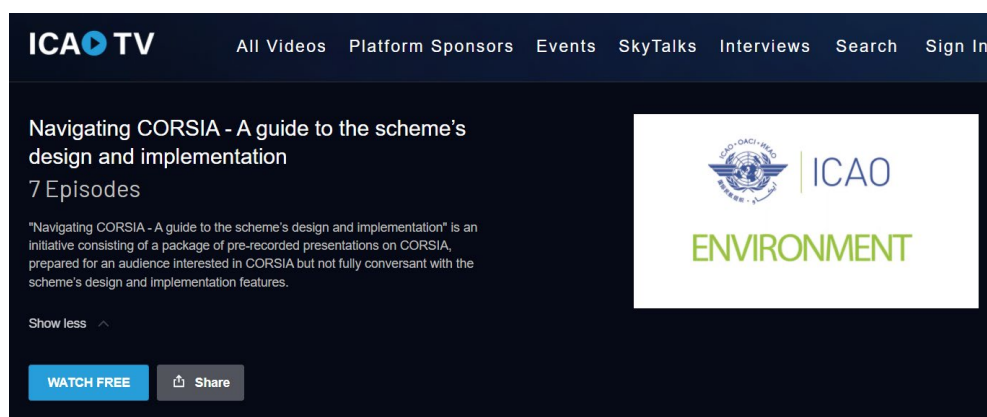


FIGURE 2: Frontpage of Navigating CORSIA video on ICAO TV

4 ICAO Webinar on CORSIA verification - <https://www.icao.int/environmental-protection/CORSIA/Pages/2020VERCORSIA.aspx>

5 2021 ICAO CORSIA Forum - <https://www.icao.int/Meetings/CORSIA-Forum/Pages/default.aspx>

6 Navigating CORSIA on ICAO TV - <https://www.icao.tv/navigating-corsia>



FIGURE 3: Main webpage of CORSIA Verification course

Launch of CORSIA Verification Course

In May 2020, ICAO launched an online version of the CORSIA Verification Course⁷ to continue to support training of potential verifiers and other CORSIA stakeholders (particularly, those with experience in the verification of CO₂ emissions using ISO 14064-3:2006) on the relevant provisions of CORSIA third-party verification. The four-day long virtual course provides a full explanation of the CORSIA monitoring, reporting, and verification (MRV) requirements, with practical exercises and case studies focused on the verification of CO₂ Emissions Reports that have been prepared by aeroplane operators.

CORSIA Newsletter

The CORSIA Newsletter was launched in early September 2020, as a monthly outreach publication with a view to continuously inform Member States and the wider public on the status of CORSIA implementation. Since the launch, it has become a major medium and a most valued outreach material on CORSIA, where a snapshot of all progress made on CORSIA implementation in the preceding month is showcased, amongst others: information on the evolution of the CO₂ emissions reported by States through the CCR; new publications and updates of ICAO Documents and tools necessary for CORSIA implementation; progress made on the 2022 CORSIA Periodic Review; and, upcoming

events and implementation deadlines. The newsletter also provides a periodic update on carbon market transactions data of CORSIA-eligible emissions units, thanks to a new partnership between ICAO and Ecosystem Marketplace.

All past newsletters are published and archived on the CORSIA Newsletter website⁸.

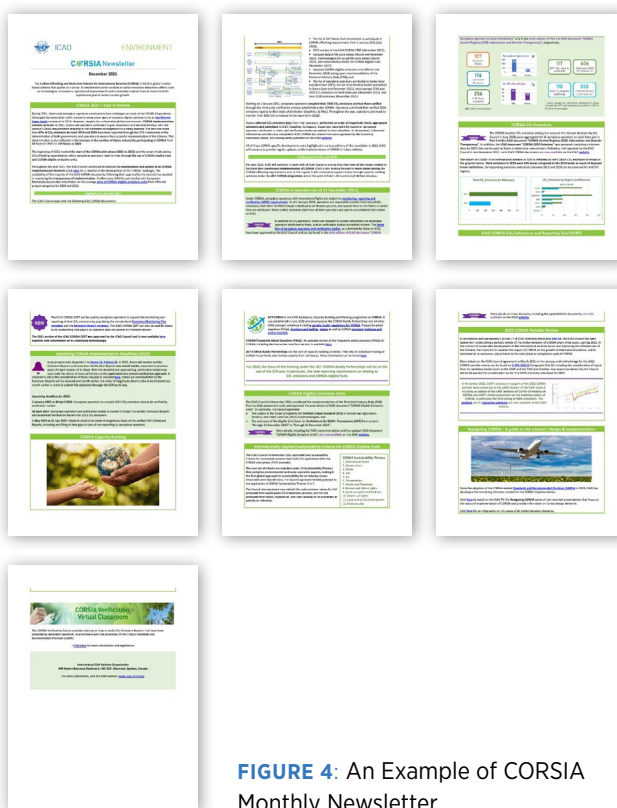


FIGURE 4: An Example of CORSIA Monthly Newsletter

⁷ <https://www.icao.int/training/Pages/CORSIA.aspx>

⁸ CORSIA Monthly Newsletter - <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIANEWSLETTERS.aspx>

ICAO ACT-SAF Programme: Supporting States to realise their SAF potential

By ICAO Secretariat

Introduction

The importance of Sustainable Aviation Fuels (SAF) to the sustainable future of aviation is critical. Over the past decade, the aviation sector has experienced an exponential increase in SAF production facilities, advancements in production pathways, as well as airports regularly supplying SAF. The SAF market developments, such as airline-producer offtake agreements, buyers' alliances, novel book and claim accounting frameworks, have also facilitated increased access to SAF. In addition, many International Civil Aviation Organization (ICAO) Member States are now looking towards policy support, in various forms - such as mandates and subsidies - to stimulate greater SAF demand.

During the ICAO Committee on Aviation Environmental Protection (CAEP) twelfth meeting (ICAO CAEP/12), held in February 2022, ICAO CAEP Members unanimously adopted the technical report on the feasibility of a long-term global aspirational goal for international aviation (LTAG). The LTAG report is now available to the public on the ICAO website¹. The report foresees the largest CO₂ reductions by 2050 coming from fuels and cleaner energy sources, vis-à-vis aircraft technologies and operational improvements.

Recognising the importance of SAF in the decarbonisation of the aviation sector, ICAO launched the Assistance, Capacity-building and Training for SAF (ICAO ACT-SAF) on 1 June 2022. This article explains ACT-SAF in further detail, and its next steps moving forward.



FIGURE 1: ICAO ACT-SAF

What is ICAO ACT-SAF

ACT-SAF is an initiative aimed at facilitating States' development and deployment of sustainable fuels. As there will not be a 'one size fits all' approach, ACT-SAF will incorporate tailored support for ICAO Member States, which may comprise feasibility studies, policy and regulatory developments, and specific SAF implementation projects. ACT-SAF will also provide a targeted platform to encourage knowledge sharing and recognition of all SAF initiatives.

Under the umbrella of ICAO coordination, ACT-SAF will facilitate partnerships and cooperation on multiple SAF initiatives, which may include bilateral/multilateral agreements between ICAO Member States and various stakeholders (industry, international organisations, financial institutions).

¹ <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx>

Why the need for ACT-SAF?

ACT-SAF builds on the existing ICAO ACT-CORSIA experience, further providing opportunities for partnership and cooperation. With the LTAG Report foreseeing the largest CO₂ reductions coming from fuels and cleaner energy sources, there is a need for immediate concerted action to fully realise these SAF potentials, especially in ICAO Member States or regions that have little to no experience or knowledge in SAF.

ICAO ACT-SAF will therefore provide opportunities for ICAO Member States to develop their full potential in SAF development and deployment. This is aligned with the ICAO's *No Country Left Behind* initiative, the 2050 ICAO Vision for SAF, and the three main pillars of sustainable development recognised by the United Nations.

As more ICAO Member States and partners get involved in the Programme, ACT-SAF is expected to create positive ripple effects globally and help unlock feedstock potentials for SAF markets over the coming decades. ICAO Member States and partners may also work together in addressing the challenges associated with SAF adoption, such as sustainability of the fuel, affordability and pricing issues, as well as diversification of feedstock, stakeholders and access to cleaner energy supporting sustainable aviation.

The 41st Session of the ICAO Assembly, which will be held 27 September – 7 October 2022, provides an opportunity for a decision on a long-term global aspirational goal for international aviation (LTAG). The increased ambition on sustainable aviation would allow ICAO to explore extending the existing model used in ACT-SAF, galvanise support and implement similar programmes for additional aspects contributing to aviation CO₂ reductions (aircraft technologies and operational improvements).

Current progress of ACT-SAF, and next steps

As of June 2022, ICAO has since invited all ICAO Member States to join ACT-SAF and is in the process of engaging other stakeholders (financial institutions, educational/research institutions, industry) on their participation, recognising the critical role they will play in scaling up ICAO Member States' SAF capabilities.

Following which, under ICAO's coordination, it will identify, match, and set up specific SAF implementation projects, tailored to the States' needs. Further details on ACT-SAF will be regularly updated on the ICAO ACT-SAF website².

² <https://www.icao.int/environmental-protection/Pages/act-saf.aspx>



| ICAO

CHAPTER TWELVE

Multistakeholder Cooperation

ICAO's Cooperation with UN Bodies and International Organizations

By ICAO Secretariat

Introduction

Cooperation is one of ICAO's main hallmarks and is ingrained in the organization's core daily activities to achieve its vision of safe, secure and environmentally sustainable development of international civil aviation. The Preamble to the Convention on International Civil Aviation¹ itself, which was established in 1944 and sets forth the purpose of ICAO, underlines the need to promote "co-operation between nations and peoples, upon which the peace of the world depends".

The importance of cooperation is reaffirmed in the ICAO Assembly Resolution on environment, which mandates the ICAO Council to continue to cooperate closely with international organizations and other United Nations system. The main purpose of maintaining this cooperation is to ensure that ICAO continues to:

1. Take the leadership role in the international community on all environment-related matters related to international aviation;
2. Obtain a better technical and scientific understanding of aviation's impact on the environment through exchange of views and information;
3. Build synergies for policymaking in the field of aviation and the environment; and,

4. Steer the development and implementation of measures to limit or reduce aviation's adverse impacts on the environment, with a view to ensuring a sustainable future for international aviation. To achieve the environmental objectives of international aviation, all key stakeholders need to be actively engaged in cooperation under the auspices of ICAO.

ICAO cooperates with more than 50 entities from the UN family, the aviation industry network, and civil society, providing inputs on all matters related to international aviation.

United Nations Framework Convention on Climate Change (UNFCCC)

In 1992, the international community agreed on a framework for addressing global warming through the adoption of the United Nations Framework Convention on Climate Change (UNFCCC)². The objective of the Convention is to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system".

The Paris Agreement³, adopted at the Paris climate conference (COP21) in December 2015, builds upon the Convention and brings all nations into a common cause to

¹ <https://www.icao.int/publications/pages/doc7300.aspx>

² <https://unfccc.int/>

³ <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>

undertake ambitious efforts to combat climate change and adapt to its effects. The Paris Agreement charted a new course in the global climate efforts, previously undertaken within the framework of the Kyoto Protocol⁴ to the UNFCCC adopted in December 1997. The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

While emissions from international aviation and maritime sectors are not included as part of the Nationally Determined Contributions (NDCs) under the Paris Agreement, these are separately addressed by ICAO and the International Maritime Organization, respectively, to complement the achievement of the Paris Agreement goals. Emissions from domestic aviation can be addressed by the Parties to the UNFCCC through their NDCs, as part of their efforts to reduce greenhouse gas emissions from all domestic sources.

ICAO regularly provides the UNFCCC conferences with regular statements, submissions⁵, and side events⁶, on recent ICAO developments related to international aviation and climate change⁷.

In the spirit of cooperation between the two organizations, ICAO Secretariat maintains a close relationship with the UNFCCC Secretariat, by following the development of the UNFCCC discussions, and by regularly providing information and perspectives on issues related to international aviation and on those matters considered by the various UNFCCC deliberative bodies that may have an impact on the international aviation sector. For example, the relationship between CORSIA and the approaches/mechanism being discussion under Article 6 of the Paris Agreement is important to be followed-up.

2021 COP26 Glasgow Conference

At the recent 2021 UNFCCC COP26 in Glasgow, United Kingdom, following intense negotiations among Parties, the conference adopted a series of decisions, including the agreement on Article 6 of the Paris Agreement. The Article 6 decisions clearly recognized the possible use of internationally transferable mitigation outcomes (ITMOs) for other international mitigation purposes (such as for CORSIA), together with the need for corresponding adjustments by Parties to avoid double counting. Clarification was also given to the timing of transition of the Clean Development Mechanism (CDM) activities of the Kyoto Protocol to be registered as the activities under the Article 6.4 mechanism, as well as the decision to allow the use of CERs for activities registered from 2013 and in respect of emissions reductions by the end of 2020, towards the achievement of the first round of NDCs submitted by 2020.

The COP26 also reached overarching decisions, entitled “Glasgow Climate Pact”, including the resolution to pursue efforts to limit the temperature increase to 1.5 degree Celsius and, while noting with serious concern the current level of contributions of NDCs, requested the strengthening of emissions reduction targets in the NDCs and long-term low GHG emission development strategies, toward the achievement of the temperature goal.

ICAO will continue follow developments under the UNFCCC process, including the further operationalization of the COP26 decisions on the Article 6 and further guidance on corresponding adjustments to be considered at the COP27 conference in November 2022.

4 https://unfccc.int/kyoto_protocol

5 <https://www.icao.int/environmental-protection/Pages/statements.aspx>

6 ICAO outreach activities in recent UNFCCC COP26: <https://www.icao.int/environmental-protection/Pages/cop26.aspx>

7 <https://www.icao.int/environmental-protection/pages/climate-change.aspx>

Marrakech Partnership for Global Climate Action (MPGCA)

At COP22, the UNFCCC High-Level Champions⁸ launched the Marrakech Partnership for Global Climate Action (MPGCA)⁹ with the objective of strengthening collaboration between Parties and non-Party stakeholders to allow greater ambition in terms of mitigation and adaptation actions.

The MPGCA Transport Initiatives represent a broad range of multi-stakeholder coalitions expanding to cover for all transport modes (including freight, rail, bicycle, and other types of land transport), although most of them are not globally regulated by an international convention or a State driven process, such as for international civil aviation and shipping sectors.

Two initiatives on aviation are included in the Transport Thematic Group under the MPGCA¹⁰, which are the Aviation's Climate Action Takes Off initiative (by ICAO and the Air Transport Action Group (ATAG)) and the Airport Carbon Accreditation programme (by Airports Council International (ACI)).

Launched at COP 25, and updated ahead of COP26, the Climate Action Pathways¹¹, including one on the Transport thematic area, were developed by different coalitions and initiatives of the MPGCA to provide an overview of the transformational actions and milestones across the thematic and cross-cutting areas of the Partnership. The Pathways aim to provide a roadmap to help Parties and non-Party stakeholders alike to identify actions needed by 2021, 2025, 2030 and 2040 as steps to get to the 2050 vision, and ICAO cooperates with the MPGCA on the review of the Climate Action Pathways. As such, they are intended as living documents, to be updated periodically with the latest information and lessons learned as the state of climate action evolves.

UN Climate Action Summit

To boost ambition and accelerate actions to implement the Paris Agreement on Climate Change, UN Secretary-General António Guterres hosted the Climate Action Summit in 2019¹² in New York. The Summit aimed at showcasing a leap in collective national political ambition, and at demonstrating massive movements in the real economy in support of the climate change agenda. The Summit launched different initiatives in 12 thematic areas - including transport - providing the foundation for scaled-up action.

ICAO participated in the UN Climate Summit, as part of cooperation with other UN bodies, with the aim of maintaining ICAO's leadership role related to international aviation and climate change. At various events in conjunction with the Summit, ICAO highlighted its achievements in addressing international aviation CO₂ emissions, and the importance of partnerships among ICAO Member States, aviation industry and other stakeholders to accelerate the progress in the ICAO basket of measures to address international aviation CO₂ emissions, using the UN Climate Summit as a platform for the advancement of climate actions.

In this regard, ICAO launched the Global Coalition for Sustainable Aviation¹³ at the Summit. As part of the Coalition initiative, the ICAO aviation in-sector CO₂ emissions reduction initiatives tracker tool¹⁴ was also developed and has been updated to provide all information related to measures and initiatives to reduce the environmental footprint of aviation.

ICAO maintains a close cooperation with the Climate Action Summit Team in the UN Executive Office of the Secretary General (EOSG)¹⁵ based in New York, to follow up on the various initiatives announced during the Summit and on other climate change related issues.

8 <https://unfccc.int/climate-action/marrakech-partnership/actors/meet-the-champions>

9 <https://unfccc.int/climate-action/marrakech-partnership/background>

10 https://slocat.net/wp-content/uploads/2020/02/PPMC_2018_Overview-of-Global-Climate-Action-Transport-Initiatives.pdf

11 https://unfccc.int/climate-action/marrakech-partnership/reporting-and-tracking/climate_action_pathways

12 <https://www.un.org/en/climatechange/2019-climate-action-summit>

13 <https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx>

14 <https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx>

15 <https://www.un.org/sg/en/global-leadership/executive-office-of-the-secretary-general/all>

United Nations Department of Economic and Social Affairs (UN-DESA)

ICAO's long-standing cooperation with UN-DESA¹⁶ continues including the organizations of various UN system wide events: such as the Conference on Sustainable Development (Rio+20)¹⁷, and the Global Sustainable Transport Conference¹⁸. The second UN Global Sustainable Transport Conference was held in 2021, following the first Conference held in 2016 in Turkmenistan, and discussed a way forward for sustainable transport to help achieve the objectives of the 2030 Agenda for Sustainable Development. ICAO provided inputs to different sessions of the Conference on the themes of noise and local air quality, innovation, climate change and adaptation.

United Nations Environment Programme (UNEP)

As part of the UN system, ICAO, along with other UN agencies, funds and programmes, is an active member of the UN Environment Management Group (EMG)¹⁹, which was established in 2001 pursuant to a Resolution from the General Assembly, and chaired by the United Nations Environment Programme (UNEP)²⁰. The EMG identifies issues on the international environmental agenda that warrant cooperation and finds ways of engaging its collective capacity in coherent management responses to those issues. The EMG regularly reports on its work to the UN Chief Executive Board (CEB)²¹.

The EMG works through technical meetings: Issue Management Groups (IMGs)²² and task forces, to which representatives of intergovernmental bodies, civil society and international non-governmental organizations are invited to contribute. The IMGs cover areas of work related to various environmental topics, such as biodiversity, drylands, green economy, sound management of chemicals, e-waste, sand and dust storms, and others. Much of ICAO work, such as aspects related to Sustainable Aviation Fuels (SAFs), aircraft end-of-life and recycling, adaptation to climate change, is directly connected to these issues and widely benefits from an extended cooperation and consultation on these topics with UN system organizations.

Environmental Sustainability of UN System and ICAO Carbon Emissions Calculator

In addition, the EMG and IMG seek to advance the environmental sustainability management of UN internal operations. In 2019, the EMG endorsed the Strategy for sustainability management in the United Nations system, 2020 - 2030 (Phase I)²³, with a general sustainability vision as well as targets with related indicators for strengthening environmental sustainability in UN facilities and operations. In 2021, the Strategy for sustainability management in the United Nations system, 2020-2030 (Phase II)²⁴ was endorsed by the EMG, the UN High Level Committee on Programme (HLCP)²⁵, the UN High Level Committee on Management (HLCM)²⁶ and the UN Chief Executives Board (CEB), by encompassing a wider set of environmental and social sustainability considerations to be embedded in UN system policies, programming and support functions. The theme of environmental sustainability within the UN system was also addressed by the Joint Inspection Unit Report JIU/REP/2020/8²⁷.

16 <https://www.un.org/en/desa>

17 <https://www.icao.int/environmental-protection/Pages/Rio+20.aspx>

18 <https://www.un.org/en/conferences/transport2021>

19 <https://unemg.org/>

20 <https://www.unep.org/>

21 <https://unsceb.org/>

22 <https://unemg.org/our-work/>

23 <https://unsceb.org/strategy-sustainability-management-united-nations-system-2020-2030>

24 https://unemg.org/wp-content/uploads/2021/11/CEB.2021.2.Add_1-Sustainability-Strategy-Virtual-Endorsement.pdf

25 <https://unsceb.org/high-level-committee-programmes-hlcp>

26 <https://unsceb.org/high-level-committee-management-hlcm>

27 https://www.unjiu.org/sites/www.unjiu.org/files/jiu_rep_2020_8_english.pdf

ICAO has been actively involved in this work on the UN environmental sustainability management since 2008, when the ICAO Carbon Emissions Calculator²⁸ was officially adopted by the EMG as the official UN tool to calculate CO₂ emissions from air travel. Since then, GHG inventories of more than 50 UN organizations²⁹ have been compiled using the ICAO tool to estimate the air- travel related portion of the UN inventories.

Stockholm+50 and ICAO ACT-SAF programme

Recently in June 2022, UNEP organized Stockholm+50³⁰ in close consultation with the co-hosts Kenya and Sweden. The Stockholm+50 commemorated 50 years since the 1972 United Nations Conference on the Human Environment, which was the first global meeting that made environment a pressing global issue. The purpose of Stockholm+50 was to contribute to the environmental dimension of sustainable development, and to accelerate the implementation of action, including a sustainable recovery from the COVID-19 pandemic.

As an Associated Event of Stockholm+50, ICAO launched its Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF)³¹ on 1 June 2022, to showcase ICAO's achievements and further efforts for decarbonizing aviation. ACT-SAF will provide opportunities for States to develop their full potential in SAF development and deployment, in line with the ICAO's No Country Left Behind³² initiative, the 2050 ICAO Vision for SAF³³, and the three main pillars of sustainable development recognized by the United Nations. ACT-SAF will create positive ripple effects globally and help unlock feedstock potentials for SAF markets over the coming decades. It will also build upon the action already taken by ICAO on SAF, for example

leveraging the successes of the organization in setting global standards for the sustainability of aviation fuels.³⁴

Intergovernmental Panel on Climate Change (IPCC)

The ICAO's collaboration with the IPCC³⁵ started with the development of the IPCC Special Report on Aviation and the Global Atmosphere in 1999³⁶, which was the first sectoral report from IPCC providing consolidated information on the science on aviation's climate impact, briefing policymakers on the challenges ahead and highlighting key mitigation options.

ICAO also provided substantial input and actively supported the IPCC in the development of the Guidelines for National Greenhouse Gas (GHG) Inventories by providing the necessary expertise for the development and refinement of a methodology for the calculation of aviation emissions.

ICAO has also collaborated with the IPCC on the development of IPCC Assessment Reports on climate change, in particular the Fifth Assessment Report (AR5)³⁷, and continued this collaboration during the AR6³⁸ cycle. For example, ICAO provided input to the IPCC in order to ensure that issues related to aviation and climate change were covered in the AR6, including trends of aviation GHG emissions and the latest ICAO work on mitigation measures.

In this regard, the IPCC Working Group I report "AR6 Climate Change 2021: the Physical Science Basis"³⁹ approved by 195 member governments of the IPCC, is the first instalment of the IPCC's Sixth Assessment Report (AR6), completed in 2022. The report provides new estimates of the chances of crossing the global warming level of 1.5°C in the next decades, and finds that unless there are immediate, rapid

28 <https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx>

29 <https://www.greeningtheblue.org/reports/greening-blue-report-2021>

30 <https://www.stockholm50.global/>

31 <https://www.icao.int/environmental-protection/Pages/ACT-SAF.aspx>

32 <https://www.icao.int/about-icao/nclb/Pages/default.aspx>

33 <https://www.icao.int/environmental-protection/GFAAF/pages/ICAO-Vision.aspx>

34 <https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx>

35 <https://www.ipcc.ch/>

36 <https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/>

37 <https://www.ipcc.ch/assessment-report/ar5/>

38 <https://www.ipcc.ch/assessment-report/ar6/>

39 <https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/>

and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C or even 2°C will be beyond reach. In addition, achieving net zero global CO₂ emissions by 2050 will maximize the possibility of limiting the global average temperature increase to 1.5 °C above pre-industrial levels. The IPCC findings were considered as part of the ICAO work on the feasibility of a long-term global aspirational goal for international aviation⁴⁰.

The IPCC Working Group II report “AR6 Climate Change 2022: Mitigation of Climate Change”⁴¹ was also released in 2022. This report recognizes that progress in climate change adaptation planning and implementation has been observed across all sectors and regions, but it is still being unevenly distributed with several adaptation gaps observed, including potential vulnerabilities of key transport infrastructures such as international aviation systems and infrastructures, meaning that their design standards should give due consideration to account for projected climate impacts and risks.

World Meteorological Organization (WMO)

WMO⁴² and ICAO cooperate closely through the on-going review of the requirements of meteorological services for aviation, in the adoption of procedures for the provision of these services, and in keeping them up to date. In addition, ICAO has been working with WMO to establish a global programme enabling commercial aircraft to take meteorological measurements. This collaboration is a vital part of the global atmospheric observing system, with approximately 250,000 observations per day being made available to scientists, researchers and weather forecasters. These observations provide invaluable data that contributes to a better understanding of weather, volcanic ash dispersion and global climate.

Within the context of the collaboration between the two organizations, WMO maintains an observer status under CAEP, and the WMO Secretary General recently participated as keynote speaker in the 2020 ICAO Aviation Green Recovery Seminar⁴³, acknowledging how the WMO can partner with ICAO to green the aviation sector through advances in science, technology, and enhanced service delivery.

International Maritime Organization (IMO)

IMO⁴⁴ is the UN specialized agency responsible for the prevention of marine pollution from international shipping. ICAO and IMO cooperate and share best practices in developing climate policies, including GHG mitigation measures and actions for respective international transport sectors, in connection with the on-going UNFCCC process.

In 2018, IMO adopted a climate change strategy⁴⁵ for shipping which envisages to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 levels, while, at the same time, pursuing efforts towards phasing them out entirely. The strategy includes a specific reference to “a pathway of CO₂ emissions reduction consistent with the Paris Agreement temperature goals”.

Sustainable Mobility for All (SuM4All)

SuM4All⁴⁶ is a global, multi-stakeholder partnership of more than 50 international organizations established under the leadership of the World Bank in 2017, including multilateral development banks, United Nations agencies, bilateral donor organizations, non-governmental organizations, civil society, and academic institutions, with the aim to promote sustainable mobility, thus contributing to the achievement of the sustainable development goals (SDGs).

40 <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx>

41 <https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/>

42 <https://public.wmo.int/en>

43 <https://www.icao.int/Meetings/GreenRecoverySeminar/Pages/default.aspx>

44 <https://www.imo.org/>

45 <https://www.imo.org/en/MediaCentre/PressBriefings/Pages/O6GHGinitialstrategy.aspx>

46 <https://www.sum4all.org/>

In 2019, SuM4All released the “Global Roadmap of Action Toward Sustainable Mobility” Report⁴⁷, and the online decision-making tool on mobility⁴⁸. The green mobility is covered in the Green Chapter of the Global Roadmap of Action (GRA) Report, to which ICAO extensively contributed. The ICAO’s contribution was to make sure that any policy recommendation under the SuM4All partnership on international aviation and environment would respect and be consistent with decisions already taken by States through ICAO. For example, while the Green Chapter of the GRA proposes some GHG goals for the transport sector, it is important to highlight that they do not apply to international aviation, for which the sectoral global aspirational goals have already been established by ICAO, together with a process to explore the feasibility of long-term global aspirational goals for the sector.

In 2020 South Africa announced as the first country to pilot the use of the GRA and the Global Tracking Framework for Transport (GTF)⁴⁹ to accelerate progress on the SDGs. In 2021 SuM4All hosted a session at the United Nations Sustainable Transport Conference⁵⁰ to consult with countries in the Global South on the draft discussion paper produced for COP26.

United Nations Development Programme (UNDP) and Global Environment Facility (GEF)

As part of facilitating the provision of assistance for actions on climate change, and in particular for the preparation and implementation of States’ action plans on aviation CO₂ emissions reduction activities, ICAO successfully undertook an assistance project⁵¹ with the UNDP⁵² with the financing provided by the GEF⁵³. The UNDP is the authorized implementing agency of GEF, which was established as a programme within the World Bank to

assist in the protection of the global environment and to promote environmental sustainable development.

World Tourism Organization (UNWTO)

ICAO collaborates with UNWTO⁵⁴ in several areas of strategic importance to air transport and tourism with the aim of maximizing synergies when dealing with cross-sectoral policy issues. In particular, at the Sixth Worldwide Air Transport Conference⁵⁵ in March 2013, ICAO and UNWTO signed a Joint Statement, acknowledging the intention of the two UN agencies to begin cooperating more closely on areas of common interest, including the reduction of GHG emissions from aviation and tourism.

Organisation for Economic Co-operation and Development (OECD) and International Transport forum (ITF)

The Organisation for Economic Co-operation and Development (OECD)⁵⁶ is an intergovernmental organisation with 37 member countries, founded in 1961 to stimulate economic progress and world trade. The International Transport Forum (ITF)⁵⁷ is an intergovernmental organisation with 62 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is a global body that covers all transport modes and is administratively integrated with the OECD.

Although these organizations represent only as portion of ICAO Member States, they are very active on recommending transport policies and organizing events on the theme of international aviation and environment. Close coordination

47 <https://sum4all.org/gra>

48 <https://sum4all.org/online-tool>

49 <https://www.sum4all.org/global-tracking-framework>

50 <https://www.sum4all.org/events/challenges-and-opportunities-equitable-transition-towards-transport-decarbonization-global>

51 https://www.icao.int/environmental-protection/pages/icao_undp.aspx

52 <https://www.undp.org/>

53 <https://www.thegef.org/>

54 <https://www.unwto.org/>

55 <https://www.icao.int/meetings/atconf6/Pages/default.aspx>

56 <https://www.oecd.org/>

57 https://www.itf-oecd.org/modes/Aviation?f%5B0%5D=field_theme_tax%3A3

with these organizations is thus vital in order to ensure the alignment, harmonization, and consistency with decisions taken by ICAO Member States for the international aviation sector.

UN Office for Disaster Risk Reduction (UNDRR)

The Sendai Framework for Disaster Risk Reduction is the global blueprint for the UN disaster risk reduction (DRR). Target E of the Sendai Framework calls to “substantially increase the number of countries with national and local disaster risk reduction strategies by 2020”. ICAO is coordinating with the United Nations Office for Disaster Risk Reduction (UNDRR)⁵⁸ in order to provide technical guidance on integrating aviation climate change adaptation related aspects into the national DRR strategies.

While the efforts of ICAO are focused on reducing the impact of international civil aviation on the global climate, the impact of climate change to aviation infrastructure and operations has also been identified as a significant risk for the aviation sector. In this regard, the ICAO’s work on climate adaptation, covered in the Climate Adaptation Synthesis Report⁵⁹, provides the foundation of risk reduction and preparedness. In order to ensure the resilience of the international aviation system, the role of ICAO in disseminating best practices and guidance is instrumental. Indeed, the ability to engage all stakeholders effectively, from the airports, airlines, air navigation services providers to the energy suppliers and local authorities is a prerequisite to avoid the creation of islands of resilience, with no connection to the rest of the network.

UN Joint Inspection Unit (JIU)

The Joint Inspection Unit is the independent external oversight body of the United Nations system mandated to conduct evaluations, inspections and investigations of cross-cutting issues across the UN system, including environmental themes. ICAO’s work on this theme has been covered by several JIU reports such as JIU/REP/2010/1⁶⁰ (Environmental profile of the United Nations system organizations), JIU/REP/2014/4⁶¹ (Post-Rio+20 review of environmental governance within the United Nations system), and JIU/REP/2015/5⁶² (Review of Activities and Resources devoted to address Climate Change in the United Nations system organizations).

The report from 2015 for example, refers to the cooperation between ICAO and the UNFCCC on aviation bunker fuels as “a modality of inter-agency interface to be followed”. The JIU is now in the process of releasing a new report on the review of environmentally sustainable policies and practices across organizations of the United Nations system, as a follow up of JIU/REP/2010/1, which extensively covered the cooperation between ICAO, UNEP and UN EMG organizations on greening UN system operations (refer to the UNEP paragraphs above).

World Economic Forum (WEF)

The World Economic Forum (WEF)⁶³ is the International Organization for Public-Private Cooperation which engages the political, business, cultural and other leaders of society to shape global, regional and industry agendas.

