United States 2024

Aviation Climate Action Plan

Contents

Section I. Introduction

Background: Objective and Commitment to Action

On November 9, 2021, Secretary of Transportation Pete Buttigieg announced the 2021 United States Aviation Climate Action Plan (2021 Action Plan). The 2021 Action Plan laid out a whole-of-government approach to achieve a goal of net-zero greenhouse gas (GHG) emissions from the U.S. aviation sector[1] by 2050 (2050 goal). In addition to serving as the public-facing statement of the U.S. government's plans to address aviation's climate impact, this document served as the United States State Action Plan (State Action Plan), which is submitted to the International Civil Aviation Organization (ICAO) every three years. The United States provided an initial State Action Plan in 2012, as well as a revision in 2015. We expect further updates every three years in the future.

The 2021 Action Plan included the net-zero goal for the U.S. aviation sector for the first time. That goal was developed through a careful analysis of U.S. government policies and programs, as well as U.S. industry initiatives.

This 2024 Action Plan update seeks to capture the progress made over the past three years and identifies opportunities for the United States to make continued progress toward this goal. The 2024 Action Plan should be read in the context of the U.S. government's previously announced economy-wide commitment to cut emissions 50-52% below 2005 levels by 2030.[2]

Much like the 2021 Action Plan, this document summarizes key actions the Federal Government is taking, in collaboration with stakeholders across the entire U.S. aviation ecosystem. This public-private collaboration includes airlines, manufacturers, suppliers, airports, energy companies, state, local and Tribal Nations, universities, and communities, to reduce and eventually achieve a net elimination of climate pollution from the aviation sector.

Importantly, the 2024 Action Plan also (1) reports actual CO_2 emissions in context of relevant actions taken since 2021; and (2) updates projections of CO_2 emissions through 2050 based on the latest forecasts, accounting for the updated policy landscape.

The United States is committed to addressing the global climate crisis. Due to the long technology development cycles and fleet renewal process, aviation is a "hard-to-abate" sector. The sector contributes approximately 2-3% of human-caused climate impact annually, and possibly more in the future; at the same time, it is a major driver of economic growth and prosperity in the United States and around the world. Thus, it is essential to develop and implement policies that preserve and enhance the economic contributions of the sector while reducing and eventually eliminating its climate impact consistent with the 2050 goal.

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[1] The U.S. aviation goal encompasses CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators, (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators, and (3) airports located in the United States.

[2] White House, "*FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies,*" April 22, 2021, available at: www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

Section II outlines the progress toward the net-zero goal. Section III provides updates to the Action Plan that highlight the specific efforts underway across the United States.

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Section II: Progress towards the 2050 Goal

in the context of the 2021 U.S. Aviation Climate Action Plan

The U.S. Aviation Climate Goal

In 2021, the United States Government announced a U.S. economy-wide goal of reducing net GHG emissions by 50-52% by 2030, relative to 2005 levels.[3] This was soon followed by a longer-term commitment to an economy-wide target of net-zero GHG emissions by 2050.[4] In 2023, the four federal agencies (U.S. Departments of Transportation, Energy, and Housing and Urban Development, and the Environmental Protection Agency) published the first ever U.S. National Blueprint for Transportation Decarbonization, which reaffirmed the importance of addressing transportation emissions from all sources, including aviation.[5]

The ***Blueprint*** lays out a strategy to reduce nearly all greenhouse gas (GHG) emissions in the U.S transportation sector, in line with the U.S. economy-wide goal of net-zero GHG emissions by 2050.[6] The transportation sector is the largest source of greenhouse gas emissions in the United States, contributing to the climate crisis that is worsening the quality of life in cities, towns, and rural communities throughout America. Emissions from the transportation sector also contribute to poor air quality. These effects disproportionately impact underserved and disadvantaged communities. As stated in the Blueprint, we aim to eliminate nearly all GHG emissions from each part of the transportation sector by 2050 and implement a holistic strategy to achieve a future mobility system that provides clean, safe, resilient, accessible, and equitable transportation options for people and goods. The Blueprint provides a roadmap for how we can provide better transportation options, expand affordable and accessible options to improve efficiency, and transition, where practical, to zero-emission vehicles and fuels. The Blueprint is built on five principles:

1. Initiate bold action.
2. Embrace creative solutions across the entire transportation system.
3. Ensure safety, equity, and access.
4. Increase collaboration.
5. Establish U.S. global leadership.

Consistent with the U.S. Transportation Decarbonization Blueprint, the 2021 Action Plan included the net-zero goal for the U.S. aviation sector for the first time. That goal was developed through a careful analysis of U.S. government policies and programs, as well as U.S. industry initiatives. This 2024 Action Plan update seeks to capture the progress made over the past three years and identify opportunities for the United States to make continued progress toward this goal. The 2024 Action Plan should be read in the context of the U.S. government's previously announced commitment to cut emissions 50-52% below 2005 levels by 2030.

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[3] *Id*.

[4] White House, *"THE LONG-TERM STRATEGY OF THE UNITED STATES Pathways to Net-Zero Greenhouse Gas Emissions by 2050,"* Nov. 2021, available at: www.whitehouse.gov/wp-content/uploads/2021/10/us-long-term-strategy.pdf

[5] U.S. National Blueprint for Transportation Decarbonization https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.

[6] The White House, *"FACT SHEET: President Biden to Catalyze Global Climate Action through the Major Economies Forum on Energy and Climate,"* April 20, 2023, available at: www.whitehouse.gov/briefing-room/statements-releases/2023/04/20/fact-sheet-president-biden-to-catalyze-global-climate-action-through-the-major-economies-forum-on-energy-and-climate.

Under the Blueprint, the four federal agencies made commitments to develop modal plans that discuss, in detail, actions, investments, and research needed decade by decade to reach net-zero carbon targets by 2050. This U.S. Aviation Climate Action Plan, first issued in 2012, but first establishing a net-zero goal in 2021, and with this update, represents the high-level aviation decarbonization strategy. A more detailed modal plan for aviation will be developed next year that covers the broad range of actions needed from aircraft to airports to fuels and new air mobility technology. Thus, this updated Action Plan should be read as a supplement to the overall national decarbonization work, providing a high-level aviation decarbonization strategy that can help put the aviation sector on a path to further reductions in later years.[7]

In late 2021, the United States set a national goal of net-zero GHG emissions from the U.S. aviation sector by 2050 and launched the 2021 Action Plan. The U.S. also launched the Sustainable Aviation Fuel (SAF) Grand Challenge, focusing on SAF that achieves at least a 50% reduction in lifecycle emissions, and setting goals of producing three billion gallons of domestic SAF by 2030 and 35 billion gallons by 2050.[8]

U.S. Aviation Climate Goal:
Net-Zero GHG Emissions from the U.S. Aviation Sector** by 2050*

* Aviation GHG emissions include life cycle carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions. Aircraft engines produce negligible amounts of nitrous oxides and methane, so this plan has a focus on aviation combustion CO_2 emissions and well-to-tank life cycle GHG emissions (CO_2, N_2O, and CH_4). The U.S. Aviation 2050 Goal is based on emissions that are measurable and currently monitored. Research is ongoing into the climate impacts of aviation-induced cloudiness and the indirect climate impacts of aviation combustion emissions (see section 7 for details on the climate impacts of aviation non-CO_2 combustion emissions).

** This U.S. aviation goal encompasses CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators, (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators, and (3) airports located in the United States.

Approach and Methodology

The 2021 Action Plan used historical data through 2019 and forward-looking projections (i.e., forecasts) of CO_2 emissions from 2020[9] to 2050. In the 2021 Action Plan, CO_2 emissions for 2020, 2021, and 2022 were based on forecasts. In this 2024 update, the data have been replaced with actual, historical data collected by the U.S. government. The 2024 update provides the opportunity to:

- Review and analyze historical data from 2020-2022 to understand the factors influencing the U.S. aviation sector's climate impacts in recent years;

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[7] *Supra* note 5.

[8] Note that each gallon of SAF must achieve a minimum of 50% reduction in GHG emissions to count towards the Grand Challenge.

[9] The 2021 Action Plan analyzed historical data through 2019, as these were the most recent, complete datasets available for analysis during the Action Plan development timeline.

- Track progress by comparing monitored, actual data against the 2021 Action Plan to understand how the U.S. aviation sector is progressing towards the 2050 goal established in the 2021 Action Plan; and
- Assess drivers and root causes of differences between actual and forecasted data that, among other information and considerations, may help inform future strategic decisions and policies that would be reflected in future U.S. Aviation Climate Action Plan iterations.

The methodology to track progress towards the goal combines two key components:

(1) A backward-looking assessment of the 2021 Action Plan's projected CO_2 emissions for 2020-2022 versus actual data (presented in this Section), along with,
(2) Updated/refreshed forecasts towards 2050 (presented in Section III).

The metrics and scope used in the methodology for tracking progress towards the 2050 goal in this 2024 update are aligned with the metrics and scope of the 2021 Action Plan and results in a repeatable, annual process. This allows for understanding of progress and contribution from measures to reduce emissions, an approach that can constructively inform future policy options and decision-making necessary to achieve the 2050 goal.

Assessment of the 2021 Action Plan's Projected CO_2 emissions for 2020-2022

The U.S. aviation sector experienced a severe downturn in 2020 caused by the impacts of the COVID-19 pandemic across all domestic and international markets. The sector's CO_2 emissions, which are largely driven by jet fuel combustion, reflect the downturn and subsequent recovery.

Figure 1 shows the 2021 Action Plan's projected CO_2 emissions for 2020-2022 against actual data. Given the data and information available at the time of its development, the 2021 Action Plan anticipated that, by 2022, combustion and residual CO_2 emissions from the U.S. aviation sector would reach approximately 85% of their 2019 level. Actual data in this 2024 update show that CO_2 emissions from the U.S. aviation sector in 2022 reached 93% of their 2019 level. Despite some contributions to emissions reductions from aircraft technology, operations, and emissions reductions from SAF, the higher than projected combustion and residual CO_2 emissions were largely driven by the U.S. aviation sector's rapid recovery from the COVID-19 downturn.

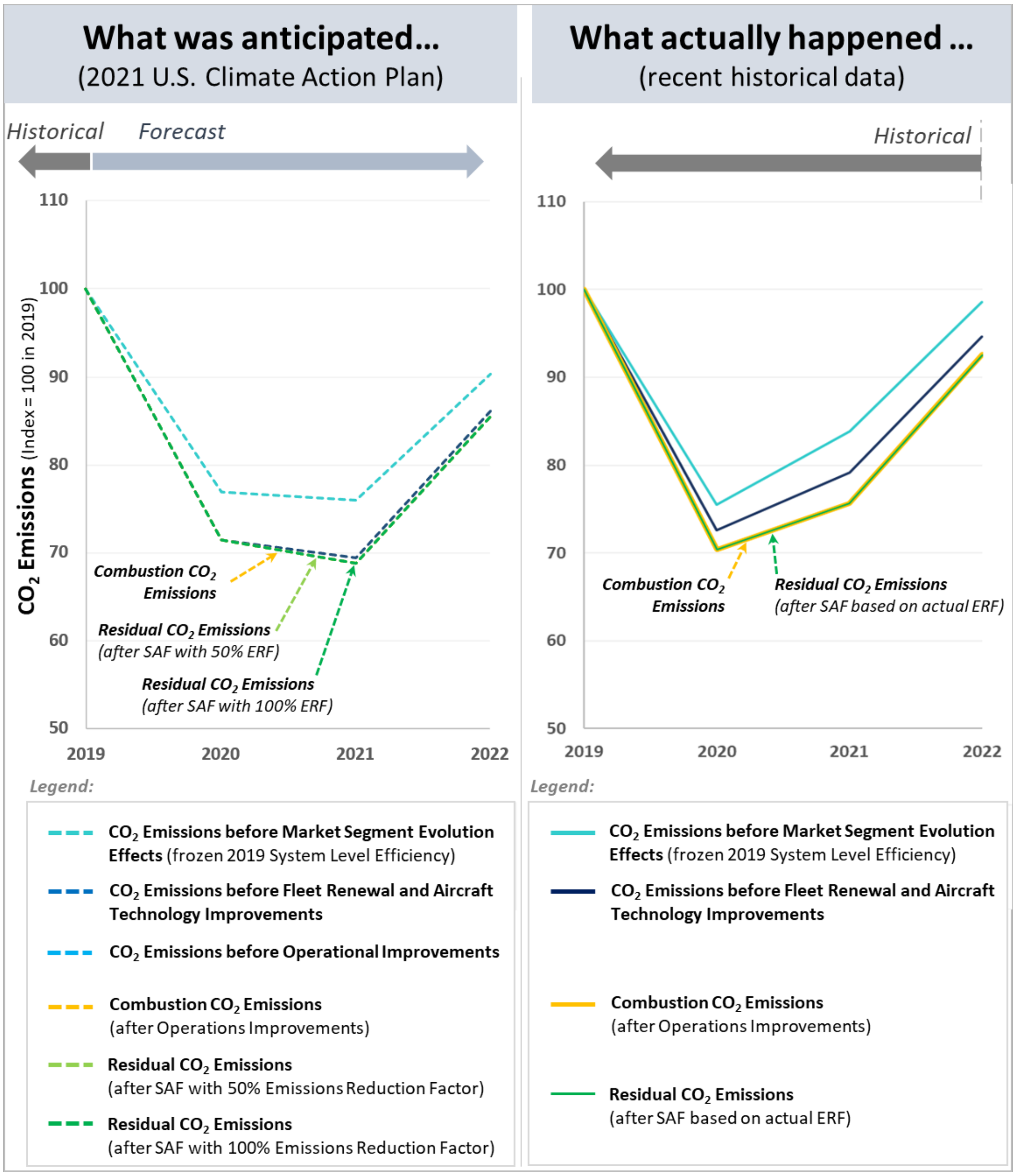

Figure 1. Evolution of CO_2 emissions from the U.S. aviation sector between 2019 and 2022 compared to the projections from the 2021 U.S. Aviation Climate Action Plan.

Figure 2 breaks down the factors influencing the evolution of CO_2 emissions from the U.S. aviation sector between 2019 and 2022 to help explain the key drivers for differences between actual data and the 2021 Action Plan's projection. As shown in Figure 2, traffic, capacity, and load factors in 2022 were higher than anticipated by the 2021 Action Plan. Despite emissions reductions from fleet renewal, new aircraft technology, and operational improvements close to those anticipated in the 2021 Action Plan, this increased traffic resulted in higher combustion CO_2 emissions from the U.S. aviation sector in 2022. Increases in SAF volumes from 2019 to 2022 had modest impacts on residual CO_2 emissions (i.e., CO_2 emissions after Emissions Reductions from SAF).

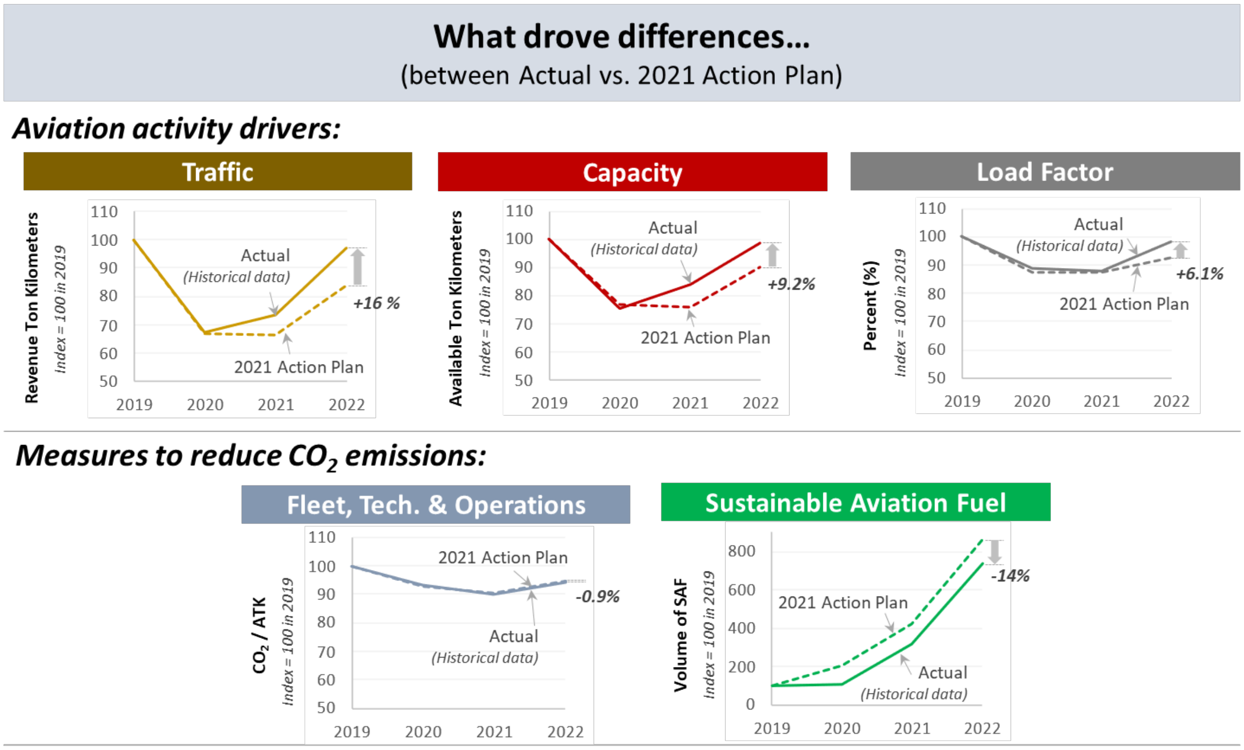

Figure 2. Factors influencing the evolution of CO_2 emissions from the U.S. aviation sector between 2019 and 2022 compared to the 2021 U.S. Aviation Climate Action Plan projections.

