DECARBONIZING AVIATION IN THE U.S. AND CHINA

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* Organizations are noted for affiliation purposes only. This paper represents authors' views, and not necessarily those of their institutions.

BACKGROUND AND CHALLENGES

Aviation currently accounts for 2.5% of anthropogenic carbon dioxide (CO_2) emissions. However, demand for aviation is growing rapidly, and so is aviation's contribution to climate change. Aircraft CO_2 increased by 44% over the past 10 years and was recently on pace to triple again by 2050 (ICAO, 2019). The sector is projected to contribute about 50 billion tonnes (Gt) of cumulative CO_2 emissions in the next 30 years (ICAO, 2016). This is 12.5% of the world's total 400Gt carbon budget under a 67% probability to limit temperature increase to 1.5 ºC, from the start of 2020 (IPCC, 2021). Moreover, the non-CO_2 impact of short-lived climate pollutants like nitrogen oxides, black carbon, and water vapor can triple the sector's climate impact (EASA, 2020).

China and the U.S. are the two biggest aviation markets in the world. Flights departing these two countries account for 35% of global passenger operations and 36% of CO_2 emissions in 2019 (Graver et al., 2020). Specifically, aircraft departing China burned 33 million tonnes of jet fuel and emitted 103 million tonnes of CO_2; aircraft leaving the U.S. consumed 57 million tonnes of jet fuel and emitted 179 million tonnes of CO_2.

Table 1 | Passenger CO_2 emissions in 2019 from the United States and China

Departure country	Passenger CO_2 [MT]	% of total CO_2	Revenue Passenger Kilometers (RPK) [billions]	% of total RPKs	CO_2 Intensity [g CO_2 / RPK]
United States	179	23	1,890	22	95
China	103	13	1,167	13	88

(Graver et al., 2020)

Aviation fuel efficiency (volume of fuel per revenue tonne-kilometer) is currently projected to improve 1.53% per annum between 2015 and 2050 under the most optimistic scenario (ICAO, 2022a). Demand for passenger air travel, on the other hand, has tracked about 4.2% annual growth prior to the COVID-19 pandemic and is projected to grow 3.6% each year after rebound (ICAO, 2021a). This highlights the need to develop low-carbon, or eventually zero-emission, planes and fuels. In order to meet a Well Below 2 ºC Paris compatible temperature goal without increasing its share of the global carbon budget, the aviation industry needs to cut 2021-2050 cumulative emissions by more than half, to less than 23 Gt. (Graver et al., 2022).

Between 2010 and 2016, the United Nations International Civil Aviation Organization (ICAO) established two aspirational goals for international aviation: 2% annual fuel efficiency improvement through 2050 and carbon neutral growth from 2020 onward (ICAO, 2019). Recognizing the challenge of reducing emissions in the near term, ICAO implemented a market-based mechanism called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Under the scheme, participating carriers are obligated to purchase carbon offsets for emissions growth above a circa 2020 baseline. The U.S. volunteered their carriers for the pilot phase, which began in 2021, while Chinese carriers will join during the mandatory phase starting 2027. As part of the scheme, carriers can reduce their offsetting requirements by using eligible low-carbon fuels. ICAO is currently developing an international sustainability framework for SAF based on fuel pathways' life-cycle emissions.

In 2016, ICAO published the world's first CO_2 standard for new aircraft. Aircraft models that do not meet the emission threshold as a function of their maximum takeoff mass (MTOM) cannot be sold for international use. Individual countries must adopt a domestic standard that is at least as stringent as the ICAO standard. The standard will enter into force for all newly delivered aircraft in 2028. However, the design of the standard is technology-following, and the average new aircraft delivered in 2016 already pass the standard (Zheng & Rutherford, 2020). The contribution of this current standard to emissions reduction is limited.

More recently at COP26, twenty-eight states formed the International Aviation Climate Ambition Coalition and pledged to take actions to reduce aviation emissions at a rate consistent with the 1.5 ^{o}C pathway (UK COP26, 2021). The pledge expressed support for ICAO's long-term climate goal, commitments to implementing CORSIA effectively, and priority investments in sustainable aviation fuels (SAF) and zero-carbon aircraft.

Looking forward, ICAO member States are working to finalize a net-zero long-term aspirational goal (LTAG) at the 41st ICAO Assembly this September (ICAO, 2022b). The agency has investigated the feasibility of setting such a goal and published a report confirming that deep cuts in GHG emissions are possible (ICAO, 2022c). How ambitious the goal would be depends on the negotiation among member states at the Assembly. The LTAG would be instrumental in promoting in-sector emissions reduction that the carbon neutral growth goal and CORSIA do not accomplish on their own.