The WEF Clean Skies for Tomorrow Coalition⁶⁴ provides a crucial mechanism for top executives and public leaders, across and beyond the aviation value-chain, to align on a transition to sustainable aviation fuels as part of a

58 <https://www.undrr.org/about-undrr>

59 <https://www.icao.int/environmental-protection/Pages/Climate-Adaptation.aspx>

60 https://www.unjiu.org/sites/www.unjiu.org/files/jiu_document_files/products/en/reports-notes/JIU%20Products/JIU_REP_2010_1_English.pdf

61 https://www.unjiu.org/sites/www.unjiu.org/files/jiu_document_files/products/en/reports-notes/JIU%20Products/JIU_REP_2014_4_English.pdf

62 https://www.unjiu.org/sites/www.unjiu.org/files/jiu_document_files/products/en/reports-notes/JIU%20Products/JIU_REP_2015_5_English.pdf

63 <https://www.weforum.org/>

64 <https://www.weforum.org/cleanskies>

meaningful and proactive pathway for the industry to achieve carbon-neutral flying

The Mission Possible Platform⁶⁵ is a coalition of public and private partners working on the industry transition to set heavy industry and mobility sectors on the pathway towards net-zero emissions by mid-century. It focuses on developing partnerships to deliver key initiatives for enabling industries to achieve net-zero CO₂ emissions.

Industry Groups

ICAO works with industry groups to help guide policymaking, provide support to its Member States, and coordinate actions across the environment agenda. These groups include the Air Transport Action Group (ATAG), Airports Council International (ACI), the Civil Air Navigation Services Organization (CANSO), the International Aviation Transport Association (IATA), the International Co-ordinating Council of Aerospace Industries Associations (ICCAIA), the International Business Aviation Council (IBAC), and the International Air Cargo Association (TIACA). These industry groups help ICAO promote aviation's sustainable growth for the benefit of the international community by investing in technology, improving operational efficiency, and building and using efficient infrastructures.

Within the spirit of this collaboration, ICAO recognizes the collective commitments announced by ACI, CANSO, IATA, IBAC, and ICCAIA on behalf of ATAG, to continuously improve CO₂ efficiency by an average of 1.5 per cent per annum from 2009 until 2020, to achieve carbon neutral growth from 2020 and to achieve a long-term goal of net-zero carbon emission by 2050⁶⁶, in support of the UNFCCC 1.5 °C temperature goal.

Non-Governmental Organizations

The International Coalition for Sustainable Aviation (ICSA) is a structured network of environmental non-governmental organizations (NGOs) which share common concerns with civil aviation's contribution to air quality, climate change and noise issues. As an observer to ICAO's Committee on Aviation Environmental Protection (CAEP), ICSA provides technical expertise and brings an NGO perspective to developing policy positions and strategies to reduce emissions and noise from the aviation sector.

⁶⁵ <https://missionpossiblepartnership.org/>

⁶⁶ <https://www.icao.int/Newsroom/Pages/ICAO-welcomes-new-netzero-2050-air-industry-commitment.aspx>

Message from Patricia Espinosa

Executive Secretary of UN Climate Change

The world is at a critical point in human history. It is a world beset with devastating geopolitical conflict, with resulting energy, food, and economic crises and a global pandemic that is still with us.

Aviation has been particularly affected by the COVID-19 pandemic, with a dramatic decrease in demand for commercial flights. Increasing fuel costs this year have presented further difficulties to the aviation industry.

As nations and industries struggle to deal with the immediacy of these problems, the urgency of tackling climate change now has never been clearer.

During the past 10 months, the UN's Intergovernmental Panel on Climate Change (IPCC) has released a trilogy of reports, which contain the most up-to-date science on climate change.

Together, these three reports are a dire warning about the consequences of inaction. The reports confirm that human activities are causing climate change and human influence is making extreme climate events more frequent and severe.

The reports found that human activities have warmed the planet at a rate not seen in the past 2,000 years, putting the world on track to global warming of 1.5 degrees Celsius within the next two decades.

Climate change is moving exponentially — and we can no longer afford to move incrementally. To put it simply: if the aviation and other industries do not transform and adopt net-zero carbon policies fast enough, they will not have a future.

Current levels of government ambition to tackle climate change, as indicated in the latest available national climate action plans (or NDCs), are clearly insufficient.

That is why at the UN Climate Change Conference last year, the Glasgow Climate Pact requested countries to revisit and strengthen the 2030 targets in their NDCs by the end of 2022.

But government plans are only part of the equation. Every sector must do their part and, as a substantial greenhouse gas emitter, international aviation has a significant role to play in keeping our climate goals within reach.



The ICAO 2022 Environmental Report is a crucial step that will help governments make informed policy decisions based on sound science.

Through market mechanisms, research and development into new fuels and high efficiency operations in the air and on the ground, the international aviation industry can help nations meet their Paris Agreement goals and give aviation a future.

ICAO has laid the foundation for meaningful climate action over years through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and the capacity-building programme for sustainable aviation fuels. When ICAO's 41st Assembly meets in Montreal this September, ICAO member states have the opportunity to make bold commitments and take action, including a long-term global aspirational goal for international aviation CO₂ emission reductions.

Given the sense of urgency highlighted by the Glasgow Climate Pact and by the IPCC, I urge ICAO to continue showing leadership for keeping 1.5 degrees Celsius alive by collectively contributing not only to net-zero by 2050 but also to urgently reduce the global emissions gap by 2030.

UN Climate Change stands ready to support your work and I am confident that ICAO will help build a more sustainable future for this sector and for this planet.

Message from Prof. Petteri Taalas

Secretary-General, World Meteorological Organization (WMO)¹

For nearly three decades the World Meteorological Organization (WMO) has published annual reports on the state of the global climate. The reports were initiated because of concerns that were being raised regarding projected climate change. As we have increased our understanding of the climate system, through rapid advances in science and technology, we have been able to show that there have been significant increases in temperature over land and in our seas, accompanied by other changes including sea-level rise, melting of sea ice and glaciers, and changes in precipitation patterns.

Climate change pervades all aspects of society and ecosystems. And the aviation industry is certainly not immune from its damaging impacts. Climate change is a global concern that demands a global response. The Paris Agreement, brokered by world leaders at the United Nations Climate Change Conference of Parties (COP21) in December 2015, established long-term goals to guide all nations to, *inter alia*, substantially reduce greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees. The legally binding Agreement includes commitments from all Parties to reduce their emissions and to work together to adapt to the impacts of climate change. It also calls on the Parties to strengthen their commitments over time.

As evidenced by WMO's annual state of the global climate reports as well as the latest Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)², it is fair to say that the alarm bells are not only ringing but they are getting louder.

Doing nothing is not an option. While the Coronavirus disease (COVID-19) pandemic of the past several years has caught the world's attention and has had a devastating impact on the aviation industry, more frequent and intense weather events that may be linked to climate change have continued



unabated. Also, while the drop in air traffic during the pandemic resulted in a reduction of the aviation sector's fossil fuel carbon dioxide emissions, global atmospheric concentrations of major greenhouse gases, carbon dioxide, methane and nitrous oxide continued to increase in 2020 and 2021.

As the aviation industry aspires to recover from the COVID-19 pandemic in more economically-sustainable and more environmentally-responsible ways – with increased attention placed, for example, on greener fuels and the 2050 net-zero economy – one should also expect increased focus on climate change adaptation, mitigation and resilience.

The WMO is committed to supporting ICAO and wider industry partners in their efforts reduce the harmful effects of aviation on the environment and to mitigating the damaging impacts of climate change on aviation. Strengthened partnerships, both nationally and internationally, are key to success. Together, let's turn the challenges into opportunities.

1 The WMO is the United Nations specialized agency dedicated to international cooperation and coordination on the state and behaviour of the Earth's atmosphere, its interaction with the land and the oceans, the weather and climate it produces, and the resulting distribution of water resources.

2 The IPCC is the United Nations body responsible for assessing the science related to climate change. It was created by WMO and the United Nations Environment Programme (UNEP) in 1988 with the objective to provide governments at all levels with scientific information that they can use to develop climate policies.

Message from Zurab Pololikashvili

Secretary General, United Nations World Tourism Organization (UNWTO)

Rebuilding a sustainable and resilient tourism sector

Tourism is one of the economic sectors most impacted by the COVID-19 pandemic. In 2020, international tourist arrivals dropped by 72% amid widespread travel restrictions, bringing the sector back to the level of 30 years ago.

As highlighted by the UN Secretary-General in his Policy Brief COVID-19 and Transforming Tourism¹, the pandemic not only had a direct impact on tourism, but also had many spillover effects on livelihoods, public services, and opportunities across all continents. This crisis is an opportunity to rethink the tourism sector and its contribution to the people and planet; it is an opportunity to build back better towards a more sustainable, inclusive and resilient tourism sector that ensure the benefits of tourism are enjoyed widely and fairly.

As outlined in the One Planet Vision for a Responsible Recovery of Tourism from COVID-19² which was released by UNWTO in June 2020 and subsequently reaffirmed in the UNWTO Recommendations for the Transition to a Green Travel and Tourism Economy³, developed in 2021 in partnership with the G20 Tourism Working Group, recovering from the pandemic must also tackle underlying sustainability challenges, such as unsustainable consumption and production patterns.

The pandemic has emphasized the need to strengthen the resilience of the tourism sector, highlighting both the fragility of the natural environment and the need to protect it, as well as the intersections of tourism economics, society, health and the environment. This will entail both improved preparedness for future emergencies, and a commitment to strengthening the sustainability and resilience of the sector. At the same time, good governance, adequate financing and digitalization will strengthen its ability to regain its capacity to generate and maintain millions of jobs, promote inclusion and provide opportunities.



Against this background, there is now a growing consensus among tourism stakeholders as to how the future resilience of tourism will depend on the sector's ability to balance the needs of people, planet and prosperity.

In the aftermath of the pandemic, many countries are realizing a new reality for tourism, recognizing it as a key driver of a sustainable and green recovery and working towards transforming the sector accordingly. The challenge is to ensure that the response is integrated, holistic and statistically based, so that the sector recovers better, providing benefits to economies and biodiversity conservation, reducing its high climate and environmental footprint, to achieve sustainable societies for all, with a special focus on making the sector more resilient, especially for tourism-dependent countries. The cross-cutting nature of the tourism sector highlights the need for coherence and cooperation between representatives of very different sectors related to tourism and across the tourism ecosystem in order to promote and strengthen sustainability.

¹ <https://unsdg.un.org/resources/policy-brief-covid-19-and-transforming-tourism>

² <https://www.unwto.org/covid-19-oneplanet-responsible-recovery>

³ <https://web.unwto.org/s3-eu-west-1.amazonaws.com/s3fs-public/2021-05/210504-Recommendations-for-the-Transition-to-a-Green-Travel-and-Tourism-Economy.pdf>

According to UNWTO/ITF research⁴ released in December 2019 at the United Nations Climate Change Conference COP25 in Madrid, the tourism sector was on track to increase its CO₂ emissions by at least 25% by 2030 if the current climate ambitions of the sector remain unchanged. While the COVID-19 pandemic led to a reduction of greenhouse gas (GHG) emissions globally in 2020, emissions already rebounded in 2021, reaching their highest ever absolute level. It is therefore expected that emissions from tourism will also rapidly rebound as operations restart and therefore the need to transform tourism operations for climate action continues to be of utmost importance for the sector to remain in line with international goals.

In light of the above, and in order to address one of the biggest threats that modern humans have ever faced, in November 2021, at UNFCCC COP26 in Glasgow, UNWTO launched the Glasgow Declaration on Climate Action in Tourism⁵ with the aim of building a consistent approach that will accelerate climate action in tourism.

The Glasgow Declaration developed within the framework of the One Planet network is a voluntary commitment which requests organizations make the following commitments:

- to support the global commitment to halve emissions by 2030 and achieve Net Zero by 2050 at the latest;
- to deliver climate action plans (or update existing plans) within 12 months of becoming signatories and implement them;
- to align their plans with five pathways, namely: measure, decarbonize, regenerate, collaborate and finance;
- to report publicly on progress made implementing those commitments;
- and to work on a collaborative spirit.

The Glasgow Declaration has already welcomed more than 500 signatories⁶ ranging from destinations, businesses and supporting organizations. It is one of the sector's clearest and strongest commitments to address the challenges of climate change and to lead the necessary transformation of tourism.

4 <https://www.unwto.org/sustainable-development/tourism-emissions-climate-change>

5 <https://www.unwto.org/the-glasgow-declaration-on-climate-action-in-tourism>

6 <https://www.oneplanetnetwork.org/programmes/sustainable-tourism/glasgow-declaration/signatories>

Message from Inger Andersen

UN Under-Secretary-General and Executive Director, UN Environment Programme

The world is in the grip of a triple planetary crisis: the crisis of climate change, the crisis of nature and biodiversity loss, and the crisis of pollution and waste. The crisis threatens to undermine achievement of the sustainable development goals.

The latest Intergovernmental Panel on Climate Change (IPCC) report is clear: current climate commitments and ongoing efforts imply a global temperature rise of well beyond 2°C above pre-industrial levels. The World Meteorological Organization in early 2022 warned that there is a 50/50 chance we will hit 1.5°C, at least temporarily, within five years. Meanwhile, nature and biodiversity loss continue at unprecedented levels, undermining the systems that keep humanity healthy and prosperous, while pollution and waste claims millions of lives each year and poisons our land, air and water.

The world is heading for disaster unless we reform our systems – and the aviation sector is no exception. Since the 2019 International Civil Aviation Organization (ICAO) Environment Report, the COVID-19 pandemic has gravely impacted the aviation sector. 2020 passenger numbers were 55 per cent lower than 2019, and air cargo 12-15 per cent lower. As a result, greenhouse gas emissions briefly dipped.

However, this is only a blip in a long-term upward trend. Emissions from aviation grew by 27 per cent between 2015 and 2020, while passenger numbers grew by 38 per cent. Aviation emissions are already showing a clear rebound after the pandemic.

We cannot revive our economies at the expense of the environment because economy is environment, and environment is economy. Sustainability is no longer an add on or luxury, but it is fundamental to the survival of every industry. We need to invest in zero-carbon, sustainable and more resilient infrastructure. In 2021, we saw encouraging pledges for carbon neutrality. Now we need these to turn into concrete plans – with the aviation sector backing these changes through strategies and investments.

One of the most impactful actions the aviation industry can take is transitioning away from fossil fuels to alternative, more climate-friendly alternatives. We need to promote the uptake of biofuels that are sustainably produced, without causing land-use conversion, biodiversity loss and redirection of precious water resources. I am thrilled to see, for the first time, a biodiversity chapter in the ICAO Environmental Report.



We also need to innovate and advance on the research front. Electric and hybrid-electric propulsion systems are revolutionising mobility technologies in many industries, from automotive to marine, a payoff of years of research and development. Similar efforts are underway in the aviation industry, laying the groundwork for wide adoption of electric flight.

We need to push for renewable-based energy solutions for aviation, and to make these more competitive by putting a high price on emissions. The current global energy crisis must incentivize many to move away from fossil fuels because of rising uncertainty and increasing prices.

At the fifth session of the UN Environment Assembly, countries delivered a historic result by deciding on the need for a global agreement to end plastic pollution, recognizing that while plastics is a product on which our societies and economies depend, it is also a product that should generally not be for single use. People are increasingly paying a hefty price because of the throwaway culture. The airline industry has a big role to play, in the global shift away from single-use plastic products. Another important area of focus in the journey towards sustainability is in addressing waste. The International Air Transport Association estimates that food waste, packaging, print media, duty free, buy-on-board services and amenities collectively generate over 6 million tonnes of waste a year. By far the majority goes to landfill and incineration. But we need the aviation industry to invest in safe waste recovery and increased circularity.

The aviation sector has a significant way to journey to align with net-zero targets and the goal of living in harmony with nature. The journey ahead is not an easy one. But working together, we can find pathways to sustainability.

Message from Sebastian Mikosz

Senior Vice President for Environment and Sustainability, International Air Transport Association (IATA)

A legacy of sustainability leadership

The climate crisis is an international crisis that can only be resolved through coordinated global action. Nowhere is this more the case than with aviation – the very definition of an international business sector. For air transport to work, it needs transparent rules that work globally. That is the case for traffic rights, for safety, and for operations, to name just three. It should be no different for sustainability.

This is why ICAO is the foundation of our business. We rely on ICAO's Member States to set the governance framework through which air transport can operate fairly and efficiently. And on climate change, ICAO has already delivered some far-reaching goals, the most significant of which is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA is the bridge between ongoing efficiency improvements that have already delivered substantial emissions reductions per km flown, and a world in which overall CO₂ from aviation begins to decline. By stabilizing emissions to an agreed baseline, CORSIA caps the growth in emissions from international traffic, giving aviation vital breathing space while we ramp up the deployment of Sustainable Aviation Fuels (SAF) and the research into radical new zero-emissions propulsion technology.

The success of the CORSIA agreement was one of the elements that underpinned the decision by airlines to commit to net-zero CO₂ by 2050. This historic agreement, made by IATA members at our 77th AGM in October last year, reveals the depth of the industry's commitment to sustainability, even in the teeth of COVID-19, the worst crisis to ever hit our business in peacetime. The concurrent commitment by airports, air navigation service providers, and key manufacturers to net zero was equally important, showing the collective will of our entire industry. But while we are determined to reach our goal, we know that we cannot do it alone—government support will be essential.

Therefore, a signal from ICAO that it is looking to build a long-term aspirational goal for aviation emissions is vitally important. An LTAG that is the industry's own commitments will be a huge boost to airlines looking to work with their stakeholders and governments for practical environmental solutions. ICAO can



help set the framework for coordinated global action, rooted in a desire to continue to enable more and more people to have access to the freedom and prosperity air travel creates, and to do so sustainably.

A collective global vision and framework for managing and reducing aviation CO₂ would set a realistic goal for emissions that is rooted in science and aligned with the UNFCCC Paris Agreement to keep global warming to 1.5 degrees. It would focus on strategies to develop SAF on a substantial scale, while understanding the possibilities afforded by electric and hydrogen propulsion. It would outline the opportunities to make air traffic control more efficient, help maximize the efficiency of infrastructure, adopt a pragmatic approach to carbon capture solutions, and look to ensure that climate financing is raised in a way that helps accelerate the deployment of CO₂ reduction initiatives, rather than seeking to “punish” passengers for their choice of travel mode through a regulatory patchwork introduced by regions and states.

A long-term goal for aviation's climate impact, reconfirming ICAO's leadership of this vital issue, would be a fine legacy for this year's Triennial Assembly, and IATA and our members stand ready to assist and work with the ICAO Secretariat and member states in its historic task of growing the unique and positive power of sustainable air connectivity.

Message from Jan Pie

Chairman of the Board of the International Coordinating Council of Aerospace Industries Associations (ICCAIA)

As aviation recovers from the COVID-19 pandemic, the environmental challenge remains the most significant issue facing the aviation sector in the 21st century. Expectations from governments and civil society are high. Recognising the challenge that lies ahead and acknowledging our part in developing solutions, the manufacturing and services sector, represented by ICCAIA, has issued a statement committing to a Net-Zero Carbon future by 2050. Our statement aligns with the common ambition expressed by many in the sector globally, both within our membership and by other parts of the industry.

Our immediate future is tied to the recovery of aviation from the pandemic, presenting opportunities to build back more sustainably. When the crisis first arrived, significant parts of the fleet were permanently taken out of service and dismantled using processes that allow between 90 and 95% (by weight) of the aircraft to be reused or recycled. These ageing aircraft had higher fuel burn and worse noise characteristics than the modern aeroplanes that are increasingly replacing them. As a result, a step change in the environmental performance of the global fleet after 2019 can be foreseen.

Within the ICAO Committee on Aviation Environmental Protection, the past couple of years have seen one of the most important pieces of work conducted in recent times: assessing the feasibility of setting a Long Term Aspirational Goal, or LTAG, for the reduction of carbon emissions from international aviation. The manufacturing and services sector has contributed substantial resources to supporting this effort, with a particular focus on the technology workstream. Engine and airframe manufacturers have shared their visions of the future for alternative fuels and new technologies, including electric and hydrogen powered aircraft.

The most significant and immediate contributor to aviation carbon reduction comes from the use of Sustainable Aviation Fuels. As they are drop-in-fuels, aircraft can already take benefit from operating on a 50% blend of SAF mixed with oil-based kerosene. However, the industry is not content to rest here. Work is ongoing to enable operation of our products using 100% SAF. Our challenge, though, is the availability of the fuels at a price point which is acceptable to both the airlines and, ultimately, the consumer when it is translated to their ticket price. Whilst international cooperation is ongoing between manufacturers and fuel producers to secure compatibility, the industry needs States to work together on the incentives for production and enabling global availability of these fuels.



In the medium and long term, the industry is focused on progressively reducing the dependence on burning kerosene-type fuels that continue to emit CO₂ into the atmosphere. Implementation of new technologies for reducing the fuel burned by conventional configurations is an ongoing task while more revolutionary aircraft configurations are developed that promise even larger fuel burn reductions. Small electric passenger aircraft are already flying in limited numbers, and several companies have projects to bring electrically powered commuter airliners into service. By the middle of the next decade, some manufacturers foresee the development of hydrogen powered aircraft coming to market, initially for shorter range operations. Both of these alternative energy supplies will require the development of new infrastructure to store and supply the energy, requiring international, cross-sectoral collaboration between manufacturers, airports and airlines to ensure worldwide deployment. ICAO will have a key role to play in securing a global framework of international standards applicable to the vehicles and propulsion systems resulting from the new energies across all aspects of rulemaking.

Ultimately, a commonly agreed long-term goal driving a common approach for the sector will be essential for a unified environmental vision as the industry recovers from the COVID-19 crisis. Cooperation between States, regions and the industrial sectors, with guidance from ICAO, will be an essential part of creating a sustainable, decarbonised, future for aviation.

Message from Luis Felipe de Oliveira

Director General, Airports Council International World

Aviation connects the world. It also contributes to a prosperous and sustainable world. But climate change remains the biggest existential threat of our time.

On 8 June 2021, following a feasibility assessment¹, ACI was the first global aviation organization to commit to a goal of net-zero carbon emissions by 2050. Shortly afterwards, the global air transport industry, through the Air Transport Action Group (ATAG), followed suit.

Across the world, airports have long been reducing their carbon emissions and supporting a broader transition to a sustainable future. Globally 396 airports in 79 countries participate in the Airport Carbon Accreditation program. This demonstrates their progress towards reductions in carbon emissions. ACI World has developed tools to assist airports with their emissions inventory (ACERT) or with evaluating environmental and economic benefits of certain emission reduction initiatives (AGES-S), but support is needed from governments to allow more airports to develop and implement decarbonization strategies and action plans. While the net-zero goal addresses scope 1 and scope 2 emissions, many airport operators are also working in collaboration with their stakeholders to tackle scope 3 reductions.

ACI's support in sustainability transformation

To help the entire aviation ecosystem to thrive in a net-zero world, ACI has developed guidance to support the sector during the energy transition. ACI World released a whitepaper on sustainable energy sources for aviation from an airport perspective and provided further guidance on the integration of hydrogen and sustainable aviation fuels into airport operations. Regardless of the sustainable energy source, new building, ground, mobile and energy airport infrastructure might be required along with adjustments of operations, and specialized training. Furthermore, engagement with passengers is key to ensuring acceptance of new technologies, similarly to early planning and coordination with other stakeholders. The promotion of an inclusive, accessible, positive, healthy, and sustainable passenger journey must focus on the services delivered to improve customer experience. ACI's Airport



Service Quality (ASQ)² program provides solutions, expertise, and benchmarking tools to help airports measure and improve passenger satisfaction, business performance, and service quality.

ACI has produced several sustainability-related publications guiding airports as they build and continuously refine their sustainability strategies. During the pandemic, efforts focused on highlighting the advantages of incorporating sustainability into recovery plans and providing best practice to balance the environmental, social, and economic demands. Above and beyond a sustainable recovery, a long-term sustainable strategy is also key for a responsible and ethical operating model that can continuously revise and maximize the socio-economic benefits it generates. The report, Sustainability Strategy for Airports Worldwide³, provides the first overview of the most relevant and commonly reported sustainability topics by airports globally. ACI also released a first of its kind guidance on ESG management best practice⁴ to help airports with their reporting frameworks to meet investors' needs on performance and risk mitigation, while establishing an inclusive institutional framework that achieves good governance, compliance, and stewardship.

¹ <https://store.aci.aero/product/long-term-carbon-goal-study-for-airports-report-2021/>

² <https://aci.aero/programs-and-services/asq/>

³ <https://store.aci.aero/product/sustainability-strategy-for-airports-worldwide/>

⁴ <https://store.aci.aero/product/environmental-social-and-governance-esg-management-best-practice/>

ACI has also done much to combat wildlife trafficking. Wildlife trafficking is one of the world's largest organised international crimes, posing a significant threat to biodiversity, and adversely affecting communities that rely on local wildlife and tourism. Through a six-year partnership with USAID Reducing Opportunities for Unlawful Transport of Endangered Species, ACI developed training materials for airport members, including a first edition of the Combatting Wildlife Trafficking Handbook⁵.

Solving the puzzle

The transformation of the sector to net-zero emissions requires significant change and unprecedented collaboration. Enabling such change will require breaking silos, decisive leadership, strong partnerships across the aviation ecosystem, ambitious government policies, appropriate funding, new technologies, and innovation to decarbonize and create a better quality of life for all. While the availability of measures varies regionally, and depends on airports' operating context, progress will secure airports' and aviation's future license to operate.

ACI will continue to support its members and to support ICAO as it develops the necessary measures to deliver a net-zero future and a sustainable aviation ecosystem.

5 <https://store.aci.aero/product/combating-wildlife-trafficking-handbook-first-edition-2021/>

Message from Captain Jack Netskar

President, International Federation of AirLine Pilots Associations (IFALPA)

ICAO has been instrumental in the success of international aviation over the past seventy years. IFALPA underlines this pivotal role for ICAO for the next decades to overcome major environmental challenges. ICAO has been synonymous with collaboration. Strong alliances, mutual support, stakeholder commitment and technological, economic, social, and operational balance meet in Montreal. Global issues need a global approach with local or national nuances. IFALPA recognizes its own role as one of the stakeholders which must reach out and commit to these challenges.

Safety is always the primary concern for pilots, and as such, for IFALPA. Environmental sustainability is also a basic requirement for future air transport and is inextricably linked to safety.

To underline our commitment, IFALPA has strengthened its environmental goals with a renewed mission: “IFALPA will contribute to the industry’s efforts to minimize the environmental impact of commercial aviation.” Furthermore, in the IFALPA Climate Working Group, the Federation has gathered operating expertise from the global pilot community to concentrate on the many environmental challenges.

The whole operation generally boils down to the flight deck. Enhanced navigational technologies, new sustainable aviation fuels, airspace redesign, new “green” or noise abatement operating procedures, all of these measures are “felt” by the pilot in the cockpit and must be managed and balanced in the end by the flight crew during flight.

With the vantage point at the end of the chain, the pilot has the perfect overview on what can or cannot be done in operating practice. What will and will not work and how things function. In short, what measures will be effective and what will have positive or negative side-effects, so-called interdependencies. IFALPA has the ability and feels the obligation to contribute.

For instance, a continuous descent is often preferred by the pilot, as the standard descent flying technique, but as the aircraft descends into a busy airport, the pilot will encounter



many obstacles: ATC restrictions, procedural inconsistencies, navigational (FMC) or noise constraints, limited airspace and runway capacity, punctuality concerns, possibly unexpected weather, and workload issues. The pilot can identify these hurdles and work together with other stakeholders on a multi-faceted solution to create the ideal environment for an efficient descent: with clear procedures, more accurate (4D) navigation, streamlined and seamless ATC centers, better information exchange, etc.

Many initiatives for sustainable aviation are underway on different levels, many of which have pilot input: within the several research centers and national development programs (FAA, SESAR, Nav Canada, UK CAA), within ICAO (OPSP and CAEP), regionally (NATS, in the pacific region, at Eurocontrol) and locally at airports, with national authorities, ANSPs and airline operators. All these collaborative efforts should improve the safety and sustainability of aviation, capable of meeting the demands of today, and facing the challenges of tomorrow.

Message from Tim Johnson

Lead representative for the International Coalition on Sustainable Aviation (ICSA)

In 2021, the stark warning from the Intergovernmental Panel on Climate Change to policymakers was that “global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO₂ and other greenhouse gas emissions occur in the coming decades.” Its advice on the need to limit cumulative CO₂ emissions, reaching at least net zero CO₂ emissions along with strong reductions in other greenhouse gas emissions, was equally unambiguous. There is no room for complacency and we can’t afford to delay action.

More recently, IPCC’s report on mitigation highlighted that international cooperation is a ‘critical enabler’ for achieving ambitious climate change mitigation goals, noting that effective and equitable climate outcomes are influenced by engagement with civil society actors, political actors, businesses, youth, labour, media, Indigenous Peoples and local communities.

The International Coalition for Sustainable Aviation (ICSA), which represents environmental NGOs active in finding solutions to aviation’s environmental impacts, has been providing a civil society voice at ICAO since 1998. ICSA sees this year’s 41st ICAO Assembly as a key moment for ICAO to define a decarbonisation pathway for international aviation by agreeing a long-term climate goal that aligns with scientific advice and a 1.5°C temperature goal. The negotiation of such agreements begins with the availability of robust scientific and technical evidence, and we have been actively involved in the Committee for Aviation Environmental Protection’s (CAEP’s) work which provides states with a good understanding of the potential contribution that technology, operations and sustainable aviation fuels can make to reduce emissions.

While CAEP initially focused on technology standards, the wider scope of its work in recent years – including market-based measures and sustainable aviation fuels – has emphasised the continued and increasing need for collaboration, not only with civil society but with experts in other fields. The technical work underpinning ICAO’s offsetting scheme, CORSIA, benefitted from understanding the experiences and lessons learned from



existing carbon markets, while ongoing work to account for sustainable aviation fuels has necessitated a wide-ranging look at land use issues and industrial processes.

Looking ahead to potential technologies of the future, such as electric and hydrogen technology, we will need to collaborate with a wide range of interests including renewable energy producers, investors, consumers, communities and local governments in order to gain public acceptance that could, potentially propel aviation into a new era of fossil-free travel.

Good practices and policies require transparency and trust, and engagement is critical to both especially in the climate crisis where the public expects urgent and effective action. This is particularly true for ICAO’s work as aviation’s environmental performance remains firmly in the public spotlight. ICSA is committed to working through open processes at CAEP and ICAO to find effective answers to these issues.

Introduction



SALVATORE SCIACCHITANO

Mr. Salvatore Sciacchitano is the President of the Council of the International Civil Aviation Organization (ICAO) since 2020. He graduated in Telecommunications Engineering from the University of Catania and began his career in aviation in 1980, joining the Italian Airworthiness Authority (RAI), serving as Regulation Director in 1992, then as Technical Director and, in 1996, as Director General. He was also Deputy Director General of the Italian Civil Aviation Authority (ENAC) for 11 years. He was entrusted with multiple international mandates, chairing the Permanent Commission of EUROCONTROL, representing Italy in the Management Board of European Aviation Safety Agency (EASA), holding the Vice-Presidency of the EUROCONTROL Provisional Council and coordinating the Italian delegation during ICAO Assemblies. He was appointed Executive Secretary of the European Civil Aviation Conference (ECAC) in 2010. He joined the Italian Delegation on the Council of ICAO in 2019, where he served until assuming his duties as President of the Council.



JUAN CARLOS SALAZAR

Mr. Juan Carlos Salazar is the Secretary General of the International Civil Aviation Organization (ICAO), since 2021. His career in international civil aviation spans over 27 years in various advisory and leadership roles. Prior to his appointment as Secretary General, he served as Director General of Aeronautica Civil of Colombia – Aerocivil. Previously, Mr. Salazar was a Senior Advisor to the UAE General Civil Aviation Authority for 12 years. His professional experience also includes terms as the President of Latin American Civil Aviation Commission, Secretary of the Colombian Civil Aviation Board and Director of its Air Transport Office, Director General of Air Transport at the Colombian Ministry of Transport, Corporate Secretary and Director of the Legal Department of Tampa Cargo. He is a lawyer and has earned advanced degrees from Harvard University (Master in Public Administration) and McGill University (Master in Air and Space Law).