Notable differences between actual and projected CO_2 emissions from 2020-2022:

- The U.S. aviation sector recovered more rapidly from COVID-19 than anticipated in 2021.
  - Actual traffic, measured in Revenue Ton Kilometers (RTK), or Revenue Ton Miles (RTM), was +16% higher than previously projected for 2022. Despite higher load factors (+6.1% actual vs. projected), this resulted in higher capacity measured in Available Ton Kilometers (ATK) i.e., +9% actual vs. projected for 2022.
- Combustion CO_2 emissions in 2022 were +8% higher than forecasted primarily due to higher traffic and capacity.
- The CO_2 intensity of the U.S. aviation sector (measured in CO_2 per ATK) was approximately 6% lower (i.e., better) in 2022 than in 2019. This is 0.9% better than projected in the 2021 Action Plan.
  - While traffic and capacity were the largest contributing factors to higher CO_2 emissions than forecasted, these emissions are lower than what they could have been due to the effects of fleet renewal, aircraft technology and operational improvements as well as the effects of changes in market segment structure during the COVID-19 pandemic (i.e., increased share of cargo aircraft, which are more fuel efficient than passenger aircraft on a CO_2 per ATK basis).
- SAF investments yielded an eight-fold increase in the volume used by U.S. operators between 2019 and 2022.
  - While the recent historical growth is below the growth projected in the 2021 Action Plan to meet the U.S. SAF Grand Challenge goal of 3 billion gallons by 2030, this eight-fold increase is an encouraging trend in SAF development, production, and uptake.

The following sections provide additional details on each of the contributing factors to differences between projected and actual CO_2 emissions for 2020 to 2022.

Aviation Traffic: Recovery from the COVID-19 pandemic

As a result of the COVID-19 pandemic, U.S. passenger air traffic in 2020 saw its lowest level since 1984 with a year-over-year 60% decrease.[10] In contrast, demand for air cargo remained robust throughout the pandemic.

The U.S. aviation sector has recovered from the COVID-19 pandemic. In 2022, system traffic grew 60% year-over-year,[11] while system enplanements rose by 49%. Domestic Revenue Passenger Kilometers (RPKs) were 46% higher in 2022 compared to 2021. After falling in 2020 and 2021, international RPKs more than doubled in 2022, surging by 132% while enplanements rose by 84%.

Figure 3 shows historical trends in traffic, load factor, and capacity for the U.S. aviation sector from 2019 to 2022 compared to projections from the 2021 Action Plan.

Traffic[12] (measured in RTKs) grew faster (+11%) than projected under the 2021 Action Plan based on 2021-2041 traffic forecasts. Overall, actual system level RTKs in 2022 were higher by +16% compared to the 2021 Action Plan projections. In addition to load factors being higher than projected (+1.4 and +5.0 percentage points actual vs. projection for 2021 and 2022 respectively), aviation capacity was also higher than anticipated (+8.2% and +6.9% actual vs. projection for 2021 and 2022).

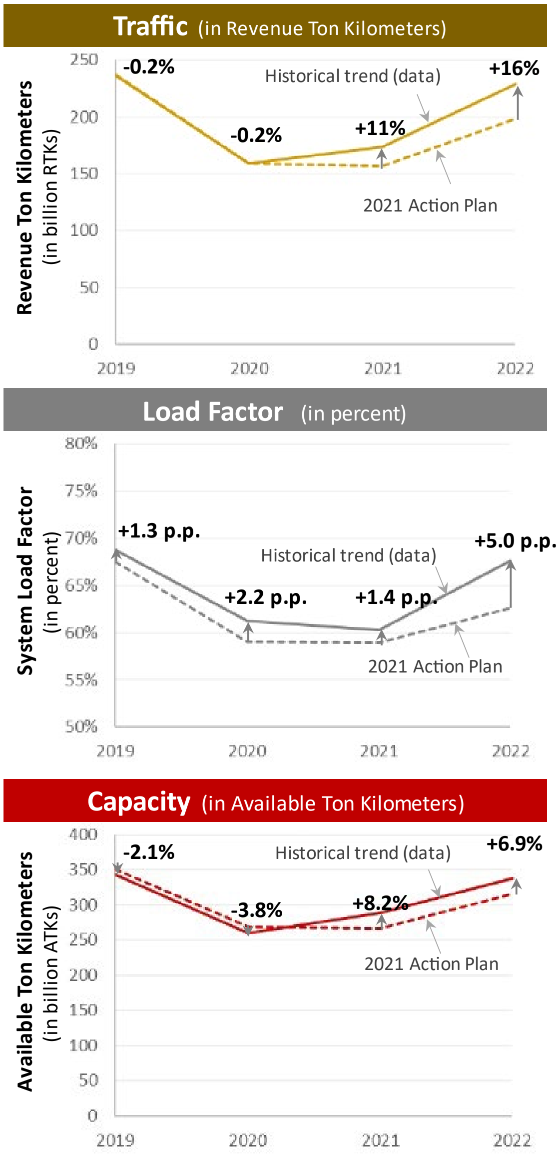

Figure 3. Historical trends in traffic, load factor, and capacity for the U.S. aviation sector from 2019 to 2022 in context of the projections from the 2021 U.S. Aviation Climate Action Plan.

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[10] U.S. DOT Bureau of Transportation Statistics, "*Full Year 2020 and December 2020 U.S. Airline Traffic Data*," Release Number: BTS 18-21, available at: https://www.bts.gov/newsroom/full-year-2020-and-december-2020-us-airline-traffic-data.

[11] Measured by revenue passenger kilometers (RPKs).

[12] Traffic measured in RTK combines passenger and cargo transported. See glossary for details on aviation activity metrics and definitions.

Aircraft Technology and Operational Efficiency: Tracking progress on aircraft technology improvements and operational improvements.

While increased traffic and capacity were the largest contributing factors to higher-than-forecast combustion CO_2 emissions[13] in 2020-2022, these emissions are less intense than in 2019 due to fleet renewal, new aircraft technology and operational improvements. These effects can be tracked through changes in CO_2 intensity measured in CO_2 per Available Ton Kilometers (CO_2/ATK).

Figure 4 shows the historical trends in CO_2 intensity for the U.S. aviation sector from 2019 to 2022 in context of the projections from the 2021 Action Plan. Year-over-year (YoY), the CO_2 intensity of the U.S. aviation sector improved substantially in 2020 (-6.8%) followed by -3.3% in 2021. The trend reversed in 2022 with an increase by +4.2% from 2021. However, CO_2 intensity remained 6% below the 2019 level.

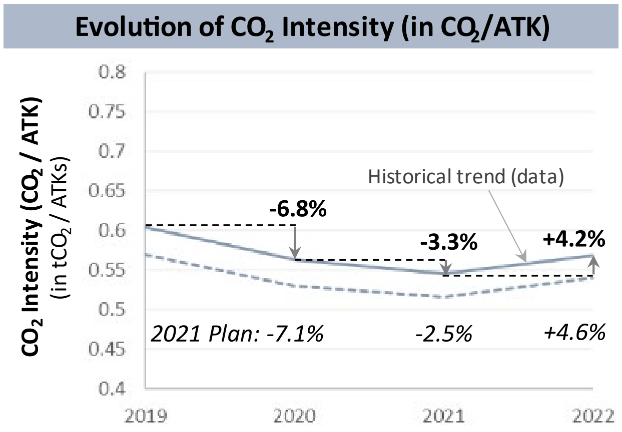

Figure 4. Historical trends in combustion CO_2 intensity (in CO_2/ATK) for the U.S. aviation sector from 2019 to 2022 in context of the projections from the 2021 U.S. Aviation Climate Action Plan.

Generally, changes in combustion CO_2 intensity are influenced by: (1) fleet renewal (i.e., retirement of less fuel-efficient aircraft and/or entry into service of more fuel-efficient aircraft); (2) new aircraft technology (i.e., development and entry into service of new generations of aircraft or engines more fuel-efficient than the previous generation); and (3) operational improvements. Changes in market segment structure during the COVID-19 pandemic (i.e., increased share of cargo aircraft with lower CO_2/ATK than passenger aircraft) also contributed to changes in overall combustion CO_2 intensity.

During the COVID-19 pandemic, aviation cargo activity was boosted by consumers' purchases and by surface transportation disruptions. The capacity share for wide- and narrow-body aircraft operated for dedicated cargo increased from 29% to 37% from 2019 to 2022 while the capacity share of passenger aircraft declined from 71% to 63%. The passenger market recovery and cargo market normalization in 2022 contributed to the slight reversal of trends.

Overall, given the combined effects of the factors described above, combustion CO_2 emissions from the U.S. aviation sector declined by 30% in 2020, increased by 7% in 2021, and further increased by 22% in 2022. As a result, 2022 CO_2 emissions reached 93% of their 2019 level.

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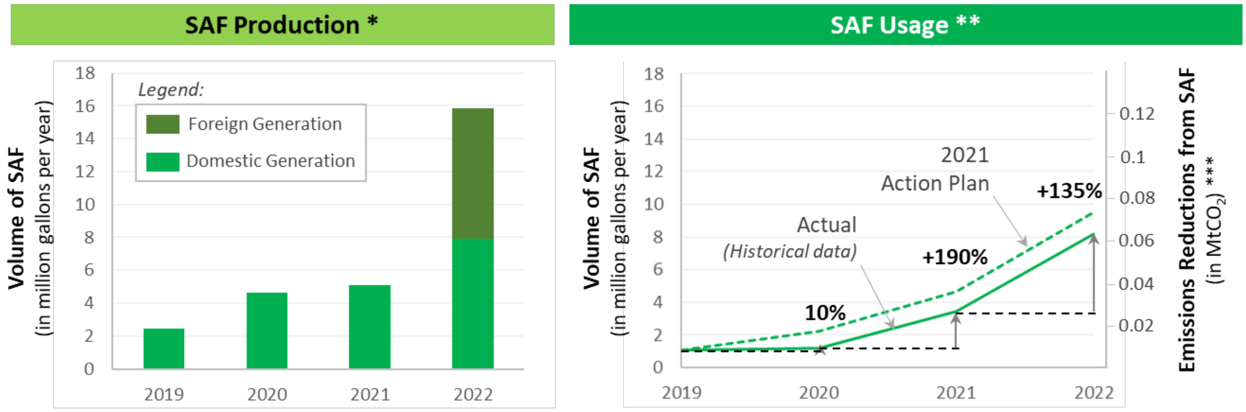
[13] In this section, CO_2 emissions refer to combustion CO_2 emissions, not lifecycle CO_2 emissions.

Sustainable Aviation Fuels (SAF): Tracking progress on SAF.

SAF[14] progress can be monitored through the production of SAF, as well as its use by U.S. airlines and operators; however, these indicators might vary given potential for SAF exports and SAF purchased and claimed by international operators. The left-hand side of Figure 5 shows the SAF production volumes; the right-hand side shows volumes of SAF used, based on reports from U.S. airlines between 2019 to 2022.

In 2019, the production of SAF was approximately 2.4 million gallons. SAF production climbed to about 16 million gallons in 2022.[15] The domestic production of SAF does not guarantee its use by U.S. airlines, or the inclusion of associated emissions reductions by U.S. operators in the tracking process used by the U.S. government. Domestically produced SAF can be exported outside of the U.S., and airlines may also import and use SAF produced abroad.

As shown on the right in Figure 5, U.S. airlines reported use of approximately 1.1 million gallons of SAF in 2019. Despite modest increases from 2019 to 2020, there was a substantial year-over-year increase in 2021 and 2022 (+190% and +135% respectively). SAF usage by U.S. airlines reached approximately 8.2 million gallons in 2022. For context, the right side of Figure 5 also illustrates projections under the 2021 Action Plan that assumed an exponential growth trend between the actual 2019 SAF use and the U.S. SAF Grand Challenge goal of three billion gallons in 2030 (the dashed line).[16] Despite actual use trending below the 2021 Action Plan projections, the eight-fold increase in SAF usage by U.S. airlines from 2019 to 2022 represents a significant increase during this period.



* EPA, Renewable Fuel Standard (RFS) reporting, "Renewable Jet Fuel".

** SAF usage in given year based on airlines' ESG reports and analyses.

*** Estimated emissions reductions from SAF (based on average emissions reductions factor of 80%)

Figure 5. Volume of Sustainable Aviation Fuels produced along with SAF Volumes used by U.S. Airlines from 2019 to 2022.

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[14] See Section III – 3. Sustainable Aviation Fuel for more information about SAF.

[15] U.S. Environmental Protection Agency, "Public Data for the Renewable Fuel Standard," available at: https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions.

[16] See discussion of the SAF Grand Challenge in Section III.3, below.

Section III. The 2024 U.S. Aviation Climate Action Plan

The 2021 Action Plan was developed during the COVID-19 pandemic, at a time of significant uncertainty regarding the recovery and future evolution of the U.S. aviation sector as well as uncertainty regarding federal or state support of SAF production and development. Given the anomalous nature of 2020 data, the 2021 Action Plan used 2019 as its reference year. At the time of this report release, 2020 to 2022 is available. This section provides a review of the new reference year (2022) used as a starting point for the projections through 2050. It then presents updated details on the measures being taken to achieve the goal of net-zero GHG emissions from the U.S. aviation sector by 2050.

Reference Year

As shown in the left-hand side of Figure 6, the combustion of jet fuel from domestic and international aviation[17] accounts for more than 97% of U.S. aviation CO_2 emissions[18] in 2022,[19] with the remaining emissions coming from airport operations and fuel use from aviation gasoline used by piston engines. Although jet fuel combustion emissions were calculated using actual 2022 data, the airport operations emissions were approximated using 2019 data. Notably, 80% of domestic aviation emissions and 94% of international aviation emissions come from en-route operations.[20] Given the disproportionate role of en-route combustion of jet fuel in aviation's emissions footprint, this document focuses on jet fuel and the aircraft that use it.

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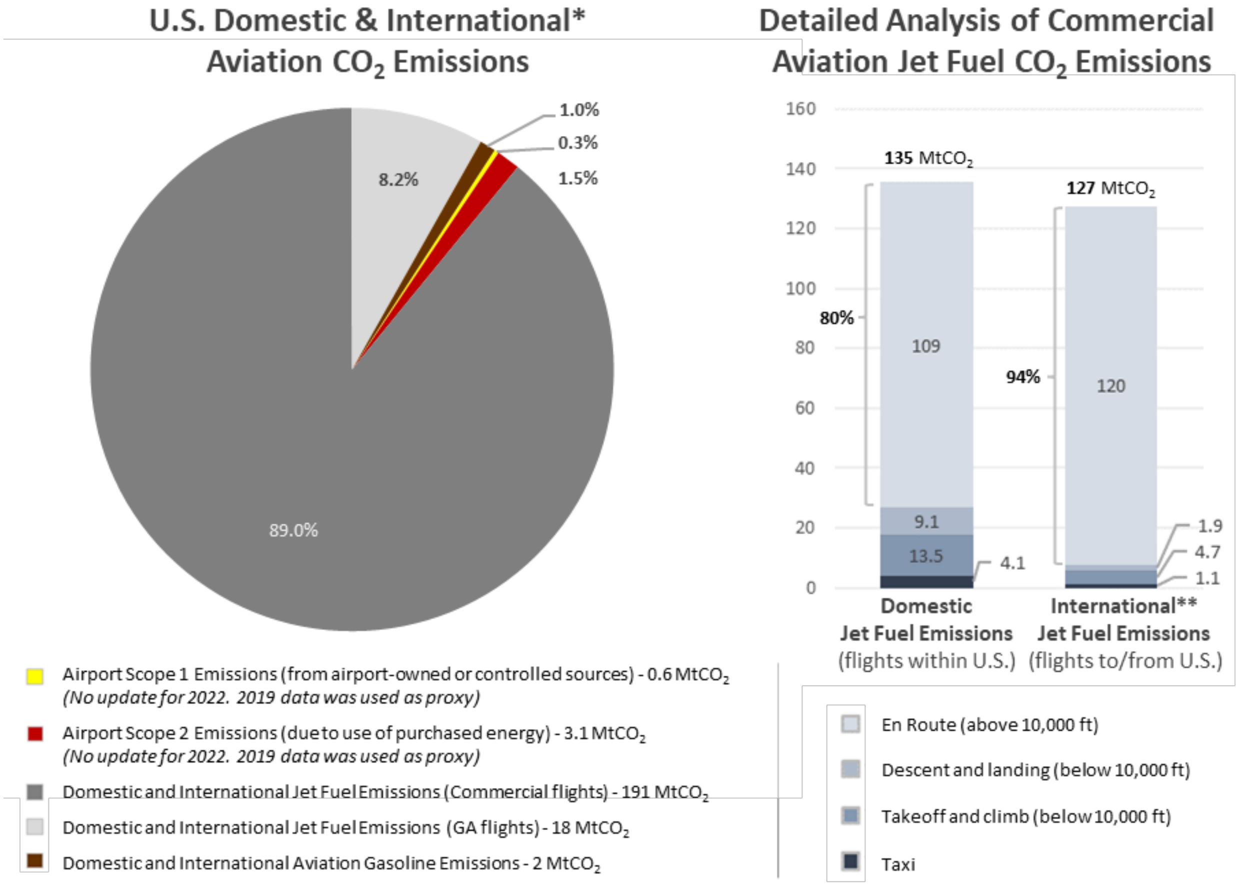
[17] In the context of Figure 6, domestic flights are those that take place within the U.S. and its Territories. International flights are those to and from the U.S. and its Territories. In both cases, the data includes operations by U.S. and foreign operators.

[18] Not including the life cycle emissions associated with production and distribution of fuels, also referred to as well-to-tank emission.

[19] This share (i.e., 97%) has remained constant between the 2021 Action Plan and this version of the Plan.

[20] These shares (i.e., 80% and 94%) have remained unchanged between the 2021 Action Plan and this version of the Plan.



* CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators and (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators (only). Airport scopes 1 and 2 added for this specific analysis (figure).
** International aviation to / from the United States, regardless of the operator of the flights i.e., including both U.S. and foreign operators.
Definition: General Aviation (GA) based on the scope of the FAA Aerospace Forecast derived from the General Aviation and Part 135 Activity Survey (GA Survey). Includes general aviation activity (Parts 91, 125, 133, 135, and 137) from fixed wing (piston, turboprop, turbojet), rotorcraft (piston and turbine), experimental, special light-sport and other aircraft.

Figure 6. Analysis of U.S. Aviation CO_2 Emissions in 2022[21]

In 2022, civil aviation emitted about 2.4% of total U.S. CO_2.[22] In 2022, U.S airlines carried about 830 million passengers accounting for 910 billion revenue passenger miles.

