US Aviation Climate Action Plan

Overview of Efforts to Address Aviation's Climate Impacts

By: Dr. Jim Hileman
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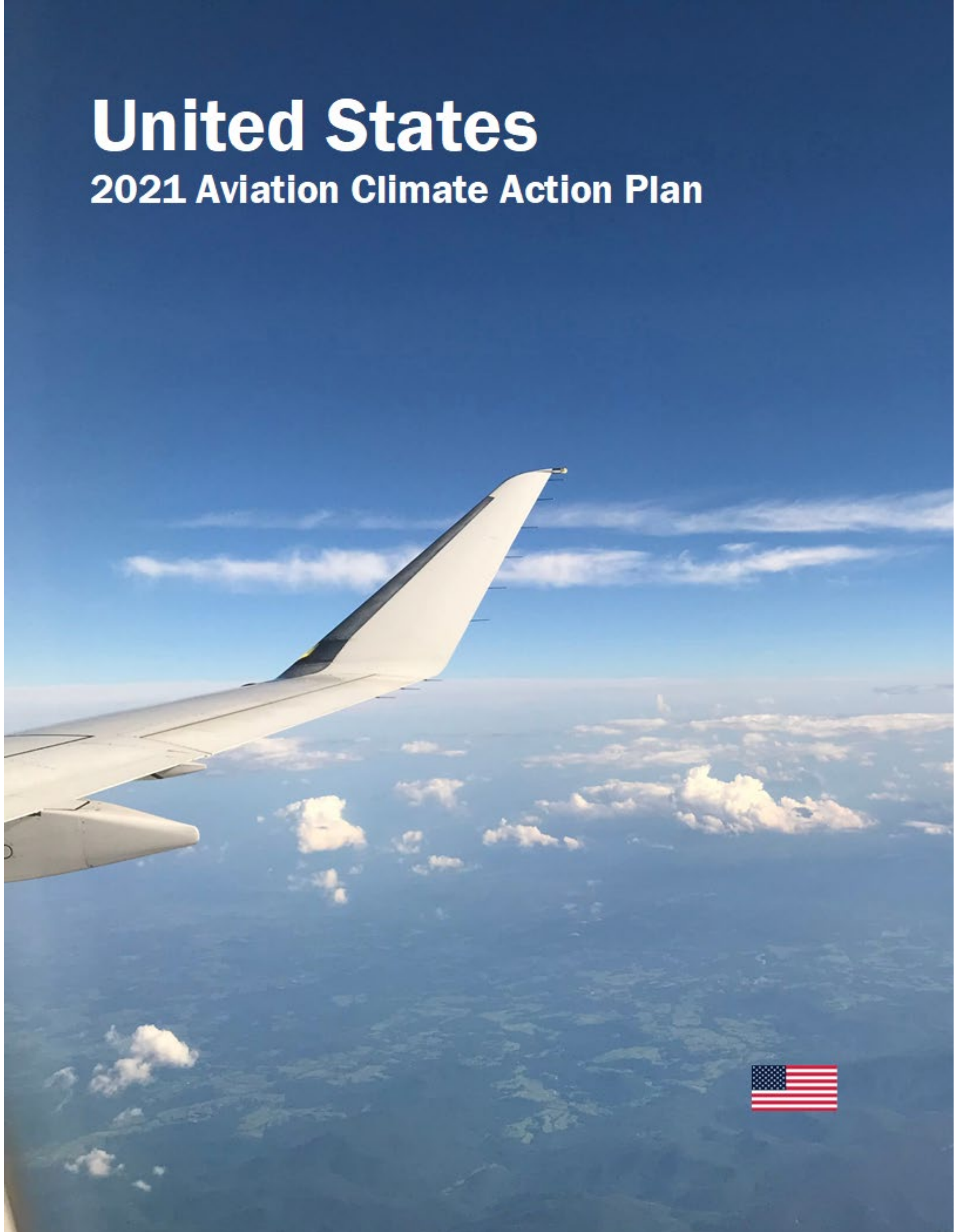
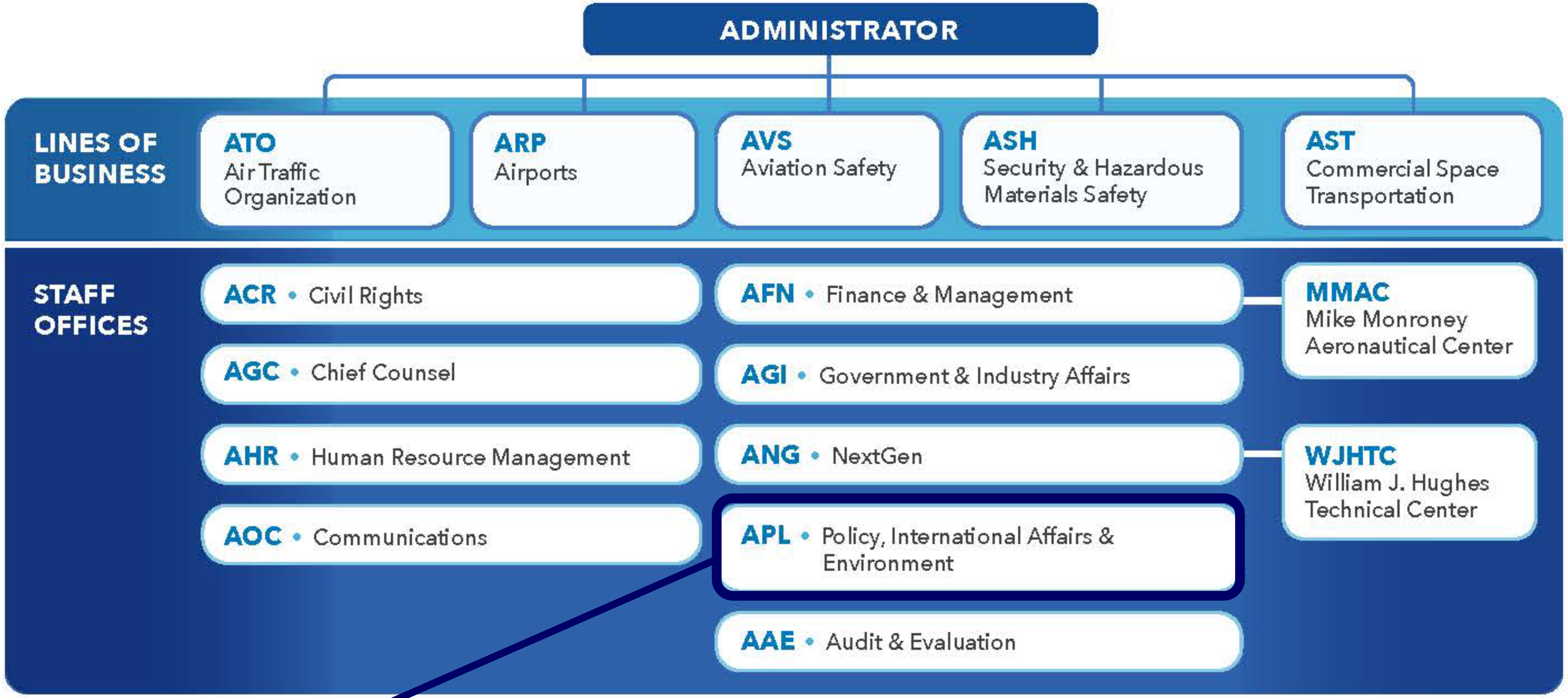
Office of Environment and Energy
Federal Aviation Administration