Policy ambition is needed because progress to scale low-carbon technologies has been slow. Drop-in alternatives to fossil jet fuel, known as sustainable aviation fuel (SAFs), are 2 to 5 times more expensive than fossil fuel, and in 2020 they only accounted for about 0.05% of global aviation fuel supply. Few countries and regions have crafted policies to accelerate SAF adoption. In 2021, the European Union proposed the ReFuelEU initiative as part of its "Fit for 55" climate policy package, requiring an increasing share of SAF be supplied at member state airports over time. The blending mandate by 2030 is 5% of total fuel supply, with an ambitious plan to increase to 63% by 2050 (EC, 2021). The United Kingdom proposed a similar blending target under its Jet Zero consultation, aiming at 10% by 2030 and 75% by 2050 (UK, 2022). California's Low Carbon Fuel Standards (LCFS) also enables SAF suppliers to opt in and generate carbon credits (CARB, 2022).

Therefore, the main challenges of decarbonizing aviation are three-fold. First, international policymaking through ICAO requires reform via state action. Second, deployment of low-carbon technologies (especially SAF) currently lacks government support and large-scale public or private investments. Third, demand grows rapidly and unevenly, raising equity concerns when implementing decarbonization levers.

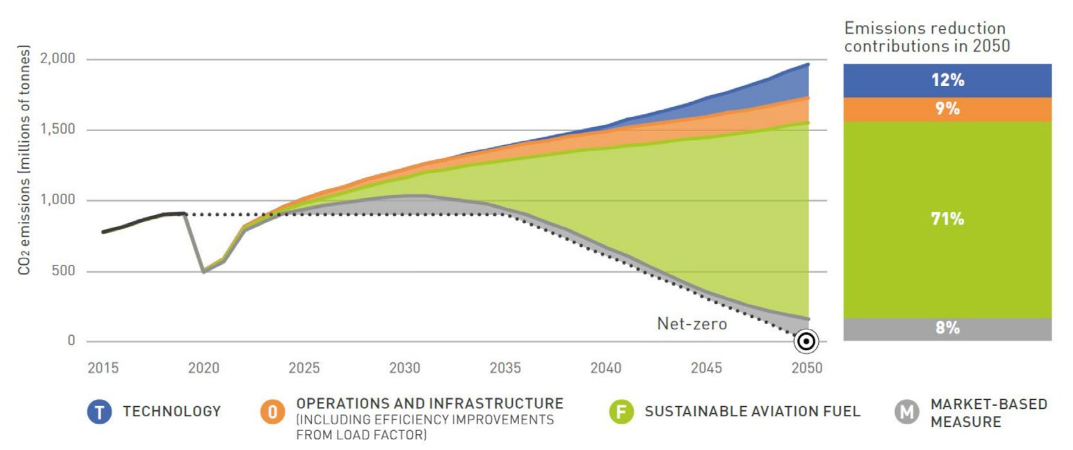
CARBON REDUCTION POTENTIAL

Various organizations have analyzed the potential of aviation decarbonization through mid-century and published global aviation emissions reduction roadmaps. This includes the Waypoint 2050 report released by the Air Transport Action Group (ATAG, 2021), the ICAO (2022b) LTAG feasibility report, and the Vision 2050 report (Graver et al., 2022) produced by the International

Council on Clean Transportation (ICCT). These reports represent the perspectives from industry stakeholders, international regulators, and non-governmental organizations, respectively. All three roadmaps demonstrate the potential for aviation CO_2 to be reduced in-line with a 1.75 °C pathway through the development of advanced aircraft and clean fuels. Limiting climate change to 1.5 °C would require out-of-sector actions such as carbon capture and storage. The ICCT report also highlights that CO_2 emissions need to peak by 2030 at latest, and as soon as 2025, to align with the Paris Agreement.

All roadmaps point to clean fuels as the biggest lever, followed by aircraft technology, operations, and demand reductions due to market-based measures. Figure 1 shows an example of the relative contribution of these levers. These levers present similar opportunities and challenges to China and the US.

Figure 1 | Waypoint 2050 Scenario 1 emissions projection



(ATAG, 2021.)

Clean fuels

SAF is the collective term for jet fuel produced from non-fossil sources. The use of SAF can contribute about 60% of total emissions reductions according to all three roadmaps. SAF is the only feasible alternative energy source for long-haul flights for the foreseeable future, as both hydrogen and electricity face range constraints. As a drop-in fuel, SAFs can blend with conventional jet fuel by up to 50%, with efforts underway to certify 100% blending.