Given the recovery from the COVID-19 pandemic, aviation demand is projected to continue to grow. Figure 7 provides the CO_2 emissions that would accompany this growth in a business-as-usual scenario,[23]

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[21] Airport scope 1 and 2 emissions are from the ACI 2021 Long-Term Carbon Goal Study for Airports (Fig 23). Jet fuel and aviation gasoline emissions based on the FAA Aerospace Forecast (Federal Aviation Administration, FAA Aerospace Forecast, Fiscal Years 2021-2041, 111, Table 23). Detailed analysis of commercial aviation jet fuel emissions based on AEDT analysis. International jet fuel emissions include U.S., international, and foreign airspace.

[22] U.S. Environmental Protection Agency, "*Inventory of U.S. Greenhouse Gas Emissions and Sinks*," available at: www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

[23] CO_2 emissions calculated based on 3.16 and 3.10 $kgCO_2$/kg fuel for jet fuel and aviation gasoline, respectively. CO_2 emissions are reduced by Emissions Reductions from SAF based on ratios of life cycle values for SAF vs. conventional fuels.

as computed based on the FAA Aerospace Forecast,[24] alongside different interventions to reduce the sector's emissions to 2050. The future emissions analysis considers the cumulative impact of key measures (e.g., aircraft technology and fuels). In this 2024 Action Plan, projected combustion CO_2 emissions in 2050 under the frozen 2022 efficiency scenario are approximately 11% higher than in the 2021 Action Plan due to the revised and greater traffic and capacity forecasts than previously anticipated.

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[24] The forecast traffic growth is from the FAA Aerospace Forecast data (2023-2043) with extrapolation to 2050.

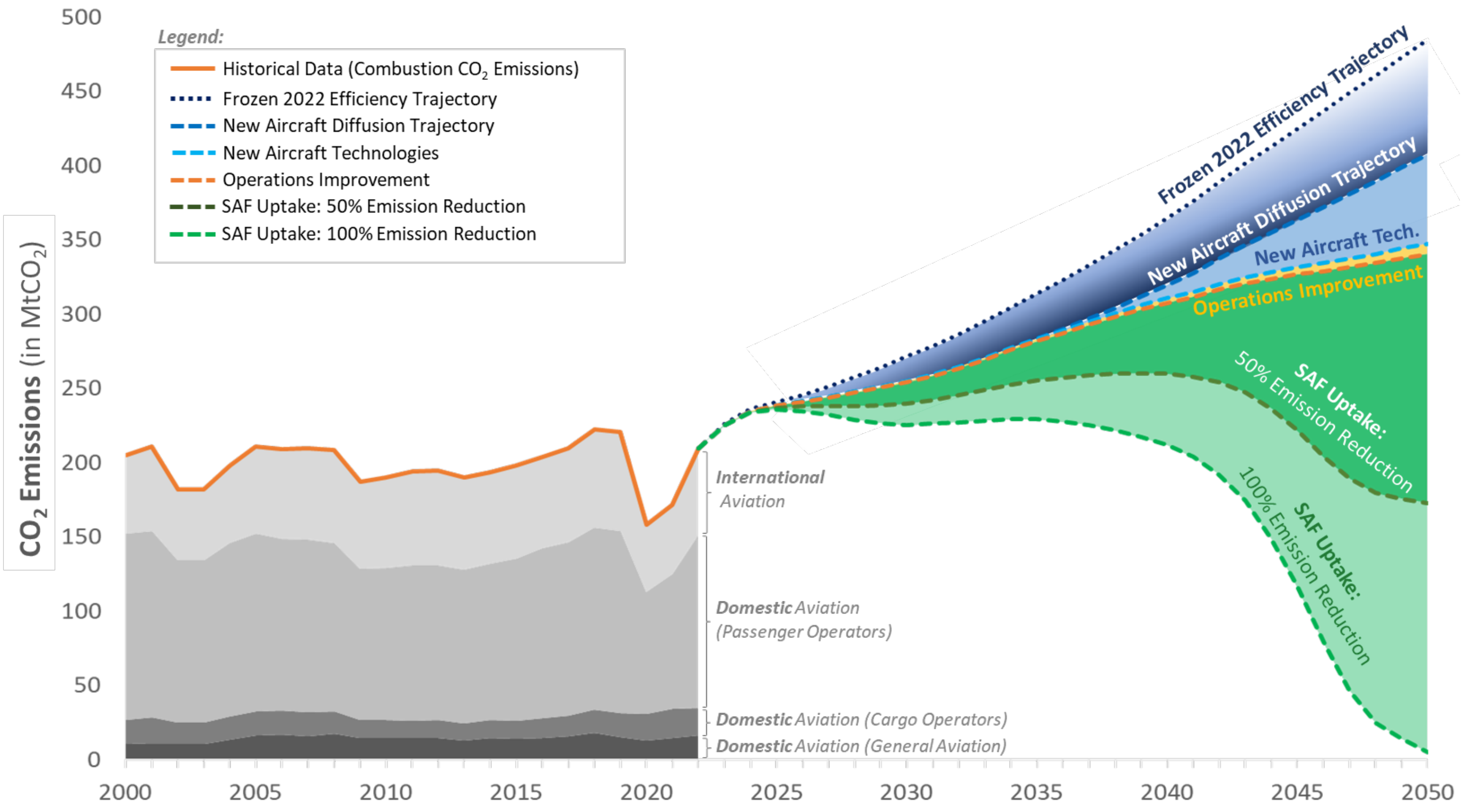

Figure 7. Analysis of Future U.S. Domestic and International Aviation CO_2 Emissions[25]

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[25] Analysis conducted by BlueSky leveraging R&D efforts from the FAA Office of Environment & Energy (AEE) regarding CO_2 emissions contributions from aircraft technology, operational improvements, and SAF.

These projections are presented for in-sector reductions; however, we recognize that high-integrity offsets, (i.e., reductions from other sectors, accounted for against sectoral and national totals) might be needed to achieve net-zero emissions. The contributions from the various measures are discussed below and in the following sections. We also note that current data does not support and thus this analysis does not show potential contributions from other technologies discussed later in this document that are under development and could be part of the technology mix in 2050, such as aircraft powered by electricity or hydrogen. As more data becomes available, analysis will be updated in future iterations to reflect developmental improvements in these areas.

The multiple trajectories of Figure 7 capture expected actions by the airlines to use new aircraft and engine technologies that are currently being produced by the original equipment manufacturers (OEMs). The **Frozen 2022 Efficiency** trajectory illustrates a scenario that captures projected growth in traffic, but the fleet remains unchanged, and therefore, the fleet-wide fuel efficiency remains at the 2022 levels.[26] The **New Aircraft Diffusion** trajectory accounts for the currently known actions airlines and OEMs are taking. Airlines are continuing to retire older aircraft and acquire new aircraft with improved fuel efficiency. This includes a variety of new aircraft types, which have recently entered the fleet and aircraft expected to enter the fleet in the coming years. The **New Aircraft Technology** trajectory accounts for further aircraft technology developments from the next generations of aircraft expected to enter the fleet in the 2035-2040 timeframe. The **Operations Improvement** trajectory take into account net efficiency improvements in the operations of the National Airspace System (NAS). CO_2 Emissions after technology and operations are often referred as combustion CO_2 emissions. Finally, the green wedges on Figure 7 depict the potential contribution from emissions reductions from Sustainable Aviation Fuels where the **SAF Uptake** (50% and 100% Emissions Reductions) trajectories capture potential residual CO_2 emissions from U.S. aviation.

The measures shown in Figure 7 provide a roadmap for how U.S. aviation could reach net-zero levels through coordinated actions by U.S. industry and the U.S. Government (USG). These measures are discussed in greater depth in the sections that follow.

Finally, as highlighted throughout this 2024 Action Plan, partnership with industry and civil society is necessary to achieve a sustainable, decarbonized aviation sector. Engaging with the full ecosystem of aviation stakeholders will be critical to advance technological innovation, create new job opportunities, and contribute to the Administration's economy-wide goal of net-zero emissions by 2050. Commitments by the aviation sector, including airlines, aircraft manufacturers, fuel providers, and airports—in concert with government investment and well-designed policy measures—will significantly reduce emissions by 2030 and put us on the pathway to a net-zero aviation sector.

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[26] Note: This Frozen 2022 Efficiency trajectory is not labelled as a "business as usual" scenario and is not intended to represent a real scenario given orders and expected future aircraft deliveries. Fleet renewal is expected to happen in the absence of further actions. This Frozen 2022 Efficiency trajectory is however a useful depiction of the growth trajectory of capacity (i.e., traffic divided by load factor) that is a key input to this forward-looking modeling and assessment.

Community Co-Benefits through Improved Air Quality and Reduced Noise

In addition to its impacts on climate change, aircraft operations have impacts on human health and welfare via noise pollution and local air pollution. These impacts are felt in communities near airports as well as much further away in the communities that surround our metropolitan areas. The actions outlined in this document will both put us on a course to achieve net-zero GHG emissions by 2050 and reduce the impacts of noise and air pollution on airport communities.

New aircraft and engine technologies can reduce noise and fuel burn. Advanced engine combustor designs reduce non-volatile particulate matter (nvPM) and nitrogen oxides (NO_X or $NO+NO_2$) emissions, reducing local air pollution. Air space modernization and advanced operations could change the distribution of flight paths around airports, providing noise relief and lessening community exposure to pollutants. By focusing on fuel burn reductions from en-route operational improvements, there could be opportunities to enable operations close to airports that mitigate noise for communities even if fuel burn increases marginally, resulting in a net reduction in both emissions as well as exposure to noise. SAF provides life cycle GHG emissions reductions and reduces emissions of nvPM. Further, these fuels have no sulfur content; thus, their use will eliminate aircraft sulfur oxide emissions, another pollutant that degrades air quality and impacts human health and welfare.

1. Aircraft and Engine Technology Development

The evolution of more efficient airframes and engines has produced significant aviation emissions reductions; coordinated efforts across the U.S. Government will improve aircraft energy efficiency and reduce emissions through 2050.

Background / Context

Historically, advances in aircraft technology have been the primary factor in mitigating aviation's environmental impacts. Technological advancements over the past 50 years have improved fuel efficiency by 70%. These efficiency and emissions gains have come from public and private sector investments in engines and airframe technologies and designs; however, they can pose significant financial and technical risks for manufacturers. In addition, the decades-long lifespan of aircraft limits the pace of fleet renewal by aircraft operators and the ability of manufacturers to rapidly recoup significant investments in developing new technologies. Given the urgency of emissions reductions from technological improvements as the sector continues to grow, continued USG investment, paired with private investment, is critical to limiting aviation's climate impact, and will create well-paying jobs within the U.S. aviation manufacturing industry while decreasing total emissions.

Figure 8 shows the aircraft development scenario accounting for the introduction of new narrow-body aircraft in 2035 and new wide-body aircraft in 2040 to replace the current generation. In both cases, it may be possible for the next generation to achieve fuel burn improvements of 30% compared to current best-in-class aircraft.[27] The fuel efficiency improvements of these new aircraft will be a direct result of research and development (R&D) investments made by the USG and industry over the next five years.

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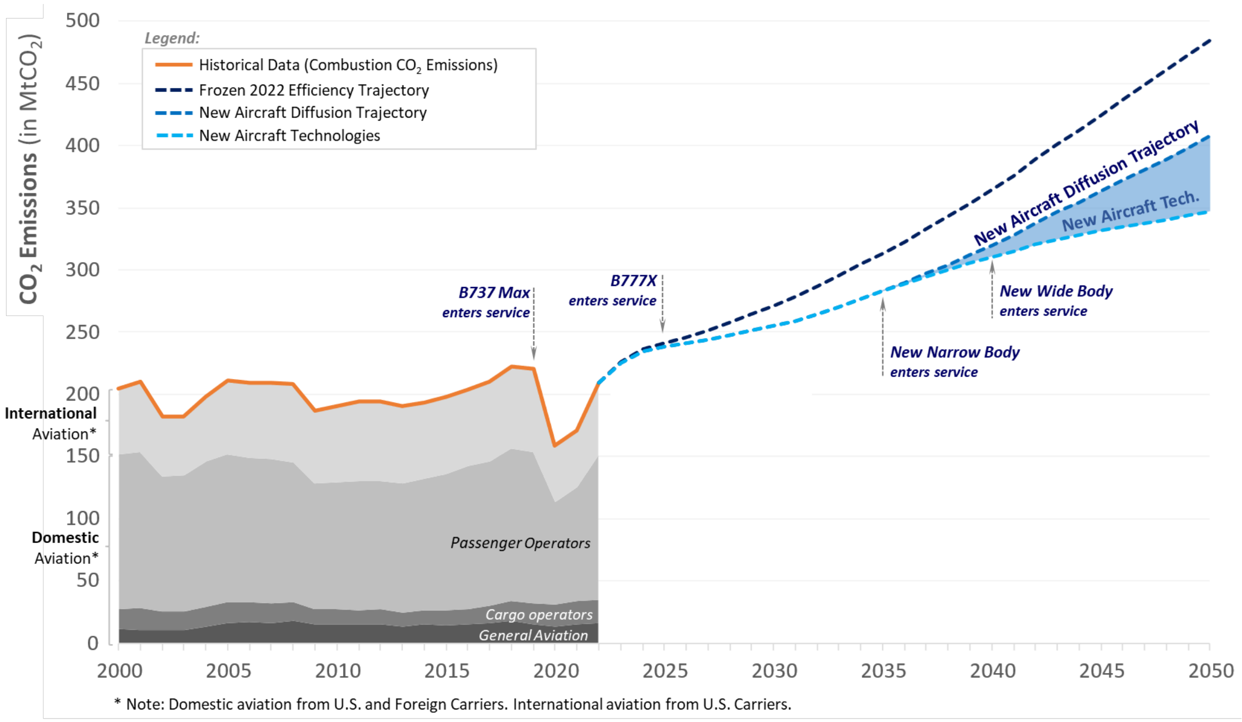
[27] Jensen L., Bonnefoy P., Hileman J., Fitzgerald J., *"The carbon dioxide challenge facing U.S. aviation and paths to achieve net zero emissions by 2050,"* Progress in Aerospace Sciences, Vol. 141, Aug. 2023, 100921, available at: www.sciencedirect.com/science/article/abs/pii/S0376042123000374.



* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.

Figure 8. Analysis of Future Domestic and International Aviation CO₂ Emissions: New Aircraft Development Scenario

Summary of Actions

- Utilize coordinated R&D efforts across the USG to conduct tests to demonstrate aircraft and engine technologies and designs that can deliver a step change improvement in environmental performance, with a particular focus on improved energy (or fuel) efficiency that will yield reduced emissions.
- Pursue ambitious international standards to incentivize the most effective technologies to safely ensure reductions in aircraft-level emissions while limiting the growth of the sector's total emissions.
- Coordinated federal research on enabling aircraft and propulsion technology to potentially use hydrogen or other alternative fuels for aircraft is in the beginning stages of coordination across the FAA, Department of Energy (DOE), National Aeronautics and Space Administration (NASA), and Department of Defense (DOD) with a coordinated research plan expected to be completed by 2026.

Progress and Current Activity

Emission reduction technologies are regulated at the aircraft and engine level as a part of airworthiness certification. These environmental standards are harmonized internationally through ICAO. Today, standards exist at the airplane level for CO_2 and noise, and at the engine level for NOx, nvPM mass and particle number, smoke, carbon monoxide (CO), and unburned hydrocarbons (UHC). The United States promulgates new ICAO standards via rulemaking. e.g., recent implementation of the fuel efficiency standard governing CO_2 emissions.[28] While these standards are not technology-forcing, they ensure new

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[28] Airplane Fuel Efficiency Certification, 89 Fed. Reg. 12,634 (Feb. 16, 2024). https://www.govinfo.gov/content/pkg/FR-2024-02-16/pdf/2024-02330.pdf.

generations of aircraft are not worse than previous generations and protect a level playing field internationally. This approach will continue as technology evolves, consistently reinforcing the application of the best available technology to reduce emissions and noise. These standards also serve as a benchmark for environmental goals in USG aircraft technology R&D programs.

The USG is leading several efforts in collaboration with industry to mature new technology (i.e., increase the Technology Readiness Level (TRL)) to increase fuel efficiency and reduce emissions. USG R&D efforts for civil aircraft are led by the FAA and NASA for mid- to near-term in-service application in the 2030s with mid- to far-term (approaching 2050) R&D by FAA and NASA supplemented by DOE. U.S. DOD-focused R&D could have civil aircraft applications as well.

The FAA's Continuous Lower Energy, Emissions, and Noise (CLEEN) Program is a public-private partnership to develop certifiable aircraft and engine technologies that reduce fuel burn, engine emissions, and noise. CLEEN supports expedited integration of advanced technologies into current and future aircraft. The CLEEN Program, established in 2010, has matured technologies for adoption into the existing fleet and continues to develop additional technologies that will enter service in the coming years as opportunities arise for their adoption into new aircraft and engine designs.[29]

Since the publication of the 2021 Action Plan, the FAA has continued to execute the third phase of CLEEN technology development projects. This program includes an array of technology development efforts focused on the engine, airframe, and aircraft systems. These CLEEN third phase efforts are planned to conclude in 2026 with major ground and flight test demonstrations. At that point, the program will have matured the technologies, reduced their technical risk, and demonstrated their benefits, enabling industry partners to incorporate these technologies into future engine and aircraft products in the early 2030s.

Additionally, the FAA is directing aircraft technology research at universities around the country through ASCENT—the Aviation Sustainability Center (also known as the Center of Excellence for Alternative Jet Fuels and Environment)—to advance and expand industry's technical knowledge base broadly.[30] In recent years, ASCENT's aircraft technology portfolio of research has included aircraft system-level modeling and design, propulsion-airframe integration, and aircraft engine and airframe component technology modeling and development projects. ASCENT complements CLEEN by including work to enhance modeling and analysis tools and testing capabilities that inform development of a broad array of future technologies to reduce aviation's environmental impacts.

In 2022, with the passage of the Inflation Reduction Act, the FAA initiated planning for a new grant program, Fueling Aviation's Sustainable Transition (FAST).[31] Awarded in 2024, the FAST grant program is making investments to accelerate production and use of SAF and the development of low-emission aviation technologies to support the U.S. aviation GHG emissions reduction goal. The low-emission aviation technologies element of the program differs from CLEEN and ASCENT with a focus specifically on development of low-emissions technologies that yield fuel efficiency and GHG emissions reductions. FAST does not have specific targets for noise or other non-GHG emissions reductions. FAST includes

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[29] Additional information on the CLEEN Program is available at https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/.