MOHAMED KHALIFA RAHMA

Mr. Mohamed Khalifa Rahma assumed his position as Director, Air Transport Bureau, of the International Civil Aviation Organization (ICAO) in April 2020. Before his appointment, Mr. Rahma was the Regional Director of the ICAO Middle East Regional Office since March 2016. His current work portfolio covers a wide range of global aviation domain including Air Transport, Aviation Security and Facilitation and Environmental protection. He is currently the Secretary of the Council Aviation Recovery Task Force (CART). Prior to Joining ICAO, Mr. Rahma was the Undersecretary of International and Internal Affairs at the Ministry of Civil Aviation of Egypt and previously the advisor to the Egyptian Minister of Civil Aviation. Mr. Rahma was a board member of various companies including Cairo Airport Company, Aerotel Company and EMAC Aqaba Company and chaired many strategic committees under the umbrella of the Ministry of Civil Aviation for special projects. He holds a master's degree in Aviation Management.



JANE HUPE

Ms. Jane Hupe is the Deputy Director responsible for the Environment programme at International Civil Aviation Organization (ICAO), and serves as the Secretary of the ICAO Council's Committee on Aviation Environmental Protection (CAEP). Ms. Hupe has a vital role in providing leadership for ICAO's efforts to define and promote policies and Standards for environmentally sustainable aviation. Under her leadership, ICAO is prioritizing the work on the feasibility of a long-term global aspirational goal (LTAG) for international aviation. Ms. Hupe was at the forefront of the conceptualization and development of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which was agreed in 2016 as the first global market-based mechanism for any industry sector. Prior to 1998, Ms. Hupe worked as a consultant with ICAO's Technical Cooperation Bureau and for 15 years with the Brazilian Civil Aviation Authorities.

Chapter 1 – Aviation & Environmental Outlook



URS ZIEGLER

After having completed his studies in natural sciences, Dr. Urs Ziegler worked in the field of environmental protection for a civil engineering company as well as for more than 10 years for the Swiss Office for Environmental Protection. During this time, he also acquired a masters degree in public administration. In early 2005, he joined the Swiss Federal Office of Civil Aviation as Head of the Office's Environmental Protection Unit. Since then he has also been the Swiss member of ICAO's Committee on Aviation and Environmental Protection CAEP, which he chaired until 2022. He is also chairing the Environmental Forum of the European Civil Aviation Conference ECAC.



TAN KAH HAN

Mr Tan Kah Han is the Senior Director (Unmanned Systems Group) of the Civil Aviation Authority of Singapore (CAAS). As a member of CAAS' senior management team, his responsibilities include developing safety policy, the development of civil aviation, safety oversight and facilitating the use of unmanned aircraft systems and, future aviation technologies in Singapore. Prior to joining CAAS, he spent 25 years and held many senior appointments in the Republic of Singapore Air Force. He is Singapore member in the ICAO Committee Aviation Environment Protection and the ICAO Flight Ops Panel. Mr. Tan is a pilot and is rated in Airbus A-320 and Boeing B737.



RICARDO ANTONIO BINOTTO DUPONT

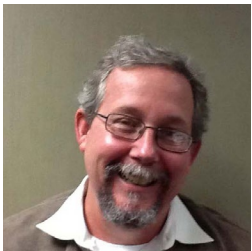
Ricardo Antonio Binotto Dupont is coordinating environmental activities at the Brazilian Civil Aviation Agency (ANAC)'s Office for International Affairs and Environment. He is an ICAO Committee on Aviation Environmental Protection (CAEP) member, representing Brazil. He was Vice-Chair of CAEP from 2020 to 2022.

**GREGG G. FLEMING**

As the director of U.S.DOT/Volpe's Center for Policy, Planning, and Environment, Gregg G. Fleming has over 30 years of experience in all aspects of transportation-related issues. He has guided the work of numerous multifaceted teams on projects supporting government, industry, and academia, including the Office of the Secretary of Transportation, the United Nations' International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), the Federal Highway Administration (FHWA), the National Park Service, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the National Academy of Sciences

**IVAN DE LÉPINAY**

Ivan de Lépinay is a senior expert on noise and standards within EASA's Environment & Sustainability section. He is actively contributing to various projects and standardisation groups aiming at quantifying the environmental impact of aviation and was co-rapporteur of ICAO CAEP's Modelling and Databases Group from 2018 to 2022. Before joining EASA in 2011, he worked for ten years as a consultant in aviation and environment for several European organisations. Ivan holds a degree in civil engineering and applied acoustics and a master's degree in sociology.

**ROGER SCHAUFELE**

Roger Schaufele, Jr. is Manager of the U.S. Federal Aviation Administration's Forecasts and Performance Analysis Division in the Office of Aviation Policy and Plans. He oversees the development of the FAA's forecasts of U.S. aviation demand and activity as well as forecasts of demand and activity for individual airports contained in the Terminal Area Forecast (TAF). He has more than 35 years' experience in forecasting aviation demand in various regions of the world. Prior to coming to the FAA, he was Manager of System Forecasts at US Airways. He holds degrees in economics from the University of California, Berkeley and Northwestern University.

**CLYDE HUTCHINSON**

As General Partner at TEAM ABC, Clyde is investing in early-stage startups in sustainable air, land and sea transportation. He has led several international innovation and startup programs such as Propeller Shannon (backed by Boeing), Founder of Viva Air Labs, Latin America's first innovation hub for Aviation (Medellín, Colombia). Experienced mentor/evaluator working with EU commission and other international startup programs. Spent his early career as academic researcher working at University of Cambridge, ZSL/London Zoo, Imperial College and Tokyo University.

**BRIAN MARRINAN**

Brian is a General Partner of Team ABC, a specialist VC focused on investing in a future of efficient, emissions free transportation and travel. With a long track record in innovation and entrepreneurship, Brian helped to create one of the world's first Fintech incubators in Boston, USA, 20 years ago, and established the first startup accelerator in Ireland over 15 years ago. He has since developed several corporate and independent programmes, specialising in aviation and travel over the past decade.



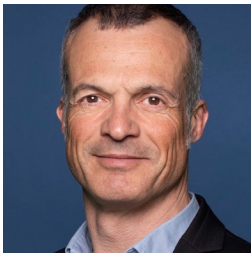
MICHAEL HALABY

Michael Halaby has 20+ years of providing strategic funding advice to C-suite executives in the aviation, automotive and financial institution sectors on accessing the US\$ and international bond, secured bank debt, and regional financing markets. He is Managing Director – Head of Aviation Advisory at MUFG Bank, Ltd. In this capacity, Michael's role is to build and supervise the Aviation Advisory business for its global aviation partners including lessors, airlines and investors which aims to help its clients raise capital, offer aviation financial consultancy services such as a lease versus buy analysis or fleet financing options and provide advice on ESG strategies. He is an active speaker on ESG.



CHRISTIAN PHO DUC

Christian Pho Duc is the CTO & Managing Director H2 & PtL Projects at Smartenergy Group AG and the Vice Chair of the Renewable Hydrogen Workstream at Solar Power Europe. He graduated as a Physicist from Munich and Cambridge University. Christian has accumulated 25 years working experience in Semiconductors (Siemens, IBM, G&D, Infineon Technologies), Renewable Energies & Hydrogen (Solyndra, Nanosolar, Smartenergy) and Electric Mobility (Torqeedo) in various management positions. With his multi-national background he speaks fluently German, English, French, Italian and some Spanish.



LAURENT JOLY

Laurent Joly has been a full professor in fluid mechanics since 2002 and was director of the Aerodynamics, Energetics and Propulsion Department at ISAE-SUPAERO from 2011 to 2019. As Deputy Director of Research, he has been expanding his scientific field to low-emission aircraft design since 2020. He attended the 2020-2021 cycle of the Institut des Hautes Études pour la Science et la Technologie (IHEST), devoted to the use of the scientific method to inform decisions. Laurent Joly is the Director of the Institute for Sustainable Aviation of Toulouse since January 2022.



TIM RYLEY

Tim Ryley joined Griffith University in 2015 as the inaugural Professor of Aviation. He has over twenty-five years of transport research experience across universities in the UK and Australia, which has typically been industry-linked, transdisciplinary and problem-based. Collaborations have been with a wide range of industry and Government partners, including major airports and airlines. Prof. Ryley's research has increasingly focused on the environmental aspects of aviation, and he is an internationally leading expert in decarbonising the aviation industry.



SUZANNE KEARNS

Dr. Kearns is an Associate Professor of Aviation at the University of Waterloo and Founding Director of the Waterloo Institute for Sustainable Aeronautics (WISA). She is an aviation academic, an accomplished educator both in the classroom and through electronic courseware, and a former airplane and helicopter pilot. She is the author or co-author of six books, including the textbook "Fundamentals of International Aviation" which is used around the world in multiple translations.

**DAVID ZINGG**

David Zingg is the University of Toronto Distinguished Professor of Computational Aerodynamics and Sustainable Aviation. His research is concentrated on applying aerodynamic shape optimization to the design of unconventional low-drag aircraft configurations motivated by the need to reduce greenhouse gas emissions from aircraft. He was awarded a prestigious Guggenheim Fellowship in 2004 for research in the design of environmentally friendly aircraft and contributed to the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft for ICAO in 2017-18.

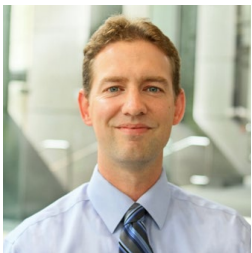
Chapter 2 – Aircraft Noise

**JULIEN CAILLET**

Dr. Julien Caillet is an acoustic expert at Airbus Helicopters, also in charge of noise certification activities. He had a PhD on helicopter interior noise diagnosis and modelling in 2006. He has over 20 years of acoustics engineering and project management experience with expertise in developing low noise technology for helicopters. He currently supports UAM acoustics activities within Airbus Group and coordinates research projects on Helicopter & eVTOL Low noise design and acceptance.

**DAVID JOSEPHSON**

David Josephson studied electrical engineering at University of California, Berkeley and worked in systems engineering for airborne geophysical survey 1979-1988. He is a Fellow of the Audio Engineering Society and chairs several standards committees in electroacoustics. In 1988 he founded and continues to head Josephson Engineering, a specialized manufacturer of microphones for sound recording and acoustic analysis. Since 2015 he has focused on aircraft noise and is the noise/acoustics advisor for Joby Aviation, a leading manufacturer of electric VTOL aircraft.

**DAN RUTHERFORD¹**

Dan Rutherford directs ICCT's aviation and marine programs. In that capacity, he helps national and international regulators develop policies to reduce air pollution and greenhouse gases from planes and ships. He is an internationally recognized expert on measures to promote the fuel efficiency of international transport, to control short-lived climate pollutants, and to phase out the use of fossil fuels. Dan holds a B.A. in Chemistry from the University of Minnesota at Morris and a M.S. and Ph.D. in Environmental Engineering and Science from Stanford University.

¹ This authors also contributed to Chapter 6 - Climate Change Mitigation : Operations



ALEXANDRA LOUBEAU

Alexandra Loubeau is a Research Aerospace Engineer at NASA Langley Research Center in Hampton, Virginia (U.S.). She received her M.S. and Ph.D. in Acoustics from The Pennsylvania State University and has been researching sonic boom acoustics since then. As a team co-lead for sonic boom community testing research at NASA, she is involved in the planning, execution, and analysis of experimental, modeling, and psychoacoustics research. She is also a technical advisor to the U.S. FAA in the ICAO CAEP Working Group on noise for the development of standards for supersonic aircraft.



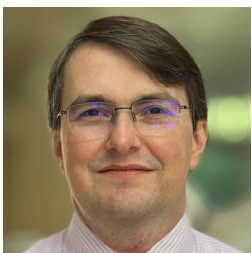
PIERRE-ELIE NORMAND

Pierre-Elie Normand is Dr Engineer in the Modeling and Tools department of Dassault Aviation Technical Directorate. He has 10 years of experience in Computational Fluid Dynamics development and applications, in particular for unsteady approaches, and novel numerical methods. He received his thesis in applied mathematics on « High order finite element methods for aerodynamics». He is in charge of unsteady turbulence modeling, maintaining in-house CFD code and is in charge of maintaining the far-field propagation code. Within the RUMBLE project, he contributed to sonic boom modelling and assessment activities.



SANDY RICHARD LIU

Mr. Sandy Liu is an Aerospace Engineer in the Office of Environment and Energy at the Federal Aviation Administration (FAA). He joined the FAA Noise Division in 2000 and is responsible for aircraft environmental noise certification regulations, associated international standards and policy development. Mr. Liu is the United States technical representative on the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Working Groups in the development of standards for aircraft, including rotorcraft, subsonic, supersonic and emerging technology aircraft. He is the FAA ASCENT Center of Excellence R&D technical project manager for supersonic aircraft noise reduction and sonic boom mitigation projects and led the Continuous Descent Approach (CDA) procedures implementation project. Mr. Liu previously worked at Bell Helicopter Textron and U.S. Army Aeroflightdynamics Directorate at NASA Ames Research Center. Mr. Liu received his Master of Science degree in Mechanical Design & Engineering from San Francisco State University, CA and his Bachelor of Science degree in Aerospace Engineering from Syracuse University, NY.



STÉPHANE LEMAIRE

Mr. Stéphane Lemaire is head of the external noise group at Dassault Aviation. He has 24 years of experience in aircraft noise and he is responsible for the noise certification of new Dassault Aviation aircraft. He has been a member of the International Coordinating Council of Aerospace Industries Association (ICCAIA) since 2013, participating to the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Working Group 1 (WG1) dealing with aircraft noise topics. Mr. Lemaire graduated from Ecole Polytechnique and Ecole Supérieure de l'Aéronautique in France.

**VICTOR W. SPARROW**

Victor W. Sparrow is the United Technologies Corporation Professor of Acoustics in the Graduate Program in Acoustics at the Pennsylvania State University. He has been a Penn State faculty member in Acoustics since 1990, and he served as Director of the Program between 2010 and 2021. His research interests include physical acoustics, noise, audio, and the history of acoustics. His most recent research has focused on the sonic boom noise of future civilian supersonic aircraft, and he serves as the Research Focal Point for the United States in the area of sonic booms, under the auspices of ICAO. Dr. Sparrow regularly teaches Penn State courses in the areas of outdoor sound propagation, nonlinear acoustics, computational acoustics, and spatial sound and 3-D audio. He has previously served the Acoustical Society of America in a variety of roles, including as President.

Chapter 3 - Local Air Quality

**DIDIER HAUGLUSTAINE**

Dr Didier Hauglustaine is a senior researcher at CNRS at the Laboratory for Climate and Environmental Sciences in Gif-sur-Yvette (Paris area) and has 30 years research experience in atmospheric sciences. He works in the field of atmospheric chemistry modelling and climate-chemistry interactions with a focus on tropospheric ozone evolution and the atmospheric nitrogen cycle. He has also been a lead author for three IPCC assessment reports and has authored over 150 publications.

**RICHARD C. MIAKELYE**

Dr. Richard C. Miakelye is a Vice President, Principal Scientist and Director at Aerodyne Research, Inc. He leads both theoretical numerical modeling and experimental measurement projects to understand the environmental impact of airplanes. He was recognized for contributions to IPCC's 2007 Nobel Peace Prize and to the USEPA 2007 Climate Protection Award. He has been Chair of SAE's E-31 committee on aviation emissions and has served in many roles in support of CAEP and continues to serve with both groups.

**DANIEL JACOB**

Daniel Jacob was the Senior Aviation Emissions Policy and Research Specialist at the U.S. Federal Aviation Administration Office of Environment and Energy. In his capacity as Program Manager at the FAA, he oversaw projects on non-volatile particulate matter emissions testing, air quality and climate impacts of aviation. He also managed the development of operational benefits-costs analyses tools that incorporate state-of-the-art science to inform policy and decision making. He co-lead the Particulate Matter Task Group of the CAEP WG3 during the CAEP/10 and CAEP/11 cycles. He co-lead of Emissions Characterization Task Group of Working Group 3 during CAEP/13 and is a co-rapporteur of the Impacts Sciences Group. He is currently the FAA Senior Representative for South Asia based in New Delhi, India.

**MARTIN PLOHR**

Martin Plohr has been working for more than 20 years as a research engineer in the Engine section of the German Aerospace Center's (DLR) Institute of Propulsion Technology. The focus of his work is placed on the investigation of aero engine performance and emissions, advanced and new concepts and technologies. He is also supporting the German contribution to the ICAO/CAEP process as a member of the CAEP's Working Group 3 (WG3). His doctoral thesis on emissions modelling for advanced aircraft engine combustors was published in 2015. He co-led WG3's Emission Characterization Task Group (ECTG) in the CAEP/12 and the current CAEP/13 cycle.

Chapter 5 - Climate Change Mitigation: Aircraft Technologies

**BETHAN OWEN**

Dr Bethan Owen has more than 20 years' experience in air quality and climate assessment, with particular expertise in the field of aviation. Principally her experience lies in research projects in the field of emission estimations and predictive modelling in the context of aviation, air quality and climate, providing leadership and support on a number of national and European research projects on aviation and the environment. She is a scientific advisor to the UK government at meetings and on working groups with senior levels of industry and government. Since 2016, Dr Owen has been a co-Rapporteur of the ICAO CAEP international technical emissions working group 3.

**RALPH IOVINELLI**

Mr. Ralph Iovinelli has served as the Manager of the Emissions Division for the United States Federal Aviation Administration's Office of Environment and Energy since 2011. He advises the Executive Director of Environment & Energy (AEE-1) and the Assistant Administrator for Policy, International Affairs, and Environment (APL-1). He represents AEE and the FAA at meetings and on working groups with senior levels of industry and government, which involves coordinating with other relevant FAA offices. Since 2013, he serves as co-Rapporteur of the ICAO CAEP international technical emissions working group 3.

**SUSAN X. YING**

Dr. Ying has devoted over three decades to the aerospace industry, with experience at NASA, Boeing, the Commercial Aircraft Corporation of China, and most recently an electric aircraft start-up, Ampaire. She is the Senior Vice President of Ampaire, responsible for global partnerships. She is also a board member of the Lindbergh Foundation. Dr. Ying is the immediate past President of the International Council of the Aeronautical Sciences (ICAS), serving on the Executive Committee which leads in shaping the agenda of this multinational professional aerospace organization. Dr. Ying is recognized as a Fellow of the AIAA and Fellow of the Royal Aeronautical Society (RAeS). With a deep passion for flight, Dr. Ying holds a Commercial Pilot License and is a FAA-Certified Flight Instructor (CFI). She received her PhD degree in Aeronautics and Astronautics from Stanford University and BS from Cornell University.



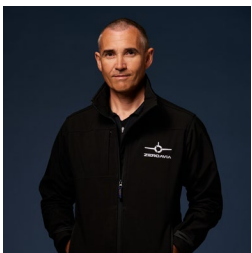
ROELOF VOS

Dr. ir. Roelof Vos is Assistant Professor at the Aerospace Engineering Faculty of Delft University of Technology. His research is focused on new airplane configurations and technologies to reduce the climate impact of aviation. He leads the research project into the Flying V aircraft. He teaches university courses on Aircraft Design and Aerodynamic Design as well as professional courses on Aerodynamic Design and Hybrid-Electric Aircraft Design. Vos is an Associate Fellow of the American Institute of Aeronautics and Astronautics former secretary of the AIAA Aircraft Design Technical committee. He holds a BSc (2004) and Msc (2005) degree in Aerospace Engineering from Delft University of Technology and a PhD degree from the University of Kansas (2009) under sponsorship of the Fulbright Program.



GLENN LLEWELLYN

Glenn Llewellyn is Vice President, Zero-Emission Aircraft at Airbus, the world's leading aircraft manufacturer and an international pioneer in the aerospace sector. Glenn is widely recognised as a top-tier thought leader on climate strategy for aviation. Glenn is at the helm of a zero-emission revolution at Airbus with the mission to unite all the ingredients needed to launch the world's first zero-emission commercial aircraft programme, ZEROe. Prior to his current role, Glenn spearheaded the research & technology portfolio dedicated to reducing the climate impact of Airbus products.



VAL MIFTAKHOV

Val Miftakhov, ZeroAvia Founder and CEO, is a serial cleantech entrepreneur who knows how to scale technology for use by existing transportation industries. Val's previous venture was eMotorWerks. Val held executive business strategy & operations positions at Google, McKinsey & Company, and Nielsen. He launched and managed three startup companies, in all of which he held the CTO positions. Prior to his industry experience, Val was a high energy physics researcher at Stanford Linear Accelerator. Val received his PhD in Physics from Princeton University and his MS in Physics from Moscow Institute of Physics and Technology. He was a two-time winner of the Nationwide Russian Physics Competitions.



TOM GRUNDY

Tom Grundy is Hybrid Air Vehicles' CEO. Previously Head of Business Management for BAE Systems' Tornado Availability Support Service, Tom holds degrees in Aerospace Engineering and Advanced Systems Engineering, an MBA, and is a Chartered Engineer and a Fellow of the Royal Aeronautical Society.



SÉBASTIEN BOUGON

Sébastien Bougon is FLYING WHALES' CEO and founded the company in 2012. After spending eight years in the construction industry and then working on the financing of concessions, he joined the TF1 Group, where he held positions in finance and general management. Sébastien holds a degree in Civil Engineering.

Chapter 6 - Climate Change Mitigation: Operations



JONAS VAN DORP

Jonas van Dorp is Head of Aviation Marketing & Development at Groningen Airport Eelde (GRQ). He has a MSc degree of Air Transport Management at Cranfield University. Starting his career as a tour operator and mobility management consultant, Jonas has since 2002 been working for GRQ, specialized on new business and air services development. Regarding innovation and sustainability, Jonas initiated several projects, varying from the Interreg-supported Green Sustainable Airport (GSA) project, NXT Airport and Hydrogen Valley Airport.



YUKIO NAKATANI

Yukio Nakatani is the General Manager of Technical Headquarters. He was in charge of master planning and development of KIX, and countermeasure project against the settlement of the ground surface. He was also engaged in establishing policy against earthquake and tsunami at the Ministry of Land, Infrastructure, Transport and Tourism of Japan. In 2018, he led recovery from Typhoon Jebi and BCP measures. Since 2021, he has been supervising the Technical Headquarters that deals with matters including environmental initiatives.



YUKA TAKEUCHI

Yuka Takeuchi joined Kansai Airports as an engineer and was appointed as the Manager of Environment & Master Plan Group. She takes the lead in enhancing the environmental measures of the three airports (Kansai International Airport, Osaka International Airport and Kobe Airport) and is responsible for creating and realizing sustainable master plans. Based on the long-term target of net zero CO₂ emissions by 2050, she is promoting energy conservation, the use of renewable energy and hydrogen, and zero emission vehicles.



JULIANA SCAVUZZI²

Juliana Scavuzzi is the Senior Director, Sustainability, Environmental Protection and Legal Affairs at ACI World. Ms. Scavuzzi is the ACI Observer to the ICAO Committee on Aviation Environmental Protection (CAEP) and Secretary of the ACI World Environment Standing Committee. Ms. Scavuzzi leads international negotiations on environmental matters for ACI World, and leads the team developing technical material to support environmental protection and sustainable development at airports. She was the project director from ACI World of the ROUTES partnership. Ms. Scavuzzi is a lawyer and policy expert with a MSc in Juridical Science and a LLM in Air and Space Law: she has 10+ years of progressively responsible experience in International Aviation and Space Law and policy, of which 7 have been dedicated to environmental protection. She has authored several publications on the subject, including book chapters.

2 This author also contributed to Chapter 10 - Biodiversity



VINCENT ETCHEBEHERE

A 16-year veteran of the Group Air France-KLM, Vincent Etchebehere began his career in Stockholm as a business intelligence analyst. He then worked in Paris, then Rome occupying various revenue management positions. Back in Paris, he was performance manager for Europe Area, before becoming chief of staff to the EVP commercial, sales and alliances for the AF-KL Group. In 2016, he was named General Manager Mexico, and in 2018, General Manager for Canada. He took the position of VP Sustainability and new mobilities for Air France in Jul 2020. Vincent is also Vice President of A Tree for You association's Board, a plantation operator that enables individuals and companies to support planting projects around the world; and animator of the Climate Fresk.



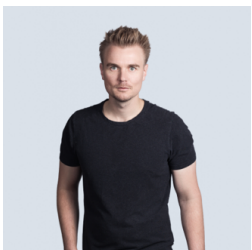
HEDWIG SIETSMA

Hedwig Sietsma is Director Climate policy at KLM. Her main goal is to reach out to industry and policymakers for more ambitious climate ambitions in the aviation industry. Hedwig is an MSc in Business Administration and worked in the NGO sector before joining KLM 6 years ago. She started as a Corporate Management trainee, and became Unit Manager Preparation & Boarding Intercontinental for almost 3 years after that. Her current position is one that combines her personal values with her career objectives; creating sustainable aviation.



DAVID BRAIN

David previously has over 25 years extensive experience in ATC, ATM, Project Management and operational analysis. David currently works in the Aviation Sustainability Unit in EUROCONTROL, focusing on reducing the environmental efforts of operations. David co-chaired the European CCO/CDO Taskforce as well as leading several other European operational projects. David is a co-rapporteur of the ICAO-CAEP Airport and Operations Working Group and has previously been responsible for leading the work assessing the global environmental benefits from the planned implementation of ICAO's ASBU framework. David also was responsible for leading the first ever global flight efficiency analysis using a harmonised surveillance data source. David has a private pilot's license, a degree in Geography and a Master's degree in Sustainable Aviation.



PHILLIP BUCKENDORF

Phillip Buckendorf is Co-founder and CEO at Airspace Intelligence, a software-first aerospace company that helps the world's most complex air operations succeed. The company is navigating and optimizing air traffic for some of the biggest airlines operating in US airspace. Prior to Airspace Intelligence, Phillip designed and deployed predictive systems across autonomous driving, e-commerce and health care.

**DIVYA SUKUMAR**

As Signal's Behavioral Science Lead, Divya has helped build a brand new app and communication service that nudges airline and shipping captains to save fuel and carbon. Before joining Signal, Divya completed a Ph.D. in Psychology & Law at the University of Warwick. During her studies, she won the Three Minute Thesis Challenge and Psychology Publication Prize. Divya is passionate about understanding what drives people's behavior and how we can nudge them into achieving better life outcomes.

**DANIEL WHITE**

Dan has been innovating with behavioral science and environmental technologies for the last 15 years, culminating in his position as CEO and co-founder of Signal. An environmental expert, 'street' behavioral scientist and innovator, Dan successfully delivered one of Europe's first field experiments on energy consumption, and founded a behavioral economics consultancy. Working with academic colleagues, he recognized the massive untapped carbon opportunity for behavioral change on fuel efficiency margins in aviation, and more recently maritime, and founded Signal in 2017.

**ALEXANDRE FERAY**

Alexandre Feray is CEO of Open Airlines. He has 25 years of experience in the Software and Airline Industry, not including his teen years when he invented a programming language that was awarded and commercialized by Apple. He holds an MSc in Engineering and IT from École Centrale Paris and started his career at IBM Thomas J. Watson Research Center in New York, USA. He was the head architect of Air France Operations Control Center's reengineering program and head of Air France Crew Management IT Department. In 2006, he founded OpenAirlines, an innovative company that provides consulting and software solutions to reduce the costs of the airline operations.

**LAURENT TABERNIER**

Laurent Tabernier led the EUROCONTROL study on Economic tankering. He led the analysis and performance evaluation of the European air traffic management research programme, SESAR, for many years and joined the Aviation Sustainability Unit of EUROCONTROL two years ago, where he conducts studies related to reducing the environmental impact of aviation. He is a senior expert in aviation performance with more than 30 years of experience in international programmes. Laurent holds a Master's degree in Computer Science and Artificial Intelligence from EPITA Paris.



ROBIN DERANSY

Robin Deransy leads the Research and innovation activities of the Aviation Sustainability Unit of EUROCONTROL. Since 2010, Robin is leading studies aimed at ensuring that aviation progresses toward climate neutrality. He promotes and supports projects offering environmental solutions within and outside the SESAR programme. Robin is a member of the ICAO Committee on Aviation Environmental Protection (CAEP); the tools and databases maintained by his team IMPACT, STAPES, Open-ALAS are recognised and used in the context of the CAEP Modelling and Database Group. Robin holds a degree in software engineering from the Conservatoire National des Arts et Métiers in Paris.



M. MUTHUKRISHNAN

Dr. M. Muthukrishnan, Head - EHS & Sustainability – Airport Sector (C), GMR GROUP, having more than 16 years of experience in EHS & Sustainability Management. He is a Chemical Engineer and have done Doctorate in Chemical Engineering in the stream of Separation Technology at IIT Delhi, India. He is acting Chair of Airport Council International (ACI) Asia Pacific Region – Environment Committee. He is a certified Course Developer of International Civil Aviation Organization (ICAO) and ICAO Safety Management System Professional. Also developed International training program on Leadership in Energy and Environmental Design and Operation of Airport Infrastructure for ICAO.



REKIBUDDIN AHMED

Rekibuddin Ahmed - Manager- Sustainability at Delhi International Airport Limited (DIAL), has more than 12 years of experience in Environment & Sustainability domain. He is currently driving sustainability initiatives at Delhi Airport. Some of the key focus area includes- climate action, green building programs, waste management, sustainability and ESG reporting, green financing, engagement with international associations and government agencies, training and competency development etc. He is representing Asia Pacific Airports as Expert Member in Airport Carbon Accreditation Global Task Force. He has Master of Technology (M. Tech) degree in Energy & Environment Management from Indian Institute of Technology (IIT) Delhi and Master of Science degree in Energy Systems from University of Petroleum and Energy Studies, Dehradun, India. He is a certified Lead Auditor in ISO 14001:2015 and Indian Green Building Council Accredited Professional (IGBC AP).



JONATHAN BECK

Jonathan Beck is the fello'fly project leader since January 2022, and previously was the technical director of the fello'fly demonstrator from 2019 to 2021. Graduated from Supaero engineering school in 2006, Jonathan has been with Airbus since 2010. After contributing to A350 XWB training simulator design, he joined the A330 family flight control design and certification teams. Jonathan is passionate about new technologies and innovation, and endeavors to apply it to aerospace sustainability.



MONICA ALCABIN

Monica Alcabin is a Technical Fellow at The Boeing Company and the ICCAIA Focal to ICAO CAEP Working Group 2 (Airports & Operations). Monica has expertise in the evaluation of operational benefits of avionics, airports and Air Traffic Management procedures and contributed to the development of the Rules of Thumb for the environmental benefits of the ICAO Aviation System Block Upgrades. She is tracking the regulatory landscape for Unmanned Aircraft and was the task lead for the work covered in this article.



ROBERTO DE OLIVEIRA LUIZ

Roberto de Oliveira Luiz is Head of Aviation Business Development at Inframerica, currently manages Brasília and Natal airport and is controlled by Corporación América Airports since 2012. He also has an additional function as Commercial Aviation Advisor at Corporación América Airports, supporting and coordinating the design and execution of the routes development strategies for the all the international airports of the group. Roberto has extended experience in the business aviation. He started at VARIG and held various positions within the company, such as, Manager of Cargo Revenue Accounting, Inspector of Branches and General Manager. In Pluna was responsible for coordinating the business activities of the subsidiaries of the company.



FRANCIS MWANGI

Mr. Francis Mwangi is currently the Senior Planning Officer at Kenya Civil Aviation Authority (KCAA). He is the ICAO CAEP Member for Kenya and Second Focal Point on CORSIA and Climate Change initiatives in Kenya. He is also a Panel Member in ICAO Aviation Data and Analysis Panel (ADAP) since 2014. He has extensive knowledge and experience on economics and environment matters on aviation industry for over 15 years. He holds a B.Sc. in Mathematics (First Class Honours); M.Sc. (Finance) and M.A. Economics all from University of Nairobi; a Certificate in Sustainable Aviation from Manchester Metropolitan University, a Certificate in Airport Green House Gas (GHG) Management from Incheon Airport Aviation Academy, a Certificate in Civil Aviation Management from Singapore Academy.



THOMAS CUDDY

Thomas Cuddy is an expert in aerospace policy, planning, and analysis at the U.S. Federal Aviation Administration, with extensive knowledge of environmental programs, infrastructure financing, and research. He has participated in ICAO's 'Airports and Operations' working group since 2010, and is FAA's representative to the Airport Carbon Accreditation advisory board. He currently manages the Systems and Policy Analysis division at FAA, with the goal to bring enterprise-wide solutions to the most difficult aerospace challenges.

**MARIO SANTI**

Mr Mario Santi has worked for Flughafen Wien AG since 31 years. Responsible for the coordination and communication of the sustainability management system in the company. Collaboration in the practical application of the European Eco Management and Audit Scheme (EMAS). Participation in selected regional working groups and task forces in the context of regional management.