ICCT estimates that 315 million tonnes of SAF is needed in 2050 to completely replace fossil jet fuel under a 1.75 °C pathway. The quality of SAF matters greatly. Taking into account land use change and displacement emissions, the life-cycle emissions of an alternative fuel should be at least 50% lower than conventional jet fuel for it to be considered sustainable. Fuels produced from corn, soy, and palm typically do not meet these criteria (ICAO, 2021b; Pavlenko & Searle, 2021). Near-term SAF supply will mostly come from waste fats, oils, and greases (FOGs). In the medium term, advanced biofuels derived from cellulosic agricultural and forestry wastes are expected to become more common. Further out, synthetic fuels (also known as e-kerosene) are likely to dominate as the costs of renewable electricity and carbon capture fall. However, for high-integrity SAFs providing high lifecycle emission reductions to penetrate the market, a comprehensive strategy will be needed to overcome near-term cost, supply, and sustainability barriers.

To supplement SAFs, hydrogen and electricity can also serve as alternative energy sources. Designs of zero-emission planes are still in their nascency, but their potential should not be overlooked. Airbus is working to develop a hydrogen-powered regional and narrowbody aircraft that may enter into service around 2035. ICCT estimates that an evolutionary hydrogen aircraft could address about one-third (31 to 38%) of all passenger operations starting in 2035 (Mukhomadhaya &

Rutherford, 2021). This technology is relevant for both China and the U.S., as they each have a large domestic, short-haul aviation market. In order to realize the potential of hydrogen planes, lightweight cryogenic storage tanks and infrastructure for hydrogen production, delivery, storage, and refueling will be needed.

Electric planes have much lower potential due to the low energy density of batteries, which carry about one-fortieth the energy per unit mass of fossil jet fuel. They could replace two-thirds of the commuter aircraft market and one-quarter of the turboprop market. By 2050, electric aircraft could mitigate 3.7 Mt of CO_2e annually. This would represent 0.2% of the projected emissions from passenger aviation (Mukhopadhaya & Graver, 2022).

Fuel Efficiency

Improving fuel efficiency can deliver another 30% to 35% of emissions reduction. Efficiency improvements can be achieved through deployment of newer-generation aircraft and adoption of more fuel-efficient operational strategies. Efficiency is an important lever that helps reduce emissions near-term and align energy demand with clean fuel supply.

Historically, each new generation of aircraft burns 15-20% less fuel than their predecessors. Therefore, retiring old aircraft and replacing them with newer models delivers significant reductions. However, aircraft investment is very capital intensive; government policy is needed to incentivize carriers to accelerate their fleet turnover and improve fleetwide fuel efficiency. Scrappage policies promoting material recycling and reuse will also be necessary.

In terms of technology, very few new designs have been announced in recent years besides Boeing 777X. According to ICCT analysis, a clean-sheet design with advanced efficiency technologies (such as hybrid laminar flow wing, adaptive compliant trailing edge, and open rotor engine) can deliver 40% reductions in fuel burn compared to a new aircraft delivered in 2015, starting in 2034 (Kharina et al., 2016). These new designs can deliver about 2% annual efficiency improvement between 2035 and 2050. The average improvement between 2019 and 2050 is projected to be 1.6% per annum.

Operational fuel efficiency is tied to many factors. One area of improvement is for carriers to increase payload efficiency, in other words flying planes with more seats installed and filled. The other lever is higher traffic efficiency, achieved through measures such as single-engine taxiing, electric tows to gates, continuous climb and descent, smart air traffic management, reduced fuel loading (EASA, 2022), and formation flying (Airbus, 2022). These two areas combined can deliver about 0.6% of annual efficiency improvement between 2019 and 2050.

Demand change

The price premium of clean fuels over fossil jet fuel means that governments likely need to implement market-based mechanisms (e.g., California's LCFS) or directly provide tax credits to subsidize the fuels. A combination of the two could help SAF to achieve economies of scale and lower production costs, which is crucial for eventually reaching 100% clean fuel saturation. In the meantime, fuel price will likely increase, and travel demand will decrease slightly, delivering secondary emissions reductions. The effects of market-based measures and demand change are modeled in various roadmaps.

Another small yet non-negligible lever is modal shift. Switching from short-haul flights to high-speed rail (HSR) can deliver additional reductions in regions where rail infrastructure is mature. Research on existing HSR shows that it can typically replace flights under 1000km and up to 2300km as we have seen in China. As HSR service on a route matures, about 20% of air travel demand may be substituted (Zheng, 2022). In 2019, the average carbon intensity of flights under 2000 km ranged from 80 to 220 g CO_2 per passenger-km depending on aircraft type, while an electric train running on the U.S. electricity grid emits about 38 g CO_2 per passenger-km (Graver et al., 2020; Miller, 2021). Therefore, modal shift can enable a 50-80% reduction in carbon intensity and even more with cleaner electricity grids. This lever has been considered in the EU and is highly relevant for China and US domestic operations.