[30] Additional information on ASCENT is available at https://ascent.aero/topic/Aircraft-Technology/.

[31] Additional information on FAST is available at https://www.faa.gov/general/fueling-aviations-sustainable-transition-fast-grants.

collaboration with both industry and academic partners and provides greater government cost share to accelerate technologies towards application and relevance to the 2050 goal.

Complementary to CLEEN, ASCENT and FAST, FAA supports research on lower maturity technologies that may have great potential benefit, but in some cases have longer timeframes to implementation. However, all of FAA's aircraft technology R&D programs focus on applied research to drive technologies toward implementation in a timeframe relevant to materially impact the aviation sector's GHG emissions by 2050.

NASA conducts foundational research to identify, explore, and mature advanced tools, technologies, and system concepts; it also conducts ground and flight demonstration of the most promising technologies to meet national and international environmental goals. The research is implemented across its Advanced Air Vehicles Program (AAVP), Integrated Aviation Systems Program (IASP), Transformative Aeronautics Concepts Program (TACP), and the Airspace Operations and Safety Program (AOSP). These programs include research on new vehicle technologies and safe, efficient airspace operations with the potential to significantly reduce aviation's impact on the environment.[32] NASA engages with U.S. industry, academia, and other government agencies on a sustainable aviation strategy that spans technical maturity levels from low (far-term exploratory for long-term impact) to high (complex, integrated technology and operations demonstrations for near- to mid-term impact).

Since 2021, NASA has fully established the Sustainable Flight National Partnership (SFNP) as an R&D portfolio of collaborative, public-private partnerships with industry to reduce GHGs through improved energy efficiency with reduced noise and no compromise to safety via advanced aircraft and propulsion technology and more efficient operations within the national airspace. Through the SFNP, NASA intends to demonstrate and transfer the most promising technologies beyond the risk threshold of industry alone to enable up to a 30% reduction in fuel use for aircraft that may enter service in the 2030s.

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[32] Additional information on NASA Aeronautics Research Mission Directorate programs is available at https://www.nasa.gov/aeroresearch.

Within the SFNP, NASA and its partners are making significant progress toward game-changing technology demonstrations built on the exploratory and developmental research of past decades.

- The Sustainable Flight Demonstrator project, or SFD, will mature key airframe technologies. In January 2023, Boeing was selected to develop and demonstrate the Transonic Truss Braced Wing (TTBW) concept through the design, modification, and flight demonstration of large-scale, single-aisle class aircraft. The aircraft has been designated the X66 and development is progressing towards first flight in 2028. NASA and Boeing are also reducing risks of the TTBW concept beyond the scope of the X66.

- The Hi-Rate Composite Aircraft Manufacturing project (HiCAM) will mature key composite airframe technologies to meet single-aisle aircraft needs for weight, cost, and manufacturing quality at high rate to ensure rapid fleet insertion in the 2030s. HiCAM is currently maturing multiple concepts for wing and fuselage applications with partners through an established U.S. Advanced Composites Consortium. In late 2024, the project will down select the most promising concepts for capstone manufacturing and structural demonstrations beginning in 2027.

- The Electrified Powertrain Flight Demonstration (EPFD) project will mature key electrified components and integrated powertrain systems suitable for next generation aircraft. In September 2021, teams lead by magniX and GE Aerospace were selected to demonstrate in-flight, vehicle-level integration of megawatt-class electrified aircraft propulsions systems to address technical and integration risks and achieve safe flight. The teams are on track for first flights in late 2026 to early 2027.

- The Hybrid Thermally Efficient Core (HyTEC) project will mature key gas turbine engine technologies suitable for single-aisle aircraft through ground demonstration of an integrated high-power density core engine with mild hybrid-electric technology. Teams led by RTX/Pratt & Whitney and GE Aerospace were selected to mature a suite of advanced material, aerodynamic, combustion, and electrical technologies. In December 2023, GE Aerospace was selected to design, build, and test the integrated core demonstrator with a target to begin testing in 2028.

These key large-scale integrated demonstrations along with smaller investments in other technologies will contribute to industry decision making by the end of 2020s for potential aircraft and engine products entering service in the 2030s.

NASA/Boeing Transonic Truss-Braced Wing

The Transonic Truss-Braced Wing (TTBW) aircraft is a concept aircraft with extra-long, thin wings stabilized by diagonal struts. This design has potential to be much more fuel efficient than a traditional airliner due to a shape creating less drag, resulting in less fuel burned. The TTBW concept is designed to cruise near Mach 0.80, a similar speed to current narrow-body jetliners and faster than any previous truss-braced wing concept. Wind tunnel tests have so far established an 9-10% reduction in fuel burn for the wings alone; however, NASA and Boeing project a potential next generation plane could achieve up to a 30% reduction in fuel burn compared to today's best-in-class narrowbody jets, like the A320neo or 737 MAX when combined with other emerging technologies.

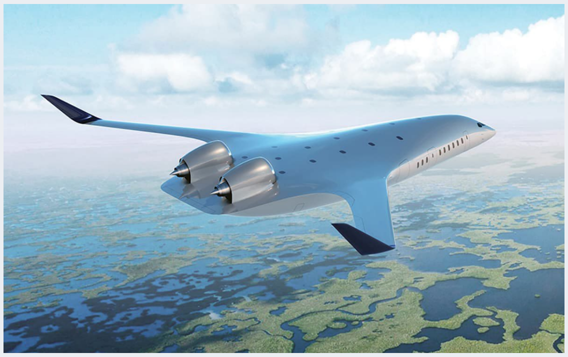
Lastly, the DOD and DOE are making investments in gas turbine efficiency and battery and energy storage technologies that could help civil aviation's climate impact. In 2021, the DOD established a blended wing body flight demonstrator project with an award to JetZero in 2023 to design, build, and fly a demonstrator aircraft with potential commercial and military dual-use. First flight is targeted for 2027.

At a more local level, the development of advanced air mobility (AAM) and unmanned aircraft systems (UAS), presents an opportunity to replace combustion-engine vehicles, e.g., helicopters, with electric powered aircraft systems. Further, the development of AAM and UAS technologies present an opportunity to enhance the development of these new energy and aerospace technologies into larger aircraft, further helping to progress the decarbonization of the sector.

JetZero Blended Wing

The Blended Wingis a naturally stable design requiring no tail surfaces, which eliminates unnecessary complexity. A shorter, wider fuselage is combined with the wing surface to provide lift. This reduces the surface needed, creating a lighter aircraft with less drag.

With less drag and weight, engine size is reduced, which further reduces drag and weight. The result is an aircraft with the passenger capacity and range of a small wide body that uses the engines of existing narrow-body planes. This potential breakthrough is designed to fill the mid-market gap with an aircraft that achieves half the fuel burn and emissions of the aging fleet it will replace.



Actions

While developments in aircraft and engine technology require longer timescales than other measures to realize their environmental benefits, significant improvements in fuel efficiency from new and improved technologies are needed to reduce aviation's climate impact and make SAF go further. To achieve this goal, the USG is pursuing a sustained and coordinated major technology development initiative, described above, with NASA and the FAA working with industry to accelerate the maturation of aircraft and engine technologies enabling a step-change reduction in fuel burn and CO_2 emissions.

NASA's investments support this target via the SFNP, which includes a suite of integrated, large-scale aircraft and propulsion technology ground and flight demonstrations, including ultra-efficient wings (such as TTBW), small-core gas turbines, electrified and hybrid electric aircraft propulsion system(s), and new techniques for high-rate composite manufacturing to enable rapid production of such new aircraft. The SFNP technology demonstrations will be key to U.S. industry decision-making for new aircraft, so the learning from and timing of the demonstrations are critical. FAA's efforts will be executed primarily under the CLEEN Program, with support from ASCENT, and the newly awarded FAST technology projects. The FAA plans to launch a fourth phase of CLEEN in 2025, driving a new five-year period of industry partnership.

This continued collaboration builds upon a long and proven history of successful cooperation between FAA, NASA, and industry on R&D to explore and accelerate the maturation of technologies onto real airplanes to improve fuel efficiency and reduce noise and engine emissions. Continued USG investments in public-private partnerships will reduce the technical and financial risks associated with these transformative technologies and enable industry to take the lead to the next level of environmental performance in their products.

The narrow-body aircraft family initially targeted by these coordinated aircraft efficiency efforts is of considerable importance, accounting for 55% of future global market value ($3.7 trillion), 40% of CO_2 emissions from commercial operators globally, and 60% of domestic population exposure to significant noise. Although the initial focus is on a narrow-body aircraft, the technologies demonstrated by USG research programs are generally applicable to the next generation of wide-body designs in the 2040s. Narrow-body and wide-body aircraft together account for more than 80% of global market value, global CO_2 emissions from commercial operators, and domestic population exposure to significant noise. In addition, some of the technologies may be candidates for retrofitting on existing aircraft.

In parallel to SFNP demonstrations during the 2020s, NASA is pursuing exploratory research and early-stage development with academia and industry aimed at the generation after next aircraft to further power aviation toward net-zero and beyond with technologies for cleaner, quieter airplane concepts that may use alternative propulsive power generation systems (e.g., more or all-electric or cryogenic fueled systems) and rely on major energy infrastructure changes globally. Such technologies can be incubated and matured through small aircraft (i.e., turboprop class and smaller) demonstrations with an eye to scale up for demonstration in larger aircraft in the 2030s for in-service impact in the 2040s or beyond. Additionally, the FAA is supporting this exploration with new projects under ASCENT and FAST. Combined with extensive energy and airport infrastructure changes, these additional advances could yield significant climate and efficiency benefits for future generations of aircraft.

In addition to the above aircraft technology maturation initiatives, the USG continues to actively support development of global environmental standards at ICAO. Consensus on international standards drive manufacturers to integrate technologies to reduce CO_2 emissions, noise around airports, and engine emissions that impact local air quality (LAQ). Ongoing work at ICAO supported by the USG is examining the interdependencies between the environmental impacts of CO_2 and noise limits. Additional background, details, and actions related to International Leadership are presented in Section III.4.

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2. Operational Improvements

Efficiencies can be gained through every phase of flight, helping to reduce fuel burn and emissions from aviation; improvements in trans-oceanic flights could provide substantial benefits.

Background / Context

Air traffic management (ATM) improvements and related infrastructure upgrades have contributed to a highly efficient global air transport system. ICAO estimates horizontal flight efficiency levels between 94% and 98% globally based on 2017 traffic.[33] It is important to note that the ATM system will always have some inherent level of inefficiency due to necessary operating constraints and interdependencies, such as safety, capacity, weather, noise, and airspace fragmentation. Airspace modernization efforts—including the Next Generation Air Transportation System (NextGen) in the United States—are developing and introducing innovative technologies leading to a safer, more efficient, and more predictable system, which may contribute to reduced fuel burn, emissions, and noise. However, it will be a challenge to maintain and improve upon current efficiency levels as demand for airspace increases and modernization efforts focus on safely accommodating that demand.

Figure 9 presents the scenario of potential net operational improvement and accounts for potential improvements during surface, takeoff, cruise, and landing operations based on investments in infrastructure and development of operational concept improvements. Updated net operational improvement scenarios (i.e., improvements in fuel and CO_2 intensity given or despite increases in aviation activity across the National Airspace System (NAS) as captured in the traffic and activity forecasts from 2023) are assumed to improve by 0.5% by 2035 and 2% by 2050.

Summary of Actions

- Complete operationalization of NextGen to realize the full potential of modernized infrastructure and systems, including through the transformation of the NAS to trajectory-based operations.
- Enhance data quality, information distribution, and automation systems to enable operators to fly more fuel-efficient trajectories, especially during the cruise flight phase.

Progress and Current Activity

Many of NextGen's planned infrastructure improvements are complete, having deployed advanced navigation, surveillance, communication, automation, and information infrastructure across the U.S. NAS. Performance Based Navigation (PBN) procedures have been rolled out across the NAS, leveraging satellite-enabled technology to create precise, repeatable, predictable, and efficient 3-D flight paths. Automatic-Dependent Surveillance - Broadcast (ADS-B) has improved surveillance of aircraft, providing higher accuracy and faster update rates for situational awareness of aircraft position using modernized aircraft equipage. Data communications have revolutionized the way air traffic controllers and pilots communicate, saving time and enabling complex route instructions not possible before. These improvements have enhanced air traffic efficiency in the United States and are estimated to have saved more than 900 million gallons of fuel from 2010 through 2023.[34]

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[33] ICAO, "*Destination Green, the Next Chapter, 2019 Environmental Report*," 138-44, available at: www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg138-144.pdf.

[34] Federal Aviation Administration, "*Performance Reporting and Benefits*," available at: www.faa.gov/nextgen/reporting/.

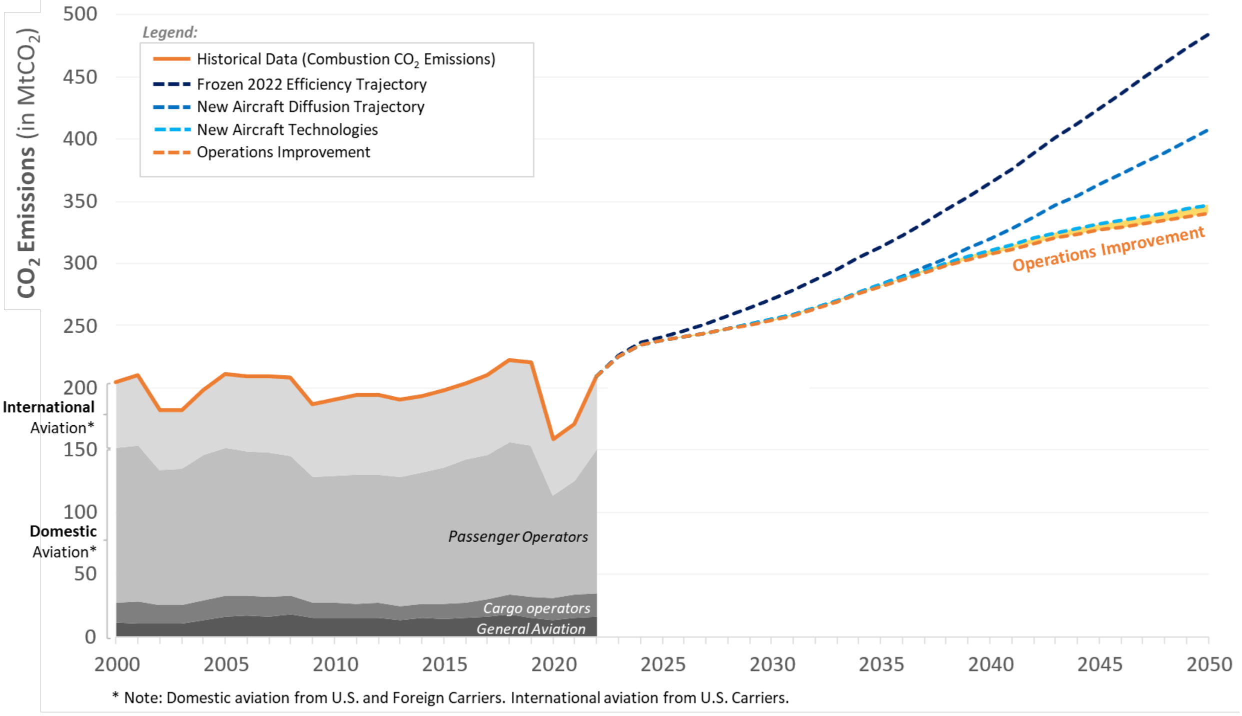

Figure 9. Analysis of Future Domestic and International Aviation CO$_2$ Emissions: Operations Improvement Scenario

FAA is completing operationalization of NextGen, leveraging the modernized infrastructure to realize the full operational potential of the system. This includes transformation of the NAS to trajectory-based operations (TBO). TBO is an ATM method for strategically planning, managing, and optimizing flights throughout the operation by using time-based management, information exchange between air and ground systems, and the aircraft's ability to fly precise paths in time and space. The vision for TBO will be accomplished through improved ATM strategic planning initiatives along with the predominant use of time-based management using precise and repeatable paths defined by PBN procedures and routings. NASA is focused on partnering with FAA and industry in development, demonstration, and transfer of technologies to enable TBO and PBN. The suite of capabilities will deliver opportunities for reduced noise and emissions, allowing airlines to request the most fuel-efficient flight profile from FAA and automate the operator and FAA route request negotiation.

Together, time-based management and PBN comprise a four-dimensional trajectory (latitude, longitude, altitude, and time) airspace users negotiate with the Air Navigation Service Providers to identify a solution that best accommodates both their needs. The trajectory includes a path between origin and destination with predicted crossing time estimates at key points along the path that are much more accurate than the estimates used today for strategic planning. The trajectory facilitates integration across air traffic control domains, enables the FAA to plan while accounting for user objectives, and allows for more collaborative and flight-specific solutions in response to airspace constraints. This represents a great improvement over today's strategic planning initiatives and tactical flow management techniques, addressing many of today's operational shortfalls.

TBO will provide efficiency benefits by allowing flights to absorb delays caused by merging and sequencing in a more fuel-efficient manner over the full trajectory. For example, delays that are typically absorbed by low-altitude vectoring in the current system will instead be shifted upstream to more efficient means such as speed-control, vectors at higher altitudes, or ground delays at the origin airport, where the aircraft can stay on the ground with no, or markedly lower, fuel burn (see Section III.6, Airport Initiatives, below).[35] Additionally, TBO is necessary for accommodating anticipated growth in aviation demand, which could result in increased congestion and excess fuel burn without these capabilities.

Actions

The foundation of the future for air traffic services in the United States is a fully shared information environment. In this paradigm, broader data distribution, information connectivity, delivery of actionable information to decision-makers, and persistent situational awareness will enable improved NAS performance by distributing decisions and allowing stakeholders to best manage their operations. This mode of operation could contribute to fuel efficiency by allowing operators to more regularly fly a preferred, optimal trajectory, while taking full advantage of weather conditions including prevailing winds. Additionally, a more connected, data-rich aviation ecosystem could enable exploration of more complex operational opportunities to reduce aviation environmental impacts, such as contrail avoidance (for more detail on this topic, see Section 7). NASA's Airspace Operations and Safety Program, working in partnership with the FAA, will develop the digital framework, concepts for operation, and technologies for this digitally enabled, service-oriented future airspace.