**JOHANNES DEIMEL-ZELENTKA**

Mr Johannes Deimel-Zelenka has worked for the Austrian Ministry for Climate Adaptation since 2017. Responsible for environmental issues in aviation and European coordination in aviation for the Ministry. Prior to his current role he worked in the private business sector for one of the largest energy companies in Europe, for the Austrian Ministry for European and Foreign Affairs, and completed a training in the European Commission.

Chapter 7 - Climate Change Mitigation: Sustainable Aviation Fuels

**MATTEO PRUSSI**

Matteo Prussi is an Industrial engineer, with a scientific background in renewable energy conversion technologies. He is a senior researcher at the Polytechnic University of Turin, and former employed at the Sustainable Transport Unit of the European Commission Joint Research Center. His activity focuses on the assessment of the environmental impacts of the various modes of transport and on the potential for alternative sustainable fuels, in particular for aviation and maritime sectors.

**ROBERT MALINA**

Robert Malina is a professor for environmental economics at Hasselt University in Belgium and Director of the U Hasselt Centre for Environmental Sciences. He is also a Research Affiliate at the Laboratory for Aviation and the Environment of the Massachusetts Institute of Technology. His main area of research is sustainable aviation, in particular the environmental and economic viability of sustainable aviation fuels. For this topic, he also serves as a technical expert to the International Civil Aviation Organization.



ANDREI MUNGIU³

Andrei Mungiu works for the European Commission on EU environmental policies since 2012, and on aviation specific matters since 2017. He works on ICAO affairs, also being involved in work on environment protection, with a focus on Sustainable Aviation Fuels and Market-Based Measures. He serves as expert on ICAO CAEP, in Working Group 4 for CORSIA, Fuels Task Group, Long-Term Aspirational Goal Task Group. He has extensive experience in the private sector in management of software products in Romania, China, US and Belgium. He holds an engineering master degree from the Polytechnics University of Bucharest, Romania.



NATE BROWN

Nate Brown is SAF Project Manager in the U.S. Federal Aviation Administration (FAA) Office of Environment and Energy responsible for a portfolio of SAF research and development efforts. He manages FAA support for the Commercial Aviation Alternative Fuels Initiative (CAAFI) for which he serves as Head Advisor for Strategy and Implementation. Nate leads FAA coordination with U.S. government agencies on SAF, is co-chair of the SAF Interagency Working Group and responsible for developing and implementing the government-wide SAF Grand Challenge. Nate is also a U.S. expert member of the ICAO Fuels Task Group and co-chairs its Technology Production and Policy (TPP) subgroup.



MARK RUMIZEN

Mark Rumizen has been the Federal Aviation Administration's (FAA's) regulatory and technical expert for aviation fuels for over two decades. He has been employed by the FAA since 1991 and is currently the Senior Technical Specialist for aviation fuels in the Aircraft Certification Division. He is also a member of the Commercial Aviation Alternative Fuels Initiative (CAAFI) steering committee and is the leader of the CAAFI Certification & Qualification Panel. He is chairman of the ASTM International Aviation Fuels Subcommittee and formerly led that subcommittee's Emerging Fuels section. Mark also helps guide aviation fuel research as the FAA representative on the Coordinating Research Council (CRC) Aviation Fuels Steering Committee. He was employed by aircraft engine manufacturers Pratt & Whitney Aircraft and GE Aviation prior to joining the FAA.



STEVE CSONKA

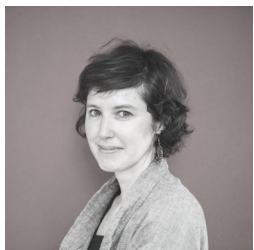
Steve Csonka is an aviation professional with 36 years of broad, strategic airline, aviation OEM, and sustainable aviation fuel (SAF) experience. He leverages his expertise in the nexus of advanced technologies, policy, and market forces to advocate for a strong industry, focusing on development of pragmatic solutions to the challenges of aviation growth. From 2012, Steve has served as Executive Director of CAAFI (www.caafi.org), a public-private-partnership fostering the development and commercialization of SAF.

3 This author also contributed to Chapter 11 – State Action Plan & Capacity Building



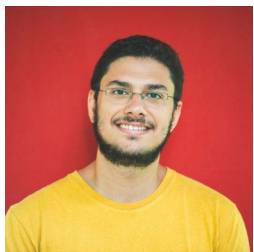
KRISTIN C. LEWIS⁴

Dr. Kristin Lewis is the principal technical advisor for energy analysis and sustainability at the U.S. DOT Volpe Center with a focus on resilience in transportation, alternative fuels, sustainability, and environmental impact risk assessments. Dr. Lewis supports the Federal Aviation Administration (FAA) as the head research and technical advisor to CAAFI®, as co-rapporteur of the ICAO Sustainability Certification Scheme Evaluation Group, and as a member of the ICAO CAEP Fuels Task Group.



JOANA PORTUGAL-PEREIRA

Joana Portugal Pereira is an Assistant Professor at Energy Planning Program of the Federal University of Rio de Janeiro (PPE/COPPE/UFRJ). She is a Visiting Fellow at the Centre for Environmental Policy of Imperial College London and a Visiting Assistant Professor at the Mechanical Engineering Department of Instituto Superior Técnico, University of Lisbon. Professor Portugal Pereira is a Lead Author in the IPCC Sixth Assessment Report (AR6) and in the UNEP Emissions Gap Reports. She was a Senior Scientist of the Technical Support Unit of IPCC WG III and coordinated the development of the IPCC Special Reports on 1.5C pathways and Climate Change and Land. She holds a MSc degree in Environmental Engineering (University of Lisbon) (2006), and a PhD in Urban Engineering (The University of Tokyo) (2011), with emphasis on life cycle assessment modelling of alternative fuels. Since 2021, she is an Associate-Editor of the Environmental Science and Policy Elsevier Journal.



EDUARDO MULLER-CASSERES

Eduardo is a doctoral candidate at the Energy Planning Program (COPPE/UFRJ) and a guest researcher at PBL (Netherlands Environmental Assessment Agency). He holds a bachelor's degree in Electrical Engineering from UFRJ and a diplôme d'ingénieur from Mines-Télécom Lille Douai, in addition to a master's degree in Energy Planning from COPPE/UFRJ. Eduardo acted as a Chapter Scientist in the IPCC Sixth Assessment Report (WG III, chapter 3). His research focuses on the role of international shipping and aviation in long-term climate mitigation scenarios.



DEREK B. WHEELER

Derek Wheeler is a Senior Policy Advisor at ExxonMobil. He has spent over 25 years there in various roles related to equipment design, facilities operation and manufacturing of transportation fuels. Over the past 12 years he has supported advocacy involving the development of carbon reduction policies in the United States and abroad. He is currently focused on aviation policy such as CORSIA and has been a member of the Fuels Task Group in the ICAO Committee on Aviation Environmental Protection since 2019.

4 This author also contributed to Chapter 8 CORSIA



JIM HERBERTSON

Jim worked for Ipieca between 2017 and 2022 as Technical Director, Climate and Energy, after nearly 40 years in the oil and gas industry. He graduated in Chemistry from Oxford University and spent the first part of his career in various technology roles. During that time he worked in the UK, France and the USA and led global teams developing new fuels and lubricants and providing support to refining and marketing. More recently, he worked on environmental and safety for the upstream business functions with a focus on policy development.



FRANCISCO BOSHELL

Mr. Francisco Boshell leads the work on Innovation for Renewable Energy Technologies at the International Renewable Energy Agency (IRENA). He focuses primarily on providing policy advice and guidance to countries regarding technology innovation, quality control and standardisation programmes for a successful deployment of renewables. During his 18 years professional career, Mr. Boshell has also: developed technical standards for quantifying GHG emission reductions from CDM projects and supported the climate change negotiations under UNFCCC; provided consultancy services for the development of renewable energy and energy efficiency projects at DNV GL, formerly KEMA Consulting; and designed and implemented infrastructure and energy related projects in the automotive manufacturing sector at General Motors. His background is in Mechanical Engineering and he holds a MSc. in Sustainable Energy Technology from the Eindhoven University of Technology, in the Netherlands.



MAISARAH ABDUL KADIR

Maisarah Abdul Kadir is an Associate Programme Officer at International Renewable Energy Agency (IRENA), working for renewable energy roadmaps (REmap) program, focusing on global level and regional analysis including South East Asia. Prior to joining IRENA, she was working in the energy sector in Malaysia and Indonesia.



RICARDO GORINI

Ricardo Gorini is an economist, holds an MBA in Finance and MSc. and DSc. in Energy. He joined IRENA, in 2018 as Senior Program Officer – REmap, responsible for the Renewable Energy roadmaps program at global, regional and country level. He is co-author of the IRENA global roadmap series including the latest World Energy Transitions Outlook 2050. Previously he has worked in the financial market and mining sector, as well as advisor for energy policies and regulation in Brazil, including as the Director of the Brazilian Energy Office (EPE) in charge of the Brazilian energy planning. He was also involved in the Brazilian NDC formulation and he coordinated the energy group of the Brazilian Climate Change Forum. He was the sherpa for Clean Energy Ministerial (CEM) and Mission Innovation (MI).



SONIA RUEDA

Sonia Rueda works as advisor at the PtX Hub of the GIZ in Berlin, with focus on solutions for the aviation sector and the chemical industry. She is passionate about sustainable solutions and actions that contribute solving one of the biggest problems facing society today: Climate change. Sonia holds a degree on Chemical engineering from Colombia and a masters in Renewable energy technologies from Germany. Before starting at the PtX Hub, Sonia gained multidisciplinary experience in the private and public sector; on the areas of process engineering and energy efficiency while working for the chemical industry in Colombia and, on capacity building and technical support around renewable energy and energy statistics while working for the International Renewable Energy Agency in the UAE. Sonia is Colombian, has lived in Kenya, Germany and the UAE and has worked with several developed and developing countries



FRANK MISCHLER

Frank Mischler is with the PtX Hub Brussels, a platform for knowledge exchange, capacity building, policy dialogue and international cooperation on PtX, commissioned by the German government and implemented by GIZ, the German government's agency for development cooperation. Frank leads the policy work of the PtX hub, including regulations on aviation. The Hub supports sustainable aviation fuel production in Brazil and Kenya and are in initial discussions with more countries, and set-up an in-depth training module on PtL/SAF. Before joining the PtX Hub, Frank supported the EU's climate diplomacy efforts with G20 countries.



RUTH HORSTMANN BARBOSA

Ruth Horstmann Barbosa is specialist on Education and Communications strategies within international cooperation. She holds a master's degree in Educational Leadership and Innovation from Duisburg-Essen University, Germany. Between 2020 and 2022 she worked for the German cooperation office of GIZ in Brazil, supporting project management on Technical and Vocational Education and Training (TVET) and advising the project ProQR - Climate-neutral Alternative Fuels on Human Capacity Development and Communication, focusing the promotion of PtX technologies and SAF production in Brazil.



JACOB TETER

Jacob Teter leads IEA's team of transport analysts in the Energy Technology and Policy Division. In this role, he aims to further the global dialogue on policies to promote quality transport services while minimising emissions and other environmental impacts. Jacob is a lead author of the IEA's "Future of Trucks" and "Future of Rail" reports, and has contributed to the IEA's "Net Zero by 2050" report, to the annual Global EV Outlook series, and to recent Energy Technology Perspectives and World Energy Outlook reports, among others. He completed his PhD in Transportation Technology and Policy from the University of California, Davis in 2015.



PRAVEEN BAINS

Praveen Bains is currently a Clean Energy Modeller within the Energy Technology and Policy division at the International Energy Agency (IEA). She works within the alternative fuels team, modelling the global alternative fuel production that supplies the energy required by the demand sectors. Her works focuses on bioenergy/biofuels and sustainable aviation fuels, including synthetic kerosene. Ms. Bains has a Master's degree from the Department of Energy Resources Engineering at Stanford University, and a Bachelors of Engineering in Chemical and Biomolecular Engineering from the University of Pennsylvania.



PEDRO PIRIS-CABEZAS

Director, Sustainable International Transport & Lead Senior Economist, Environmental Defense Fund (EDF). Pedro, Ph.D., is an economist and a professional engineer working for EDF since 2007. He directs analysis and policy advocacy to promote the use of high-integrity, sustainable alternative fuels as well as carbon markets and other robust policy frameworks to address emissions from international transportation. In the context of ICAO, Pedro has participated in the design of CORSIA since 2013 and co-led the task group working on sustainability matters related to sustainable aviation fuels within the CAEP, which led to the adoption of ICAO's SAF sustainability framework.



XAVIER VIGOR

Xavier Vigor began his professional career in 1988 within the Air Liquide Group. He has successively held positions in research and development, sales, engineering and management, always in innovative fields. In particular, he has been Managing Director of two of the Group's Research Centers (Chicago, Illinois, and Paris, France), as well as Standard Plants Engineering, and of the Group industrial IT. More recently he was the Managing Director of Air Liquide advanced Technologies in Grenoble. Since 2017, he is Vice-President Technologies (CTO) and Industrial Management of the Air Liquide Hydrogen Energy World Business Line. Xavier Vigor is a graduate of École Centrale des Arts et Manufactures.

Chapter 8 – CORSIA



RACHID RAHIM

Mr. Rachid Rahim is the Head of Aviation Environmental Protection at Qatar Civil Aviation Authority (QCAA), Doha. He is primarily responsible for the drafting and implementation of aviation environmental regulations, Aviation Environmental protection oversight and Aviation Environmental strategy design. He is an expert with a professional experience of more than 20 years at various positions dealing with aviation and environment at the international level. Previously, he worked at the International Air Transport Association (IATA) as leader civil aviation consulting. He holds a Master's in Environmental Engineering from DTU, Denmark and a Master's in Environmental Policy and regulation from Roskilde University, Denmark.

**JUAN HERMIRA**

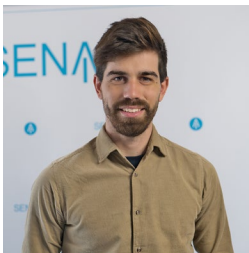
Mr Juan Ignacio Hermira holds a BA Honors degree in Environmental Studies from Staffordshire University and also a Masters in Environmental Management. He is senior environmental officer and technical expert for State sponsored group SENASA/Spanish Aviation Authority, AESA. He has been working for aviation industry for 20 years, 15 years' of experience in aviation environmental protection and 10 years' of experience at Aircraft Operator level. He provided assistance and representation on behalf of the Spanish Authorities in a variety of international working groups, including ICAO CAEP WG4 (related CORSIA) and SCSEG (undertaking the evaluation of Sustainability Certification Schemes for SAF). Also qualify expert for ACT-CORSIA programme under ICAO CORSIA Buddy Partnerships.

**KERRI HENRY**

Kerri Henry has worked with the Government of Canada for 20 years, focused primarily on climate change policy. In her current role she is one of the leads for Transport Canada on the development of climate change measures for international transportation. In this role she has worked on the development and implementation of CORSIA at ICAO since 2014 and was the lead for domestic implementation in Canada. She is currently the co-rapporteur of ICAO's Working Group 4: CORSIA.

**STEPHEN ARROWSMITH**

Mr. Arrowsmith has worked in the area of aviation and environmental protection for the last 25 years, and in the European Aviation Safety Agency (EASA) since 2005. He has led work in developing global environmental standards on aircraft NOx and CO₂ emissions, as well as market-based measures where he is currently co-Rapporteur of the CAEP Working Group 4 on CORSIA. During the past 5 years, he has instigated the EASA European Aviation Environmental Report, which provides an objective overview on the environmental performance of the European aviation sector and how it can be improved. Most recently, he has been supporting the development of SAF initiatives to facilitate their uptake within Europe.

**DANIEL RIVAS BROUSSE**

Daniel Rivas Brousse is programme officer and representative from Spain, SENASA. SENASA provides specialised technical assistance to public entities in the Spanish aeronautical sector. Daniel is a specialist in sustainable aviation fuel, with several years' experience in the field. He also assists in the organisation of technical discussions at ICAO, and promoting engagement with other international and national organisations. Since 2022, he has been co-rapporteur for the fuel task group that reports to ICAO's aviation environmental protection committee.



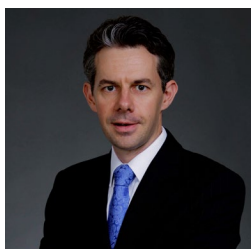
JAMES HILEMAN

Dr. James (Jim) Hileman is the Chief Scientific and Technical Advisor for Environment and Energy for the Federal Aviation Administration. He has responsibility for the Environment and Energy research portfolio of the FAA, which includes the CLEEN Program, the ASCENT Center of Excellence, and the Commercial Aviation Alternative Fuels Initiative (CAAFI), among other efforts. Dr. Hileman is the co-rapporteur of the Fuels Task Group of the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP). Prior to joining the FAA, Dr. Hileman was a Principal Research Engineer within the Department of Aeronautics and Astronautics at MIT. He holds a B.S., M.S., and Ph.D. in Mechanical Engineering from the Ohio State University.



STEFANO MANCINI

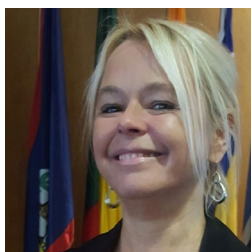
Stefano Mancini is working in EUROCONTROL since 1998. In the last 20 years, he has worked primarily on market-based measures addressing aviation sustainability and decarbonisation. Having contributed to the analyses carried out during the design of the inclusion of aviation in the European Union (EU) Emissions Trading System (ETS), he is managing since 2010 the EUROCONTROL Environment Management Information Service (EMIS, formerly ETS Support Facility) supporting States' authorities, aircraft operators, the EU and ECAC in the implementation of the EU, Swiss and UK ETs and ICAO's CORSIA. Expert nominated by the EU in the ICAO-CAEP GMTF, since its inception in 2013, and subsequently in the WG4, he co-led the WG4 CORSIA Tools and Analysis Group (CTAG) till March 2022.



PHILIPPE BONNEFOY

Dr. Philippe Bonnefoy is Founder and Principal at BlueSky. Dr. Bonnefoy leads a team of experts in strategy and analytics focusing on aviation decarbonization through technology, operations, sustainable aviation fuels and market-based measures. Dr. Bonnefoy is an expert nominated by the United States (since 2009) to the ICAO-CAEP where he currently leads the Working Group 4 CORSIA Tools and Analysis Group (CTAG) and the Long-Term Aspirational Goal Task Group (LTAG-TG) Cost and Estimations ad hoc group. He is also contributing to several ICAO CAEP groups; MDG, FESG, WG1, WG3, FTG and ACCS.

Chapter 9 - Climate Change Adaptation & Resilience



RACHEL BURBIDGE

Rachel Burbidge joined EUROCONTROL in 2005. She has been leading EUROCONTROL's work on climate change adaptation and resilience since 2009, authoring the organisation's ground-breaking Challenges of Growth work on Climate Adaptation, and several peer-reviewed journal articles. She leads EUROCONTROL's contribution to the ICAO CAEP Working Group on CORSIA, where she leads tasks on MRV, and is also a member of the ICAO CAEP Working Group on Airport and Operations, where she co-leads the work on climate adaptation. She has degrees in Environmental Studies and Sustainable Development.

**ANDREA SCHWARTZ FREEBURG**

Andrea Schwartz Freeburg is a Foreign Affairs Specialist with the U.S. Federal Aviation Administration (FAA) Office of International Affairs. She currently serves as the Southeast Asia desk officer, where she is responsible for coordination with USG and international partners to promote collaboration in civil aviation safety, security, and efficiency in the region. Andrea previously served as the Caribbean desk officer (2017-2021), and in the FAA office of Environment and Energy as an Environmental Protection Specialist and agency lead for climate adaptation (2011-2017). Andrea has a Master of Arts in International Security from George Mason University and a Bachelor of Arts in International Relations from The College of William and Mary.

**JARLATH MOLLOY**

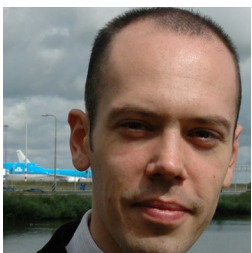
Dr Jarlath Molloy is Senior Environmental Affairs Manager at NATS. His professional interests include the environmental performance of the aviation industry, international climate change policy, non-financial reporting, climate change resilience and green finance. He has worked in the public, private and non-profit sectors and is a Chartered Physicist.

**BEATRICE TURRINI**

Beatrice is Business Continuity Manager at NATS, responsible for enhancing the wider organisational resilience and preparedness to ensure NATS is able to sustain operations during times of disruption. She has over ten years' experience managing IT operations with a large telecoms company, and is undertaking an MBA in Risk and Resilience.

**TREVOR SMITH**

Trevor is a senior engineering manager at NATS. He is responsible for the operation and support of all technical support facilities at ATC centres and remote sites underpinning the NATS ATM technical operation. He has a background in systems engineering applied to aviation related services and is Chartered Engineer.

**NANCO DOLMAN**

Nanco Dolman is leading professional at Royal HaskoningDHV, with a MSc in Civil Engineering from Delft University of Technology (1998). For over 20 years Nanco is the Strategic Adviser of Amsterdam Airport Schiphol for coping with climate change, airport planning and water management. Nanco has been also involved in other climate resilient airport studies, which include New Orleans; JFK, New York; Mexico City; Sydney; Kansai, Osaka; Vancouver and Changi, Singapore. Currently he is the team lead for the Global Study on Disaster Resilience for Airports, commissioned by the Coalition for disaster resilient infrastructure (CDRI).



VIVEKANANDHAN SINDHAMANI

Vivekanandhan Sindhamani is Sustainable Aviation Lead at Netherlands Airport Consultants (NACO, a company of Royal HaskoningDHV), with an MSc in Aerospace Engineering from Delft University of Technology (2012). Vivek has successfully delivered international aviation multi-disciplinary projects around the world in over 20 countries and on 5 continents. Vivek has been involved in the development of a roadmap to make Changi Airport climate resilient and supported the Kansai Airport flood management study. He is core team member in the development of the ICAO Guideline on Airport Climate Change Adaptation. Currently, he is the project coordinator for the Global Study on Disaster Resilience for Airports, commissioned by the Coalition for disaster resilient infrastructure (CDRI).

Chapter 10 - Biodiversity



ANASTASIOS ANAGNOSTOPOULOS

Anastasios is Biologist and joined the Environmental Services Department of Athens International Airport S.A. (AIA) in 1997, after employed for a decade as academic researcher in botany, ecosystem management and database engineering in biology. He is currently the leader of the Wildlife and Biodiversity Management Team and AIA's SME Trainer on WHM. He has contributed as Safety Assessor for WHM at the ACI APEX in Safety Review Project. He is founding member of the World Birdstrike Association (WBA) and founding member of WBA regional branch for Europe (WBA-EUR), elected as Regional Vice-President for Europe for 2015-2018.



WENDY AVIS

Wendy Avis is the Manager, Climate and Environment with the Vancouver Airport Authority where she is responsible for executing YVR's Environmental Management Plan and Roadmap to Net Zero by 2030. She has over 25 years' experience in the environment and sustainability field specializing in environmental management systems and sustainability strategies including carbon, energy, waste and water management. She is the Vice-Chair of the Canadian Airports Council Environment Committee and on the Board of the BC Chapter of Women in Aviation.



NICK GABRIEL

Nick is a passionate environmental practitioner and chartered environmentalist with the Institute of Environmental Management and Assessment. He has experience in environmental impact assessment, permitting and approvals, and management systems. At Gatwick Nick leads the environment team and oversees environmental matters relating to both operations and development. Prior to joining Gatwick Nick worked on significant infrastructure, transport and energy projects in the UK and Australia.



MELINA SANTOS VANDERLINDER

Melina Elizabeth Leonora Santos Vanderlinder is an Environmental and Sustainability Engineer currently working in aviation. She has professional experience in environmental and social impact assessment, due diligence, and audits and development of environmental, health and safety management systems under ISO standards. Since 2018, Melina is working on aviation implementing the global environmental strategy of VINCI Airports which focuses on achieving net zero emissions of their airports, protecting natural resources and biodiversity, and promoting circular economy. She is currently working at VINCI Concessions operating 59 airports in 12 countries. She is also the Vice-chair for the Environmental Committee of ACI-LAC.



ARTUR MIRZOYAN

Graduated from the Moscow Aviation Institute in 1979. Since 1978, he worked at the Central Institute of Aviation Motors (CIAM) in the Propulsion & A/C Matching Department. His main researches are connected with multidisciplinary analysis and optimization of fuel/environmental efficiency of civil aircraft propulsion system. He has more than 100 scientific and technical publications. He supervised the CIAM activities in the several European projects (HISAC, DisPURSAL, AGILE). In 2016, he received the RAeS Gold Award for publication in the Aeronautical Journal. Since 2012, as an expert, he participated in the CAEP, especially in the development of the ICAO CO₂ Standard. Since 2018, he is CAEP Member from Russian Federation.



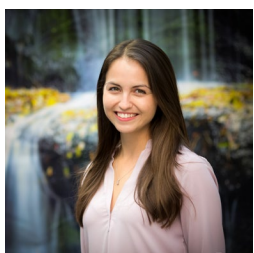
KONSTANTIN B. GONGALSKY

Konstantin B. Gongalsky is a specialist in soil macrofauna and terrestrial isopods in particular. Conducting research on soil ecology and forest functioning mainly after disturbances: industrial pollution and forest fires. Applying spatial soil ecology studies and application of geostatistic methods in biodiversity research. Conducting research on soil biogeography and biodiversity. He is Head of both Laboratory of Ecological Soil Functions at A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences and Laboratory for Biogeography of Soils at Moscow State University. He is the author/co-author of more than 70 papers indexed in Web of Science.



CRAWFORD ALLAN

Crawford leads national and international wildlife conservation programs related to trade, trafficking, and sustainability, with 30 years of experience. Based in Washington DC, Crawford served on the Federal Advisory Council to the U.S. Presidential Task Force on Wildlife Trafficking, 2013-2017. He leads large-scale projects combating nature crimes and building private sector solutions. Including the co-creation/oversight of the USAID ROUTES Partnership and as founder of the Coalition to End Wildlife Trafficking Online, with 47 of the largest tech companies globally.



CORI MACFARLAND

Working for the world's leading environmental nonprofit, Cori taps into the power of the private sector to address some of the toughest challenges facing our planet. In this role, she collaborates with industry leaders to reduce environmental impacts, raise funds for field programs, and inspire support for WWF's mission. Cori led on building corporate collaboration under the ROUTES Partnership. Cori received her MBA from George Washington University in Washington DC and a BA in Anthropology from UCLA, USA.

Chapter 11 - State Action Plan & Capacity Building



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Oyetoun is a Deputy General Manager, Economic Regulation, Facilitation & Aviation Environment at NCAA, where she started her career in aviation in 1994. She is the Focal Point and coordinator for the Nigerian State Action Plan on reduction of CO₂ emissions and CORSIA. Oyetoun is a member of ICAO Technical Advisory Body (TAB) and serves as a Trainer for ICAO ACT-CORSIA. She holds a BSc in Microbiology and an MBA.

Chapter 12 - Multistakeholder Cooperation



PATRICIA ESPINOSA

Patricia Espinosa is the Executive Secretary of UN Climate Change since 2016. Ambassador of Mexico to Germany since 2012 and from 2001 to 2002, Ms. Espinosa was Minister of Foreign Affairs of Mexico from 2006 to 2012, bringing more than 30 years of experience at highest levels in international relations, specialized in climate change, global governance, sustainable development, gender equality and protection of human rights.



INGER ANDERSEN

Inger Andersen is Under-Secretary-General of the United Nations and Executive Director of the United Nations Environment Programme, headquartered in Nairobi, Kenya. Between 2015 and 2019, she was the Director-General of the International Union for Conservation of Nature (IUCN). Between 1999 and 2014, she held several leadership positions at the World Bank including Vice President of the Middle East and North Africa; Vice President for Sustainable Development and Head of the CGIAR Fund Council. Ms. Andersen has more than 30 years of experience in international development economics, environmental sustainability, strategy and operations.



PETTERI TAALAS

Prof. Petteri Taalas is the Secretary-General of the World Meteorological Organization, with its headquarters in Geneva, Switzerland. Having been elected by the World Meteorological Congress, he took up his position in January 2016. Previously, Prof. Taalas was Director General of the Finnish Meteorological Institute. He has a PhD in Meteorology from the Department of Physics at the University of Helsinki and is the author of around 50 peer-reviewed papers on satellite technology, global change, climate and atmospheric chemistry.



ZURAB POLOLIKASHVILI

Zurab Pololikashvili has been Secretary-General of the World Tourism Organization (UNWTO) since January 2018. Under his leadership, UNWTO gained unprecedented visibility and prominence within the United Nations system, strengthening bonds with other key agencies and placing tourism at the heart of the wider agenda for recovery and sustainable development. After graduating with a degree in Banking, the Georgian national worked in a number of high-level roles in both the private and public sectors. His experience in the public sector includes posts like Deputy Minister of Foreign Affairs of Georgia, Minister of Economic Development of Georgia, Ambassador Extraordinary and Plenipotentiary of Georgia to Spain, Andorra, Algeria, and Morocco. He has also had prominent roles in one of Georgia's biggest banks and as CEO of the country's leading football team, FC Dinamo Tbilisi.



SEBASTIAN MIKOSZ

Sebastian is the Senior Vice President for Environment and Sustainability at the International Air Transport Association (IATA). Representing 190 airlines, IATA's mission is to represent, lead and serve the airline industry. Sebastian is responsible for guiding and implementing IATA's strategic work on sustainability including the work towards the industry's net zero CO₂ target. He is the former Group Managing Director and CEO of Kenya Airways. Prior to that, he was the CEO of eSKY Group - the largest Polish Online Travel Agent. He is a graduate of the Institute of Political Studies (IEP Paris) in France with a master's degree in Economics and Finance.



TIM JOHNSON

Tim is the Director of the UK-based Aviation Environment Federation (AEF), an NGO campaigning on aviation's impacts for people and the environment. He is a lead representative for the International Coalition for Sustainable Aviation (ICSA) at the UN's International Civil Aviation Organisation (ICAO), where he has co-led CAEP's expert group responsible for developing the emission unit eligibility criteria for CORSIA, and continues to lead the support group for ICAO's carbon emissions calculator. In the UK, he is a member of the Department for Transport's newly created Jet Zero Council.



CAPTAIN JACK NETSKAR

Jack has a military background and is based in Oslo, Norway. Captain Netskar flies Boeing 737NGs for SAS, his employer for the past two decades. Soon after starting at SAS, he got involved in union work and has been elected to a variety of positions in national, regional, and global organizations. He has served the SAS Pilot Union as Board member, Deputy Chairman, and Chairman, as well as International Director of the Norwegian Airline Pilots Association and as Executive Vice-President, Professional & Government Affairs at the International Federation of Air Line Pilots' Associations (IFALPA). As IFALPA President, Captain Netskar is responsible for all aspects of IFALPA's activities and guides the Federation's participation in the International Civil Aviation Organization. His academic background includes the Air Force Academy, a bachelor's degree in organizational psychology, and a master's degree in Aviation Leadership.



JAN PIE

Jan Pie has been Secretary General of the AeroSpace and Defence Industries Association of Europe (ASD) since 2013. During 2021 and 2022, he is also Chairman of the Board of the International Coordinating Council of Aerospace Industries Associations (ICCAIA). Jan served as the Chairman of the Board during 2013-2014 and 2017-2019. Jan is a delegate in the Consultative Commission on Industrial Change (CCMI) as part of the European Economic and Social Committee (EESC). Since 2021 he serves as an expert in the European Commission Industrial Forum. He holds an IFL Executive Management degree from the Stockholm School of Economics and an IHM Masters from the IHM Business School in Gothenburg.



LUIS FELIPE DE OLIVEIRA

Luis Felipe de Oliveira has led Airports Council International (ACI) World as Director General since June 2020, applying his vast experience in commercial and technical aviation. He believes that aviation has a crucial role to play in fostering social and economic growth worldwide and is committed to helping ACI members and business partners sustainably recover from the impact of the pandemic.