Non-CO_2 impacts

The global warming potential of non-CO_2 aviation emissions can be double that of CO_2 emissions (EASA, 2020). Reductions in non-CO_2 emissions can take effect quickly, balancing out some increase in CO_2 emissions and buying us more time for decarbonization (Klower et al., 2021). Research has shown that SAFs emit less sulfur, aromatic hydrocarbon, and particulate matter during combustion than conventional jet fuel, translating to a lower non-CO_2 climate impact. Nevertheless, widespread use of SAF is far on the horizon; we cannot count on fuel switching as the only solution to non-CO_2 impacts of aviation. Other solutions include adjusting cruise altitude to avoid dense cold air. This approach can reduce contrail formation by up to 60% (Teoh et al., 2020) but would require a lot of air traffic coordination. Another solution, hydrotreating conventional jet fuel to reduce aromatic content, may be more achievable in the near term (EASA, 2020; Voigt et al., 2021). It can effectively reduce contrail formation and involves fewer stakeholders.

RECOMMENDATIONS FOR CHINA

The Chinese aviation industry is actively trying to align with the national climate strategy of peaking emissions by 2030 and reaching carbon neutrality by 2060. In early 2022, the Civil Aviation Administration of China (CAAC) published its 14th five-year (2021-2025) special plan for green development of civil aviation (China Government, 2022). The plan includes a goal to achieve carbon neutral growth for commercial aviation and peak airport carbon emissions by 2035.

Specifically, CAAC plans to take action in four areas: governance framework, low-carbon strategy, pollution control, and innovation capacity building. The low-carbon strategy encompasses ambitions to reduce fuel intensity of commercial flights, accelerate fleet renewal, pilot SAF at airports with greater than 5 million annual throughputs, increase SAF deployment to 20,000 tonnes annually by 2025, promote hybrid and fully electric planes, and transition into smart energy systems at airports. The plan also emphasizes the need for fiscal support for implementation and encourages private stakeholders to leverage green finance.

In addition to the action plan, China plans to integrate the aviation industry into their national carbon market. China has also built an extensive high-speed rail network over the past two decades, offering low-carbon alternatives to busy short-haul flights.

China takes a holistic approach to aviation sector decarbonization, with emphases on aircraft and airport emissions as well as pollution mitigation. However, according to the current plan, it is not clear whether resources are being prioritized for the most important decarbonization levers. Promoting the production and adoption of high-integrity SAF should be China's top priority. To date, there is only one domestic SAF production facility operating and another one planned. A national roadmap for scaling SAF is urgently needed; some policy options are discussed below.

In 2021, China launched the online trading of its national emissions trading system (ETS). It currently covers the electricity sector and will gradually expand to seven additional sectors including aviation. The market opened at around 48 CNY/tonne (7 USD/tonne), and it is projected to increase to 139 CNY/tonne (20 USD/tonne) by 2030 (CSIS, 2021; Slater et al., 2021). This intensity-based ETS is well suited to generate revenue for closing the price gap between clean and conventional fuels. But first the government needs to integrate aviation into the ETS and channel the corresponding revenues towards SAF development. The revenue generated should be prioritized for advanced biofuels and synthetic fuels, rather than food-based biofuel pathways. Defining emission boundaries between carriers, airports, fuel suppliers, and other stakeholders will be crucial in safeguarding against double counting.

Besides ETS, direct financial support is another promising option for the Chinese government. Subsidizing SAF through tax credits to level the playing field with conventional jet fuel is one way. Establishing public-private partnerships to mitigate investment risks and guarantee uptake by airports is another. For example, Japan established a 2 trillion yen (about $16 billion) Green Innovation Fund in 2022 to start providing government grants to SAF producers (USDA, 2022). CAAC can also put in place operational incentives for carriers to invest in SAF and more fuel-efficient aircraft, such as priority gate assignments or increased market share on a route. In addition, China is undergoing a lot of airport construction and expansion; these are the perfect opportunities to integrate infrastructure for SAF and zero-emission planes.

In addition to SAF, China can play a more active role in ICAO policymaking. China recently manufactured the first commercial aircraft of their own, Comac C919. The state has not had a strong presence in ICAO environmental standard setting processes due to limited exposure to aircraft and engine production. It is now time for China to step up its environmental leadership at ICAO. China should acknowledge the importance of an international climate goal for aviation and help ensure that it considers countries' different levels of historical emissions.

China can also lead by promptly submitting an ambitious State Action Plan to ICAO. Since 2015, CAAC has been tracking the fuel consumption and fuel intensity of civil aviation operations. China should develop a national decarbonization roadmap based on its fuel efficiency trend, SAF targets, and other planned measures. The level of ambition can be better quantified when comparing the projected emissions pathway with the business-as-usual emissions. In addition, building capacity to measure and project non-CO_2 impacts (e.g., contrail formation) will also be crucial.