The FAA is collaborating with industry to enable different operational characteristics for existing vehicle types and new entrants to the NAS. Technological developments will allow the FAA to envision and pursue new automation architectures, increased integration of cloud services for automation and decision support, potentially leading to faster integration of capabilities benefitting efficiency.

The FAA is implementing a future vision of the NAS that will be composed of automation capabilities using layered enterprise components and reusable services that can be developed, acquired, and sustained independently. The Automation Evolution Strategy (AES) is FAA's strategy to modernize its automation by adopting a services-based architecture, with emphasis on more timely development and delivery of new capabilities. In many of today's automation systems, each system independently maintains similar technological infrastructure elements (e.g., hardware, operating systems, data management tools). These systems generally do not take advantage of shared, enterprise-based infrastructure elements and methodologies that could optimize operating costs, scale to meet dynamic user demands, and enable the use of common data flows to ultimately improve ATM service delivery.

The AES aims to migrate these systems to a modern, layered architecture to accrue several benefits for the FAA and support the transition into the future NAS. By focusing on these areas of innovation and efficiency, the FAA can significantly reduce its environmental impact while maintaining safety and reliability. Collaboration among government, industry, and research institutions will be essential to accelerate and achieve meaningful environmental results.

Operations in oceanic airspace are an important target for environmental efficiencies because the operations: (a) are dominated by large, long-haul aircraft, and (b) could especially benefit from enhanced availability of information and operational flexibility. In oceanic airspace, radar and ground-based ADS-B surveillance systems are not available, so aircraft must navigate using separation standards and track systems that may limit access to the most fuel-efficient trajectories. The FAA is evaluating enhancements in surveillance technology supporting reduced separation between aircraft and improved

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[35] Federal Aviation Administration, "*TBO Benefits*," available at: https://www.faa.gov/air_traffic/technology/tbo/benefits/.

accommodation of altitude, speed, and route-change requests, thereby providing safety and efficiency benefits in oceanic Flight Information Regions. In addition, the FAA is developing capabilities to provide aircrews, airline operations centers, and air route traffic control centers with near-real-time visual depictions of rapidly changing weather events, such as thunderstorms over remote areas. Currently, aircrews have limited weather information availability in these regions beyond the traditional range of on-board weather radar. These new capabilities, which have undergone extensive operational testing showing promising climate benefits, allow aircrews to avoid hazardous weather well in advance.

NASA will develop a service-oriented architecture for the future NAS to deliver digitally auto negotiated operational improvements for the entire integrated gate-to-gate flight path domain with consideration of pre- and post-flight events. These improvements can yield efficiencies on regional and NAS wide operations with the potential for reduced emissions. In addition, technologies will be developed for identification of the most optimum high-altitude trajectory for reduced climate impacts accounting for contrail formation. The capabilities will use a fusion of data among all stakeholders for shared situational awareness, and machine learning and artificial intelligence algorithms to deliver solutions to the users for optimum aircraft operations. These NASA capabilities will advance integrated ground- and flight-based technologies for trajectory optimization through every phase of flight, reducing fuel burn and CO_2 emissions. In addition, the digital aviation services and deployment process in the current operational environment will help ready the system for adoption of solutions to mitigate the climate impacts of aviation induced cloudiness (AIC) (for more detail on this topic, see Section 7).

Operational demonstrations supporting the SFNP mission will validate tools and system designs improving efficiency and safety for all future airspace users. The first demonstration will use digital communications and cloud services to enhance and streamline pre-departure operations. The second demonstration will focus on a live oceanic flight demonstration of airborne trajectory negotiations and re-routing. NASA will develop and demonstrate prototype services that will enable pre-departure/en-route trajectory negotiation resulting in a more efficient route that can be communicated to stakeholders across the globe. This oceanic flight demo is currently scheduled for 2027.

Continued USG investment in airspace modernization research and technology development, in collaboration with industry, is critical to achieving the safety and efficiency goals of the future NAS.

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3. Sustainable Aviation Fuels

Sustainable Aviation Fuels (SAF) will be critical to the long-term decarbonization of aviation. Through a range of policy instruments, including the SAF tax credits and FAST grant program of the Inflation Reduction Act (IRA), the USG will work with relevant industries to rapidly scale up SAF production with the goal of meeting 100% of U.S. aviation fuel needs by 2050.

Background / Context

Jet fuel is a critical component of the safe, reliable, and efficient global air transportation system businesses and individuals rely on today. Jet fuel provides a unique combination of chemical and physical properties that enable aircraft to safely carry hundreds of passengers and tons of freight for thousands of miles at high speeds. Relevant properties include remaining in liquid form at the very low temperatures of flight, not vaporizing at the low atmospheric pressures experienced in the upper atmosphere during cruise flight, tolerating relatively high engine temperatures without breaking down and clogging fuel lines, and providing considerable energy both in terms of energy per unit mass and per unit volume. Further, refining crude oil into petroleum jet fuel is a mature, cost-effective industrial process with relatively low production costs, able to deliver a consistent product at scale globally. While jet fuel's properties play a key role in enabling today's aviation system, they also make the sector difficult to decarbonize because they are hard to replace with sustainable components.

Sustainable Aviation Fuels

SAF are "drop-in" liquid hydrocarbon fuels with the same performance and safety as conventional jet fuels produced from petroleum, are fully fungible with the existing fuel supply, and can be used in the same infrastructure, engines, and aircraft. SAF can be created from either renewable or waste materials. For purposes of U.S. policy, SAF reduce life cycle GHG emissions by at least 50% relative to conventional jet fuel. As drop-in fuels compatible with the existing fleet, SAF are hydrocarbon fuels and thus emit CO_2 when combusted in an aircraft engine. SAF provides a climate benefit based on the SAF's life cycle emissions profile, which considers direct and indirect emissions from the production, transportation, and combustion. Finally, in addition to the life cycle GHG emissions reductions with SAF, the composition of SAF also enables additional Local Air Quality (LAQ) and health benefits compared to conventional, petroleum-derived fuels. SAF has lower aromatic and essentially no sulfur compounds compared to conventional jet fuel, which results in reductions in particulate matter emissions. Data from recent in-flight measurements has shown that 100% SAF with negligible amounts of aromatic and sulfur compounds not only reduced non-volatile particulate matter emissions, but also the formation of contrail ice crystals which mitigates contrails and aviation induced cloudiness.

Elsewhere in the transportation sector, several approaches to decarbonization are under consideration to replace petroleum-based fuels (e.g., electrification and hydrogen). While these technologies have the potential to play an important role in decarbonizing shorter-distance flights in the coming decades, they cannot provide a solution for the medium- and long-haul flights that generate most of the aviation sector's GHG emissions without significant technology advancements in fuel cell efficiencies and onboard energy storage.[36] A recent ICAO report stated that "all-electric propulsion systems are not likely even for business jets by the 2037 timeframe."[37] To understand the challenge of electrifying aviation it helps to consider that, at takeoff, the engines of a large wide-body jet are generating power levels comparable to a small power plant.[38] Cryogenic hydrogen has also been proposed as an option to power commercial aircraft, but hydrogen has lower energy per unit volume than conventional fuel or SAF, currently limiting its potential viability to shorter ranges due to the amount of space needed to store the fuel. Another challenge is the lack of a global distribution network to get the hydrogen fuel to the airports—a challenge not facing SAF. Simply put, there is no realistic option that could completely replace liquid fuels in the commercial aircraft fleet in the coming decades to achieve the net-zero goal by 2050. While hydrogen may play a limited role on shorter-range flights before 2050, and a larger role beyond 2050, hydrogen-powered aircraft are not expected to make a significant contribution toward achieving net-zero aviation emissions by 2050.

Rigorous standards have been developed by ASTM International to ensure the safety of liquid hydrocarbon fuels under the demanding conditions of flight operations.[39] These standards cover not only jet fuel production from conventional petroleum, but also alternative jet fuel pathways that could use renewable and waste feedstocks to produce a liquid hydrocarbon fuel that can be safely used in today's jet engines, known as synthetic aviation turbine fuels (SATF). Thus far, ASTM International has approved eight SATF pathways for blending with conventional jet fuel and three pathways for co-processing of renewable feedstocks with conventional petroleum in today's refineries.[40] These ASTM pathways represent potential SAF production routes, and additional pathway approvals are anticipated in the coming years. These pathways use technologies that can convert wastes, residues, biomass, sugars, oils, and gaseous sources of carbon into a fuel that can be used by today's aircraft fleet.

High conversion costs and limited feedstock and production infrastructure have inhibited SAF expansion despite significant interest. Expanding SAF availability and maximizing SAF's climate and LAQ benefits requires addressing key challenges and risks across the supply chain.

Figure 10 shows two SAF Uptake Scenarios depicting potential emissions reductions from SAF use. Two bands are shown in the figure corresponding to life cycle GHG emissions reductions of 50% and 100%—alternate values between 50% and 100% can be interpolated.

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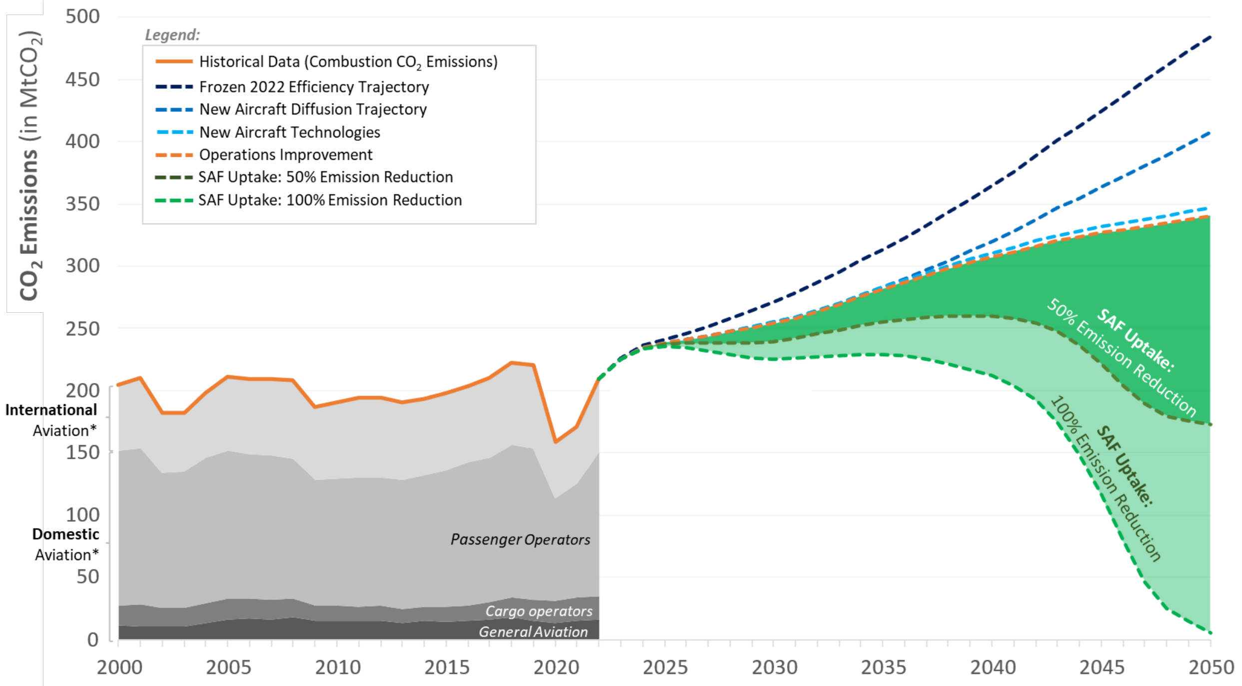
[36] In 2021, flights over 1,000 nm represented 20% of operations and 65% of total fuel burn.

[37] ICAO, "*Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft*," p.118 (2019) available at: https://store.icao.int/en/independent-expert-integrated-technology-goals-assessment-and-review-for-engines-and-aircraft-english-printed.

[38] Commercial aircraft have maximum power between roughly 30 and 300 MW, for single-aisle to wide-body jets, respectively. Commercial nuclear reactors typically produce 1,000 MW but their output can be as small as 500 MW.

[39] ASTM D1655: Standard Specification for Aviation Turbine Fuels. ASTM D7566: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons.

[40] Additional information on the fuel qualification process as well as a full list of approved fuels is available at: https://www.caafi.org/focus_areas/fuel_qualification.html.

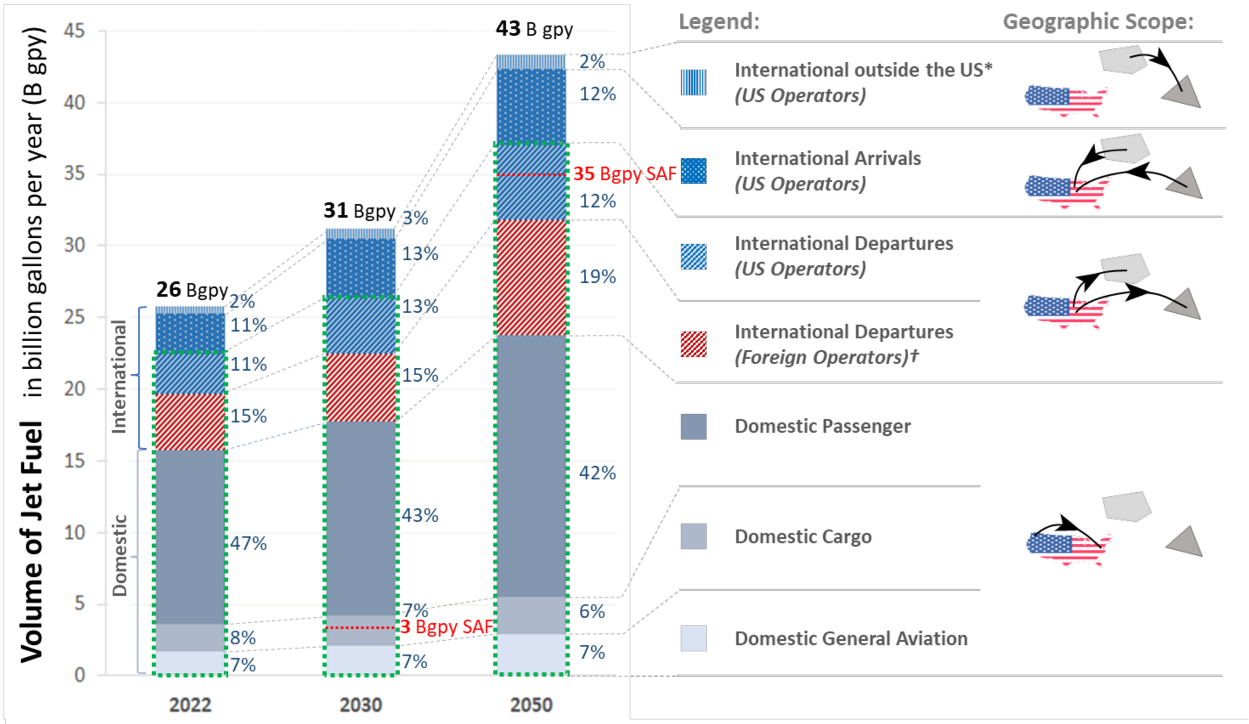


* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.

Figure 10. **Analysis of Future U.S. Domestic and International Aviation CO_2 Emissions: SAF Scenario**

Trends for 2030 to 2050 are based on the goals of the SAF Grand Challenge with roughly all of U.S. SAF production capacity available to meet 2050 U.S. domestic and international aviation fuel demand from U.S. carriers (assuming limited export of SAF).

Figure 11 provides a breakdown of the jet fuel demand by geographic areas (e.g., domestic, international) and by categories of operators (e.g., U.S. carriers, foreign operators) in 2030 and 2050. In 2022, jet fuel consumption reached approximately 26 billion gallons. Demand for jet fuel is expected to increase to 31 billion gallons by 2030, of which three billion could be supplied by SAF based on the U.S. SAF Grand Challenge 2030 goal. Furthermore, 2050 jet fuel demand may reach 43 billion gallons, including about 37 billion gallons of jet fuel uplift in the United States. The SAF produced under the U.S. SAF Grand Challenge is expected to meet the fuel demand from domestic and international departures, although the climate benefits of this SAF would depend, as noted above, on the life cycle benefits of that fuel. Expected jet fuel volumes have increased compared to projections contained in the 2021 Action Plan, due to the latest U.S. aviation activity growth projections.



Notes:

Jet Fuel Uplift from the United States

* *Flights between two different ICAO Member States (other than the United States) e.g., Germany -> UAE, UK -> China.*
† *Not in scope of Climate Action Plan, shown to facilitate comparisons with U.S. SAF Grand Challenge.*

Data Sources and Assumptions:

International outside the US* ***(US Operators)***: 2022: BTS T-2 (International operations reported by US carriers).

International Arrivals and Departures: 2030-2050: CO_2 emissions based on FAA Aerospace traffic Forecast, after technology and operations improvements. Assuming breakdown of flows (departures from US, arrivals in US and foreign-foreign based on 2022 CORSIA breakdown).

Domestic Passenger and Cargo: 2022: EPA GHG Inventory, international departures by foreign operators scaled based on 2022 traffic mix (FAA Data). 2030-2050: FAA Modeling based on EPA GHG Inventory (Domestic) scope. CO_2 emissions based on FAA Aerospace traffic Forecast, after technology and operations improvements.

Domestic General Aviation: 2022-2050: General Aviation from FAA Aerospace Forecast (2023-2043).

Figure 11. Potential demand for jet fuel in gallons per year (GPY) across domestic operations (by U.S. and Foreign Carriers), international departures from foreign carriers and international operations by U.S. carriers. Red text indicates SAF Grand Challenge volumetric production goals.

Summary of Actions

- Continue to support critical USG programs on research, development, demonstration, and deployment of feedstock systems, conversion, testing, analysis, and coordination on SAF directly with industry, research partners, and through the Commercial Aviation Alternative Fuels Initiative (CAAFI).
- Implement the SAF Grand Challenge Roadmap, alongside DOE and the U.S. Department of Agriculture (USDA), to reduce cost, enhance sustainability and expand domestic production and end use of SAF to supply 35 billion gallons per year by 2050.