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ICAO Environmental Publications

ICAO Annexes

- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume I — Aircraft Noise
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume II — Aircraft Engine Emissions
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume III — Aeroplane CO₂ Emissions
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume IV — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

ICAO Environmental Technical Manual

- Environmental Technical Manual Volume I – Procedures for the Noise Certification of Aircraft (Doc 9501, Vol I)
- Environmental Technical Manual Volume II – Procedures for the Emissions Certification of Aircraft Engines (Doc 9501, Vol II)
- Environmental Technical Manual, Volume III – Procedures for the CO₂ Emissions Certification of Aeroplanes (Doc 9501, Vol III)
- Environmental Technical Manual, Volume IV – Procedures for demonstrating compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (Doc 9501, Vol IV)

ICAO CORSIA Implementation Documents

- CORSIA Eligible Emissions Units (7th edition, 2022)
- CORSIA States for Chapter 3 State Pairs (2nd edition, 2021)
- ICAO CORSIA CO₂ Estimation and Reporting Tool (2021 version)
- CORSIA Sustainability Criteria for CORSIA Eligible Fuels (2nd edition, 2021)
- CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels (3rd edition, 2021)
- CORSIA Methodology for Calculating Actual Life Cycle Emissions Values (2nd edition, 2021)
- CORSIA Central Registry (CCR): Information and Data for the Implementation of CORSIA¹
 - CORSIA Aeroplane Operator to State Attributions (6th edition, 2021)
 - CORSIA 2020 Emissions (1st edition, 2021)
- CORSIA Central Registry (CCR): Information and Data for Transparency:
 - Part I: Verification bodies accredited in States (9th edition, 2021)
 - Part II: Total Average CO₂ Emissions (in tonnes) for 2019 and 2020 Aggregated for all Aeroplane Operators on each State Pair (1st edition, 2021)
- CORSIA Approved Sustainability Certification Schemes (1st edition, 2020)
- CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (1st edition, 2019)
- CORSIA Emissions Unit Eligibility Criteria (1st edition, 2019)

1 Umbrella document containing the following two documents

ICAO Guidance Documents and Manuals

- CORSIA Central Registry User Manual (2nd edition – 2022)
- Operational Opportunities to Reduce Aircraft Noise (to be published in 2022)
- ICAO Airport Economics Manual (Doc 9562- 4th edition, 2020)
- Procedures for Air Navigation Services - Volume II – Construction of Visual and Instrument Flight Procedures (Doc 8168 - Seventh Edition, 2020)
- Guidance on the Development of States' Action Plans on CO₂ Emissions Reduction Activities (Doc 9988 – 3rd edition, 2019)
- Procedures for Air Navigation Services — Volume I – Flight Procedures (Doc 8168 - Sixth Edition, 2018)
- Procedures for Air Navigation Services -Volume III – Aircraft Operating Procedures (Doc 8168 - First Edition, 2018)
- Airport Planning Manual, Part 2 - Land Use and Environmental Management (Doc 9184 - 4th Edition, 2018)
- Recommended Method for Computing Noise Contours around Airports (Doc 9911- 2nd edition, 2018)
- Transforming Global Aviation Collection: Sustainable Aviation Fuels Guide, Version 2 (2018)
- Transforming Global Aviation Collection: Renewable Energy for Aviation (2017)
- Transforming Global Aviation Collection: Financing Aviation Emissions Reductions (2017)
- Transforming Global Aviation Collection: Regulatory and Organizational Framework to Address Aviation Emissions (2017)
- Global Air Navigation Plan for CNS/ATM Systems (Doc 9750 – 5th edition, 2016)
- Tariffs for Airports and Air Navigation Services (Doc 7100, 2016)
- Operational Opportunities to Reduce Fuel Use and Reduce Emissions (Doc 10013 - 1st Edition, 2014)
- Guidance on the Balanced Approach to Aircraft Noise Management (Doc9829 - 3rd Edition, 2014)
- Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes (Doc 10031, 1st edition, 2014)
- ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082 – 9th edition, 2012)
- Airport Air Quality Manual (Doc 9889 – 1st edition, 2011)
- Continuous Descent Operations (CDO) Manual (Doc 9931 – 1st edition, 2010)
- Guidance on the Use of Emissions Trading for Aviation (Doc 9885 – 1st edition, 2008)
- Guidance on Aircraft Emission Charges Related to Local Air Quality (Doc 9884 – 1st edition, 2007)

Reports

- Overview of 2021 ICAO Seminar on Green Airports - Innovation and Technology at Sustainable Airports (to be published in 2022)
- Report on the feasibility of a long-term global aspirational goal for international civil aviation CO₂ emissions reductions (LTAG) (2022)
- Status Report on Noise Technology Research for Fixed Wing Aircraft (2022)
- Assessment Report on impacts of aviation NO_x emissions on air quality, human health and climate (2022)
- Assessment Report on fuel composition effects on nvPM emissions (2022)
- Assessment Report on the potential environmental impacts from supersonic aircraft (2022)
- White Paper on non-acoustic factors in community annoyance (2022)
- Final Report of the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft (Doc 10127 – 2019)
- Promoting Synergy Between Cities and Airports for Sustainable Development (2018)
- Report by the Second CAEP Noise Technology Independent Expert Panel (Doc 10017 – 2014)
- Final Report of the Independent Expert Operational Goals Group (IEOGG) (Doc 10021, 2014)
- Report on Environmental Management System (EMS) Practices in the Aviation Sector (Doc 9968 – 1st edition, 2012)

- Report of the High-level Meeting on International Aviation and Climate Change (Doc 9929, 2010)
- Report to CAEP by the CAEP Noise Technology Independent Expert Panel. Aircraft Noise Technology Review and Medium and Long Term Noise Reductions Goals (Doc 9943, 2010)
- Report on Voluntary Emissions Trading for Aviation (VETS Report) (Doc 9950, 2010)
- Report of the Independent Experts to CAEP/8 on the Second NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x (Doc 9953, 2010)
- Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction from Technology (Doc 9963, 2010)
- Independent Experts NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x (Doc 9887, 2008)

CAEP Reports

- Report of the Committee on Aviation Environmental Protection, Twelfth Meeting Montréal, 7 – 17 February 2022 (Doc 10176, CAEP/12)
- Report of the Committee on Aviation Environmental Protection, Eleventh Meeting Montréal, 1 – 12 February 2016 (Doc 10126, CAEP/11)
- Report of the Committee on Aviation Environmental Protection, Tenth Meeting Montréal, 1 – 12 February 2016 (Doc 10069, CAEP/10)
- Report of the Committee on Aviation Environmental Protection, Ninth Meeting Montréal, 4 – 15 February 2013 (Doc 10012, CAEP/9)
- Report of the Committee on Aviation Environmental Protection, Eighth Meeting Montréal, 1 – 12 February 2010 (Doc 9938, CAEP/8)
- Report of the Committee on Aviation Environmental Protection, Seventh Meeting Montréal, 5 – 16 February 2007 (Doc 9886, CAEP/7)
- Report of the Committee on Aviation Environmental Protection, Sixth Meeting Montréal, 2 – 12 February 2004 (Doc 9836, CAEP/6)
- Report of the Committee on Aviation Environmental Protection, Fifth Meeting Montréal, 8-17 January 2001

ICAO Environmental Reports

- ICAO Environmental Report, 2019
- ICAO Environmental Report, 2016
- ICAO Environmental Report, 2013
- ICAO Environmental Report, 2010
- ICAO Environmental Report, 2007

Studies

- Scoping Study on the Application of Emissions Trading and Offsets for Local Air Quality in Aviation, First edition, 2011 (Doc 9948 – 1st edition, 2011)
- Scoping Study of Issues Related to Linking “Open” Emissions Trading Systems Involving International Aviation, 2011 (Doc 9949 – 1st edition, 2011)
- Offsetting Emissions from the Aviation Sector (Doc 9951 – 1st edition, 2011)
- Noise Abatement Procedures: Review of Research, Development and Implementation Projects - Discussion of Survey Results (Doc 9888 – 1st edition, 2010)

Feasibility Studies

- Feasibility Study on the use of Solar Energy at Piarco International Airport – Trinidad and Tobago (2018)
- Feasibility Study on the use of Sustainable Aviation Fuels – Burkina Faso (2018)
- Feasibility Study on the use of Sustainable Aviation Fuels – Kenya (2018)
- Feasibility Study on the use of Sustainable Aviation Fuels – Dominican Republic (2017)
- Feasibility Study on the use of Sustainable Aviation Fuels – Trinidad and Tobago (2017)

ICAO Circulars

- Community Engagement for Aviation Environmental Management (Cir 351, 2017)
- Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions (Cir 317, 2008)

ICAO E-Publications

- Guidance on Potential Policies and Coordinated Approaches for the Deployment of Sustainable Aviation Fuels (to be published in 2022)
- Report on Environmental Metrics of Relevance to the Global Aviation System (to be published in 2022)
- Report on Climate Change Risk Assessment, Adaptation and Resilience (to be published in 2022)
- Report on the Investigation on Possible Indicators for Encroachment (to be published in 2022)
- [Aviation Green Transition Chartering a path to sustainable flying future](#) (2021)
- [Innovation Driving Sustainable Aviation](#) (2021)
- [Eco-Airport e-collection](#): Waste Management at Airports
- [Eco-Airport e-collection](#): An Environmental Management System for Airports
- [Eco-Airport e-collection](#): A Focus on the production of renewable energy at the Airport site
- [Eco-Airport e-collection](#): Eco-Design of Airport Buildings
- [Eco-Airport e-collection](#): Sustainable Considerations for Airport Surface Access
- [Eco-Airport e-collection](#): Climate Resilience
- [Eco-Airport e-collection](#): Water Management
- [Eco-Airport e-collection](#): Air Quality Management
- [Environmental Community Engagement for Performance-Based Navigation](#)
- [Climate Adaptation Synthesis](#)
- [Monthly CORSIA Newsletter](#)



| ICAO

SPECIAL SUPPLEMENT

Long-Term Aspirational Goal

Overview of Climate Goals and ICAO's Work on a Long-Term Aspirational Goal for International Aviation (LTAG)

By ICAO Secretariat

Introduction

The 2010 International Civil Aviation Organization Assembly adopted the existing global aspirational goals for the international aviation sector of 2% annual fuel efficiency improvements and carbon neutral growth from 2020. The establishment of these global goals changed the shape and the pace of the aviation response to climate change. Since then, much has happened in the aviation industry with regards to climate change action, with multiple commitments for further action from ICAO Member States and industry partners. This special supplement provides an overview of the current aviation goals related to climate, and describes the ICAO's work on the feasibility of a long-term global aspirational goal for international aviation (LTAG).

scientific findings and in support of the 1.5°C temperature goal, in 2021 the aviation industry had further raised their level of ambition and collectively committed to achieve net-zero carbon emissions by 2050¹. This would be supported by accelerated efficiency measures, energy transition, and innovation across the aviation sector and in partnership with governments around the world.

Several ICAO Member States have also committed towards the decarbonization of aviation, including 39 ICAO Member States which are signatories of the “International Aviation Climate Ambition Coalition”², and 37 Member States (27 EU Member States and 10 other Member States of the European Civil Aviation Conference (ECAC)), which are the signatories of the “Toulouse Declaration” in support of the goal of carbon neutrality in the air transport sector by 2050³.

Commitments by States and Industry

In 2009, the world's major aviation industry associations, including the Airports Council International (ACI), the Civil Air Navigation Services Organization (CANSO), the International Air Transport Association (IATA), the International Business Aviation Council (IBAC), and the International Coordinating Council of Aerospace Industries Associations (ICCAIA) announced their collective commitment to reduce aviation carbon emissions by 50 per cent by 2050 compared to 2005 levels. In light of recent

LTAG overall process

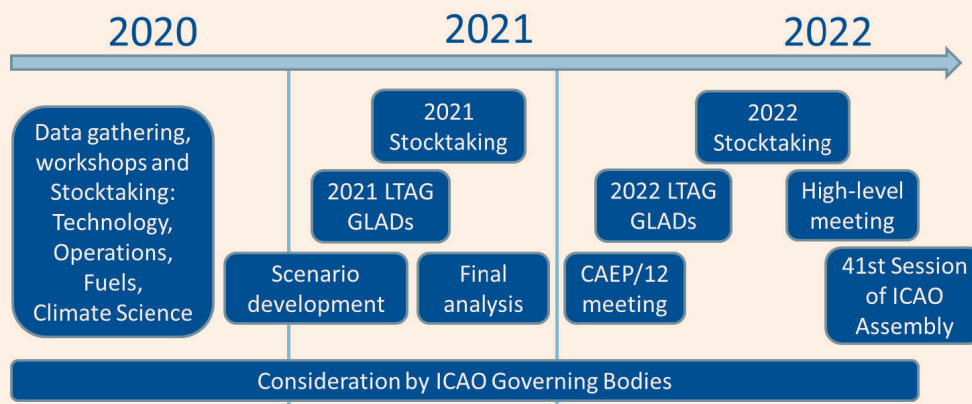
Following the request of the 40th ICAO Assembly in 2019 and in line with that momentum on climate change action, ICAO made dedicated efforts to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation, including data collection and information sharing; technical assessment of aviation CO₂ emissions reduction scenarios with analyses of costs and necessary investments; consultation and dialogues among stakeholders; and

1 Commitment to Fly Net Zero: <https://aviationbenefits.org/FlyNetZero>

2 International Aviation Climate Ambition Coalition: COP 26 declaration: International Aviation Climate Ambition Coalition - GOV.UK (www.gov.uk)

3 Toulouse Declaration: <https://presidence-francaise.consilium.europa.eu/en/news/european-aviation-summit/>

ICAO LTAG process and timeline



engagement of high-level representatives to facilitate decision. The overall ICAO process and timeline related to LTAG during the triennium is illustrated in the Figure above.

Data Collection and Information Sharing

As part of the ICAO LTAG work, the 2020 and 2021 ICAO Stocktaking events were convened in September 2020⁴ and September 2021⁵, respectively, for data collection and information sharing on aviation in-sector CO₂ emissions reductions. Further details on the Stocktaking Events are provided in article “ICAO Stocktaking on Aviation in-sector CO₂ Emissions reductions” in Chapter 4 of ICAO Environmental Report 2022.

Additionally, with a view to providing one single source of information that is frequently updated to access all the latest CO₂ reduction innovations for aviation, ICAO developed a series of Tracker Tools⁶. They provide the latest information on aviation CO₂ emissions reduction initiatives, and are updated from three streams – technology, operations and fuels, as well as on aviation net zero initiatives. Further information on these trackers are provided in article “ICAO Aviation CO₂ Reduction Initiative Trackers” in Chapter 4 of ICAO Environmental Report 2022.

The ICAO CAEP LTAG Report

Over the last two years, the ICAO Committee on Aviation Environmental Protection (CAEP) undertook its technical work on the feasibility study on LTAG. It has focused on the attainability and readiness of aviation in-sector CO₂ reduction measures, including innovative aircraft technologies, operations and fuels, as it would be necessary to assess the in-sector CO₂ reduction potentials before considering the need and extent of any complementary measure.



The LTAG report, which was unanimously approved at the CAEP/12 meeting in February 2022, consolidates cumulative efforts of over 280 experts over nearly 2 years of intensive work. The LTAG report is available on the ICAO website⁷, and includes scenarios that highlight the potential for substantial CO₂ reductions from innovative aircraft technologies, operations, and fuels, with the assessment of required costs and investments. More details on the LTAG report and its results are provided in the following articles of this special LTAG supplement to ICAO Environmental report 2022.

4 2020 Stocktaking website: <https://www.icao.int/Meetings/Stocktaking2020/Pages/default.aspx>

5 2021 Stocktaking website: <https://www.icao.int/Meetings/Stocktaking2021/Pages/default.aspx>

6 ICAO Tracker Tools website: Aviation CO₂ emissions reduction initiatives - Tracker Tool ([icao.int](https://www.icao.int))

7 ICAO LTAG report website: <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx>

LTAG consultative process

As part of the consultative process on LTAG among ICAO Member States and stakeholders, ICAO organized the LTAG Global Aviation Dialogues (GLADs) as a series of five regional events held both in May 2021⁸ and March/April 2022⁹. The goals and objective so of these events were to share information and raise awareness on the LTAG process and technical analyses, as well as to allow for the exchange of views and expectation to facilitate further LTAG work and decision-making.

The GLADs supported the well-informed deliberations at the High Level Meeting on LTAG (HLM-LTAG), held in July 2022 (more details on HLM-LTAG are provided in a dedicated article “High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO2 emissions reductions” of this special supplement. The GLADs participants also exchanged views on possible building blocks for LTAG considerations, such as: scientific

understanding and context, expected potential contribution of technology, operations and fuels, and the level of LTAG ambition. The participants also discussed on possible means of implementation, expected support to ICAO Member States with action plans, roadmaps, and ways of monitoring progress (more details on GLADs are provided in the a dedicated article “Global Aviation Dialogues (GLADs)” of this special supplement).

Conclusion

Aviation is moving to address its responsibilities on the climate crisis. ICAO is steadily following up on these developments, with the extensive work associated with the feasibility of a long-term global aspirational goal for international aviation. The LTAG deliberations at the ICAO 41st Assembly will be of crucial importance to consolidate the aviation’s efforts towards decarbonization.

8 2021 GLADs website: <https://www.icao.int/Meetings/2021-ICAO-LTAG-GLADS/Pages/default.aspx>

9 2022 GLADs website: <https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Pages/default.aspx>

CAEP Report on the Feasibility of a Long-Term Aspirational Goal for International Civil Aviation CO₂ Emissions reductions (LTAG)

By Hajime Yoshimura (Japan), Michael Lunter (the Netherlands) and Mohammed Habib (the Kingdom of Saudi Arabia)¹

Introduction

The 40th Session of the ICAO Assembly in October 2019 requested the Council to explore the feasibility of a long-term global aspirational goal (LTAG) for international aviation for consideration by its 41st Session (Resolution A40-18, paragraph 9). The CAEP LTAG Task Group (LTAG-TG) was established in March 2020 with the agreement of the ICAO Council to provide technical support to the Council in exploring the feasibility of a LTAG.

CAEP LTAG-TG undertook:

- **data gathering** from internal and external sources in a transparent and inclusive manner,
- **development of combined in-sector scenarios** from technology, fuels, and operations that represent a range of readiness and attainability based on the data gathering, and
- **conducted final analysis** of the scenarios to understand those **impacts on CO₂ emissions** and **cost associated with the scenarios** and **economic impacts on aviation growth, noise and air quality**, in all countries especially developing countries and the results was placed **in context of the latest consensus scientific knowledge**.

The final report from CAEP consolidates cumulative efforts of over 280 experts and provides a technical assessment of the feasibility of an LTAG.

Methodology: Overview

Figure 1 illustrates the overall methodology used for the LTAG feasibility study. The LTAG feasibility study started from the Data Gathering process, embracing Aircraft Technology, Operations and Fuels areas, which contributed to each element of the Integrated Scenarios.

On the Economic Modeling and Traffic Forecast, the Fleet Evolution was evaluated, which was fed into the CO₂ emissions modeling. Additionally, the consensus scientific knowledge on climate change formed the basis and context for the output of the analysis.

The detailed results from each subgroup of LTAG-TG will be covered in a separate subsequent articles and will cover:

- CO₂ Emissions Trends;
- Cost and Investment Estimations;
- Additional Analyses results, such as sensitivity analyses, for example;
- Results on Aviation in Context of Scientific Knowledge.

¹ Hajime Yoshimura (Japan Civil Aviation Bureau), Chairperson of the Long-Term Aspirational Goal Task Group of the ICAO CAEP, and Michael Lunter (Ministry of Infrastructure and Water Management, the Netherlands) and Mohammed Habib (Delegation of The Kingdom of Saudi Arabia on the Council of ICAO), LTAG-TG Vice-Chairpersons would like to acknowledge the invaluable contribution of the 287 members of the Long-Term Aspirational Goal Task Group.

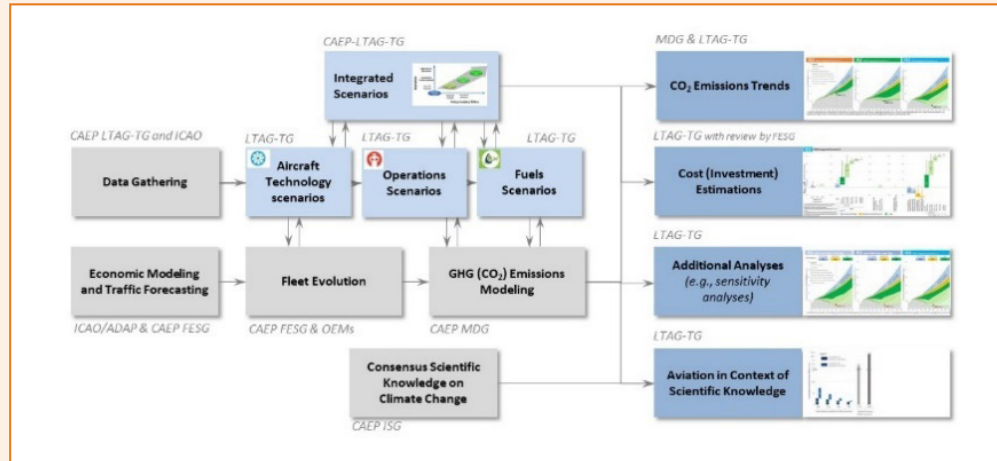


FIGURE 1: Overall Methodology used for the LTAG feasibility study

LTAG integrated scenarios

The LTAG analysis is not aimed at forecasting future emissions trends in aviation but is explicitly a scenario-based analysis. A set of scenarios (Integrated Scenarios) were developed to represent the level of effort and aspiration needed with the degree of readiness and attainability (Figure 2). With the baseline scenario numbered as zero, the Integrated Scenario 1 (IS1) represents the pathway with highest readiness level and attainability but with the lowest aspiration. While Integrated Scenario 3 (IS3) offers the highest aspiration, but requires greater efforts to attain. The Integrated Scenario 2 (IS2) is the middle path between scenarios 1 and 3.

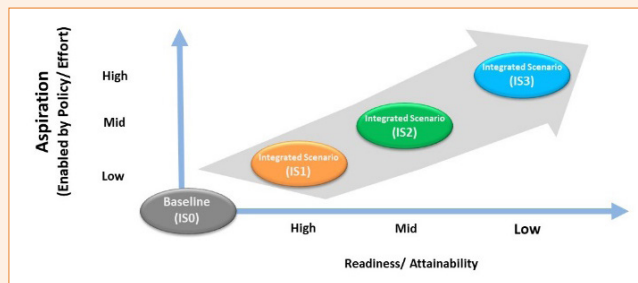


FIGURE 2: Integrated scenarios

Question 1: How could in-sector measures (i.e., technology, operations, and fuels) help reduce CO₂ emissions from international aviation through 2050 and beyond?

In terms of CO₂ emissions in 2050 taking into account reductions from aircraft technology, operations, and fuels, CO₂ emissions could reach from 950 MtCO₂ for IS1, to 200 MtCO₂ for IS3, equivalent to a 39–87% reduction

from the baseline scenario. In terms of a breakdown, the fuels part is the biggest with 15–55% range, followed by the technology with around a 20% share, and with operations ranging from 4 to 11% (Figure 3).

For your reference, the cumulative residual CO₂ Emissions from 2020 to 2070 are also provided. These are the following points with regard to the high-level observations from the LTAG analysis:

- Scenarios show the potential for substantial CO₂ reduction, however none of them reach zero CO₂ emissions using in-sector measures only.
- There will be residual emissions despite 100% replacement of conventional jet fuel with novel fuels, due to consideration of fuels' life cycle emissions.
- As other aspects of economies reduce their emissions, the life cycle value should drop as well.
- As per the LTAG Terms of Reference, out of sector measures were not considered in the LTAG-TG analysis.

Advanced tube and wing aircraft have a clear potential to improve the fuel and energy efficiency of the international aviation system with some incremental contribution from aircraft with unconventional configurations.

The technology wedge continues to grow after 2050 as these aircraft penetrate the fleet. Hydrogen powered aircraft would exhibit worse energy efficiency, relative to aircraft operating on drop-in fuels, noting that emissions reductions would come from life cycle emissions reductions from the hydrogen.

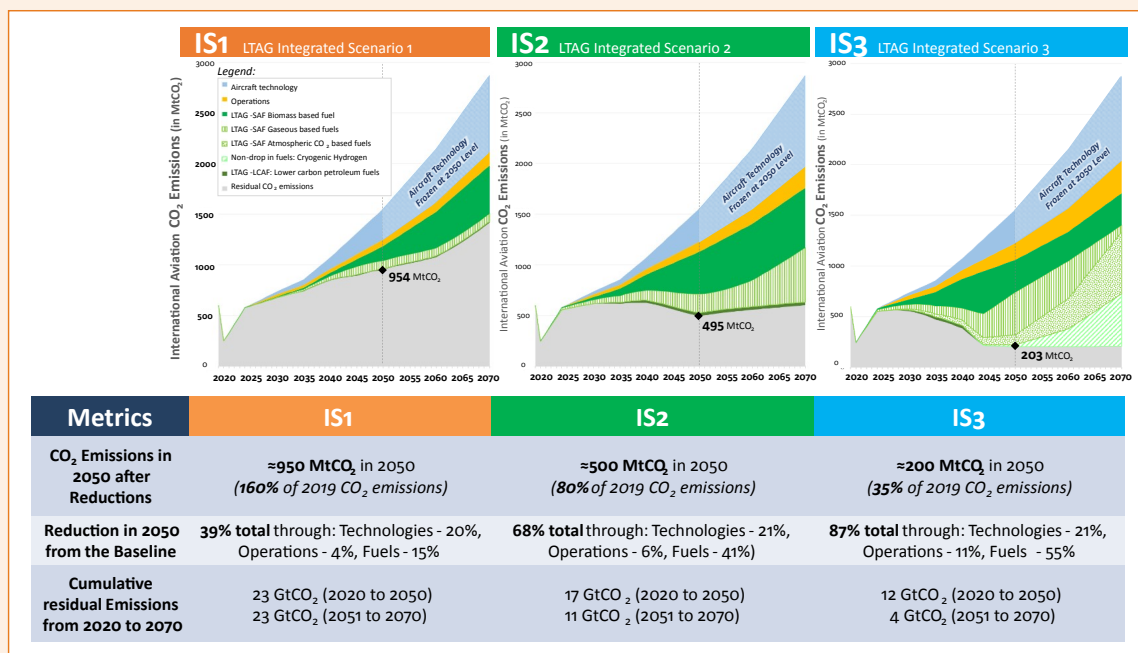


FIGURE 3: Reductions in CO₂ emissions from international aviation through in-sector measures through 2050 and beyond

The overall traffic growth rate has an important impact on residual CO₂ emissions by 2050 and after.

The analysis shows there are opportunities for operations to reduce CO₂ emissions through improvements in the performance of flights across all phases of flights, including unconventional measures such as formation flying.

Drop-in fuels have the largest impact on residual CO₂ emissions driving overall reductions by 2050, being independent—to some extent—of technology and operations scenarios.

Hydrogen is not expected to have a significant contribution by 2050 (with only 1.9% of energy share in 2050) but may increase in the 2050s and 2060s if technically feasible and commercially viable.

Question 2: How do cumulative aviation emissions compare to requirements to limit the global temperature increase to 1.5°C and 2°C?

Estimated cumulative residual global anthropogenic CO₂ emissions from the start of 2020 to limit global warming to 1.5°C is 400 GtCO₂ at 67% probability, i.e. the international aviation share could be around 4.1 to 11.3 % of this total.

For a warming limit of 2°C, the remaining allowed global carbon emissions are estimated to be 1150 GtCO₂ at 67% probability, i.e. the international aviation share could range from 1.4 to 3.9% of this total.

Question 3: What investments are required to support the implementation of the in-sector measures associated with each scenario?

Costs and investments associated with the three scenarios are largely driven by fuels. Incremental costs of fuels (i.e. minimum selling price of SAF compared to conventional jet fuels) further motivates fuel and energy efficiency improvements from aircraft technology and operations. Aircraft technology and operational measures will require investments from governments and industry. More details on placing costs associated with LTAG Integrated Scenarios in context are provided in a dedicated article of this special supplement.

Question 4: What would be the impacts of various future aviation traffic levels?

Figure 4 provides CO₂ emissions in 2050 after the implemented emissions reductions from technology, operations and fuels. After 2050, the uncertainty grows

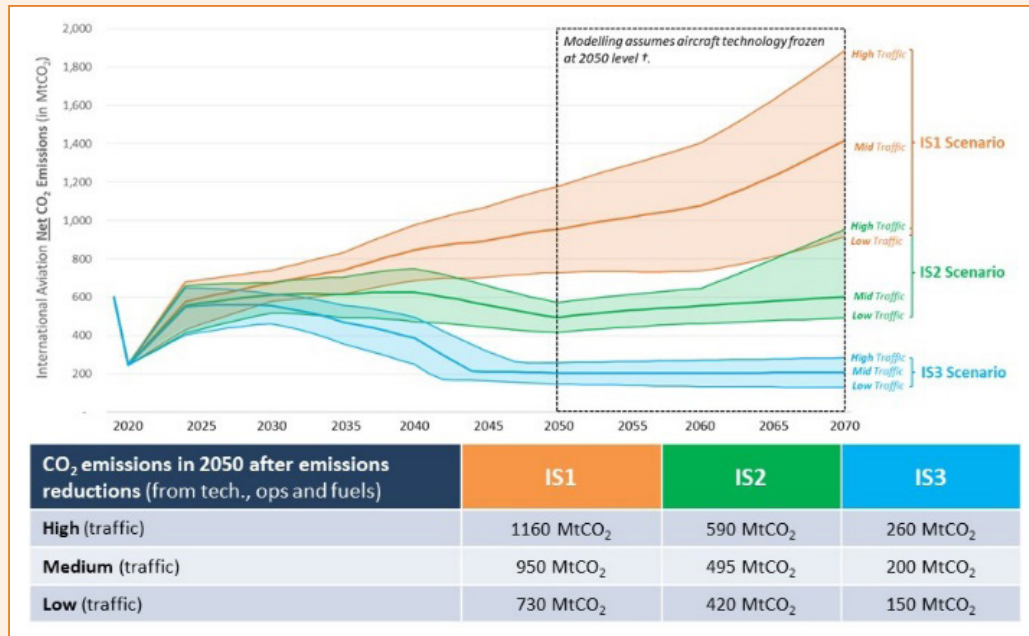


FIGURE 4: Impact of Aviation Traffic Forecast

towards 2070, with an increasing range between high, mid and low options within the scenarios. The table at the bottom shows the CO₂ emissions remaining in 2050 following the implementation of the reduction measures.

Question 5: How sensitive are the results to scenario assumptions?

In developing the integrated scenarios, LTAG-TG recognised that there could be multiple combinations of technology, operations and fuels measures to form alternative integrated scenarios. In particular, sensitivity analysis was conducted to examine the impact of lower technology and operations improvements, coupled with high reductions from fuels.

This shows that there are multiple paths that may result in similar levels of emissions. However, in all cases, the contribution from fuels is critical to decouple the growth in international air traffic from its emissions.

Considerations regarding LTAG Options

Based on the results of the LTAG feasibility study, technical options for LTAG metrics were identified. This is not an exhaustive list and other formulations may be considered.

One type of option could use annual levels of emissions:

- The annual level of emissions, for example: 950, 500 or 200 Mt CO₂ in 2050.
- Using a reference year earlier than 2050 may not give the long-term certainty expected to be a key benefit of adopting an LTAG, while using a reference year after 2070 would be subject to increased uncertainty.
- Additional intermediate waypoints in milestone years could layout a trajectory to the emissions profile.

Another option could use cumulative total emissions:

- The cumulative total emissions from the international aviation sector: for example 23, 17 or 12 GtCO₂ by 2050.
- This would most closely translate into an atmospheric temperature response.