RECOMMENDATIONS FOR THE U.S.

The U.S. aviation industry aligns itself with the national climate strategy of achieving net-zero emissions by midcentury to limit warming to 1.5 ºC. In 2021, the Federal Aviation Administration (FAA) published the latest aviation climate action plan, detailing a goal of reaching net-zero greenhouse gas emissions from the U.S. aviation sector by 2050 (US FAA, 2021). The sector includes U.S. domestic flights, international flights operated by U.S. carriers, and airports within the U.S.

The plan entails actions in eight specific areas: aircraft technology, operational improvements, SAF, international leadership, FAA leadership, airport initiatives, non-CO_2 impacts, and out-of-sector reductions. Specifically, the industry will develop and deploy next-generation aircraft that can potentially achieve 30% improvement in fuel efficiency compared to today's best-in-class models. FAA estimates that new narrowbody aircraft could be introduced by 2035, and new widebody designs by 2040. The sector will also seek operational improvements such as enabling digital, auto-negotiated flight path optimization and adjusting high-altitude trajectory to reduce contrail formation.

Moreover, the U.S. government established a multi-agency "SAF Grand Challenge" scheme, with a near-term target of deploying 3 billion gallons each year by 2030. The involved agencies will create an implementation plan that focuses on SAF cost reduction, sustainability enhancement, and wider adoption. Currently, there is one commercial SAF production facility in the U.S., and at least five more planned. The FAA is also exploring technologies to reduce non-CO_2 emissions, for example by funding research on contrail prediction using meteorological forecasts.

In addition, FAA published guidance for CORSIA implementation, as U.S. carriers began participating in the pilot phase starting in 2021. Outside of FAA, U.S. EPA finalized a domestic aircraft CO_2 standard in 2020 that is identical to the ICAO one. As discussed previously, a more stringent standard is needed to actually drive efficiency improvements and emissions reduction (US EPA, 2020).

The action plan reflects that the U.S. will leverage its strong background in aerospace technology to push for further innovation in aircraft design and air traffic management. The "SAF Grand Challenge" scheme presents great ambition and entails a comprehensive strategy. Yet, the plan needs to be translated into concrete federal- and state-level policies, with a focus on promoting advanced biofuels and synthetic fuels. The proposed Sustainable Aviation Fuel tax credit, for example, may over-incentivize food-based fuel pathways that raise concerns of displacement effects or land use change (ICCT, 2022).

The U.S. can build on existing policies to provide economic incentives for SAF. Notably, the Low Carbon Fuel Standards (LCFS) in California, Oregon, and Washington can add jet fuel as a mandatory pathway so that airlines begin to pay for SAF uptake. The standards can also allow hydrogen and electricity suppliers to opt in and generate credits. Meanwhile, the government should consider SAF blend mandates that exclude food-based biofuel pathways and come with sub-mandates for synthetic fuels. The sub-mandates are critical in preventing fuel suppliers from only producing the lowest-cost eligible fuel to comply. Promoting synthetic fuel is important as most biofuel feedstocks are finite resources. Design of blenders tax credit or other SAF incentives should follow the same principle.

Moreover, the U.S. can take a step further in emissions accounting. U.S carriers currently report fuel burn data by aircraft type to the Department of Transportation quarterly. Disclosing flight-level emissions at the point of purchase to consumers enables selection of lower-emitting flights and provides incentives for airlines to improve their fuel efficiency. In addition, building the technical capacity to measure contrail formation will also be crucial to more comprehensive greenhouse gas accounting.

Lastly, modal shift to rail remains an untapped decarbonization lever for the US. The air travel market replaceable by rail is typically routes under 2,000 km between dense urban areas, which makes up almost a quarter (24%) of U.S. domestic operations in 2019. Electric trains are about 60% less carbon-intensive than flights of similar distances; replacing all short-haul, high-density flights with train rides would reduce U.S. domestic emissions by 15% (Zheng, 2022). Realizing some of this potential by investing in HSR infrastructure will not only help lower emissions but also increase connectivity and economic opportunities for the serviced cities. Increasing the speed of existing services using funds under the Bipartisan Infrastructure Bill is a start. The U.S. can also consider HSR technology transfer from China, given their deep expertise in the sector.

OPPORTUNITIES FOR COLLABORATION

The global nature of the aviation industry makes international policymaking front and center of climate actions, especially in terms of promoting new aircraft technology. SAF deployment, on the other hand, will rely mostly on national policies for support and incentives. If China and the U.S. can collaborate on these two major areas, the two nations will add tremendous momentum to global decarbonization efforts. The collaboration can also demonstrate solutions to the three aforementioned major challenges: international governance, technology diffusion, and equity.