- Support implementation of the IRA SAF tax credits, provided in Sections 40B and 45Z of the Internal Revenue Code (IRC), and provide technical assistance on any successor tax credit program under Congressional consideration.
- Award grant money under FAST grant program.
- Catalyze bulk purchases of SAF by military and other end users.

Progress and Current Activity

The United States has a long history of support for SAF research, development, demonstration, and deployment dating back to 2006, with significant progress in recent years. In 2021, the USG established a multi-agency effort led by the U.S. Department of Transportation (DOT), DOE, and USDA to coordinate SAF-related policy efforts through the "SAF Grand Challenge" with the goals of reducing cost, enhancing sustainability, and expanding production and use of SAF that achieves at least a 50% reduction in life cycle GHG emissions compared to conventional jet fuel. In addition, the challenge has a goal of at least three billion gallons of domestic SAF production per year by 2030 and, by 2050, 35 billion gallons of domestic SAF production. Through the SAF Grand Challenge, DOE, DOT, and USDA, working with other agency partners, are accelerating the research, development, demonstration, and deployment needed for innovative solutions and technologies and developing a policy framework to enable an ambitious government-wide commitment to support U.S. industry scale up of SAF production.

The SAF Grand Challenge includes a multi-agency roadmap identifying agency roles and an implementation plan to leverage USG activities in research, development, demonstration, deployment, commercialization support, and policy in order to:

- Reduce the cost of SAF through activities that drive down cost 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 production incentives.
- Enhance sustainability of SAF by maximizing the environmental co-benefits of production; demonstrating sustainable production systems; developing low land-use change feedstock crops; reducing the carbon intensity (CI) of SAF supply chains; ensuring robust standards that guarantee environmental integrity; and enabling approvals of higher blend levels of SAF.
- Expand SAF supply and end use through support for regional feedstock and fuel production development and demonstration; outreach, extension, and workforce development; new infrastructure and commercialization support through federal programs; implementation of supporting policies that are enacted for SAF; enabling approvals of diverse SAF pathways; and continued outreach and coordination with military and industry end users.

In 2022, the U.S. Congress passed, and the President signed into law, the Inflation Reduction Act (IRA), which included three policy incentives critical to achieving government and industry goals for net-zero GHG emissions from aviation. Specifically, the IRA includes two tax incentives for SAF:

- The 40B SAF Tax Credit that came into effect in 2023 and is set to expire at the end of 2024, and
- the 45Z Clean Fuel Production Credit that includes a tax credit for SAF produced between 2025 and 2027.

Both tax credits require around 50% reduction in life cycle GHG emissions and incentivize greater reductions.

As mentioned in Section III.1, the FAST grant program[41] will make investments to accelerate production and use of SAF and the development of low-emission aviation technologies to support the U.S. aviation climate goal. The SAF elements of the program will provide $245 million to advance the deployment of SAF that provide greater than 50% reduction in lifecycle CO_2 emissions, and which can be used safely in today's aircraft and engines. FAST will support infrastructure projects related to SAF production, transportation, blending and storage, as well as scoping studies related to SAF infrastructure needs.

Beyond the IRA and the SAF Grand Challenge, agency initiatives have delivered significant advances, positioning the SAF industry for growth. USG-led research, development, demonstration, and commercial deployment support plays a critical role in encouraging investment, reducing production costs, maximizing sustainability benefits, developing supply chains, and expanding commercial production infrastructure. Ongoing R&D efforts focus on the entire SAF supply chain.

The FAA's involvement in SAF can be traced to the founding of CAAFI in 2006, a public-private partnership to support SAF development and deployment. With sponsorship of FAA and industry trade associations, CAAFI convenes government, industry, academia, and others to accelerate the development, evaluation, qualification, and deployment of SAF. CAAFI helps convene entities seeking ASTM qualification, provides tools to evaluate fuel and feedstock readiness, and helps connect supply chain entities. The FAA also supports testing to ensure fuels are safe for use; conducts analysis to understand the economics, environmental impacts, and potential production volumes of SAF; and coordinates among industry, federal agencies, civil society, and the international community. Through ASCENT, FAA leads technical work setting international standards to account for life cycle GHG emission reductions within ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and conducts the tests required by the ASTM International fuel qualification process. A major priority for the USG going forward will be working with industry to gain ASTM International approval to use 100% SAF in today's aircraft and engines, without modification. This is a hurdle that must and can be overcome to decarbonize aviation.

USDA supports programs in feedstock supply chain systems; environmental, economic, and social analysis; and funds commercialization support, providing financial assistance for the development of SAF production infrastructure via grants and loan guarantees. Importantly, they are also taking the lead in ensuring that farmers are compensated for climate-smart agricultural practices, including when those practices are relevant for SAF production.

At DOE, several Offices support scaling SAF production and deployment:

- DOE's Bio-Energy Technologies Office (BETO), the SAF portfolio includes R&D, pre-pilot, pilot, and demonstration scale conversion activities for biochemical, thermochemical, and hybrid processes. Feedstocks of interest include biomass, industrial/power exhaust gas, all types of waste feedstocks, and algae. DOE also conducts analysis into all aspects of sustainability and life cycle GHG emissions, as well as techno-economics and resource assessment.
- The DOE's Loan Program Office also has loans and loan guarantees that will be deployed to advance SAF projects.
- DOE's Office of Fossil Energy and Carbon Management (FECM) is exploring the utilization of CO_2 as a feedstock to produce biofuels including SAF. BETO and FECM are jointly funding a research

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[41] Federal Aviation Administration, *"Fueling Aviation's Sustainable Transition (FAST) Grants,"* available at: www.faa.gov/general/fueling-aviations-sustainable-transition-fast-grants.

consortium within the National Labs to develop CO_2 utilization technologies and announced a joint notice for projects converting algae and other wet waste feedstocks to low-carbon fuels, chemicals, and agricultural products.

- DOE's Vehicle Technologies Office (VTO) supports BETO's efforts by focusing on end-use issues ranging from fueling infrastructure through emissions by a combination of experimental and modeling efforts centered in the National Lab complex.
- DOE Advanced Research Projects Agency-Energy (ARPA-E) supports six projects as part of the Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management program. These projects will develop technologies to bridge the data gap in the biofuel supply chain by quantifying feedstock-related GHG emissions and soil carbon dynamics at the field-level.

DOD, NASA, and the U.S. Environmental Protection Agency (EPA) also have programs supporting SAF. Some types of SAF qualify for tradable credits under the EPA Renewable Fuel Standard program. NASA research and development of advanced combustors includes tests with various SAF to assess performance and emissions. NASA also characterizes SAF emissions with on-wing exhaust measurements.

SAF is also a key focus area for the federal multi-agency Biomass Research and Development Board,[42] which is tasked with implementing a federal strategy—the Bioeconomy Initiative—to develop bioenergy, bioproducts, and biofuels.

World Energy - Paramount

World Energy's 65-acre facility located in Paramount, California, is the world's first commercial-scale SAF production facility. Paramount is a converted petroleum refinery, and when the conversion is complete, the facility will have production capability of 25,000 barrels of SAF daily.

Various airlines have advanced pilot projects and programs to demonstrate the use of SAF or invite their customers to use SAF on a voluntary basis. The U.S. government supports these voluntary initiatives and efforts to show climate leadership and is working to ensure SAF claims are substantiated and that SAF emissions reductions are not double-counted or double-claimed.[43] At the international level, with U.S. leadership, ICAO's CORSIA has established and is developing further sustainability criteria and mechanisms aimed at ensuring the environmental credibility of SAF used to show compliance with CORSIA obligations. While CORSIA only addresses international aviation's CO_2 emissions, additional domestic policies and programs are evolving to ensure the environmental effectiveness of SAF used by U.S. airlines beyond their CORSIA obligations.

Expanding SAF availability and maximizing SAF's benefits requires robust standards giving industry confidence to invest in producing SAF with increasing

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[42] The Board is co-chaired by designees from DOE and USDA and is typically comprised by politically appointed members to represent the member departments and agencies.

[43] "Double counting" is when a single emission reduction or removal is counted more than once. "Double claiming" is when a single quantity of mitigation is used for more than one purpose.

GHG benefits, while also addressing key challenges and risks across the supply chain. To help overcome these obstacles, the United States is developing standards, and conducting USG-led research, development, demonstration, and commercial deployment support. These efforts play a critical role in reducing production costs, maximizing sustainability benefits, developing supply chains, and expanding commercial production infrastructure.

In addition to the federal efforts to incentivize SAF production and use, some U.S. states have led the way in incentivizing production and use within their borders. These compounded incentives can be powerful incubators for local investment, job creation, and emission reductions. Some examples of these state-level incentives are included in Table 1.

Table 1: State Incentives for SAF Production

State	Program	Incentive Description
California	Low Carbon Fuel Standard (LCFS)	Credits awarded for SAF production based on the CI score; fuels with lower CIs earn the producer credits and vice versa.
Illinois	Illinois SAF Purchase Credit (SAFPC)	Credit ($1.50/gallon purchased) given to air carriers operating in Illinois that buy SAF; the more SAF bought/used means increased emission reductions and the more credits air carriers earn.
Minnesota	Minnesota SAF Credit	Credit ($1.50/gallon) given for SAF produced or blended in Minnesota and for use in planes departing Minnesota airports.
Oregon	Oregon Clean Fuels Program (CFP)	Credits awarded for SAF production based on the CI score; fuels with lower CIs earn the producer credits and vice versa. Fuels used for aviation are exempt under this program.
Washington	Washington Clean Fuel Standard (CFS) Washington Business & Occupation (B&O) Tax Credit	Credits awarded for SAF production based on the CI score; fuels with lower CIs earn the producer credits and vice versa. Credit ($1-$2/gallon) given for SAF produced that has at least a 50% reduction in CI; $0.02/gallon for each 1% reduction past the 50% threshold. SAF must be produced or blended in Washington to qualify.

Actions

The USG has identified the development and deployment of SAF as a key aviation climate priority. Well-designed economic incentives, including SAF tax credits and investment tax credits, can help bridge the cost gap between SAF and petroleum jet fuel. This is why the IRA included a SAF tax credit and Clean Fuels Production tax credit. These credits will help cut costs and rapidly scale domestic production of SAF. Catalyzing and coordinating purchases by military, other governmental, industry, and other consumers can help aggregate demand for SAF that meets ambitious standards for life cycle emission reductions. Additional policy incentives may be needed to further the development and deployment of SAF.

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4. International Leadership and Initiatives

Continuing a long tradition of leadership on environmental standards in ICAO, the United States provides technical and policy leadership on climate in ICAO.

Background / Context

The United States plays a critical leadership role on aviation and the environment globally. Within ICAO and other international fora, the United States provides strong, active leadership.[44] The United States seek consensus with global partners to address aviation's climate impacts and strive for ambitious international climate goals—aligned with our domestic goals—that provide clear guidance to the global community. These international efforts also include regional and bilateral efforts with key partners on research to better understand the opportunities and challenges for addressing aviation's climate impacts.

Progress and Current Activity

The 41st ICAO Assembly in late 2022 agreed to a long-term aspirational climate goal (LTAG): "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."[45] The LTAG agreement aligns with the U.S. goal in our 2021 Action Plan and achieved near-consensus support from ICAO Member States.

ICAO LTAG

The 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal.

The LTAG does not attribute specific obligations or commitments in the form of emissions reduction goals to individual States. Each State will contribute to achieving the goal in a socially, economically, and environmentally sustainable manner and in accordance with its national circumstances.

ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies

To support the achievement of the LTAG, ICAO and its Member States strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030 through the use of SAF, LCAF and other aviation cleaner energies (compared to zero cleaner energy use). The framework also includes guidance on policy support, financing, monitoring of SAF, LCAF and other Aviation Cleaner Energies.

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[44] The U.S. Mission to ICAO (USICAO) is focused on improving the safety, security, and sustainability of civil aviation. USICAO is headed by an ambassador, supported by a Deputy Chief of Mission and Air Navigation Commissioner plus expert and support staff. On environment and climate matters, USICAO coordinates U.S. Government efforts at ICAO, working closely with the FAA, DOT, and others.

[45] ICAO, "*Long term global aspirational goal (LTAG) for international aviation,*" available at: https://www.icao.int/environmental-protection/Pages/LTAG.aspx.

At ICAO's Third Conference on Aviation Alternative Fuels (CAAF/3), convened in November 2023, the Conference agreed to a near-term vision to reduce the CO_2 intensity of international aviation fuel by 5% by 2030 using SAF, Lower Carbon Aviation Fuels (LCAF), and other aviation cleaner energies.[46] This vision will support the achievement of the LTAG through a significant level of global support for the development and deployment of fuels and energy sources to reduce aviation's GHG emissions. Achieving this vision for international aviation in 2030 would reduce CO_2 emissions by about 33 $MtCO_2$ and be the equivalent of approximately seven billion gallons of SAF annually if each gallon achieved a 50% CI reduction compared to petroleum-based jet fuel. For both ICAO's 41st Assembly and CAAF/3, the United States played a leading role in securing an outcome that could garner broad-based support.

Subsequent policy developments around the world highlight the important role of ICAO decisions in driving individual countries toward a common goal. For the United States, these agreements reinforce domestic goals and provide clarity for U.S. stakeholders that their efforts will continue to be supported by governments around the world.

The United States also supports the development of ambitious new international environmental standards at ICAO. Since 2021, the Federal Government has implemented ICAO's first airplane CO_2 standard.[47] U.S. experts are working with international counterparts at ICAO to develop a revised CO_2 standard, for new type and in production airplanes, that reflects the interdependencies between technologies to reduce fuel burn and technologies to reduce aviation noise. In February of 2025, ICAO will propose new aircraft CO_2 and noise standards.

The USG also collaborates bilaterally with a wide range of countries on environmental efforts related to aviation. This engagement is done through agreements for specific technical work and through bilateral air transport agreements. The FAA has also developed a capacity building program that leverages the work of the ASCENT Center of Excellence (COE) for Alternative Jet Fuels and Environment. ASCENT Project 93 titled "Collaborative Research Network for Global SAF Supply Chain Development," was initiated with Washington State University (WSU), the Massachusetts Institute of Technology (MIT), University of Hawaii (UH), and the DOT Volpe Transportation Center. In this project, the experience gained from developing domestic supply chains to enable SAF production and associated analytical tools are being leveraged and adapted to understand the potential environmental and economic benefits that could result from the development of global supply chains while also working to understand the barriers to their development. The overall effort focuses on three distinct geographical areas with different characteristics—Sub-Saharan Africa, Latin America and the Caribbean (LAC), and Southeast Asia. Through collaboration with the World Bank and other international partners with similar interests, the FAA is working to enable the development of SAF supply chains around the globe.

Project 93 is working with existing partners of the ASCENT COE universities in three distinct geographical areas with different characteristics—Latin America and the Caribbean (LAC), Sub-Saharan Africa, and Southeast Asia. WSU is focusing on LAC (Colombia, Dominican Republic, Ecuador, and Costa Rica), MIT (in collaboration with Hasselt University in Belgium) is focused on Africa (Kenya), and UH is working in SE Asia (Indonesia, Vietnam, Malaysia, Philippines, and Thailand). The project is working to identify waste and biomass feedstock availability, analyze new pathways to optimize SAF production, and assess

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[46] ICAO, *"Third ICAO Conference on Aviation and Alternative Fuels (CAAF/3),"* available at: https://www.icao.int/Meetings/CAAF3/Pages/default.aspx.

[47] See section III.1, above. In addition, U.S. experts lead technical efforts to develop uniform life cycle emissions values for SAF to enable harmonization and facilitate global development of these fuels.

infrastructure needs and logistical requirements for a holistic approach to SAF supply chain development for each region. The project seeks to identify existing industries and infrastructure that could be leveraged to more rapidly support SAF production, as well as undertake an updated bottom-up assessment of global SAF feedstock potential and barriers. Project 93 is also developing a network of PhD students working at each partner university to extend supply chain analysis techniques and tools from the ASCENT COE and Volpe Center to their respective regions. This will help demonstrate U.S. leadership and share practices with the international community. As climate change is a global problem, we continue to see a benefit in helping others achieve decarbonization goals, recognizing that collaborative efforts will also help the United States find ways to improve our own, domestic efforts, and offer additional import and airline procurement options.

DOT, FAA, and the State Department are also working with the governments of Singapore and Japan on rapidly delivering emissions reductions along specific routes, consistent with existing air transport agreements, a concept known as Aviation Green Lanes.[48]

Actions

International leadership and collaboration will continue to be a key driver to address aviation's climate impact, and our international efforts should reinforce our domestic efforts. As mentioned in the previous sections, many of the new technologies being developed cannot be retrofitted onto existing types of commercial aircraft. Therefore, the United States intends to examine how standards could reflect what is technologically feasible for both existing and future types.

We will also continue our mutually beneficial, bilateral technical work on aviation's climate impact with partners around the world. The USG intends to continue, extend, renew, and institute new agreements with partners to continue to support research, technical tool development, training, and increased ambition in reducing GHG emissions, extending the use of SAF, and strengthening the resilience of aviation infrastructure. This also includes expanding the partnerships within ASCENT Project 93.

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[48] Japan, Singapore, and the United States, *"Aviation Green Lane,"* ICAO Third Conference on Aviation and Alternative Fuels (CAAF/3), Nov. 2023, available at: www.icao.int/Meetings/CAAF3/Documents/CAAF.3.WP.022.2.en.pdf.

5. Airport Initiatives

While their infrastructure-based GHG emissions are relatively small compared to those from jet fuel combustion, airports play an important role in the overall effort to address transportation-sector GHG emissions by making SAF available, and by making green electricity available for new technologies like advanced air mobility. Airports also play a crucial role in aviation's resilience to impacts from severe weather.

Background / Context

Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," directs "each federal agency to develop a plan to increase the resilience of its facilities and operations to the impacts of climate change."[49] FAA's Office of Airports (ARP) is working with other federal partners, as well as airport sponsors and associations, to clarify its grant programs related to GHG emission reductions and to address infrastructure resilience. Both actions are discussed below.

In most cases, while new investments are needed to assess energy use and to purchase more advanced equipment to lower emissions, such investments are cost effective over short time horizons. As discussed below, FAA's grant programs include Congressionally authorized funding to assist airports in reducing their GHG emissions.