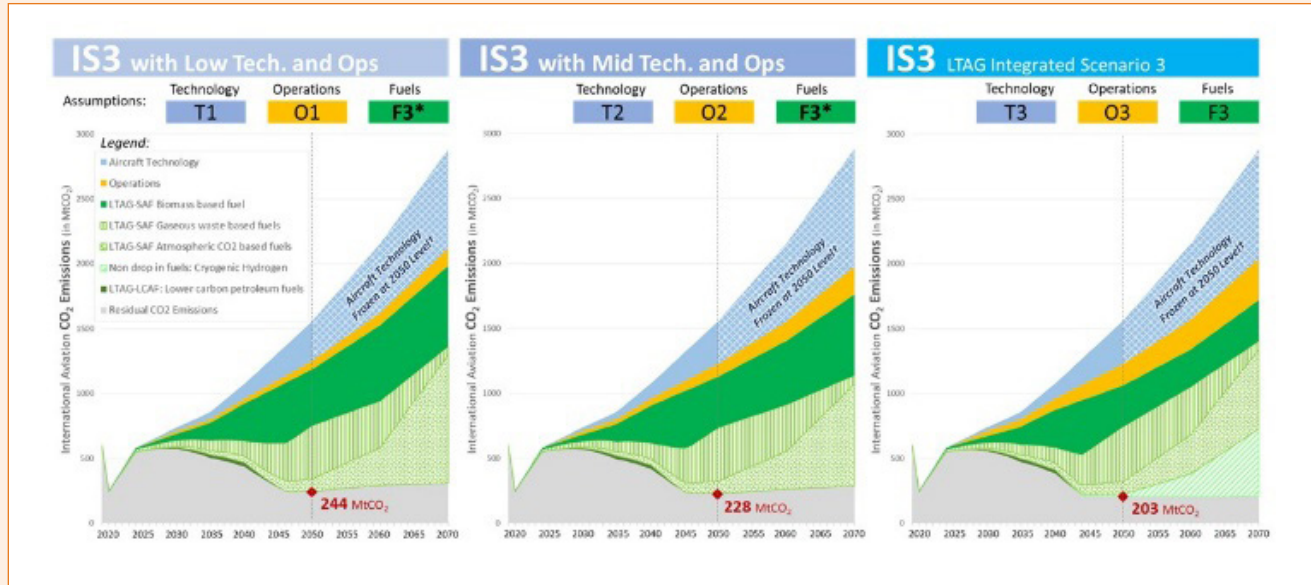


FIGURE 5: Sensitivity analysis of IS3 Scenario demonstrates the importance of fuels

Other impacts

The LTAG analysis also included consideration of the other impacts. Potential impacts on aviation growth were qualitatively considered, finding that an LTAG may increase operating costs and some costs may be passed on to passengers. This impact may be limited, however, and aviation will continue to deliver national, regional and global benefits.

Most significant regional variations are expected in production and uptake of fuels due to, for example, regional availability of feedstocks, renewable energy, and infrastructure.

With regard to the impacts on noise and air quality, in all scenarios, the traffic growth increased total noise and NOx emissions.

However, technology improvements typically reduced noise and emissions alongside fuel burn. Additionally, operational efficiencies may have co-benefits for noise but did not impact air quality. Another observation is that LTAG SAF and cryogenic hydrogen have co-benefits, for local air quality and contrail formation with no impact on noise.

Roadmaps for LTAG Implementation

On roadmaps, CAEP considered technical aspects of implementation without prejudging any future decisions. For monitoring of progress, State Action Plans may be used for States to report progress towards a goal, without duplicating existing processes.

If a goal were adopted, CAEP could conduct future work on possible metrics, reporting mechanisms, etc.

ICAO may need to review any goal to ensure it remains appropriate. For this purpose, a triennial review process could be considered similar to the CORSIA Periodic Review, for example. Finally, capacity building and assistance may be needed, for example:

- Workshops on measures, including understanding costs;
- Assistance on monitoring and measuring CO₂ emissions;
- An overarching training programme similar to ACT-CORSIA.

LTAG Assessment from a Technology Perspective

By Dimitri Mavris (USA), Wendy Bailey (Canada)¹

Introduction

At the 40th Session of ICAO Assembly in Montreal, Canada, in 2019, the ICAO Council was asked to explore the feasibility of a global long-term aspirational goal (LTAG) for the reduction of carbon dioxide emissions from international aviation. The ICAO Committee on Aviation Environmental Protection established the LTAG Task Group in 2020 for this purpose. The Technology Subgroup was formed under the Task Group to assess the feasibility, readiness and attainability of technology improvements that could contribute to in-sector CO₂ reductions, and to quantify the reductions where possible.

Specifically, the Technology Subgroup assessed the potential of evolutionary technologies for airframes and propulsion systems, as well as revolutionary technologies such as non-drop-in energy sources and new aircraft configurations up to 2050.

The methodology introduced in the 2019 Independent Expert Integrated Review (IEIR) report² was utilized as a starting point for the Technology Subgroup's work, although there were differences in scope and timeline. The IEIR methodology focused on the interdependencies between noise, emissions, and CO₂, whereas the LTAG methodology focused on carbon dioxide emissions only. While the IEIR projections went to 2037, the Technology Subgroup extended projections to 2050 based on new technologies assessed by the Airframe, Propulsion and Advanced Concepts and Energy Storage ad hoc groups. However, to give the 2050 vehicles enough time to enter the market and have a measurable impact, the fleet assessment continued until 2070.

From a high-level perspective, the LTAG Technology Subgroup methodology involved four main steps: creation of Technology Representative Aircraft for several classes of aircraft, assessment of advanced tube and wing (ATW), assessment of advanced concept aircraft (ACA), and generation of information for the fleet-wide modeling and cost assessment.

Technology Scenarios

The Technology Subgroup identified three different technology scenarios based on technology advances for the aircraft and the infrastructure changes needed. In the first Technology Scenario (T1), only ATW aircraft would be available, and no infrastructural changes are required. In this scenario, conventional aircraft continue to improve, suggesting incremental changes in CO₂ emissions. Revolutionary concepts with the potential of introducing step changes are included under the next two scenarios. Under the second scenario (T2), in addition to introducing ATWs, unconventional airframe/propulsion concept aircraft that require limited infrastructural changes also become available. Concepts such as the truss-braced wing, boxed-wing, hybrid/blended wing bodies and unducted fans could be grouped here, as well as mildly hybrid electric aircraft. The option of non-drop-in fuels (hydrogen and battery electric) appears in the third (most ambitious) scenario (T3), as these concepts require major infrastructural changes to operate.

¹ The co-Leads Dimitri Mavris (Georgia Institute of Technology, USA) and Wendy Bailey (Transport Canada) would like to acknowledge the invaluable contribution of the 102 members of the Long-Term Aspirational Goal Task Group's Technology Subgroup.

² "Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft", ICAO Doc 10127, 2019. https://www.icao.int/environmental-protection/Pages/ClimateChange_TechGoals.aspx

Technology Reference Aircraft (TRA)

Using four conventional technology reference aircraft for a Business Jet (BJ), Regional Jet (RJ), Narrow Body (NB) and Wide Body (WB), the Technology Subgroup found it necessary to add a turboprop reference aircraft to serve as a foundation for studying alternative energy sources. With guidance from the International Coordinating Council of Aerospace Industries Association (ICCAIA), notional aircraft were selected for each category. These reference aircraft represent the state-of-the-art airplanes in production in 2018. The major aircraft classes, their seat capacities, and their notional reference aircraft are listed in Table 1.

Aircraft Class	Number of Seats	Notional Aircraft
Business Jet	≤20	G650ER
Turboprop	20–85	DHC Dash 8-400
Regional Jet	20–100	E190E2
Narrow Body	101–210	A320neo
Wide Body	>210	A350-900

TABLE 1: Technology Reference Aircraft by Aircraft Class

Assessment Processes

To frame the assessment of the ATWs and the ACAs for this study, the metric of interest was defined as energy intensity (change in energy consumption per unit of transport (MJ/ATK)) because it is independent of the fuel being used. This allows an easy way to compare both conventional and unconventional concepts regardless of their energy source. The uncertainties around potential performance improvements of ATWs and ACAs were captured through a three-point confidence estimation. At each timeframe, the performance improvements were estimated through three technology progress levels: lower, medium and higher.

The modeling approach for the ATW assessment used by the Technology Subgroup assessed and quantified the performance improvement of ATW for the 2030, 2040 and 2050 timeframes. Once the TRAs were selected, aircraft models were generated using the Environmental Design Space (EDS)³ and used as the baselines to which future technologies (propulsion, system, structures/materials and

aerodynamic technologies) were applied. The impacts of these technologies were then identified for the milestone timeframes for each aircraft class at three technology progress levels (lower/medium/higher) and subsequently, through the modelling and simulation tool, for each vehicle class. The vehicle level benefits were quantified with respect to the corresponding 2018 TRA.

The ACA assessment for revolutionary technologies however, required a methodology that was based on previous credible studies because the inherent uncertainties related to ACA development did not justify the use of overly precise models. The ACA assessment began with a comprehensive search of all possible ACAs in literature through published authoritative studies and information from ICAO Stocktaking Events. Concepts were qualitatively evaluated based on potential benefits to carbon emissions reductions, and technical and non-technical barriers were identified. Subject matter experts evaluated readiness, attainability, and potential benefits of these aircraft concepts. Unlike ATWs, ACAs suggest step changes in performance. The quantification of these step changes is primarily based on the publicly available authoritative studies from research organizations. The vehicle-level benefits were estimated compared to the same-year ATW at lower/medium/higher technology progress levels. Because the ACAs were considered to be at early stages of their design processes, the earliest entry into service year was projected as 2035.

Results

The assessment processes explained previously were performed for each of the five aircraft classes. All the classes exhibited similar trends and progress, with slightly different magnitudes of improvement over time. Table 2 shows the energy intensity changes for the medium progress level only. The changes in the energy intensities of future aircraft were calculated relative to TRAs. The TRAs are represented by 100%, and the energy intensity changes of ATWs and ACAs are either above or below 100%. For all ATWs, continuous but incremental improvement in energy intensity is expected. The earliest projected entry-into-service (EIS) year for ACAs is 2035. For WB, the EISs

³ Kirby, M. and Mavris, D., "The Environmental Design Space," 26th International Congress of the Aeronautical Sciences, Anchorage, Alaska, 14–19 September 2008.

Aircraft Class	2018 TRA	Tech Scenario	Advanced Tube and Wing			Tech Scenario	Advanced Concept Aircraft		
			2030	2040	2050		2035	2040	2050
Turboprop	100%	T1	88.0%	82.2%	79.2%	T2	76.5%	-	71.3%
						T3	85.1%	-	79.2%
Regional Jet	100%	T1	93.5%	85.9%	82.2%	T2	80.6%	-	73.9%
						T3	103.0%	-	94.5%
Narrow Body	100%	T1	89.2%	81.1%	75.8%	T2	76.6%	-	68.2%
						T3	97.8%	-	87.2%
Wide Body	100%	T1	90.6%	78.0%	72.2%	T2	-	70.2%	65.0%
						T3	-	-	72.2%
Business Jet	100%	T1	90.5%	84.8%	80.1%	T2	83.2%	-	76.1%
						T3	-	89.0%	84.1%

TABLE 2: Energy Intensity Changes Relative to 2018 TRAs for All Classes (Medium Progress)

for T2 and T3 aircraft are later than other classes. It was decided that the NB or RJ would serve as a pathfinder for such technologies and then these technologies would be applied to WB. For BJ T3 aircraft, however, the EIS year has a five-year lag because flex-fuel concept is at an earlier stage in its development. Comparing the ATW values with ACA values, it can be seen that ACAs suggest step changes in performance. Similar to ATWs, ACAs are also expected to make steady improvements after they enter the market. While T2 aircraft will most likely have less energy intensity to perform the same missions, T3 aircraft may require more energy and may not fly as far as the TRA. This is due to the potential increase in aircraft size and/or weight. This increase may not be considered as a drawback if it allows a significant carbon emissions reduction through the use of cleaner energy.

Key Findings

Potential improvements for ATWs in smaller categories such as TP, BJ and RJ are lower than those of larger aircraft (NB and WB). This is due to lower benefits achievable via technology infusions and to the shorter mission ranges. It was found that CO₂ reductions may be feasible in the ranges of approximately 30 to 40% in 2050, relative to 2019.

ACAs were considered to be possible by 2035 and onward with near-term applications for smaller aircraft. Larger aircraft will take more time to develop but will have a greater impact on carbon reduction. ACA alternate airframes and propulsion concepts, with or without alternative energy, could happen by 2035 and may yield a 10–15% energy intensity reduction compared to the same year ATWs. It is important to note that alternative energy solutions are highly dependent on the availability of energy infrastructure. Both electrified aircraft propulsion and hydrogen-fueled aircraft are examples of evolutionary and revolutionary technologies that can contribute to CO₂ reductions. However, the carbon reduction possible from electrification is highly dependent on the carbon intensity of the local electrical grid, while the carbon reductions from hydrogen will be highly dependent on the carbon intensity of the production method used for hydrogen.

For long term CO₂ reduction goals to be achieved, the Technology Subgroup's analysis demonstrates that action needs to be taken as soon as possible to accelerate reductions, and that large-scale demonstrations and investments in technology will be required. In the case of non-drop-in energy, substantial changes to the energy infrastructure available to aviation is also required.

LTAG Assessment from a Operations Perspective

By David Batchelor(EU) and Muayyed Al Teneiji (UAE)¹

Introduction

This article highlights the results from the LTAG-TG Operations sub group, which was tasked to identify and evaluate existing, foreseen, and innovative in-sector measures in the area of operations that could potentially contribute to reducing CO₂ emissions from international civil aviation, and to develop and analyse in-sector scenarios of operations that represent a range of readiness and attainability.

LTAG-TG OPS SG Methodology

The methodology established an overall approach based on three phases: data collection, data analysis, and outputs to be delivered subsequently to feed the scenarios development. In addition to these three phases, the sub-group undertook additional work to develop its input to the Sample Problem. This took place after completing the data collection phase and before embarking on the data analysis.

Phase 1 – Data collection: A literature review of the information and data sources on current, foreseen and innovative measures to reduce aviation in-sector CO₂ emissions. Data sources reviewed included both internal ICAO documentation and external ICAO documentation (i.e., ICAO/ENV stocktaking questionnaires, library of documents, videos prepared by the Secretariat, additional information provided to the sub-groups by its Members). Gaps were identified and the required information was found to fill them. All measures identified during the literature review were listed in a master excel spreadsheet, and were then subject to a thorough review to ensure that measures were categorized correctly and that no measures were duplicated.

Many of the measures identified during the data collection phase had been captured in the work undertaken in the CAEP/11 WG2 environmental assessment of the Global Air Navigation Plan – Aviation System Block Upgrades (GANP-ASBU), which had assessed ASBU blocks 0 and 1 in 2019. This data had included operational improvements (OI) for the years 2028, 2038 and 2050 for Horizontal Flight Efficiency (HFE), and CAEP was also considering Vertical Flight Efficiency during the time that feasibility report was being prepared. This previous analysis, which served as the baseline, had created 53 rule of thumb fuel saving benefits to be expected from the generic implementations of 31 operational measures and estimated the expected fuel and CO₂ savings based on the planned implementation plans of ICAO States between 2015 and 2025. Table 1 below lists the 31 operational measures already assessed by CAEP.

<ul style="list-style-type: none"> ✓ Remote Tower ✓ Enhanced MET information ✓ Flexible use of airspace ✓ Flex routes ✓ Free Route Airspace ✓ User Preferred Routings ✓ Space-based ADS-B surveillance ✓ Datalink En-route ✓ Datalink Departure Clearance ✓ FF-ICE Planning Service ✓ Continuous Descent Operations ✓ Continuous Climb Operations ✓ PBN STARs ✓ PBN SIDs ✓ Flight-based Interval management ✓ Ground-based Interval Management ✓ ATFM 	<ul style="list-style-type: none"> ✓ Short-Term ATFCM Measures ✓ Advanced FUA (ATFM / Airspace Management) ✓ RNP-AR approaches ✓ Airport – Collaborative Decision Making ✓ Wake Vortex Re-categorization ✓ Time-Based Separation ✓ Arrival Manager ✓ Extended Arrival Manager ✓ Terminal Flight Data Manager ✓ Advanced – Surface Movement Guidance and Control System ✓ PBN approaches (Radius to Fix) ✓ PBN to xLS approaches ✓ GBAS CAT I/II/III ✓ Multi-segment approaches / glideslopes
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TABLE 1: List of Operational Measures assessed by CAEP

¹ The co-Leads David Batchelor (SESAR 3 Joint Undertaking, EU) and Muayyed Abdulla Al Teneiji (UAE General Civil Aviation Authority) would like to acknowledge the invaluable contribution of the 79 members of the Long-Term Aspirational Goal Task Group's Operations Subgroup.

As a result of its data collection exercise, the OPS sub-group identified a number of operational measures additional to those assessed by CAEP. These additional measures are listed in the Table 2 below.

<ul style="list-style-type: none"> ✓ Dynamic Sectorization ✓ Reduced Extra Fuel On-board ✓ Best Practices in Operations Minimizing Weight ✓ In-Trail Procedure (ITP) ✓ Airline Fuel Management System ✓ Optimized Runway Delivery Support tool and Reduced Pair-Wise Weather Dependent Separation between Arrivals ✓ Electrical Tug Detachable Aircraft Towing Equipment 	<ul style="list-style-type: none"> ✓ Support for Optimized Separation Delivery and Reduced Pair-Wise Weather Dependent Separation between Departures ✓ Formation Flight ✓ Geometric Altimetry and RVSM Phase 2 ✓ Global Air Traffic Flow Management ✓ Satellite Based VHF for oceanic/remote areas ✓ APU Shut Down ✓ MAINTENANCE - difference between maintenance and modification to aircraft, technology related
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TABLE 2: List of Operational Measures considered by CAEP

Phase 2 – Data Analysis: For the data analysis, the same methodology as that was used previously by ICAO CAEP in its assessments of individual operational measures was utilized. This involved the development of so-called “Rules of Thumb” for each individual operational measure not already included in the CAEP Global Air Navigation Plan – Aviation System Block Upgrades (GANP-ASBU) assessment and conduct a detailed analysis of each of these measures. The objective of the “Rule of Thumb” for each measure was to identify its potential contribution to CO₂ emissions reductions.

In addition to determining the potential contributions to CO₂ emissions reductions, the sub group also made estimates of the likely costs associated with implementation of these measures. The summary information is included in the Attachment A of the ICAO LTAG Report Appendix M4².

For the operational measures already assessed by CAEP, the LTAG-TG OPS sub-group updated the baseline to take into account the following sources of inefficiency, and operational measures to address these sources of inefficiency, the final three of which were new and additional to previous work performed:

- **Horizontal flight inefficiency** - the comparison between the length of a trajectory and the shortest distance between its endpoints;
- **Vertical flight inefficiency** - the flight can’t reach its optimum cruising level during the flight nor the flight is kept at a suboptimal flight level during the climb or descent phase;
- **Ground operations inefficiency** - typically infrastructure-related measures that can reduce emissions at taxiway or the gate, i.e. such as semi-autonomous tow-truck (taxibot);
- **Innovative flight inefficiency** - achieved through implementation of new operational measures in the medium term, i.e. notionally from 2038, such as formation flying;
- **Advanced flight inefficiency** - results from the introduction of advanced concept aircraft into the fleet, such as blended wing body (BWB) aircraft. It is possible that these aircraft will have different performance characteristics from conventional aircraft, e.g. in terms of speed, altitude etc.

Phase 3 – Outputs for the LTAG-TG Scenario Development sub-group (SDSG): After development of “Rules of Thumb” for each individual additional operational measure and update of the baseline which was previously established in CAEP, a high-level description of the operations scenarios was prepared. Based on the scenarios fuel savings, readiness level and associated cost related to each individual operational measure were estimated. These outputs were feed into the integrated scenarios developed by the Scenarios Development sub-group (SDSG).

2 https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM4.pdf

LTAG Operations Scenario Descriptions

The LTAG-TG OPS sub-group then prepared a high-level description of the operations scenarios to feed into the integrated scenarios developed by the SDSG. Three scenarios were proposed — conservative, medium, and aggressive. These scenarios were constructed according to different rates at which the five above categories of measures were assumed to be implemented. The three scenarios are summarised here and in Figure 1 below:

Operations Scenario 1 (O1)

O1 represents the low or conservative end of the range of potential CO₂ emissions reductions from operations. In this scenario, there is a low rate of ASBU element deployment to optimise Horizontal Flight Efficiency (HFE), Vertical Flight Efficiency (VFE) and Ground Flight Efficiency (GFE).

Operations Scenario 2 (O2)

O2 represents the middle of the range of potential CO₂ emissions reductions from operations. In this scenario, there is a medium rate of ASBU element deployment to optimise HFE, VFE and GFE, and low rate of operational measure deployment to optimise IFE and AFE.

Operations Scenario 3 (O3)

O3 represents the high or aggressive end of the range of potential CO₂ emissions reductions from operations.

In this scenario, there is a high rate of ASBU element deployment to optimise HFE, VFE and GFE, and medium rate of operational measure deployment to optimise IFE and AFE.

Results and Key Findings

Based on the assumptions on rate and extent of implementation of operational measures for O1, O2 and O3 scenarios fuel efficiency improvements from operational measures were estimated. Figure 2 below shows the average fuel efficiency improvements from operational measures across 2035, 2050 and 2070.

	Operations Scenario 1 (O1)	Operations Scenario 2 (O2)	Operations Scenario 3 (O3)
2035	3%	4.5%	7%
2050	5%	8%	13%
2070	6%	11%	16%

FIGURE 2: Average Fuel efficiency improvements from operational measures across LTAG-TG integrated scenarios

Analysis conducted by LTAG OPS sub group showed that there would be regional variances in implementation of operational measures however; there are opportunities for operations to reduce CO₂ emissions through improvements in the performance of flights across all phases, including unconventional measures such as formation flying.

LTAG-TG Scenarios			
Baseline	O1 Scenario Low CO ₂ reduction from Operations	O2 Scenario Mid CO ₂ reduction from Operations	O3 Scenario High CO ₂ reduction from Operations
No emissions reductions from operations after 2025 (implementation of ASBU blocks 0 and 1)	Conservative assumptions about rate and extent of implementation of operational measures, based on reduced/slower investment in ground and airborne systems and technologies. Low rate of ASBU element deployment to optimize HFE, VFE and GFE.	Emissions reductions and operational efficiencies in line with existing “Rules of Thumb” developed by WG2 and new “Rules of Thumb” developed by LTAG OPS for new measures. Medium rate of ASBU element deployment to optimize HFE, VFE and GFE. Low rate of operational measure deployment to optimize IFE and AFE.	Aggressive assumptions about rate and extent of implementation of operational measures, based on higher/accelerated investment in ground and airborne systems and technologies. High rate of ASBU element deployment to optimize HFE, VFE and GFE. Medium rate of operational measure deployment to optimize IFE and AFE.

FIGURE 1: Summary of LTAG-TG operations scenarios

LTAG Assessment from a Fuels Perspective

By James Hileman (USA) and Matteo Prussi (Italy)¹

Introduction

This article describes this work done by the LTAG-TG Fuels sub group, which was tasked to develop emissions reductions scenarios from the use of different types of fuels up to 2070.

For that, the Fuels sub-group gathered and analysed data from various internal and external sources — in a constant relation with the most relevant stakeholders — which were then used to support the definition of fuel classifications, methodology development, and assessments of readiness and attainability. Based on these definitions, the expert group developed projections of fuel volumes and CO₂ emission reductions for three scenarios with increasing ambition, which represent varying levels of introduction of both drop-in and non-drop-in fuels that could reduce the life cycle GHG emissions from aviation. All the work is described in detail in Appendix M5 of the LTAG report.²

Fuel classification

The assessment considered three high-level fuel categories, as follows:

- Sustainable aviation fuels (LTAG-SAF): drop-in fuels produced from renewable or waste resources;
- Lower carbon aviation fuels (LTAG-LCAF): drop-in fuels produced from petroleum resources, which demonstrates a well-to-wake carbon intensity of <80.1 gCO₂e/MJ (i.e. >10% reduction in life cycle emissions vis-à-vis conventional jet fuel); and,
- Non-drop-in fuels: fuels that require changes to existing and legacy airframes and fueling infrastructure (i.e. electricity and cryogenic H₂). They are not compatible with current aircraft and engine architectures, and have unique safety and performance considerations.

Various types of fuels were included in these three categories, depending on the carbon source in the fuel feedstock; these are described in Table 1.

	Fuel Category	Fuel Name	Carbon source in fuel feedstock
Drop-in fuels	LTAG - Sustainable Aviation Fuels (LTAG-SAF)	Biomass-based fuel	Primary biomass products and co-products
		Solid/liquid waste-based fuels	By-products, residues, and wastes
		Gaseous waste-based fuels	Waste CO/CO ₂
		Atmospheric CO ₂ -based fuels	Atmospheric CO ₂
	LTAG - Lower Carbon Aviation Fuels (LTAG-LCAF)	Lower carbon petroleum fuels	Petroleum
Non drop-in fuels	Non drop-in fuels	Electricity	Not applicable
		Liquefied gas aviation fuels (ASKT)	Petroleum gas, “fat” natural gas, flare gas, and propane-butane gases
		Cryogenic hydrogen	Natural gas, by-products, non-carbon sources

TABLE 1: Fuel categorization

¹ The co-Leads James Hileman (Federal Aviation Administration, USA) and Matteo Prussi (Politecnico di Torino, Italy) would like to acknowledge the invaluable contribution of the 120 members of the Long-Term Aspirational Goal Task Group’s Fuels Subgroup.

² LTAG Report, Appendix M5, Fuels: https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM5.pdf

Description of Fuels scenarios

The Fuels sub group developed a high-level methodology to define three fuel deployment scenarios (F1/F2/F3), to reflect low/mid/high potential levels of emissions reductions, which also represent different levels of readiness and attainability. These fuel deployment scenarios, which are described in Table 2, were developed to be aligned with the corresponding scenarios developed by the Technology and Operations sub groups. For non drop-in fuel, the main input of F1/F2 and F3 were the assessments performed by the TECH group, in terms of technologies penetration. For more details please refer to Appendix M3 of the LTAG report.³

Fuel production analysis

With the defined scenarios, potential fuel volumes and associated emissions reductions were developed for each fuel category. In some of the Scenarios, the combined projected technical production potential for LTAG-SAF and LTAG-LCAF exceeded total expected aviation fuel demand. In order to meet the expected total fuel demand, the volumes of fuels was constrained, and fuel categories prioritised:

- For F1, the scenario prioritization emphasized low cost GHG reduction, and fuels were ordered by minimum selling price (MSP).
- For F2, selection prioritized cost effective GHG reduction, using marginal abatement cost, expressed in \$/kg CO₂ reduced.
- For F3, the emphasis was on maximizing GHG reductions, and the fuel LCA values were used as ordering criterion: the lower the LCA value the higher the prioritization.

Fuels were prioritised according to the above mentioned criteria, until reaching the expected aviation fuel demand or when all projected fuel volumes were exhausted, whichever occurs first. For the latter case, remaining expected aviation fuel demand was met with conventional jet fuel use.

The figure 1 shows the fuel use projections for LTAG-LCAF, LTAG-SAF, cryogenic H₂ (LH2), and conventional jet fuel, based on mid traffic forecasts for each of the F1, F2 and F3 fuel deployment scenarios.

	LTAG-TG Scenarios		
	Fuel Scenario 1 (F1) Low GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)	Fuel Scenario 2 (F2) Mid GHG reduction from Fuels (LTAG-SAF and LTAG-LCAF)	Fuel Scenario 3 (F3) High GHG reduction from Fuels (LTAG-SAF, LTAG-LCAF and non-drop-in fuels)
Scenario Development	Emphasize low cost GHG reduction → select fuels by Minimum Selling Price	Prioritize cost effective GHG reduction → select fuels by Marginal Abatement Cost	Maximize CO ₂ reduction → select fuels by Lifecycle Value
Approved Fuel Use	ASTM Intl approves use of alternative jet fuels at blend levels above 50%.	ASTM Intl approve use of 100% Synthesized Jet Fuel in existing aircraft and engines without any modification.	
Ground Transportation and Electrification	Ground transportation and aviation have level playing field with respect to alternative fuel use.	Electrification of ground transportation leads to increased availability of SAF.	Economy-wide deep decarbonisation. Extensive electrification of ground transportation and widespread availability of renewable energy.
Incentives	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.
Fuel Availability	Using waste gases (CO/CO ₂) and variety of feedstocks (e.g., oilseed cover crops) for LTAG-SAF.	Widespread use of waste gases and increased feedstock availability for LTAG-SAF. SAF production exceeds jet fuel demand	Widespread use of atmospheric CO ₂ for LTAG-SAF and maximum LTAG-SAF feedstock availability. SAF production exceeds jet fuel demand
			Sufficient H ₂ exists to enable use of cryogenic H ₂ fuel in aircraft. Infrastructure developed to enable use of non-drop-in fuels at airports around globe.

TABLE 2: LTAG Fuels scenario descriptions

³ LTAG Report, Appendix M3, Technology: https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM3.pdf

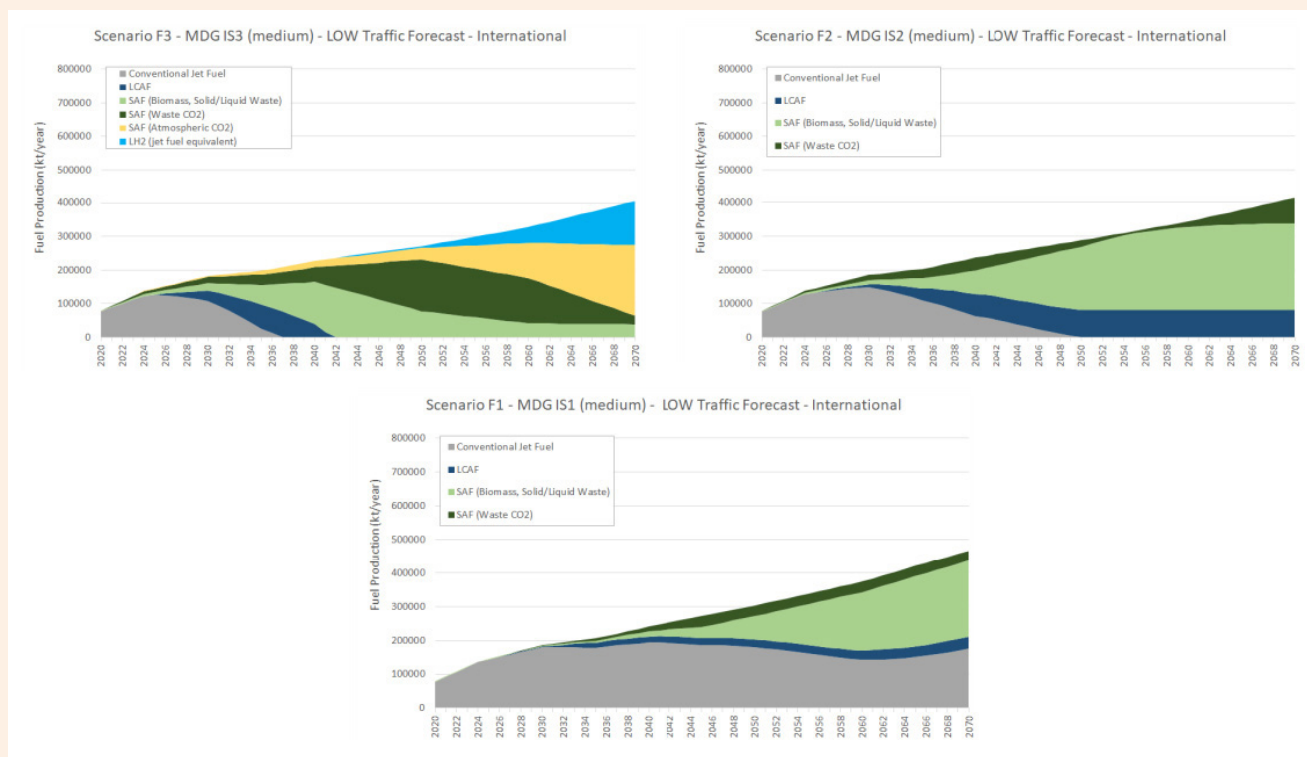


FIGURE 1: Fuel use projections for F1, F2 and F3 based on mid traffic forecasts

Emissions reduction analysis

Based on the fuel production projections for the F1, F2 and F3 fuel deployment scenarios, and the calculated life cycle assessment (LCA) values for each of the fuel categories, the potential GreenHouse Gases (GHG) saving was evaluated. This value was used to determine an overall Emissions Reductions Factor (ERF) for each of the fuel deployment scenarios across 2035, 2050, and 2070, as reflected in Table 4 below. The ERF expresses the perceptual reduction in the GHG emissions, compared to baseline constituted by the conventional fuel; this reflects the effects the use the LTAG-SAF, LTAG-LCAF, and non-drop in fuels, in accordance with projected fuel volumes and aviation fuel demand.

Key findings

The analysis carried out shows that the technical potential for the LTAG-SAF may exceed aviation demand for the F2 and F3 scenario. The benefit, in terms of GHG savings, potentially associated with the use of LTAG-SAF, LTAG-LCAF and non drop-in fuels range from 20% (F1) to 81% (F3) in 2050, and could reach the value of 90%, in 2070 (F3).