As mentioned above, ICAO is considering adopting an LTAG for aviation decarbonization at its 41st Assembly this September. Member states' positions will determine the goal's level of ambition. Similar to the Paris Agreement, the ICAO LTAG is aiming to establish a common goal with nationally determined contributions. China and the U.S. should both bring good faith into the negotiation and explore options for developing an ambitious and equitable LTAG. For instance, basing the target on cumulative emissions and allowing differentiated implementation timelines can help realize the "common but differentiated responsibilities" principle. The two nations should try to lead productive discussions on these potential features of an LTAG.

The two nations should also seek common grounds on the implementation of the potential LTAG. The U.S. can advocate for impact assessments to be conducted for any global measures, ensuring that developing nations are not unduly impacted. Meanwhile, China should support the idea of each country submitting concrete State Action Plans with ambitious reductions from their business-as-usual baseline to ensure progress towards achieving the LTAG. If these principles were followed, the LTAG would mean differentiated emissions peaking and reduction schedules among nations under a shared target.

A joint leadership between China and the U.S. at future ICAO negotiations will also be instrumental in promoting more robust and progressive environmental standards. Notably, the two nations can support an update to the ICAO's aircraft CO_2 standard, which does not yet promote new technologies. Increasing the stringency of the CO_2 standard with flexibility mechanisms such as corporate averaging or tiered standards can help manufacturers produce and sell more fuel-efficient designs in a cost-effective manner. Moreover, it will be important for the two nations to advocate for beginning ICAO work on standards for hydrogen aircraft in the next few years if those aircraft were to enter into service in the 2030s. Establishing scientific consensus on non-CO_2 impacts of aviation should also be prioritized on the international level. China and the U.S. should collectively advocate for ICAO's resource allocation to be consistent with long-term decarbonization.

Lastly, China and the U.S. can leverage their political presences at ICAO to recommend an increase in transparency of its decision-making process. The specific actions include but are not limited to releasing working papers in advance of high-level meetings and making meeting records publicly available.

Strategies to scale the deployment of clean fuels have been discussed in previous sections. There are opportunities for the two nations to collaborate beyond alignment of domestic policies. China and the U.S. can select several transpacific routes to establish a SAF corridor, where carriers from both countries will have access to 100% high-integrity SAF at Nexus airports. Such a low-carbon corridor provides a platform for both nations to coordinate the investments, infrastructure, and regulatory framework needed for SAF adoption on international flights. The corridor will also naturally aggregate the demand for SAF and lower the uncertainty for fuel suppliers as well as other stakeholders. If needed, this program can focus on business travel heavy routes where corporate travelers are more likely to pay for SAF price premium and are interested in claiming the emissions benefit. Direct government subsidy, of course, is another option. Airports participating in the corridor can pilot lowered landing charges for flights on 100% SAF to add extra incentives. The ecosystem established through the corridor activities can later expand to serving more China-U.S. routes and routes to other countries. There are precedents of zero-emissions corridors in the maritime shipping sector; the U.S. just started a green shipping corridor initiative in early 2022.

SAF adoption, however, needs to come hand in hand with a robust set of international SAF sustainability criteria. China and the U.S. both have the opportunity to set high-quality standards from the start and prevent low-integrity fuels from dominating the market. The CORSIA sustainability criteria for alternative fuels can provide a foundation for domestic and international policies that safeguard the quality of SAF.

Finally, China and the U.S. can make joint commitments to cutting aromatic content of fossil jet fuel by 50% using hydrotreating, which would abate contrails by about 30%. The two nations can advocate for common ASTM standards that mandate lower aromatic contents in jet fuel and adopt aligned regulations domestically to serve as leading examples for the rest of the world.

SUMMARY

Aligning aviation with Paris temperature goals requires significant ambition and resources, supported by robust government policies. China and the U.S., the two largest markets, play a crucial role in leading the low-carbon transition of aviation. The two states' combined efforts can help alleviate the major challenges to decarbonizing aviation: inefficient international policymaking and lack of momentum for clean fuel adoption.

Across the entire aviation industry, GHG emissions reduction needs to come from clean fuels adoption, fuel efficiency improvements, demand change associated with market-based measures and modal shift, as well as mitigation of non-CO_2 impacts.

China and the U.S. are at different stages of economic development and thus their air traffic growth in the coming decades will vary. The two countries will naturally have different plans for decarbonization. Nevertheless, we believe that the two states can agree on the urgency of peaking aviation emissions, align their priorities for decarbonization, and promote collaborations on key levers. Both countries need to provide more support and incentives for high-integrity SAF through domestic policies. China needs to strengthen its ICAO leadership, while the US needs to promote emissions disclosure and invest in HSR.