Regarding resilience, climate change leads to an increase in the intensity and frequency of severe weather events, higher temperatures, and more frequent heat waves that will severely impact some airports, including ground access links. In addition, regarding the number of days above 115°F expected in the average year, we see only three primary airports that meet or exceed at least one expected day above 115°F historically. However, by 2050 we see 10 primary airports that expect at least one day above 115°F, with three of these expecting 14 or more days above this threshold, under a moderate emissions scenario. A high emissions scenario predicts that 13 primary airports will experience at least one day above 115°F, with three of these expecting more than 20 days above this threshold.[50] Therefore, while severe weather is already the largest cause of flight delays, more substantial delays and systemic supply chain interruptions to operations have significant cost and policy implications for airports and the FAA. FAA's activities on resilience are outlined below. To address the impacts of climate change and severe weather on aviation infrastructure, FAA is working with airports to develop a resilience framework that includes an Airport Resilience Analysis Framework (ARAF) to enable airports to conduct a vulnerability analysis. The framework will also assist FAA in making project prioritization decisions. For more information, see the project fact sheet.[51]

Summary of Actions:

- Continue to fund eligible emission reduction and energy efficiency projects.
- Develop an airport resilience framework through continue research, collaboration with industry, and potential grant funding.

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[49] Tackling the Climate Crisis at Home and Abroad, 86 Fed. Reg. 7,619 (Jan. 27, 2021). https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad.

[50] Data on number of days above 115°F exist for continental U.S. airports only. Extreme temperatures, generally considered to be above 115°F, can result in performance challenges for aircraft, and potentially operational challenges, which can affect the safe and efficient operation of the NAS.

[51] Federal Aviation Administration, "*Improving Airport Resilience to Climate Change & Severe Weather*," Sep. 2022, available at: https://www.faa.gov/sites/faa.gov/files/2022-09/Airport_Resilience_Factsheet_2022_09.pdf.

Progress and Current Activity

Airports are increasingly aware of their GHG emissions and the need to work to mitigate these impacts. In June 2021, the Airports Council International established a global goal to achieve net-zero carbon emissions by 2050, recognizing that specific actions and timelines will be developed on an individual airport basis. At the same time, DOT and FAA launched the FAA's Climate Challenge to collaborate with industry on its net-zero goal.[52] FAA's objective for the Climate Challenge is to accelerate airport GHG emission reductions through the expanded use and optimization of FAA programs. As part of this effort, FAA partnered with industry to identify best practices, solutions, priorities, and opportunities to optimize GHG emission reductions through numerous stakeholder meetings, including the development of grant program guidance documents.[53] Second, ARP and FAA's Office of Environment and Energy (AEE) worked to create additional tools to quantify GHG emissions for a variety of airport projects eligible for funding through upgrades to the Airport Environmental Design Tool (AEDT).[54] In some of the supplemental discretionary funding programs described below, FAA requested that applicants quantify GHG emission reductions prior to FAA awarding funding. Finally, FAA prioritized funding within ARP's existing budget and raised awareness to promote and encourage participation in these programs.

The following airport-focused programs are authorized and funded by FAA:

Voluntary Airport Low Emissions (VALE) Program. This program addresses emission reductions at commercial airports in areas that are in "non-attainment" or "maintenance" areas under the Federal Clean Air Act. Typical projects include gate electrification, charging stations for electrical ground support vehicles, geothermal systems, and solar hot water systems.

Zero Emission Vehicle (ZEV) Program. This program provides grants for any airport in the National Plan of Integrated Airport Systems (NPIAS) to replace or convert on-road vehicles for zero-emission vehicles.[30] Presently, only electric powered vehicles and their charging infrastructure have been funded. Fuel cell vehicles and their charging infrastructure are also eligible.

Energy Efficiency Program. The program provides funding for energy assessments to identify energy reduction measures to reduce energy consumption across all airport operations. Upon completion of an energy assessment airport sponsors can seek funding to implement the measures identified in the assessment. Typical projects include installation of light-emitting diode (LED) lighting, installation of solar arrays and other energy efficiency and energy generation measures.

Sustainability Pilot Program. This program historically provided funding for development of sustainability plans as stand-alone documents. This pilot program was successful in encouraging airport sponsors to incorporate sustainability in their Master Plan updates and general planning efforts. Sustainability planning continues to be eligible for inclusion in Airport Master Plans addressing a broad array of

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[52] Press Release, Federal Aviation Administration, "*FAA, U.S. Airports Team up to Meet 2050 Net-Zero Climate Challenge*," April 22, 2022, available at: https://www.faa.gov/newsroom/faa-us-airports-team-meet-2050-net-zero-climate-challenge.

[53] Federal Aviation Administration, "*Airports Climate Challenge*," available at: https://www.faa.gov/airports/environmental/airports_climate_challenge.

[54] AEDT version 3f, released on Dec. 15, 2023, allows for GHG calculations from the major sources of airport emissions: CO_2 can now be generated in AEDT emissions reports for Auxiliary Power Units (APU), Ground Support Equipment (GSE), and commonly used stationary sources. Methane emissions are also available for applicable AEDT source types. See: https://aedt.faa.gov/3f_information.aspx#:~:text=AEDT%203f%20was%20released%20on,AEDT%202b%20up%20to%203e.

environmental and energy activities (e.g., recycling, green construction and operations, energy efficiency, renewable energy, water quality, and climate resilience).

Energy Supply, Redundancy and Microgrid Program. This program provides grants to improve reliability and efficiency of airport power supply, prevent power disruptions, acquire, and install electrical generators, separate the main power supply, and construct or modify facilities to install a microgrid.

Several of the programs noted above were eligible for funding in the FY 2022 AIP Supplemental Discretionary Notice of Funding Opportunity.[55] Subsequently, ARP awarded approximately $120 million to airports from programs related to emission reductions.

Airport Improvement Program (AIP) discretionary, supplemental discretionary, and Bipartisan Infrastructure Law Airport Terminal Projects (ATP) grants. Grant guidance for these programs includes prioritizing projects that reduce air emissions, improve energy efficiency and address resiliency.[56] The ATP grant program includes consideration of airport terminal improvement projects that improve energy efficiency (including LEED accreditation). FAA continues to implement the AIP and ATP grant programs.

Resilience Research. FAA is conducting research using case studies, including at airports, to develop an Airports Resilience Assessment Framework (ARAF) to help airports conduct vulnerability assessments to support airport sponsors in determining their risks (e.g., coastal and river flooding; sea level rise), identifying measures to reduce risks, and prioritizing infrastructure projects to adapt to identified risks. To date, FAA has engaged the following airports to develop ARAF: Seattle-Tacoma International (SEA), San Diego International (SAN), Salt Lake City International (SLC), Indianapolis International (IND), Philadelphia International (PHL), and Tampa International (TPA).

Pittsburgh International Airport - Microgrid

In 2021, Pittsburgh International Airport became the first airport in the world to be fully powered by natural gas and solar energy through a microgrid. The airport's microgrid utilizes nearly 10,000 solar panels and supplies power throughout all terminals, the airfield, and some nearby buildings. This system provides the airport with a resilient power supply system while reducing its emissions.

Actions

The following additional programs are authorized and will be implemented or reinitiated by FAA to augment efforts to address GHG emissions and/or resilience.

Environmental Mitigation Pilot Program. This pilot program is for environmental mitigation projects that measurably reduce or mitigate aviation impacts on noise, air quality, or water quality at or within five miles of an airport.

Sustainability Program. FAA is broadening this program with an emphasis on resilience planning to address climate and extreme weather risks to airports in

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[55] FY 2022 Competitive Funding Opportunity: Airport Improvement Program Supplemental Discretionary Grants, 87 Fed. Reg. 80,248 (Dec. 29, 2023) https://www.federalregister.gov/documents/2022/12/29/2022-28285/fy-2022-competitive-funding-opportunity-airport-improvement-program-supplemental-discretionary.

[56] Press Release, Federal Aviation Administration, "*FAA Invests Nearly $92 Million to Help Airports Reach President's Goal of Net Zero-Emissions by 2050*," July 11, 2023, available at: https://www.faa.gov/newsroom/faa-invests-nearly-92-million-help-airports-reach-presidents-goal-net-zero-emissions-2050.

relation to sustainability. This would leverage Congressional intent as expressed in the Federal Aviation Reauthorization Act of 2024, discussed below.

Energy Supply, Redundancy and Microgrid Program. A new program guidance letter (PGL) is being developed to provide additional guidance to sponsors.

Portland International Jetport - Alternative Energies

Portland International Jetport has Maine's largest geo-exchange/ground-source heat pump (GHX) installation and largest solar array. The Jetport estimates that these installations will reduce the Jetport's CO_2 emissions by 1,000 tons per year.

The Jetport plans to further reduce emissions through increased electrification. The Jetport has purchased several electric vehicles and received its first electric aircraft tug in 2023.

In 2024 the Jetport plans to replace passenger boarding bridges that will provide aircraft with preconditioned air. These bridges will eliminate the need for aircraft to run an auxiliary power unit.

Resilience Research and Project Funding. FAA, working with the Volpe Center, will continue to engage stakeholders to expand the ARAF tool. This will include the DoD, National Oceanic and Atmospheric Administration (NOAA), and the Army Corps of Engineers. While to date the research has been based on the continental United States, additional case studies may be conducted in Alaska to address the impacts from permafrost collapse and erosion, which has resulted in the relocation of at least one airport, with others threatened.[57] Other potential case studies include FAA-funded NPIAS airports in Micronesia. This research will help airports and FAA prioritize spending on resilience projects.

FAA will continue to research resilience to meet the Congressional intent conferred by the 2024 Act. The 2024 Act enables projects from FY 2024 AIP supplemental discretionary funding for projects that result in "improvements of primary runways, taxiways, and aprons necessary at a non-hub, small hub, medium hub, or large hub airport to increase operational resilience for the purpose of resuming commercial service flight operations following flooding, high water, hurricane, storm surge, tidal wave, tornado, tsunami, wind driven water, or winter storms."

Senate Report 118-70 directs FAA to work with NOAA and the United States Army Corps of Engineers to identify best practices for, and study the feasibility of, improving resiliency of airports in coastal or flood-prone areas.[58] The Senate Report also directs that FAA update the Advisory Circular on Airport Master Plans to provide guidance on resiliency. The first directive can augment consultation FAA has previously conducted with other governmental entities and airports regarding the resilience study noted above in this section. In addition, the effort to update the Advisory Circular on Airport Master Plans will also benefit from the resilience research noted above.

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[57] See *supra* note 49. Note sea level rise at FAA-funded airports in Micronesia is a significant risk to the viability of operations.
[58] Senate Report 118-70, "Transportation, Housing and Urban Development, and Related Agencies Appropriations Bill, 2024," available at: https://www.congress.gov/congressional-report/118th-congress/senate-report/70/1.

6. Leadership on Climate, Sustainability, and Resilience at FAA Facilities Supporting NAS Operations

Background / Context

An integral part of the Action Plan is to ensure that the FAA, as the government agency tasked with operating the NAS in the United States, is also a leader on addressing climate, sustainability, and resilience throughout its programs and activities. The FAA maintains more than 12,500 properties, structures, and facilities across the United States. Each of these properties is prone to different impacts from climate change, ranging from flooding to wildfires, and each requires targeted or specific solutions while still supporting the continued round-the-clock operation of the NAS. Increasing the resilience of the FAA's infrastructure to climate change and reducing the overall environmental footprint of FAA infrastructure across the FAA's programs, is a priority of this plan.

Since 2021 the Biden Administration has signed several executive orders (EOs) directing federal agencies to reduce their environmental impact and address climate resilience for their facilities and operations. Two notable EOs that have spurred FAA leadership on climate action are EO 14008, *Tackling the Climate Crisis at Home and Abroad*,[59] and EO 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*.[60] EO 14008 includes directions for federal agencies (including the DOT) to create climate action plans to address climate vulnerabilities and ensure buildings, infrastructure, and installations are climate ready. EO 14057 creates government-wide goals in areas such as carbon pollution-free electricity (CFE) use, zero-emission vehicle (ZEV) acquisition, and sustainable buildings to help bring the U.S. government to net-zero emissions by 2050. Many FAA employees also have transit and bikeshare benefits available to reduce the carbon intensity of their commutes.

Progress and Current Activity

In support of EOs 14008 and 14057, the FAA is taking action to address the climate crisis by bolstering adaptation and increasing resilience at FAA facilities. Consistent with the elements laid out in this plan, the agency is also increasing action to reduce carbon emissions from the aviation sector.

The FAA contributed to the DOT's 2021 Climate Adaption and Resilience Plan and subsequent annual updates as part of the requirements in EO 14008. Part of the plan includes completing vulnerability assessments at mission critical operational assets using the DOT's Climate Hazard Exposure and Risk (CHER) Tool. These assessments help the FAA identify assets that are the most vulnerable to climate change as well as what categories of environmental hazards the assets will be affected by (e.g., tornado, drought).

The FAA is also taking steps to meet the government wide goals outlined in EO 14057 to ultimately reach net-zero emissions in 2050. This includes installing more renewable energy infrastructure at our facilities, purchasing ZEVs, and building more sustainable facilities. The FAA's largest solar project to date is in progress at the Mike Monroney Aeronautical Center. The solar panels are expected to produce

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[59] Executive Order 14008, Tackling the Climate Crisis at Home and Abroad, 86 Fed. Reg. 7,619, 7,625-6 (Jan. 27, 2021), https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad.

[60] Executive Order 14057, Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, 86 Fed. Reg. 70,935 (Dec. 8, 2021), https://www.federalregister.gov/documents/2021/12/13/2021-27114/catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability.

2,600 megawatt hours annually, the equivalent needed to power 260 average homes. The FAA also continues to make energy efficiency upgrades at facilities including replacing aging HVAC systems and switching to LED lighting. Additionally, the FAA is making headway in ordering ZEVs for its government fleet and installing electric vehicle supply equipment at facilities to support this transition.

Actions

- Continue to advance climate, sustainability, and resilience as an agency priority with measurable targets and timelines, in line with Executive Orders and related agency requirements.
- Continue to reduce climate impacts from FAA facilities and operations by further lowering the agency's carbon footprint.
- Further increase the resilience of critical FAA facilities and assets, with specific and measurable milestones and targets.
- Update agency policies and orders related to sustainability, energy/water efficiency, and waste reduction, to reflect best practices and ensure long-term implementation.
- Contribute to DOT Climate Adaption Action Plan yearly updates, including progress made on completing vulnerability assessments for mission critical assets.
- Update DOT Sustainability Strategic Plan inputs from EO 14057 (including CFE Plan, Sustainable Buildings Plan, and ZEV Plan) with milestones and progress in meeting government wide goals.

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7. Non-CO_2 Climate Impacts of Aviation

Aircraft combustion emissions also have non-CO_2 impacts on the climate. The primary concern is the impact of aviation induced cloudiness (AIC).

Background / Context

Aircraft engines emit water vapor and a variety of other gases and particulate matter into the atmosphere, in addition to CO_2. These non-CO_2 combustion emissions can directly or indirectly impact climate through radiative forcing. Non-CO_2 effects of aviation can be long or short lived, and the largest anticipated impact is due to aircraft induced cirrus cloud formation from contrails (AIC). Other non-CO_2 aviation climate impacts are due to NOx, water vapor, sulfates, and soot emissions. Non-CO_2 engine emissions also affect local air quality (LAQ), and there are trade-offs between air quality and climate impacts. The United States is taking action to improve the level of scientific understanding for non-CO_2 climate impacts of aviation emissions to support future policy decisions.

Climate Impacts of Aviation Non-CO_2 Combustion Emissions

The non-CO_2 combustion emissions from aviation include water vapor (H_2O), unburned hydrocarbons (UHC), carbon monoxide (CO), NOx, sulfur oxides (SO_X) and nvPM. These emissions undergo complex interactions amongst themselves and with the changing background atmosphere. The impact of these emissions on climate has been examined for several decades. Emissions identified as potentially affecting climate include radiatively and/or chemically active species such as nvPM, NOx, UHC, CO, SO_X, and H_2O. Direct emissions of gases (e.g., CO_2, H_2O, nvPM), byproducts (e.g., O_3, stratospheric H_2O), and perturbed methane (CH_4) tend to have a warming effect, while particles like sulfates generally have a cooling effect. Gaseous emissions of SO_X and NOx evolve and partially transform into volatile nitrate and sulfate aerosols, which contribute to climate change as do the semi-volatile organic particles forming from gaseous UHC emissions.

Persistent linear contrails produced in the wake of aircraft contribute to net climate warming. Contrail-induced cirrus clouds, also known as aviation induced cloudiness (AIC), also affect the solar and terrestrial infrared radiative budget of the atmosphere—that is, they act as GHGs that have the potential to restrict heat leaving the earth at night. Latest estimates indicate that the AIC warming effect could be comparable or even higher than those due to aviation CO_2 although large uncertainties remain. Further complicating the situation, some forms of AIC may have a cooling effect during the day.

There is a wide range of spatial and temporal scales associated with atmospheric perturbations due to non-CO_2 aviation emissions. Contrails have an impact over an area measured in miles and a time span measured in hours whereas the impacts of NOx on methane has a global impact that lasts decades.

Summary of Actions:

- Improve the scientific understanding of the impacts of non-CO_2 aircraft emissions to enable the development of cost-beneficial solutions to address both air quality and climate impacts.

- Develop decision support tools that could be used by the USG and industry to cost-effectively mitigate the overall climate impacts of aviation via contrail mitigation.
- Develop the U.S. Contrails Research Roadmap (CRR) to improve understanding of the formation and climate impacts of persistent contrails and AIC to inform future policy and decision-making towards mitigating harmful AIC.

Progress and Current Activities

Current research shows that contrails have a significant effective radiative forcing (ERF)[61] which impacts climate change, but there is currently a large uncertainty surrounding the ERF from AIC.[62] The USG is currently funding research to improve its understanding of the non-CO_2 climate impacts of aircraft. The USG-funded research uses the latest scientific models and realistic emissions scenarios to quantify impacts of various short-lived climate forcers. In addition, this research examines the trade-offs between fuel efficiency and NOx emissions that manifest as trade-offs between air quality and climate impacts. The research utilizes algorithms to improve detection of contrails and AIC from satellite data, as well as the climate impact of higher-altitude stratospheric emissions. With this information, we will be better prepared to address such trade-offs in the context of existing engine emissions regulations and identify other data gaps.