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

TABLE 4: Emissions Reduction Factors for the fuel mix under F1, F2 and F3.

Costs and Investments Associated with Long-term Aspirational Goal Integrated Scenarios

By Philippe A. Bonnefoy (USA)¹

Introduction

Each long-term aspirational goal (LTAG) Integrated Scenario (IS) is defined by a combination of sub-scenarios for aircraft technologies, operations improvements, and use of fuels with lower life cycle emissions values that result in an overall emissions reduction by 2050 and beyond. The implementation of these aircraft technology, operations and fuels measures will require investments and result in costs to stakeholders involved in the operation of international aviation.

The LTAG Task Group (LTAG-TG) estimated costs and investments associated with each LTAG Integrated Scenario. While results are provided at the global international aviation level, CAEP also considered regional breakdown of costs and investments when data was available. A separate article of this supplement also provides broader information on placing costs associated with LTAG Integrated Scenarios in context.

Approach and methodologies

Costs and Investments Estimation Approach

Historically, CAEP conducted some cost analyses as part of aircraft technology standard setting processes and separate analyses on costs associated with market-based measures. This LTAG-TG study is the first integrated and comprehensive costs and investments assessment across aircraft technology, operations, and fuels measures.

The objective of the LTAG-TG cost and investment assessment was not to estimate the total operating costs or investments required to run the international aviation system through 2050. Using a *scenario minus baseline* approach, the costs and investments associated with aircraft technology, operations, and fuels measures were isolated for each LTAG Integrated Scenario to the extent possible quantified. The analysis results in incremental costs and investments against a “baseline” scenario defined as LTAG Integrated Scenario 0 (see LTAG scenario article for details).

Scope of cost (investment) estimations

The costs and investments associated with LTAG-TG Scenarios are characterized and driven by:

- **LTAG-TG Integrated Scenarios and measures:** Costs and investments are driven by the portfolio of technology, operations, and fuels measures. Figure 1 shows the scope of the cost elements considered by the LTAG-TG, including the costs and investments that were quantified and those that were acknowledged as potentially relevant and assessed qualitatively.
- **Stakeholders:** As shown in Figure 1, costs and investments span multiple stakeholders, including ICAO Member States (i.e., governments), suppliers and manufacturers (i.e., original equipment manufacturer OEMs, fuel suppliers), and operators (i.e., airports, ANSPs and airlines).

¹ The Lead Philippe A. Bonnefoy (BlueSky Consulting, USA) would like to acknowledge the invaluable contribution of the 40 members of the Long-Term Aspirational Goal Task Group's Cost Subgroup.

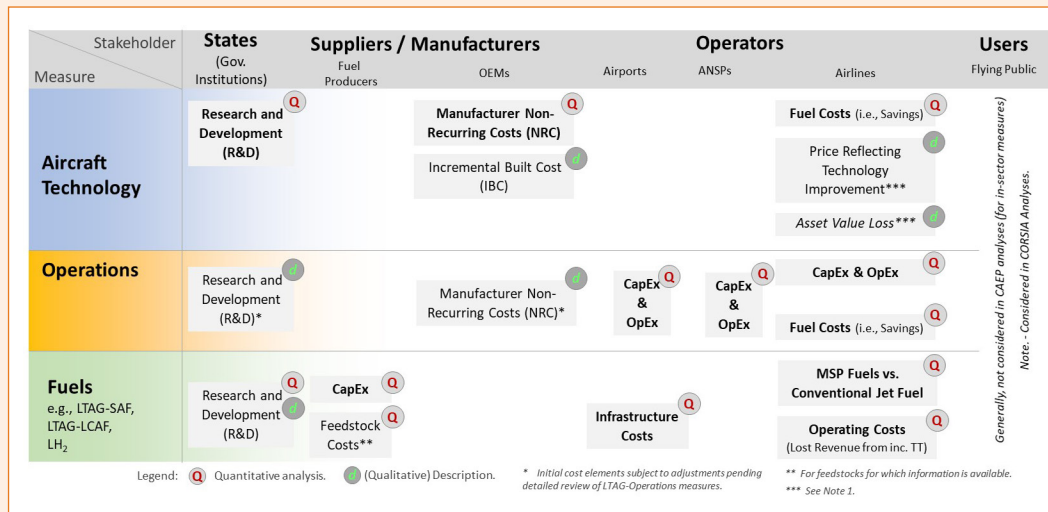


FIGURE 1: Costs and investments elements considered by the LTAG-TG

- **Aviation Sector Scope:** Given ICAO's remit, the LTAG-TG cost analysis focused on international aviation. It is therefore not a global analysis that would include domestic aviation.
- **Temporal dimension:** The cost estimation analysis captures when costs would be incurred, or investments required to deliver the associated measures. Costs and investments estimates were limited to 2020–2050-time horizon given the level of uncertainty in units costs or prices beyond 2050.
- **Geographical distribution:** Given that the LTAG would be a global goal for international aviation, costs and investments were estimated for the entire international aviation sector. When data was available, CAEP also estimated regional level costs and investments.

Aircraft Technology Costs and Investments:

Future aircraft technology developments as captured in the T1, T2 and T3 scenarios depicted in the LTAG-TG Technology section, are expected to require investments from OEMs in the form of:

- **Non-Recurring Costs (NRC)** which capture the fixed costs associated with developing the technology improvements that deliver fuel and CO₂ emissions reductions. It does not include additional production costs e.g., material, labour, or other recurring costs, and

- **Research and Development (R&D)** support from States (i.e., governments) to aerospace research institutions towards the development of technologies and commercial aircraft.

The LTAG-TG developed a model to generate bottom-up estimates of aircraft manufacturer non-recurring costs and research and development support from governments. The model uses aircraft fleet entry scenarios aligned with the LTAG Technology scenarios. Based on these scenarios, for each potential future aircraft program/family, a non-recurring cost was estimated. This non-recurring cost depends on the characteristic of the aircraft program/family, such as derivative aircraft, conventional configuration (e.g., advanced tube and wing ATWs) or unconventional drop-in powered aircraft or hydrogen powered aircraft. Forward looking non-recurring cost estimates also include escalation factors that reflect the continuously increasing aircraft development costs resulting from increasing aircraft system complexity, certification, etc. which were calibrated based on historical data. The temporal distribution of the non-recurring costs was also modelled and determined by the entry into service of the first aircraft type in the family. Costs associated with developing potential subsequent variants are also included based on a stochastic approach.

Fuel costs or savings resulting from the operations of aircraft types exhibiting the technology improvement associated with a given LTAG-TG aircraft technology scenario were also estimated.

Operations Improvements Estimations

The LTAG-TG used a bottom-up approach for estimating costs and investments associated with operational measures underlying each LTAG-TG Integrated Scenario. This analysis focused on operational measures that would be implemented primarily for fuel burn and CO₂ emissions reductions reasons.

The LTAG-TG also considered large ATM modernization programs that will also require investments but those are generally motivated by capacity increase, congestion reductions, safety, airspace integration, etc. and less driven by CO₂ emissions reductions. These ATM modernization programs were considered by CAEP but are not included in the integrated scenario specific results.

Fuels Costs and Investments Estimations

The capital investments associated with scaling the production of LTAG-Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuel (LCAF) and developing cryogenic hydrogen under IS3 were assessed. The LTAG-TG also estimated the infrastructure costs of developing hydrogen distribution networks from production facility to airport (aircraft) under LTAG-TG Integrated Scenario 3. Finally, costs to airlines in the form of incremental fuels costs i.e., minimum selling price of fuels vs. conventional jet fuel resulting from using LTAG-SAF, LTAG-LCAF or hydrogen vs. conventional jet fuel were estimated through 2050. A separate article on placing costs associated with LTAG Integrated Scenarios in context also provides details on unit fuel costs in context of historical jet fuel costs.

Approach for Geographical Breakdown of Cost Estimations

The LTAG-TG study resulted in a comprehensive, global analysis with regional level results when input data was available. It does not provide detailed regional analyses for all metrics and State level results due to the absence of disaggregate input data. Such forecast data would require substantial State and aviation stakeholder specific information that either does not exist or is highly confidential such as an aircraft manufacturer's strategic plan to develop future product lines or a SAF producer's planned production volume of SAF in the 2040s, 2050s, etc.

The LTAG-TG has also provided the data and information that underlies the LTAG-TG scenarios such that States can conduct their own assessments of their future potential for investing and benefiting from measures towards achieving an LTAG if they have data and wish to do so.

Cost and investments associated with LTAG scenarios

Figure 2 provides the summary of cumulative costs and investments associated with each LTAG scenario from 2020 to 2050 across each group of stakeholders. It is important to note that costs and investments associated with a scenario are not meant to be added towards a total cumulative cost. Some investments from upstream stakeholders are passed on downstream in the form of incremental price of products. For example, investments from fuel suppliers will be passed on to operators as part of minimum selling price. As such the costs and investments are displayed across a chain of stakeholders.

Investments from States (i.e., governments): To support aircraft technology developments, States may need to invest in research and development. Under an IS1 scenario, investments could be ≈\$50 billion (range \$15–180B) through 2050. To support advanced aircraft configurations in an IS2 scenario and/or energy systems i.e., hydrogen powered aircraft under IS3, investments could increase to ≈\$160 billion (range \$75–870B).

Investments from aircraft manufacturers: To deliver aircraft technology improvements captured in IS1, aircraft manufacturers would need to invest in the order of \$180 billion (range \$150–\$380B) between 2020 and 2050. Developing aircraft with unconventional configurations (IS2) and hydrogen powered aircraft (IS3) would require a substantial increase in investments on the order of \$350 billion (range \$260–\$1000B) between 2020 and 2050.

Investments from fuel suppliers: To start to scale the production capacity for fuels under IS1, fuels suppliers would need to invest ≈\$1,300 billion through 2050 broken down into \$480 billion for SAF biomass-based fuels by 2050 (to cover 19% of international aviation energy use in 2050), \$710 billion for SAF from gaseous waste (8%) and \$50 billion towards LTAG-LCAF (7%). Scaling the production of Fuels under IS2, would require investments of \$2,300 billion

through 2050. Finally, under IS3 investments of ≈\$3,200 billion broken down into \$950 billion for SAF biomass-based fuels by 2050 (to cover 42% of international aviation energy use in 2050), \$1,700 billion for SAF from gaseous waste (46%), \$460 billion from SAF from atmospheric CO₂ (10%), \$60 billion towards LTAG-LCAF (0%) and \$55 billion towards hydrogen (2%) would be required.

These capital expenditures are for green field fuel production plants and were not reduced by investments that would be made to the conventional fuel sector that would be needed in a baseline (ISO) scenario. In addition,

investments captured in the CAEP analyses would lead to local economic development e.g., refineries that are using renewable or waste feedstocks to produce SAF would spur economic development and opportunities for their communities.

Costs and investments for airports: Towards the implementation of operations measures, airports may need to spend or invest from \$ 2 to 6 billion across LTAG scenarios. In addition, under an IS3 scenario where hydrogen aircraft may enter service after 2035, airports may need to invest into infrastructure of ≈ \$100–150 billion by 2050.

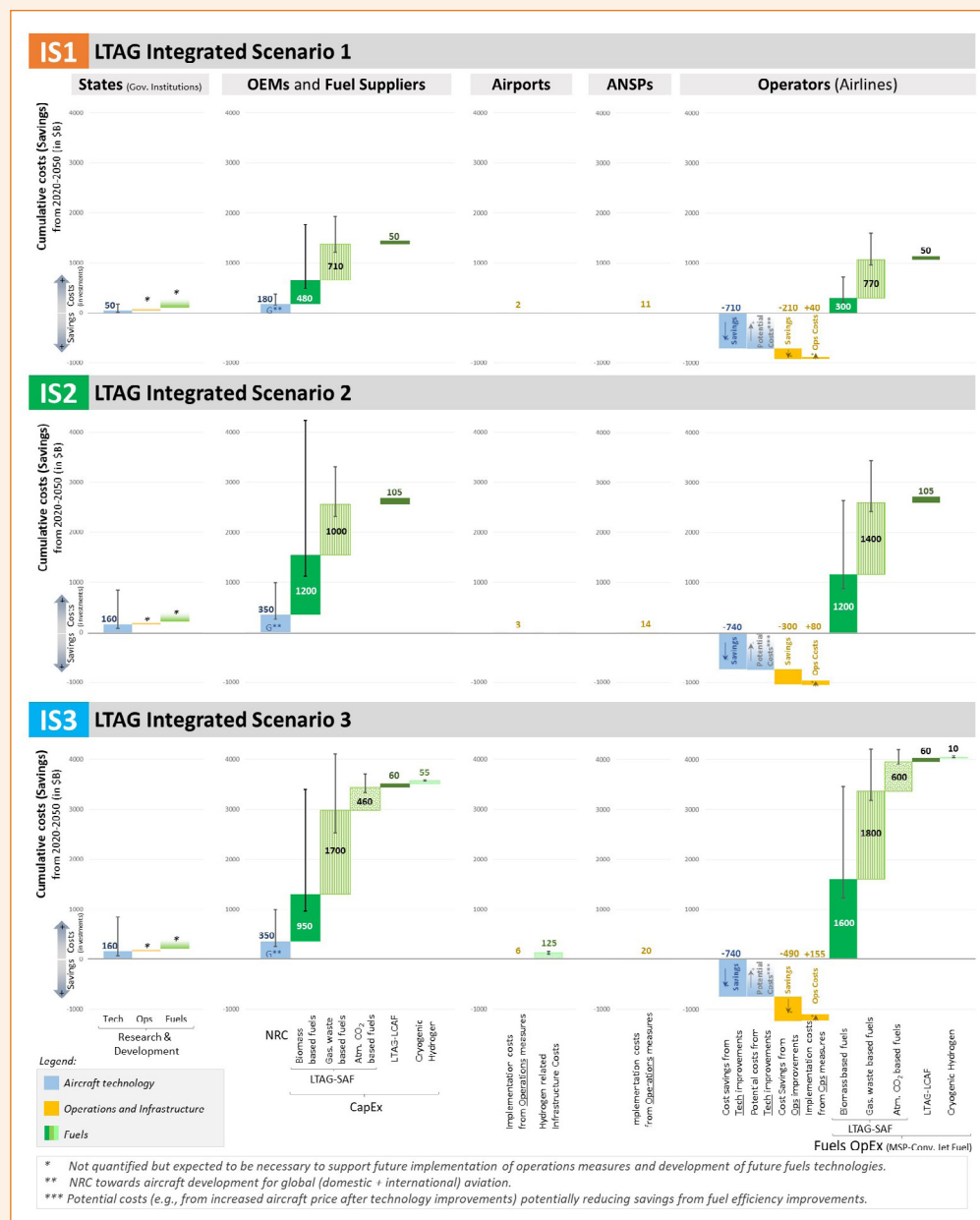


FIGURE 2: Integrated cost and investments associated with LTAG Integrated Scenarios

Costs and investments for Air Navigation System Providers (ANSPs): LTAG specific operations measures would require investments and costs by ANSPs from \$ 11 to 20 billion by 2050.

Costs and investments for Operators (airlines): The entry into the fleet of aircraft with technology improvements would reduce fuel burn and operating fuel costs to airlines of \approx \$710 to 740 billion through 2050. Investments to cover any incremental aircraft prices (after technology improvements) may be required which would reduce the net savings from aircraft technology improvements to airlines.

Note 1. - The CAEP acknowledged that fuel savings from aircraft technology improvements may be reduced by an increase in aircraft acquisition costs driven by Price After Technology Improvement i.e., aircraft technology improvements are not expected to “come for free” to airlines. Airline acquisition of new aircraft is a multi-attribute decision making process, including aircraft capabilities, operating costs (including fuel efficiency), commonality with other aircraft types in the fleet, etc. The transactions are also not publicly available, and it is challenging to isolate the contribution of aircraft technology improvement to aircraft total price.

The implementation of operational measures could reduce operators’ fuel costs by \approx \$210 to 490 billion through 2050 but would require additional costs and investments ranging from \$40 to 155 billion. Fuel related costs in the form of incremental costs of fuels minimum selling price vs. conventional jet fuel in a baseline scenario would have the largest impact on operators. In an IS1 scenario, acquisition of fuels by airlines could result in incremental costs compared to conventional jet fuel of \$1100 billion broken down into \$300B, \$77B, and \$ 50B for biomass-based SAF, waste-based SAF and LCAF respectively. Incremental fuels costs would increase under an IS2 to \approx \$2700 billion. Finally, under an IS3 scenario where 100%

of conventional jet fuel is replaced starting in 2040, the costs to airlines would reach \$4000 billion through 2050 (broken down into \$1600B, \$1800B, \$600B, \$60B, and \$10B for SAF biomass based, SAF waste-based fuels, SAF from atmospheric CO₂, LCAF and hydrogen respectively). A separate article on placing costs associated with LTAG Integrated Scenarios in context also provides details on costs in context of fuel and operating costs, as well as incremental costs per flight and per passenger.

Sensitivity to traffic forecasts: The LTAG-TG also assessed the sensitivity of the costs and investments associated with LTAG IS to traffic forecasts. To first order the investments associated with aircraft technology developments (including the research and development support from States) are independent of traffic forecasts. Regarding fuels related investments and costs, SAF biomass-based fuels and SAF from gaseous are constrained by capacity in the IS1 scenario and do not change across traffic levels. For IS2 and IS3, traffic levels do influence the demand for fuels. As a results, investments (CapEx) from fuel suppliers and incremental costs to operators (airlines) scale with the forecast traffic levels.

Conclusion

The costs and investments associated with the LTAG integrated scenarios are largely driven by fuels (e.g. SAF) acknowledging that incremental costs of fuels (i.e., minimum selling price of SAF compared to conventional jet fuels) further motivate fuel (energy) efficiency improvements from aircraft technology and operations. This will also require some investments from governments and industry.

Long-Term Aspirational Goal Scenario Development

By David Moroz (UK) and Yuxiu Chen (China)¹

Introduction

As is made clear elsewhere in this supplement, the ICAO LTAG feasibility study is based closely on the methods and models used for the CAEP Trends assessment, with important differences.

Most importantly, the LTAG analysis is not aimed at forecasting future emissions trends in aviation but is explicitly a scenario-based analysis. This means that it aims to show not what is *likely to happen*, but what *could happen* if certain conditions are met. This approach reflects the need for ‘aspiration’ in this analysis.

External conditions (primarily level of policy effort) were assumed to allow an assessment of the full range of feasibility, while “readiness and attainability” of in-sector measures (aircraft technology, operational improvements and alternative fuel use) were carefully considered by the LTAG experts in line with the Terms of Reference. This ensured that the study focussed on technical feasibility without prejudging political decisions yet to be made.

The Scenario Development Sub-Group was formed after the 2020 CAEP Steering Group to lead the development of integrated scenarios, coordinate the final analysis and lead communication and outreach. It had around 110 members and held 23 virtual meetings. The Cost Estimation ad hoc (CEahg) group was also established to review and develop an approach and methodologies for estimating cost and investments associated with the LTAG-TG Integrated Scenarios.

Importance of scenario development work

ICAO’s LTAG analysis sits in the context of a multitude of similar exercises carried out in recent years by states, industry and others. These include the ATAG Waypoint 2050 report, the Destination 2050 report from European industry and many others.²

Drawing on this prior work, but consciously aiming to take the most inclusive possible approach, it was important that the scenarios considered responded directly to the request of the ICAO Council to consider the full “range of readiness and attainability” of “in-sector measures”.

Unlike some other reports, CAEP was not asked to consider out-of-sector measures such as market-based measures. Indeed, consideration of policies required to implement the technical measures analysed by CAEP would be a matter for policymakers in ICAO, states and regional organisations, such as direct governmental and private investment, finance, technology assistance and capacity building to support implementation in developing states. The selection of these in-sector measures and out-of-sector measures is for states to consider.

The LTAG report therefore provides the technical evidence basis for consideration and possible future decision-making by the ICAO Council and Assembly, without pre-judging what those fora may decide.

¹ The co-Leads David Moroz (Department for Transport, UK) and Yuxiu Chen (Civil Aviation University of China) would like to acknowledge the invaluable contribution of the 111 members of the Long-Term Aspirational Goal Task Group’s Scenario Subgroup.

² https://aviationbenefits.org/media/167187/w2050_full.pdf, <https://www.destination2050.eu/>

LTAG integrated scenarios

CAEP was requested to “create integrated in-sector scenarios of technology, fuels and operations that represent a range of readiness and attainability”.

Rather than exhaustively define “readiness and attainability” in a quantitative way, an overarching narrative was developed for three scenarios to cover the range of feasibility.³ Technology, operations and fuels sub-scenarios were then developed and integrated to ensure internal consistency.

These three integrated scenarios range from the most easily attainable scenario, relying on measures with a high level of readiness, but the lowest climate ambition (IS1) to the least attainable scenario, relying on measures with a low level of readiness, but the highest climate ambition (IS3).

A baseline or ‘frozen technology’ scenario is also used for reference which assumes no technological, operational or fuels improvements after 2018 (IS0). Figure 1 summarises the integrated scenarios.

These are overlaid on ICAO’s COVID-impacted air traffic forecasts to give nine series of results, as presented elsewhere in this supplement.

Using a cost minus baseline approach, CEahg assessed the costs and investments associated with integrated scenarios, including costs or savings from technology, operations and fuels measures across stakeholders. This assessment is described in more detail elsewhere in this supplement.

Comparison to Trends

As mentioned above, it is important to understand the similarities and differences between the LTAG analysis and the ICAO Environmental Trends assessment.

While both use the same models, base year and underlying traffic forecasts, they are intended for different purposes.

This means that, for the LTAG analysis, not only was the time horizon extended to 2070 to capture the impact of new technology entering the fleet up to 2050, but more innovative, radical and aggressive emission reduction measures are considered, within the limits of technical feasibility.

It is also important to note that the LTAG study only considers international aviation, meaning that some measures that may have an impact on domestic aviation (e.g. electrification) do not feature prominently.

MDG/FESG Baseline (for context)	LTAG-TG Scenarios		
Integrated Scenario 0 (IS0)	Integrated Scenario 1 (IS1)	Integrated Scenario 2 (IS2)	Integrated Scenario 3 (IS3)
<ul style="list-style-type: none"> • ‘Frozen’ scenario • Projection of current technologies available in the base year (through fleet renewal) • No additional improvements from technology, operations and no emissions reductions from fuels (SAF) • No systemic change – e.g. infrastructure changes to accommodate growth only 	<ul style="list-style-type: none"> • ‘Low / nominal’ scenario • Current (c. 2021) expectation of future available technologies, operational efficiencies and fuel availability • Expected policy enablers for technology, ops and fuels • Low systemic change – e.g. no substantial infrastructure changes 	<ul style="list-style-type: none"> • ‘Increased / further ambition’ scenario • Faster rollout of future technologies, increased operational efficiencies and higher fuel availability • Increased policy enablers for technology, ops and fuels • Increased systemic change – e.g. limited infrastructure changes 	<ul style="list-style-type: none"> • ‘Aggressive / speculative’ scenario • Maximum possible effort in terms of future technology rollout, operational efficiencies, fuel availability • Maximum policy enablers for technology, ops and fuels. • High, internationally aligned systemic change - e.g. significant and broad change to airport and energy infrastructure

Decreasing readiness and attainability. Increasing aspiration.

FIGURE 1: LTAG integrated scenarios

³ The interpretations of ‘readiness and attainability’ adopted for technology, operations and fuels measures are described in the LTAG final report <https://www.icao.int/environmental-protection/LTAG/Pages/LTAGReport.aspx>

Climate science context

CAEP was requested to place the results of the LTAG feasibility study “within the context of the latest consensus scientific knowledge”, namely the allowable global emissions remaining within the temperature goals set out in the Paris Agreement.

The results of the LTAG analysis were therefore compared to the Shared Socioeconomic Pathways from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment report, as summarised by CAEP.⁴ This comparison “provides factual information to allow decision makers to do their work and does not seek to advise on a share of global carbon budgets that international aviation should consume”.⁵

This comparison shows that, over the 2020–2070 period, international aviation could represent approximately 4.1–11.3% of the global carbon budget for limiting global warming to 1.5°C (with 67% probability), depending on the integrated scenario. For limiting global warming to 2°C (with 67% probability) aviation’s share could be approximately 1.4–3.9%. For comparison, historical CO₂ emissions from global aviation (including domestic) represent approximately 1.5% of all global CO₂ emissions.

Sensitivity analysis

In developing the integrated scenarios, LTAG recognised that there could be multiple combinations of technology, operations and fuels measures to form alternative integrated scenarios. In particular, sensitivity analysis was conducted to examine the impact of lower technology and operations improvements, coupled with high reductions from fuels.

This shows that there are multiple paths that may result in similar levels of emissions but that in all cases the contribution from fuels is critical to decouple the growth in international air traffic from its emissions. It also shows that there is robustness in the LTAG scenarios and analysis.

Implementation considerations

“Roadmaps for realisation” or implementation of the scenarios were also considered, mindful of the use of these words in the report of the 40th ICAO Assembly. Some technical considerations were identified without pre-judging future decisions.

Anticipating a process for reporting progress towards any goal and the need not to duplicate existing process or place undue burden on non-state actors, it is identified that the ICAO State Action Plan process could be used by states to report progress towards any goal. Building on the expertise gained through the development of CORSIA, future work could be conducted in the process of implementation on possible metrics and reporting mechanisms.

Similarly, a triennial review process could be considered similar to the CORSIA Periodic Review, anticipating a need to review any goal adopted in light of information such as progress towards the goal, technological developments, progress in other sectors, costs and other impacts as well as the latest scientific knowledge on climate change mitigation and adaptation.

There is also a potential need for capacity building and assistance in order to realise any goal. This could include workshops on possible measures and associated costs, or assistance with monitoring and measuring emissions could form part of an overarching training programme similar to the successful ACT-CORSIA programme, as well as other assistance and support that could be considered in future.

⁴ <https://www.ipcc.ch/assessment-report/ar6/>, https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixS1.pdf

⁵ https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixR3.pdf

Global Aviation Dialogues (GLADs)

By ICAO Secretariat

Introduction

During its 40th Session, the ICAO Assembly requested to continue exploring the feasibility of a long-term global aspirational goal for international aviation CO₂ emissions reductions (LTAG). In 2021 and 2022, as part of the consultative process on an LTAG, ICAO organized the Global Aviation Dialogues (GLADs) as a series of regional online events. The presentations from the LTAG GLADs are available on the ICAO public website¹.

LTAG GLADs 2021

The 2021 LTAG GLADs held from 9 to 14 May 2021 aimed to provide information on ICAO LTAG process, and to allow for the exchange of views between States to facilitate the ICAO's further work on an LTAG.

A total of 295 participants from 94 States and 68 accredited international organizations attended the five events. Each day of the LTAG-GLADs started with an information-sharing plenary, followed by a thematic dialogue in small groups. Among different topics, the participants shared their views on top priority aviation CO₂ emissions reduction measures,

at the global level, in the short, medium and long-term (Figure 1); and discussed the main challenges and barriers to the realization of the priority measures, based on an initial list provided to foster the deliberations (Figure 2). Some of the challenges were identified by the groups as being region-specific.

It should be noted that the short, medium and long-terms were not defined and each group was free to discuss and assume the three time scales. The general view for advanced aircraft technologies was that depending on the specific technologies considered, they could be available in the three time scales, while the overwhelming majority view for revolutionary aircraft technologies was that they would be available during the medium to long-term.

With regard to the operational improvements, the participants indicated them mostly as near-term reduction measures, while acknowledging their potential for the medium- and long-term scales. Regarding fuels, Sustainable Aviation Fuel (SAF) and Lower Carbon Aviation Fuel (LCAF) were identified mostly as the medium-term CO₂ emissions reduction measures, while power-to-liquids, non-drop in fuels and electrification were considered as medium to long-term.

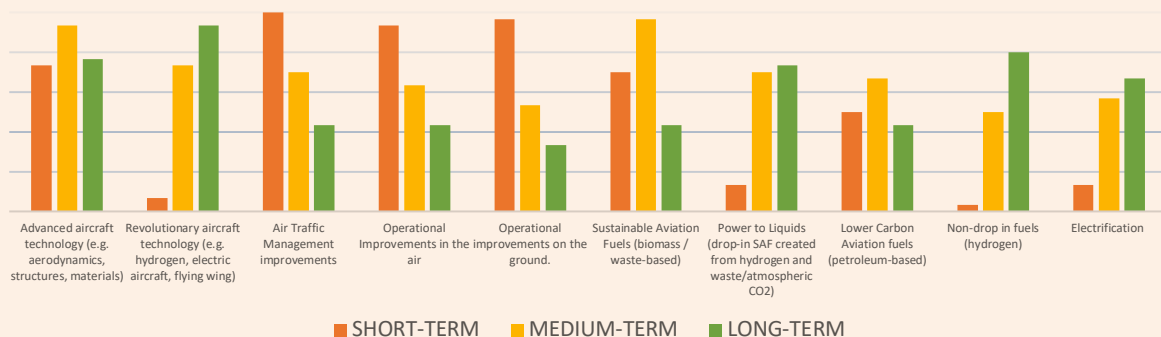


FIGURE 1: Global Average – Expectations for the CO₂ emissions reduction measures.

1 ICAO LTAG GLADs 2021:
<https://www.icao.int/Meetings/2021-ICAO-LTAG-GLADS/Pages/Agenda-and-Presentations.aspx>
 ICAO LTAG GLADs 2022:
<https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Pages/Agenda-and-Presentations.aspx>



FIGURE 2: Agreement rate with the identified challenges and barriers to the realization of aviation CO₂ emissions reduction measures – global average and regional levels.

The most frequent comment raised during the 2021 LTAG GLADs was the need for receiving more information on LTAG, including cost analysis results. In this regard, an additional series of GLADs in 2022 was requested with more information on LTAG, in particular the results of Committee on Aviation Environmental Protection (CAEP) analysis on LTAG scenarios with cost impacts.

LTAG GLADs 2022

In this triennial, ICAO worked very hard and CAEP has completed a detailed technical analysis on LTAG, which was made available, together with all the presentation materials and discussion topics². Therefore, 2022 ICAO LTAG GLADs were held from 28 March to 8 April 2022. A total of 421 participants from 108 States and 11 organizations attended the five events. Each day of the GLADs started with an information-sharing plenary, followed by a thematic dialogue.

The objectives of the 2022 GLADs were to ensure that participants understand the latest ICAO technical work on an LTAG and to allow for the exchange of views amongst States on the feasibility of an LTAG and its building blocks (recognition of scientific understanding, technical feasibility of LTAG scenarios, level of LTAG ambition, means of implementation, support to States with action plans and roadmaps, monitoring of progress to achieve LTAG), thus facilitating the well-informed deliberations at the

subsequent High-level Meeting and the 41st Session of the ICAO Assembly.

During the first day of the GLADs, participants considered and discussed the ICAO's technical work by the CAEP on the feasibility of an LTAG, including the LTAG feasibility study report overview, LTAG scenarios and costs, LTAG inputs and modelling assumptions from technology, operations and fuels. A firm basis for supporting well-informed future decision making on an LTAG was formed with the participants' discussions on the completeness and relevance of the aviation in-sector CO₂ reduction measures considered under the LTAG report, as well as on the level of aspirations under the LTAG integrated scenario options, and the associated costs and needed investments. Participants' questions related to the LTAG report and corresponding answers were compiled and made available on the GLADs website³.

During the second day, the participants were informed on the upcoming ICAO LTAG process toward the Assembly, and further exchanged their views on the elements of the LTAG analysis, such as: scientific understanding and context, expected potential contribution of technology, operations and fuels, and the level of LTAG ambition. The participants also discussed the barriers, solutions and needed support for the implementation of the CO₂ reduction measures. Finally, the participants exchanged views on the possible means of implementation, expected support to States with action plans and roadmaps, and

² ICAO LTAG Report: <https://www.icao.int/environmental-protection/Pages/LTAG.aspx>

³ ICAO LTAG GLADs 2022 FAQ: <https://www.icao.int/environmental-protection/Pages/LTAG-FAQ.aspx>

ways of monitoring progress to achieve an LTAG. The views expressed by the participants were also compiled and made available on the GLADs website⁴.

Next Steps

The 2022 series of LTAG GLADs enhanced overall understanding of the ICAO LTAG Report and paved the way for the later ICAO milestones in 2022, such as the LTAG High-Level Meeting (HLM)⁵ in July and the 41st Session of the Assembly in September, by facilitating well-informed decisions on long-term sustainability goal options for international aviation.