The potential areas for collaboration range across ICAO leadership, SAF corridor, enhancement of environmental standards, and contrail mitigation through low aromatic fuels. Immediate actions from both countries will be crucial to routing global aviation towards deep decarbonization in the coming decades and staying in line with a Well Below 2 Degrees temperature goal.

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REFERENCES

1. Airbus (2022). *fello'fly*. Retrieved from Airbus https://www.airbus.com/en/innovation/disruptive-concepts/biomimicry/fellofly
2. ATAG [Air Transport Action Group]. (2021). *Waypoint 2050*. Retrieved from the Air Transport Action Group https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050/
3. Boeing. (2021). *Commercial Market Outlook 2021-2040*. Retrieved from https://www.boeing.com/commercial/market/commercial-market-outlook/index.page
4. CARB [California Air Resources Board]. (2022). *Low Carbon Fuel Standard*. Retrieved from the California Air Resources Board https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard
5. China Government. (2022) *"十四五"民航绿色发展专项规划 The 14th Five-Year Special Plan For Green Development Of Civil Aviation*. Retrieved from http://www.gov.cn/zhengce/zhengceku/2022-01/28/5670938/files/c22e012963ce458782eb9cb7fea7e3e3.pdf
6. CSIS [Center for Strategic and International Studies]. (2021). *China's New National Carbon Trading Market: Between Promise And Pessimism*. Retrieved from https://www.csis.org/analysis/chinas-new-national-carbon-trading-market-between-promise-and-pessimism
7. EASA [European Union Aviation Safety Agency]. (2020). *Updated Analysis Of The Non-CO_2 Climate Impacts Of Aviation And Potential Policy Measures Pursuant To Eu Emissions Trading System Directive* Article 30(4). Retrieved from https://www.easa.europa.eu/downloads/120860/en
8. EASA [European Union Aviation Safety Agency]. (2022). *EASA Publishes New Fuel/Energy Rules With Positive Environmental Impac*t. Retrieved from https://www.easa.europa.eu/en/newsroom-and-events/press-releases/easa-publishes-new-fuelenergy-rules-positive-environmental
9. EC. (2021). *Proposal For A Regulation Of The European Parliament And Of The Council On Ensuring A Level Playing Field For Sustainable Air Transport*. Retrieved from the European Commission https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021PC0561
10. Graver, B., Rutherford, D., & Zheng, X. (2020). *CO_2 Emissions From Commercial Aviation, 2013, 2018, And 2019*. Retrieved from the International Council on Clean Transportation https://theicct.org/publication/co2-emissions-from-commercial-aviation-2013-2018-and-2019/

11. Graver, B., Zheng, S., Rutherford, D., Mukhopadhaya, J., & Pronk, E. (2022). *Vision 2050: Aligning Aviation With The Paris Agreement*. Retrieved from the International Council on Clean Transportation https://theicct.org/publication/global-aviation-vision-2050-align-aviation-paris-jun22/

12. (2016). *Environmental Trends Report*. Retrieved from https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

13. ICAO [International Civil Aviation Organization]. (2019). *Resolution A40-18: Consolidated Statement Of Continuing ICAO Policies And Practices Related To Environmental Protection - Climate Change*. Retrieved from https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf

14. ICAO [International Civil Aviation Organization]. (2021a). *ICAO Revenue Passenger -Kilometers (RPK) Forecasts Scenarios*. Retrieved from https://www.icao.int/sustainability/Documents/Post-COVID-19%20forecasts%20scenarios%20tables.pdf

15. ICAO [International Civil Aviation Organization]. (2021b). *CORSIA Default Life Cycle Emissions Values For CORSIA Eligible Fuels*. Retrieved from the International Civil Aviation Organization https://www.icao.int/environmental-protection/ CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20 Emissions%20-%20March%202021.pdf

16. ICAO [International Civil Aviation Organization]. (2022a). *Environmental Trends In Aviation To 2050*. Retrieved from https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art7.pdf

17. ICAO [International Civil Aviation Organization]. (2022b). *High-Level Meeting On The Feasibility Of A Long-Term Aspirational Goal For International Aviation CO_2 Emissions Reductions (HLM-LTAG) Revised Summary Of Discussions For Agenda Item 4*. Retrieved from https://www.icao.int/Meetings/HLM-LTAG/Documents/HLM-LTAG_SD_004_REV2_v2_clean.pdf

18. ICAO [International Civil Aviation Organization]. (2022c). *Report On The Feasibility Of A Long-Term Aspirational Goal (LTAG) For International Civil Aviation CO_2 Emission Reductions*. Retrieved from https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