FAA funded research is investigating the suitability of forecasted meteorological conditions to predict the likelihood of persistent warming contrails one day ahead, a few hours before the flight, and in real-time during a flight. Using the evaluated meteorological fields, the FAA developed a tool that will predict warming contrails, which when combined with flight-routing optimizations, could potentially be used to avoid the formation of warming contrails with little or no fuel burn penalty. The tool is being evaluated with contrails identified using the satellite data globally. The FAA also supports aircraft flight measurements of contrails and industry partners to evaluate and validate the performance of the tool such that it can be used more widely.

NASA funded research is building on a long history of core engine technology development and on-wing emissions characterization through ground and flight tests. Core engine technology development has long studied the trades between fuel burn (CO_2 emissions) and other emissions, such as NOx. Currently such development is focused in the HyTEC project mentioned in Section III.1. Simultaneously, NASA sponsored research is exploring propulsive power generation systems using alternative, non-drop in fuels. Additionally, NASA's Aeronautics Research and Science Mission Directorates have been partnering with industry, academia, and other U.S. and international government organizations to advance the scientific understanding of contrail formation and evolution as function of engine technology and fuel properties. Studies are underway analyzing aircraft emissions data collected from 2021-23 through ground and flight tests using lean-burn combustor technology and a range of SAF as compared to conventional and low-sulfur jet fuel.

DOE is supporting research on aviation focused on SAF. This research includes major efforts on production and deployment of SAF supply in the Bioenergy Technology Office (BETO) and work on end-use of SAF in the Vehicle Technologies Office (VTO) in the areas of fuel handling, injection and sprays, turbine modeling and experiments, and emissions. In the emissions area, particular expertise in soot

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[61] Effective radiative forcing measures the energy imbalance after allowing for atmospheric temperatures, water vapor, and clouds to adjust to the forcing agent, while keeping surface conditions (specifically temperature) unchanged.

[62] D.S. Lee, et al., "*The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*," Atmospheric Environment, Vol. 244, 2021, available at: https://doi.org/10.1016/j.atmosenv.2020.117834.

modeling and experiments are being applied to advance the science basis of contrail formation and persistence and to provide feedback on desirable fuel formulation characteristics for future SAF production pathways of promise. Additional expertise in NOx formation and control will potentially come into play in the future regarding both terrestrial emissions (impacting air quality at airports) and stratospheric NOx emissions impacting climate. While the DOE efforts are focused on SAF, much of the fundamental knowledge being developed is equally applicable to conventional jet fuels.

DOE ARPA-E launched the $10M Predictive Real-time Emissions Technologies Reducing Aircraft Induced Lines in the Sky (PRE-TRAILS). PRE-TRAILS supports five teams to develop systems to predict persistent aviation contrails capable of informing pilots and ground controllers in real-time whether an airplane is likely to produce persistent AIC with high accuracy. The innovation scope includes: 1. development of better sensors (including water vapor sensors for the troposphere), 2. validation and observation technologies to identify AIC and validate predictions, 3. training of an AIC predictive models that can reach an accuracy of F_1-score> 0.8. Five teams spanning aerospace and scientific experts have been funded to develop flight demonstrations by 2026.

After contrails, NOx is the second largest contributor to non-CO_2 effects from aviation on climate. Even though the full impact of aircraft engine NOx emissions on ERF remains uncertain (due to complex interactions with atmospheric chemistry), the EPA and FAA, through ICAO, are assessing the existing landing and take-off NOx metric related to modern engine designs and full flight emissions. In February 2025, ICAO will propose a new cruise NOx metric that takes into consideration the improvements in aircraft engine emissions. This new cruise NOx metric will help monitor some of the full flight NOx impacts on the environment.

Actions

Since the climate impact of AIC could be comparable in size to the impact of aviation CO_2, many USG efforts focus on particulate emission and the resulting contrail formation. Recent studies and demonstration flights have shown the potential to develop contrail avoidance approaches that consider both CO_2 and non-CO_2 impacts. Developing a methodology to avoid creating contrails while minimizing incremental fuel burn provides a clear opportunity to reduce aviation's overall climate impact. Combining this methodology with SAF use and advanced engine technologies would deliver emissions reductions from both CO_2 and non-CO_2 climate impacts. Therefore, the FAA is pursuing research to develop targeted approaches to predict and avoid warming contrails. As a part of this, ASCENT researchers will work to identify approaches and decision support tools that could be used by industry to cost-effectively mitigate the overall climate impacts of aviation via contrail mitigation.

NASA will advance integrated ground- and flight-based technologies for adoption readiness of solutions to mitigate the climate impact of AIC and other sustainability use cases such as ozone impact. As mentioned above, operational demonstrations supporting NASA's SFNP will validate the tools and system designs that support contrails mitigation goals.

In collaboration with NASA, DOE, and NOAA, the FAA is leading the development of a U.S. CRR to improve understanding of the formation and climate impacts of persistent contrails and AIC to inform future policy and decision-making. The CRR will detail current and planned USG research activities to better understand and potentially mitigate the impacts of contrails. Additionally, the roadmap will document roles and responsibilities for individual U.S. agencies, domestic and international coordination efforts, potential gaps, and policy considerations.

Additional research is also needed to improve meteorological predictions (especially identifying super saturation regions of the upper troposphere), understand atmospheric chemistry interactions, comprehend the formation of water vapor and sulfate emissions, and grasp the impact of technological advances. The interdependencies of all the non-CO_2 components and the CO_2 trade-offs—for instance the NOx-CO_2 trade off—also require additional scientific research. Historically, continued reductions in NOx have tended to increase fuel burn and resulting CO_2 emissions. Therefore, additional study of the technologies that limited the NOx-fuel burn tradeoff need to be conducted to address this tradeoff.

Collaboration across the USG and internationally is needed to reduce non-CO_2 impacts and improve confidence in the usability and efficacy of a decision support tool for operational contrail mitigation.

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8. Other Policies and Measures to Close the Gap

Eliminating the climate impact of the aviation sector through in-sector measures is a difficult task. Using robust out-of-sector measures, including both reductions and removals, can support the sector's climate goals and generate community co-benefits.

Background/Context

The U.S. continues to make progress toward our climate goals, but we still have a long way to go. Achieving the goal requires significant effort across government and industry. Getting the entire U.S. aviation sector to net-zero emissions by 2050 will require federal and state policies to guide innovation while not compromising on safety.

The United States has enacted policies that will enable the development and deployment of new and innovative technologies, fuels, operations, and infrastructure. Nevertheless, given the risks and long-lead times associated with development and deployment at scale of the novel technologies discussed in this report (including more fuel-efficient aircraft, SAF, and potentially hydrogen or other alternative fuel based solutions), the Federal Government has supported and will continue to support high-integrity carbon reductions and removals to address residual aviation sector emissions through 2050.

Progress and Current Activity

Importantly, the Federal Government has supported out-of-sector measures through the development of the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA establishes specific criteria and requirements to ensure the environmental credibility of offsets and SAF (discussed previously) used to show compliance with CORSIA obligations. Many of the specific SAF requirements, such as the sustainability criteria and life-cycle emission values, have been incorporated by reference into our domestic policies.

While the scope of CORSIA is international, CORSIA's emissions unit criteria provide a useful reference for federal policies and programs to help close the emissions gap through high-integrity reductions and removals for domestic flights.[63] The recently announced Voluntary Carbon Markets Joint Policy Statement and Principles, for instance, includes multiple references to the CORSIA standards for carbon offsets and builds directly on their content, providing a starting point for federal policy. The seven Principles in the Joint Policy Statement are:

1. Carbon credits and the activities that generate them should meet credible atmospheric integrity standards and represent real decarbonization.
2. Credit-generating activities should avoid environmental and social harm and should, where applicable, support co-benefits and transparent and inclusive benefits-sharing.
3. Corporate buyers that use credits should prioritize measurable emissions reductions within their own value chains.
4. Credit users should publicly disclose the nature of purchased and retired credits.
5. Public claims by credit users should accurately reflect the climate impact of retired credits and should only rely on credits that meet high integrity standards.
6. Market participants should contribute to efforts that improve market integrity.

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[63] ICAO, *"ICAO Document: CORSIA Emissions Units Eligibility Criteria,"* March 2019, available at: www.icao.int/environmental-protection/CORSIA/Documents/ICAO_Document_09.pdf.

7. Policymakers and market participants should facilitate efficient market participation and seek to lower transaction costs.[64]

Future U.S. policy in this area must ensure high levels of quality and integrity to retain public trust in the capacity for market-based measures to reduce emissions, in either the voluntary or compliance context, so that this option is available as a gap-filler for other emissions reductions efforts within the sector. Beyond developing international standards and domestic-facing principles to ensure quality and build market integrity, federal agencies are laying the groundwork for reductions and removals through additional policy efforts. Carbon dioxide removal (CDR) is a DOE focus area for crosscutting research, development, and demonstration (RD&D). Through three Offices (Fossil Energy and Carbon Management (FECM), Energy Efficiency and Renewable Energy (EERE), and Science), as well as ARPA-E, DOE coordinates multiple efforts that contribute to the Carbon Negative Shot, one of the targets within the agency's Energy Earthshots Initiative.[65] The Carbon Negative Shot is an all-hands-on-deck call for innovation in CO_2 removal pathways that seeks to enable the scale-up of multiple CDR approaches to achieve the net-zero emissions by 2050 goal in the United States. DOE is developing a wide array of CDR approaches, such as direct air capture (DAC) with durable storage, biomass carbon removal and storage (BiCRS), enhanced mineralization, ocean-based CDR, soil carbon storage, and reforestation. Together, these approaches will help achieve gigaton-scale removal by 2050 and support the United States in achieving ambitious goals for 2050.[66]

DOE's FECM has adopted a comprehensive, multi-pronged approach for carbon management that involves the coupling of carbon capture methods (i.e., CDR technologies co-located with low-carbon energy sources; and point source capture for fossil fuel-based power generation and industrial sources) with long-duration carbon storage or CO_2 utilization/conversion into long-lasting products. The National Energy Technology Laboratory's (NETL) CDR Program is fostering R&D focused on DAC, with emerging research in the areas of BiCRS, enhanced mineralization, and ocean-based and terrestrial CDR approaches to remove CO_2 that has accumulated in the atmosphere. The captured CO_2 will then be securely stored in reservoirs (geologic, bio-based, and oceanic), or in value-added products, resulting in negative emissions (i.e., more carbon is removed from the atmosphere than generated). The CDR Program also emphasizes a robust analysis of life cycle impacts and a deep commitment to environmental justice. Projects range from conceptual engineering and materials design at laboratory and bench scale (TRL 2–5) to large-scale testing and front-end engineering and design (FEED) studies (TRL 6–7) to lower both capital and operating costs and improve the economics of CDR.

Actions

- Collaborate with other agencies to deliver a unified, science-based federal policy approach to out-of-sector measures that protects demand, supply, and market integrity for high-quality reductions and removals that consider the unique requirements of the aviation sector.

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[64] White House, "*FACT SHEET: Biden-Harris Administration Announces New Principles for High-Integrity Voluntary Carbon Markets*," May 28, 2024, available at: https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/28/fact-sheet-biden-harris-administration-announces-new-principles-for-high-integrity-voluntary-carbon-markets/.

[65] Department of Energy, "*Energy Earthshots*," available at https://www.energy.gov/energy-earthshots-initiative.

[66] National Academies of Sciences, Engineering, and Medicine. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

Section IV. Continued Commitment to Action

The U.S. government and U.S. stakeholders recognize the challenge in eliminating the aviation sector's climate impact. There are no quick and easy solutions. However, as this document highlights, there are many different actions focused on unique aspects of the challenge. Taken together, these actions can and will add up to significant progress to address aviation's climate challenge. Aviation is an innovative sector, and we expect continued innovation in the future. These innovations—in technology, operations, fuels, and infrastructure—will further help decarbonize the sector. The U.S. government stands ready to support our partners and leverage our resources to maximize the innovative potential and continue our commitment to climate action from the aviation sector. Working together with industry, we are confident that the United States is up to the challenge of achieving our 2050 goal.

Appendix: Glossary of Terms

AAVP	**Advanced Air Vehicles Program**	NASA program to study, evaluate, and develop technologies and capabilities for future aircraft systems with a focus on fuel burn, noise, emissions, and safety.
ADS-B	**Automatic Dependent Surveillance – Broadcast**	Aircraft surveillance technology using satellite/GPS technology instead of radar to identify and monitor aircraft.
AIC	**Aviation Induced Cloudiness**	Clouds induced by aviation activity that includes contrails.
AOSP	**Airspace Operations and Safety Program**	NASA program to study, evaluate, and develop ATM and aircraft technologies to enable NextGen advanced automation and safety tools.
ASK	**Available Seat Kilometer**	One seat transported one kilometer; the most common measure of airline seating capacity or supply. For example, an aircraft with 100 passenger seats, flown 100 kilometers, produces 10,000 ASKs. Sometimes measured as an available seat mile (ASM).
ATK	**Available Ton Kilometer**	One ton of capacity (passenger and/or cargo) transported one kilometer. Sometimes measured as an available ton mile (ATM).
ATM	**Air Traffic Management**	Agencies and systems supporting safe, efficient, and orderly navigation of airports and airspace by aircraft (e.g., air traffic control and flow/capacity management).
CAAFI	**Commercial Aviation Alternative Fuels Initiative**	Coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants, and USG agencies working to develop and deploy alternative jet fuels for commercial aviation.
CANSO	**Civil Air Navigation Services Organization**	Representative body of air navigation service provider companies and agencies, assisting with the development of policies in regulatory and industry bodies.
CLEEN	**Continuous Lower Energy, Emissions, and Noise**	Public-private partnership administered by the FAA in cooperation with the aviation industry to develop certifiable aircraft and engine technologies that improve fuel efficiency and reduce noise and emissions.

CORSIA	**Carbon Offsetting and Reduction Scheme for International Aviation**	Market-based mechanism developed by ICAO to help the international aviation industry reach its goal of carbon neutral growth after 2020.
DOD	**Department of Defense**	Executive department of the USG charged with coordinating and supervising all military agencies and functions of the USG.
DOE	**Department of Energy**	Cabinet-level department of the USG with responsibilities including energy security, conservation, environmental impact, and production.
DOT	**Department of Transportation**	Cabinet-level department of the USG concerned with transportation, including the FAA.
EPA	**Environmental Protection Agency**	Independent executive agency of the U.S. Federal Government tasked with environmental research and regulation.
-	**Equipage**	The type and status of equipment installed on an aircraft for communication, navigation, and surveillance (e.g., ADS-B)
FAA	**Federal Aviation Administration**	Agency of the USG regulating all aspects of civil aviation, including ATM, regulations/standards, personnel, airports and aviation research.
GGE	**Gasoline-Gallon Equivalents**	Amount of alternative fuel containing the equivalent energy of one liquid gallon of gasoline.
GHG	**Greenhouse Gas**	Gas that absorbs and emits radiant energy within the thermal infrared range, causing the greenhouse effect.
IASP	**Integrated Aviation Systems Program**	NASA program to mature advanced aeronautics technology through systems-oriented flight test and integrated development.
ICAO	**International Civil Aviation Organization**	Agency of the United Nations supporting regulatory development and standardization for international civil aviation.
NAS	**National Airspace System**	Collective term for the technology, systems, regulations, and infrastructure for aviation in the United States (e.g., airports, navigational aids, ATM infrastructure, and support personnel).
NASA	**National Aeronautics and Space Administration**	Independent agency of the U.S. Federal Government responsible for the civilian space program, aeronautics research, and space research.

NextGen	**Next Generation Air Transportation System**	FAA modernization program for the NAS, including infrastructure and ATM technologies.
NOx	**Nitrogen Oxides**	Nitrogen oxide (NO) and nitrogen dioxide (NO_2) gases, which are a component of aircraft engine exhaust.
nvPM	**Non-volatile particulate matters**	Aerosol pollutants that are found in aircraft exhaust. Sometimes referred to as soot or black carbon.
OEM	**Original Equipment Manufacturer**	Manufacturers and suppliers of physical hardware employed in the NAS, including aircraft and ATM hardware.
PBN	**Performance Based Navigation**	Aircraft navigation procedures with specifications requiring accuracy, integrity, availability, continuity, and functionality capabilities.
RPK	**Revenue Passenger Kilometer**	One fare-paying passenger transported one kilometer. Sometimes measured as revenue passenger miles (RPM).
RTK	**Revenue Ton Kilometer**	One ton of revenue traffic (passenger and/or cargo) transported one kilometer. Sometimes measured in revenue ton miles (RTMs)
SAF	**Sustainable Aviation Fuels**	Liquid hydrocarbon fuels created from renewable or waste feedstocks that are fully fungible with existing fuel supply infrastructure, engines, and aircraft. For purposes of this Action Plan and U.S. policy, SAF reduce life cycle GHG emissions by at least 50% relative to conventional jet fuel.
SARP	**Standards and Recommended Practices**	International regulatory guidance documents to facilitate standardized state-level regulatory development.
SFNP	**Sustainable Flight National Partnership**	NASA framework to support development of next-generation narrow body aircraft through technology development and integrated system testing.
TACP	**Transformative Aeronautics Concept Program**	NASA program to provide research and testing resources to enable development of technologies for aviation transformation.
TBO	**Trajectory-Based Operations**	ATM concept that enhances strategic planning and flow management in the NAS through advanced time-based traffic management and PBN route definitions.
TRL	**Technology Readiness Level**	Nine-level scale developed by NASA to estimate the level of maturity of a technology from basic research through full integrated system operation.

USDA	**United States Department of Agriculture**	Executive department of the USG charged with regulating activities related to farming and food, including production of feedstocks used to manufacture certain SAF products.
USG	**United States Government**	Collective term for agencies and entities within the U.S. Government.
VALE	**Voluntary Airport Low Emissions**	FAA program to encourage and support airport modernization and environmental impact reduction through increased electrification and enhanced monitoring.
ZEV	**Zero-Emission Vehicle**	A vehicle that does not emit exhaust gas or other pollutants from the onboard source of power.