The HLM-LTAG was held on 19 to 22 July 2022 as a hybrid event and served as the forum to discuss the CO₂ emissions reduction scenarios and options for an LTAG, along with the means of implementation and the monitoring of progress (more details on HLM-LTAG and its conclusions are provided in article “High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO₂ emissions reductions” of this special supplement). The HLM was preceded by the 2022 ICAO Stocktaking, held on 18 July 2022, and enabled sharing of the latest relevant information, including the innovations on technology, operations and fuels.

The culmination of the ICAO LTAG Process will happen on the 41st Session of the ICAO Assembly in September-October 2022 and will be a turning point for the sustainable future of the international aviation.

4 ICAO LTAG GLADs 2022 Views Compilation: https://www.icao.int/Meetings/2022-ICAO-LTAG-GLADS/Documents/LTAG_GLADS_2022_Compilation_Views.pdf

5 ICAO LTAG-HLM: <https://www.icao.int/Meetings/HLM-LTAG/Pages/default.aspx>

Placing Costs Associated with LTAG Integrated Scenarios in Context

By Philippe A. Bonnefoy and Roger Schaufele (USA)

Introduction

The costs associated with each Long-Term Aspirational Goal (LTAG) Integrated Scenario were assessed as part of the LTAG-Task Group (LTAG-TG) analyses. Given the long-time horizon, from 2020 to 2050, and the scope of the sector considered (i.e., international aviation) some cost numbers run in the \$ billions or \$ trillions and may appear to be large.

These numbers raise questions such as: *“what do these costs represent in context of the costs of operating the international aviation sector during the next 30 years?”*, and *“what could it mean for an airline or passenger?”*.

The need to place the costs of LTAG Integrated Scenarios in context also became apparent during the ICAO Global Aviation Dialogues (GLADs), a consultative process on LTAG held by ICAO, through a series of five regional events that took place on 27 March to 8 April 2022.

Following the request from States on more detailed information on the costs within the ICAO LTAG Report, the ICAO Secretariat requested support from CAEP to complement the existing assessment to the extent possible with such information. The CAEP Chair and the LTAG-TG leadership provided support to address these questions to help with interpretation of LTAG-TG results and deliberations towards the 41st Session of the ICAO Assembly. This information does not replace or substitute any information agreed at the CAEP/12 meeting but rather complements the results of the assessment by putting it in a more detailed context, using the same assumptions and methodology from the ICAO CAEP LTAG assessment.

Approach

To place the potential costs associated with LTAG integrated scenarios in context, data from the LTAG-TG analyses on cost and investments were leveraged. Contextual data was also collected using a range of sources including: (1) CAEP Forecasting and Economic Study Group (FESG) traffic forecasts e.g., ATK, ASK, number of flights, (2) ICAO Air Transport Statistics for passenger data, (3) IATA Industry Statistics Fact Sheet (2010–2022) for breakdown of operating costs i.e., fuel and non-fuel costs and profit margins. The incremental costs associated with an LTAG (compared to a baseline scenario) are largely driven by fuels related costs. This analysis therefore focuses on these costs.

Unit fuel costs in context of historical jet fuel costs

Historically, the international aviation industry has experienced substantial volatility in unit jet fuel prices (measured in \$/litre). While the transition to Sustainable Aviation Fuels (SAF), Low Carbon Aviation Fuels (LCAF) and possibly Hydrogen may increase the unit costs of fuels, the increase in unit costs is expected to be gradual and by 2050 within historical volatility ranges of unit fuel prices.

Figure 1 shows the evolution over time of unit fuel prices. Over the last ten years, the average cost of fuels varied from 0.4 to 1.0 \$/L (a factor of 2.5×).

When the LTAG-TG analyses conducted by CAEP were completed and documented in November 2021 the baseline scenario assumed a unit cost of conventional jet fuel of 0.60 \$/L. As shown on Figure 1, since the LTAG-TG report

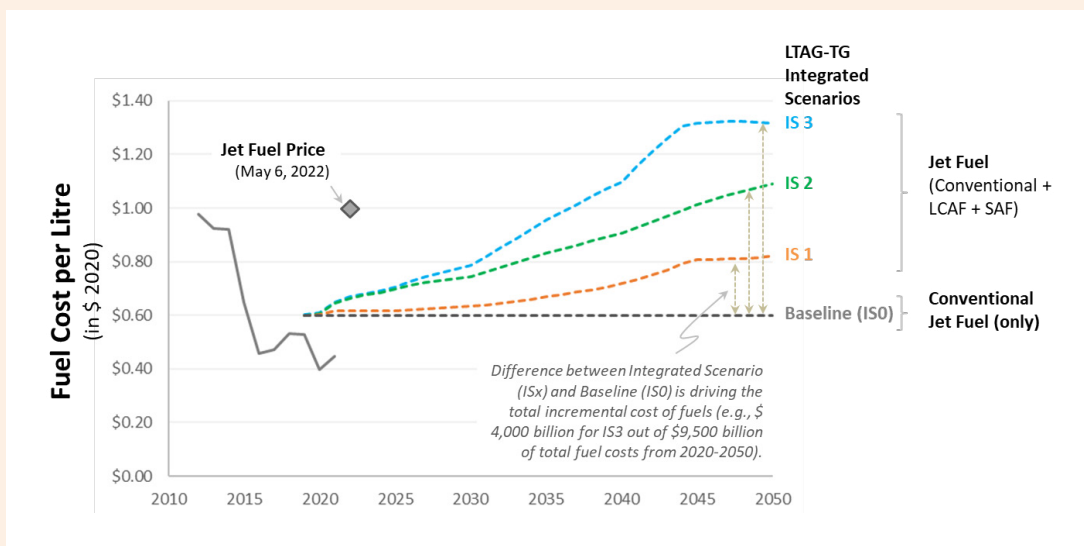


FIGURE 1: Unit fuel costs in context of historical jet fuel costs

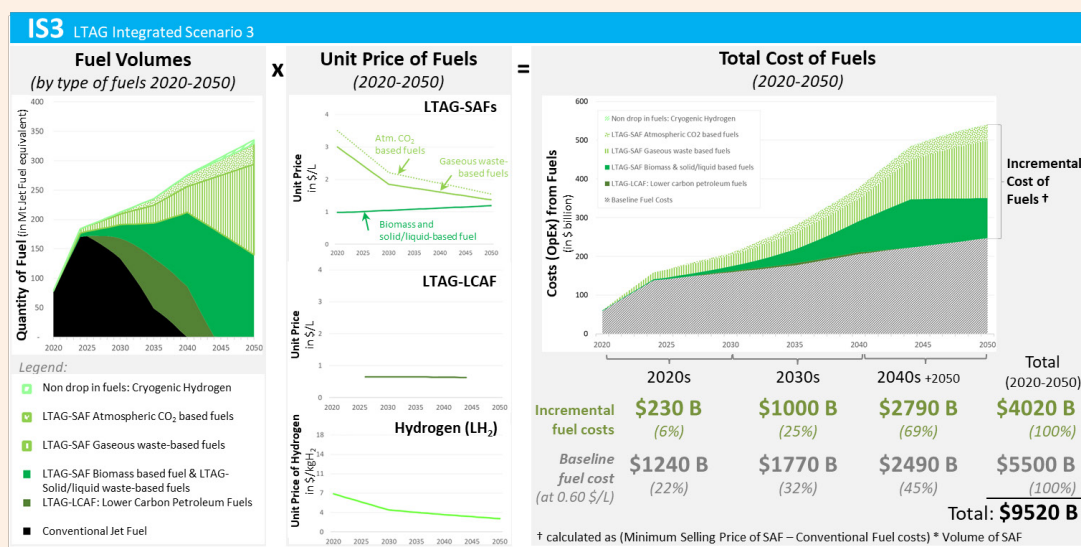


FIGURE 2: Total cost of fuels driven by fuel volumes and unit prices

was published, jet fuel price has increased to about 1 \$/L in May 2022. It should be noted that this price in May is punctual and unlike the baseline 0.6 \$/L does not represent an average annual price. Future conventional jet fuels are also uncertain.

As the shares of SAF and LCAF start to increase in the 2020s (under an LTAG Integrated Scenario 1), the average fuel cost per litre would increase slightly to 0.63 \$/L by 2030 and 0.82 \$/L by 2050 (1.4x baseline fuel cost). Under an LTAG Integrated Scenario 2, the average fuel cost per

litre would reach 1.09 \$/L by 2050 (1.8x). Under an LTAG Integrated Scenario 3, where 100% of conventional jet fuel is replaced by SAF starting in 2044, the average fuel cost per litre would reach 1.32 \$/L by 2050 (2.2x).

Under (higher) baseline fuel cost, such as jet fuel price experienced in May 2022, the incremental costs from Fuels (e.g., SAF, hydrogen) would be substantially reduced, making these fuels more competitive to acquire and use.

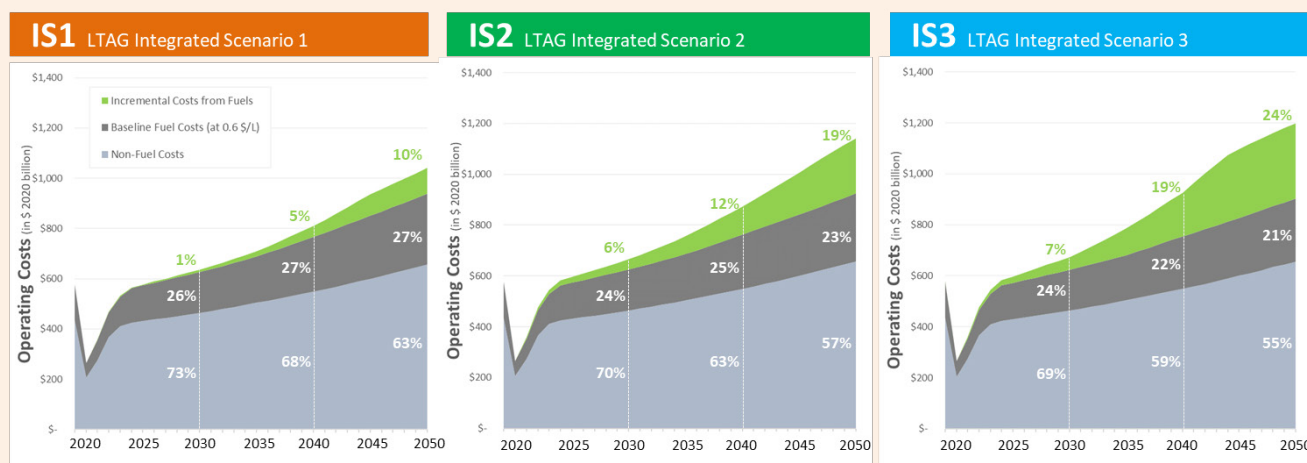


FIGURE 3: Incremental costs from LTAG scenarios in context of operating costs from international aviation

Costs in context of fuel and operating costs

Fuel costs are borne by airlines and aircraft operators and are part of their total operating costs. Figure 2 shows the total costs of fuels from 2020 to 2050 for the illustrative LTAG integrated scenario 3. The incremental costs of Fuels are driven by fuel volumes and unit prices. The incremental costs of Fuels are expected to slowly increase in the 2020s due to the gradual replacement of conventional jet fuels by LCAF, SAF and Hydrogen despite higher unit prices of these fuels. Approximately 6% of incremental fuel costs would be borne in the 2020s and 69% in the 2040s. The total incremental fuel costs of ≈\$4000 billion from 2020 to 2050 also need to be placed into context of the baseline fuel costs (i.e., costs of fuel if conventional jet fuel at 0.6 \$/L was used instead) that would represent ≈\$5,500 billion from 2020 to 2050.

It should also be noted that aircraft technology and operational improvements, that improve from LTAG integrated scenarios 0 to 3, help to mitigate the incremental costs of Fuels. Under a baseline scenario (IS0) where technology and operational improvements are limited, the cumulative baseline fuel costs would be ≈\$6,800 billion from 2020 to 2050.

Total fuel costs represent a portion of the total operating costs by airlines and should be put in context of ≈\$15,500 billion for non-fuel costs from 2020 to 2050. Figure 3




shows the evolution over time of incremental costs of Fuels, baseline fuels costs and non-fuel costs. By 2030, the incremental costs of Fuels associated with LTAG scenarios may represent from 1% to 7% of total operating costs by the international aviation industry (under IS1 and IS3 respectively). This may represent 5% to 19% by 2040 and possibly 10% to 24% in 2050.

Incremental costs per flight

From an airline perspective, the incremental cost from Fuels in 2030 may represent an additional \$650 to \$3300 (in \$2020) per flight for an average flight of about 2700 km from Montreal (Canada) to Denver (U.S.). While these costs run in the hundreds or thousands of dollars this represent an increment on top of an average costs to operate such flight of \$42,900-\$41,600 (in \$2020) under IS1 and IS3 respectively. Placing this cost in a per seat context, this represents about \$3 to \$15 per seat equivalent.


Furthermore, the incremental cost per flight would be driven by flight distances. The incremental costs per flight for a short haul flight (e.g., ≈630 km such as Zurich to Amsterdam) would range from \$130-660 per flight or \$0.8 to \$4.4 per seat. As expected, the incremental costs would be higher for long-haul flights.

By 2050, the incremental Fuel costs may add \$3,500 to \$10,000 (in \$2020) on top of an average flight may cost about \$31,000 to \$30,000 (in \$2020) to operate.

Flight Distance Illustrative Origin & Destination		Incremental Cost* per Flight (Incremental Cost** per Seat**)	
		in 2030	in 2050
Short Haul Flight  630 km (~10 th percentile of int. aviation flights) Zurich → Amsterdam Switzerland (LSZH) → Netherlands (EHAM)	IS1	\$ 130 (\$0.8)	\$ 780 (\$4.4)
	IS2	\$ 520 (\$3.3)	\$ 1600 (\$9.2)
	IS3	\$ 660 (\$4.3)	\$ 2200 (\$13)
Average Haul Flight  2700 km (average for international aviation) Montreal → Denver Canada (CYUL) → U.S. (KDEN)	IS1	\$ 650 (\$3)	\$ 3500 (\$15)
	IS2	\$ 2600 (\$12)	\$ 7200 (\$31)
	IS3	\$ 3300 (\$15)	\$ 10,000 (\$43)
Long Haul Flight  5800 km (~90 th percentile of int. aviation flights) Singapore → Dubai Singapore (WSSS) → UAE (OMDB)	IS1	\$ 1600 (\$5)	\$ 8000 (\$25)
	IS2	\$ 6600 (\$20)	\$ 17,000 (\$53)
	IS3	\$ 8300 (\$26)	\$ 23,000 (\$73)

* Costs in \$ 2020 (adjusted for inflation).
 ** Seat equivalent including available seats for passenger, equivalent seats for freighters and 13 seats (default) for business jets.

FIGURE 4: Incremental costs per flight and per seat equivalent

Potential impact on ticket price*			
		in 2030	in 2050
Average Passenger Trip Length  2900 km	IS1	\$ 3	\$ 13
	IS2	\$ 11	\$ 28
	IS3	\$ 14	\$ 38

* Proxy based on revenue per passenger, assuming an average 3% profit margin and 75% revenue from passenger (based on historical global averages from 2010-2019).

FIGURE 5: Potential impact on ticket price

Incremental costs per passenger

From a passenger perspective in 2030, the costs associated with IS1 could represent ~ \$3 to a ticket price and ~ \$14 in an IS3 scenario. While difficult to forecast, average ticket price may be on the order of \$190–\$200 (in \$2020) in 2030. By 2050, the incremental costs associated with IS1 and IS3 may represent ~ \$13 to \$38 per passenger in context of an average fare of ~\$140–\$160 (in \$2020).

This analysis also assumes that unit non-fuel costs will decline at historic rates observed due to further liberalization of the aviation sector and airline productivity improvements. It is important to understand that like average ticket prices, any forecast of unit non-fuel costs over the period 2020–2050 will have a large amount of uncertainty.

High-level meeting on the feasibility of a long-term aspirational goal for international aviation CO₂ emissions reductions

By ICAO Secretariat

Introduction

Ministers and officials from 119 Member States and International Organizations attended the High-level Meeting on the feasibility of a Long-Term Aspirational Goal for international aviation CO₂ emissions reductions (HLM-LTAG), which was convened from 19 to 22 July 2022, at ICAO Headquarters in Montréal, Canada, as a hybrid event with in-person and virtual participation.

The need for the HLM-LTAG stems from the ICAO Assembly Resolution A40-18, paragraph 9, which requested the Council to explore the feasibility of an LTAG, and for the progress of the work to be presented to the 41st Session of the ICAO Assembly. The HLM-LTAG was invited to discuss the CO₂ emissions reduction scenarios and options for a goal, along with the means of implementation and the monitoring of progress, before concluding with recommendations. The meeting documentation is available on the dedicated web-page¹.

The HLM-LTAG was preceded by the online 2022 ICAO Stocktaking, held on 18 July 2022, to enable the sharing of the latest information, including green innovations on technology, operations and fuels, and to set the scene for the subsequent High-Level Meeting. The figure below shows the ICAO LTAG process and timeline leading up to the HLM-LTAG.

HLM-LTAG Opening

On Tuesday, 19 July 2022, the HLM-LTAG was opened with an address by the President of the ICAO Council and a video on LTAG². The President welcomed the Delegations and encouraged them to demonstrate collective determination to build a sustainable future for international aviation, and to show strong political will on the part of States to work together through ICAO with each other and with the aviation industry to deliver outcomes for an ambitious LTAG. He underscored that LTAG must be delivered together with concrete and practical means of support for implementation support and for monitoring progress, as agreement of a “balanced package” for all, under the leadership of ICAO in a post-COVID world.

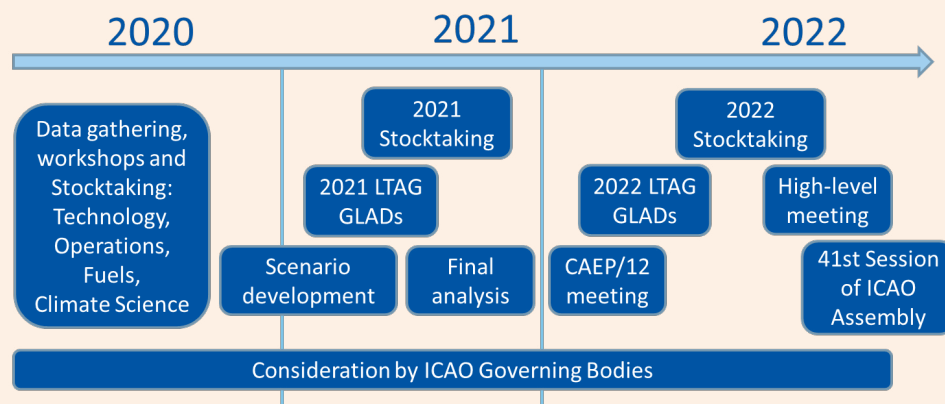
Afterwards, Dr. Bertrand Piccard, Initiator and Chairman of the Solar Impulse Foundation, provided his keynote address, underscoring the crucial role of innovations and aspirations in sustainable growth and development of the aviation sector.

Participants of the meeting unanimously elected The Honourable Bishop Juan Edghill, Minister of Public Works of Guyana, as Chairperson for the event, as well as first and second Vice-Chairpersons Ms. Aishath Nahula, Minister of Transport and Civil Aviation of Maldives, and Ms. Charity Musila, the Alternate Representative of Kenya to ICAO.

1 HLM-LTAG web-page: <http://www.icao.int/Meetings/HLM-LTAG/Pages/default.aspx>

2 ICAO LTAG video: https://youtu.be/8fCvQ_Htmqo

ICAO LTAG process and timeline



Following a comprehensive presentation from the ICAO Secretariat to set the scene for the LTAG, the floor was opened for pre-reserved oral statements from Member States' high-level representatives. The statements were delivered by high-level representatives from 27 Member States: Argentina, Brazil, Cabo Verde, Canada, Chile, China, Czechia, France, Greece, India, Indonesia, Japan, Malaysia, Maldives, Netherlands, New Zealand, Oman, Qatar, Republic of Korea, Russian Federation, Rwanda, Saudi Arabia, Singapore, Spain, United Arab Emirates, United Kingdom and the United States. Guatemala and Peru provided their views on an LTAG. The Airports Council International, Air Transport Action Group, and the European Union also delivered oral statements.

HLM-LTAG Discussions

A total of 8 Working Papers were presented by the ICAO Secretariat, and 22 by Member States and International Organizations at the HLM-LTAG. There were 12 Information Papers. The HLM-LTAG agenda (Table 1) provided the basis for the discussions.

All HLM-LTAG participants expressed the importance of taking action on the existential threat of climate change, and the need for a global long-term objective for international aviation, taking into account different circumstances and readiness levels of States, and the flexibility for each States to contribute to the collective efforts, while also recognizing the necessary means of implementation of an LTAG in the spirit of ICAO's No Country Left Behind initiative.

Many also expressed views on the critical importance of establishing practical means of implementation, including through ICAO State Action Plans (SAPs), facilitating the implementation of robust actions by States in reducing international aviation CO₂ emissions, as well as the establishment of ICAO's partnerships with States and other international organizations for assistance projects for aviation CO₂ reduction measures. They also expressed the view that capacity-building, financing and other assistance to States, in particular to developing countries, would be crucial in ensuring the implementation of any agreed LTAG, recognizing different circumstances of individual States and regions and that not one solution will fit all States and stakeholders.

Agenda Item 1:	CO ₂ emissions reduction scenarios and options for a long-term global aspirational goal for international aviation
Agenda Item 2:	Means of implementation for a long-term global aspirational goal for international aviation
Agenda Item 3:	Means of monitoring progress and next steps
Agenda Item 4:	Conclusions and Recommendations of the Meeting

TABLE 1: HLM-LTAG Agenda.

Recognizing that the largest potential impact on aviation CO₂ emissions reduction will come from fuel-related measures, participants supported the recent June 2022 launch of the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF), and noted its possible extension to additional aspects (such as aircraft technologies, operational improvements), as a means to provide implementation support for the collective achievement of any agreed LTAG.

Establishing the means to monitor the progress for the achievement of any agreed LTAG, on a regular basis, and in a non-intrusive and transparent manner would be important, building upon existing means to do so, such as the ICAO Stocktaking process and tracker tools as part of monitoring the latest innovations and initiatives for reduction of aviation CO₂ emissions, as well as information from SAPs and the CO₂ reporting mechanism under CORSIA.

HLM-LTAG Conclusions

Following the exchange of views by the participants on possible HLM-LTAG outcomes, in light of the latest IPCC scientific understanding, the meeting agreed to recommend the Conclusions³ of the HLM-LTAG to be further considered by the ICAO Council for presentation of its proposal to the 41st Session of the ICAO Assembly, as provided below.

1. ICAO and its Member States are encouraged to work together to strive to achieve a collective long-term global aspirational goal for international aviation (LTAG) of net-zero carbon emissions by 2050, in support of the Paris Agreement's temperature goal, recognizing that each State's special circumstances and respective capabilities (e.g., the level of development, maturity of aviation markets, sustainable growth of its international aviation, just transition, and national priorities of air transport development) will inform the ability of each State to contribute to the LTAG within its own national timeframe.
2. While recognizing that the LTAG is a collective global aspirational goal, and it does not attribute specific obligations or commitments in the form of emissions

reduction goals to individual States, each State is urged to contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with national circumstances.

3. Recalled the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement and acknowledged its principle of common but differentiated responsibilities and respective capabilities, in light of different national circumstances;
4. Also acknowledged the principles of non-discrimination and equal and fair opportunities to develop international aviation set forth in the Chicago Convention.
5. Affirmed that addressing GHG emissions from international aviation requires the active engagement and cooperation of States and the industry, and noted the collective commitment announced by the international air transport industry, to achieve net-zero carbon emissions by 2050.
6. ICAO and its Member States are invited to work together with relevant organizations to strive to achieve the maximum possible level of progress on the implementation of aviation in-sector CO₂ emissions reduction measures (e.g. technology, operations and fuels), recognizing that the largest potential impact on aviation CO₂ emissions reduction will come from fuel-related measures.
7. ICAO and its Member States are encouraged to keep abreast of innovative aircraft technologies, new types of operations conducive to emissions reductions, and Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other cleaner energy sources in line with the *No Country Left Behind* initiative, in order to enable timely certification, as well as timely update and development of relevant ICAO SARPs and guidance, as appropriate. ICAO and its Member States are urged to continue work on the elements of the basket of measures for the achievement of the LTAG, including:

- **Regarding Aircraft Technology:**

ICAO and its Member States are encouraged to

3 https://www.icao.int/Meetings/HLM-LTAG/Documents/HLM-LTAG_SD_004_REV2_v2_clean.pdf

work with manufacturers and aircraft operators to encourage the introduction of increasingly fuel-efficient aircraft into the market and facilitate cost-effective fleet renewal as well as to incentivize and accelerate investments in the research and development of new aircraft with zero CO₂ emissions.

- **Regarding Operations:**

ICAO and its Member States are encouraged to work with manufacturers, Air Navigation Service Providers (ANSPs), aircraft operators and airports to implement enhanced air and ground operations, including by accelerating the deployment of the ICAO Aviation System Block Updates (ASBUs) and its implementation in accordance with the Global Air Navigation Plan (GANP).

- **Regarding Fuels:**

- a) ICAO Member States are invited to incentivize, through policies and policy tools, the research, development and deployment of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other cleaner energy sources for aviation;
- b) ICAO is invited to review the 2050 ICAO Vision for SAF, including LCAF and other cleaner energy sources for aviation, at the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3) in 2023, in order to define a global framework in line with the *No Country Left Behind* initiative and taking into account national circumstances and capabilities; and
- c) ICAO and its Member States are invited to work with the relevant stakeholders to accelerate the research and certification of new fuel pathways and the certification of new aircraft and engines, to allow the use of 100% SAF, to scale up SAF supply, especially through encouraging and promoting SAF and/or LCAF purchase agreements, as well as to support timely delivery of any necessary changes to airport and energy supply infrastructure.

8. Means of implementation commensurate to the level of ambition, including financing, will promote the achievement of the LTAG. It requires substantial investments for States, according to their national circumstances, and that various possible modalities and/or funding mechanisms could be used by ICAO to facilitate financing and investment support for implementation of specific aviation CO₂ reduction measures. ICAO is invited to initiate specific measures or mechanisms so as to facilitate, in particular for developing countries and States having particular needs, better access to private investment capacities, as well as funding from financial institutions, such as development banks, for projects contributing to the decarbonisation of international aviation, as well as encourage new and additional funding to this purpose. ICAO is also invited to further consider the establishment of a climate finance initiative or funding mechanism under ICAO, while addressing the possible financial, institutional and legal challenges, and report to the 42nd Session of the ICAO Assembly.
9. This will be complementary to a robust assistance and cooperation programme dedicated to LTAG in order to share information on best practices and provide guidance, capacity building, and other technical assistance. Welcoming the establishment of the ICAO Assistance, Capacity-building and Training for SAF (ACT-SAF) programme, it should be extended to add support to the implementation of other emissions reduction measures in an ICAO ACT-LTAG programme (e.g., aircraft technologies, operational improvements, infrastructural changes, LCAF and other cleaner energy sources for aviation).
10. Additionally, ICAO is encouraged to promote the voluntary transfer of technology, in particular for developing countries and States having particular needs, to enable them to adapt to cutting-edge technology and to enhance their contribution to achieve the LTAG.
11. In line with the *No Country Left Behind* initiative, ICAO Member States are urged to make regular and substantial contributions to the ICAO Environment Fund, to address specific ICAO activities on the LTAG, including ACT-SAF programme, aiming at assisting developing States and States having particular needs. States are also encouraged to develop specific projects under the ICAO Technical Cooperation Programme.

12. All ICAO Member States are encouraged to submit and update voluntary action plans to ICAO to reduce CO₂ emissions from international aviation, with a view to achieving the LTAG. State Action Plans should outline respective actions and roadmaps, including long-term projections, and highlight respective national capacities and circumstances and any specific assistance needs for the implementation of CO₂ reduction measures. ICAO and its Member States are invited to provide assistance for preparation and implementation of such plans and the necessary capacity building, including through cooperation and assistance on identifying possible sources of financing for decarbonization of aviation, in cooperation with financial and other relevant organizations.
13. ICAO is invited to regularly monitor progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG, including through: the ICAO environment stocktaking process; the review of the ICAO Vision for SAF; further assessment of the CO₂ reduction and cost impacts of a changing climate on international aviation and regions and countries, in particular developing countries, and the impact on the development of the sector, as well as the cost impacts of the efforts to achieve the LTAG; monitoring of information from State Action Plans for international aviation CO₂ emissions; and means of implementation. To this purpose, ICAO is invited to consider necessary methodologies for the monitoring of progress, and report to a future Session of the ICAO Assembly.
14. Starting from the conclusions of the HLM-LTAG above, further deliberations among Member States will continue towards the 41st Session of the ICAO Assembly.

Towards 41st Session of ICAO Assembly

In his closing remarks to the four-day round of discussions, ICAO Secretary General Juan Carlos Salazar emphasized that recovering from the effects of the pandemic and combatting climate change go hand-in-hand. He also underscored that, as a global sector, aviation has a golden opportunity to show leadership as we “build back better”, aiming towards a sustainable decarbonized future.

The ICAO Council deliberated the outcomes of the HLM-LTAG, and agreed on the Working Paper⁴ proposing revisions to the Assembly Resolution A40-18 on international aviation and climate change. These will be considered during the 41st Session of the ICAO Assembly (27 September – 7 October 2022).

4 https://www.icao.int/Meetings/a41/Documents/WP/wp_369_en.pdf



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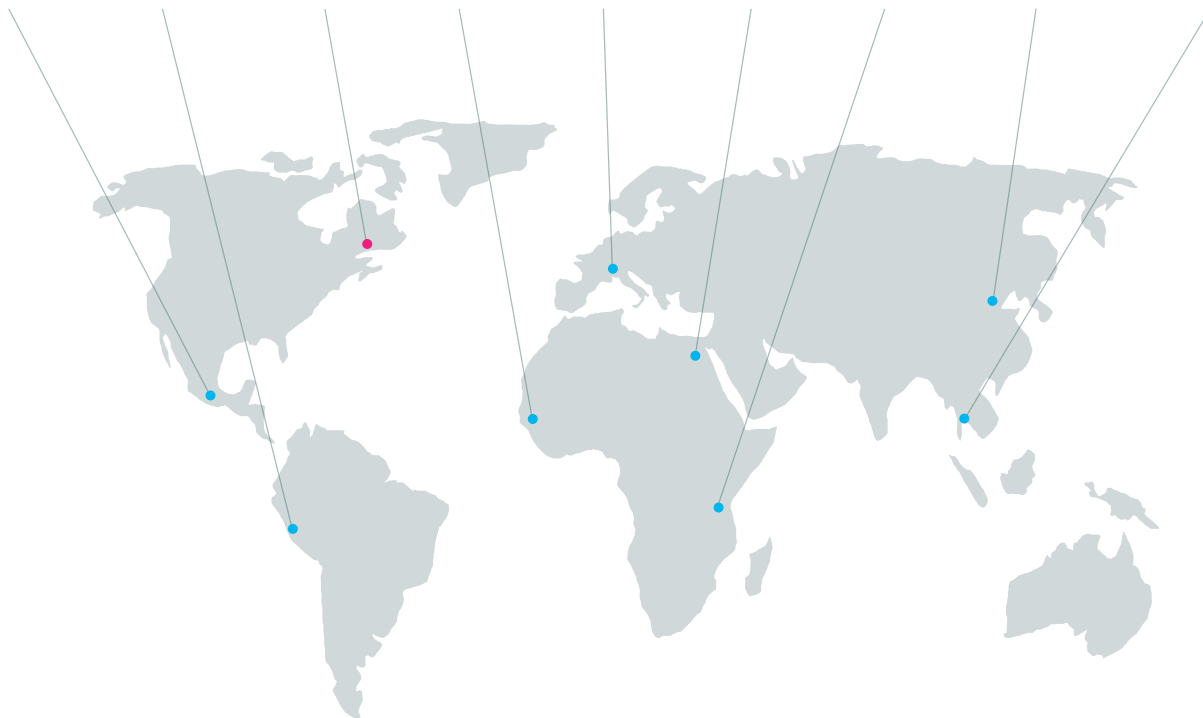
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