19. ICCT [International Council on Clean Transportation]. (2022). *Public Comment Letter: Crop-Based Biofuels Under The Sustainable Aviation Fuel Grand Challenge*. Retrieved from https://theicct.org/wp-content/uploads/2022/06/SAF-Grand-Challenge-crop-based-fuels-letter-vf.pdf

20. IPCC [Intergovernmental Panel on Climate Change]. (2021). *IPCC Sixth Assessment Report – Working Group I: The Physical Science Basis*. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

21. Kharina, A., Rutherford, D., & Zeinali, M. (2016). *Cost Assessment of Near- and Mid-Term Technologies to Improve New Aircraft Fuel Efficiency*. Retrieved from the International Council on Clean Transportation https://theicct.org/publication/cost-assessment-of-near-and-mid-term-technologies-to-improve-new-aircraft-fuel-efficiency/

22. Klöwer, M., Allen, M. R., Lee, D. S., Proud, S. R., Gallagher, L., & Skowron, A. (2021). *Quantifying Aviation's Contribution To Global Warming*. Environmental Research Letters, 16(10), 104027.

23. Miller, C. A. (2021). *Savings In Per-Passenger CO_2 Emissions Using Rail Rather Than Air Travel In The Northeastern US*. Journal of the Air & Waste Management Association, 71(12), 1458-1471.

24. Mukhopadhaya, J., & Rutherford, D. (2021). *Performance Analysis Of Evolutionary Hydrogen-Powered Aircraft*. Retrieved from International Council on Clean Transportation https://theicct.org/publication/aviation-global-evo-hydrogen-aircraft-jan22/

25. Mukhopadhaya, J., & Graver, B. (2022). *Performance Analysis Of Regional Electric Aircraft*. Retrieved from International Council on Clean Transportation https://theicct.org/publication/global-aviation-performance-analysis-regional-electric-aircraft-jul22/

26. Pavlenko, N., & Searle, S. (2021). *Assessing The Sustainability Implications Of Alternative Aviation Fuels*. Retrieved from the International Council on Clean Transportation https://theicct.org/publication/assessing-the-sustainability-implications-of-alternative-aviation-fuels/

27. Slater, H., De Boer, D., Qian, G., & Shu, W. (2021). *2021 China Carbon Pricing Survey*. Retrieved from http://www.chinacarbon.info/wp-content/uploads/2022/02/EN_2021-China-Carbon-Pricing-Survey-Report.pdf

28. Teoh, R., Schumann, U., Majumdar, A., & Stettler, M. E. (2020). *Mitigating The Climate Forcing Of Aircraft Contrails By Small-Scale Diversions And Technology Adoption*. Environmental Science & Technology, 54(5), 2941-2950.

29. UK. (2022). *Jet Zero: Our Strategy For Net Zero Aviation* (Updated 19 July 2022). Retrieved from the United Kingdom Department of Transportation https://www.gov.uk/government/speeches/jet-zero-strategy-our-approach-for-achieving-net-zero-aviation-by-2050

30. UKCOP26. (2021). *International Aviation Climate Ambition Coalition: COP26 Declaration*. Retrieved from https://ukcop26.org/cop-26-declaration-international-aviation-climate-ambition-coalition/

31. USDA [United States Department of Agriculture]. (2022). *Japan: Japanese Government And Industry Partner To Develop SAF Capacity*. Retrieved from https://www.fas.usda.gov/data/japan-japanese-government-and-industry-partner-develop-saf-capacity

32. US EPA [United States Environmental Protection Agency]. (2020). *Control Of Air Pollution From Airplanes And Airplane Engines: Ghg Emission Standards And Test Procedures - Final Rulemaking*. Retrieved from https://www.epa.gov/regulations-emissions-vehicles-and-engines/control-air-pollution-airplanes-and-airplane-engines-ghg

33. US FAA [United States Federal Aviation Administration]. (2021). *United States 2021 Aviation Climate Action Plan*. Retrieved from https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

34. Voigt, C., Kleine, J., Sauer, D., Moore, R. H., Bräuer, T., Le Clercq, P., ... & Anderson, B. E. (2021). *Cleaner Burning Aviation Fuels Can Reduce Contrail Cloudiness*. Communications Earth & Environment, 2(1), 1-10.

35. Zheng, S. (2022). *The Bullet Train To Lower-Carbon Travel*. Retrieved from https://theicct.org/aviation-rail-shift-lower-carbon-mar22/

36. Zheng, X.S., & Rutherford, D. (2020). *Fuel Burn Of New Commercial Jet Aircraft: 1960 To 2019*. Retrieved from International Council on Clean Transportation https://theicct.org/sites/default/files/publications/Aircraft-fuel-burn-trends-sept2020.pdf