Date: November 10, 2022



FAA Organizational Structure



Office of Environment and Energy (AEE)
- Office within APL, responsible for broad range of environmental policies
- Roughly 45 staff members
- Responsible for roughly one-fourth of FAA RE&D Budget

FAA Environmental & Energy (E&E) Strategy

E&E Mission: *To understand, manage, and reduce the environmental impacts of global aviation through research, technological innovation, policy, and outreach to benefit the public*

E&E Vision: *Remove environmental constraints on aviation growth by achieving quiet, clean, and efficient air transportation*

E&E Program:

ADVANCE UNDERSTANDING OF NOISE, EMISSIONS, AND THEIR IMPACTS

- Vehicle operation
- Pollutant measurement
- Atmospheric propagation
- Societal impacts

Aviation Environmental Tools Suite and Communication Tools

- Today's Fleet of Aircraft and Helicopters
- Drones and Advanced Air Mobility Vehicles
- Commercial Supersonic Aircraft
- Commercial Space Vehicles

POLICY MAKING

- Domestic Policies
- Aircraft and Engine Standards
- CORSIA
- Long Term Climate Goal Development
- Community Engagement

DEVELOP INNOVATIVE SOLUTIONS TO REDUCE NOISE AND EMISSIONS

- Aircraft and Engine Technology
- Sustainable Aviation Fuels
- Optimized Operations and Procedures

ASCENT Aviation Sustainability Center
www.ascent.aero/

CAAFI®
www.caafi.org/

Continuous Lower Energy, Emissions & Noise
CLEEN
Federal Aviation Administration
www.faa.gov/go/cleen/

the VOLPE center

ASCENT Center of Excellence

For 18 years, FAA Office of Environment and Energy has relied on university centers of excellence to:

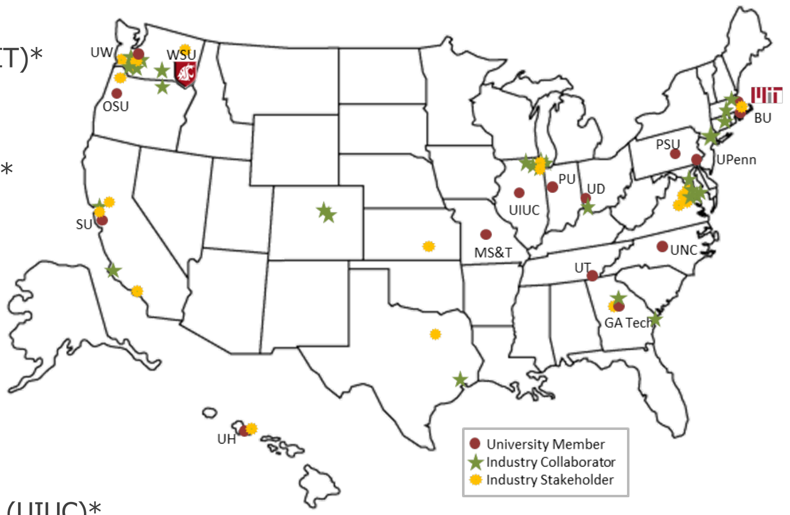
- Provide knowledge to inform decision making on environment and energy matters;
- Enable the introduction of innovative solutions to cost-effectively mitigate the environmental impacts of aviation; and
- Support the instruction of hundreds of professionals with knowledge of the environmental challenges facing aviation (*674 students supported and counting*).

ASCENT Research Portfolio

- In 2013, FAA established ASCENT to conduct research on environment and alternative jet fuels
- Portfolio covers broad range of topics on Alternative Jet Fuels, Emissions, Noise, Operations, and Analytical Tools
- Over 80 research projects with over $15M annual budget

Lead Universities:
Washington State University (WSU)
Massachusetts Institute of Technology (MIT)*

Core Universities:
Boston University (BU)*
Georgia Institute of Technology (Ga Tech)*
Missouri University of Science and Technology (MS&T)*
Oregon State University (OSU)
Pennsylvania State University (PSU)*
Purdue University (PU)*
Stanford University (SU)*
University of Dayton (UD)
University of Hawaii (UH)
University of Illinois at Urbana-Champaign (UIUC)*
University of North Carolina at Chapel Hill (UNC)*
University of Pennsylvania (UPenn)*
University of Tennessee (UT)
University of Washington (UW)



Multiple international partners

Advisory Committee (57 orgs)
5 airports
4 airlines
9 NGO/advocacy
8 aviation manufacturers
10 feedstock/fuel manufacturers
21 R&D, service to aviation sector

ASCENT Support

Federal Aviation Administration
Transport Canada
NASA
Environmental Protection Agency
Defense Logistics Agency - Energy
U.S. Dep't of Energy
U.S. Dep't of Agriculture
Air Force Research Laboratory

For more information: https://ascent.aero/

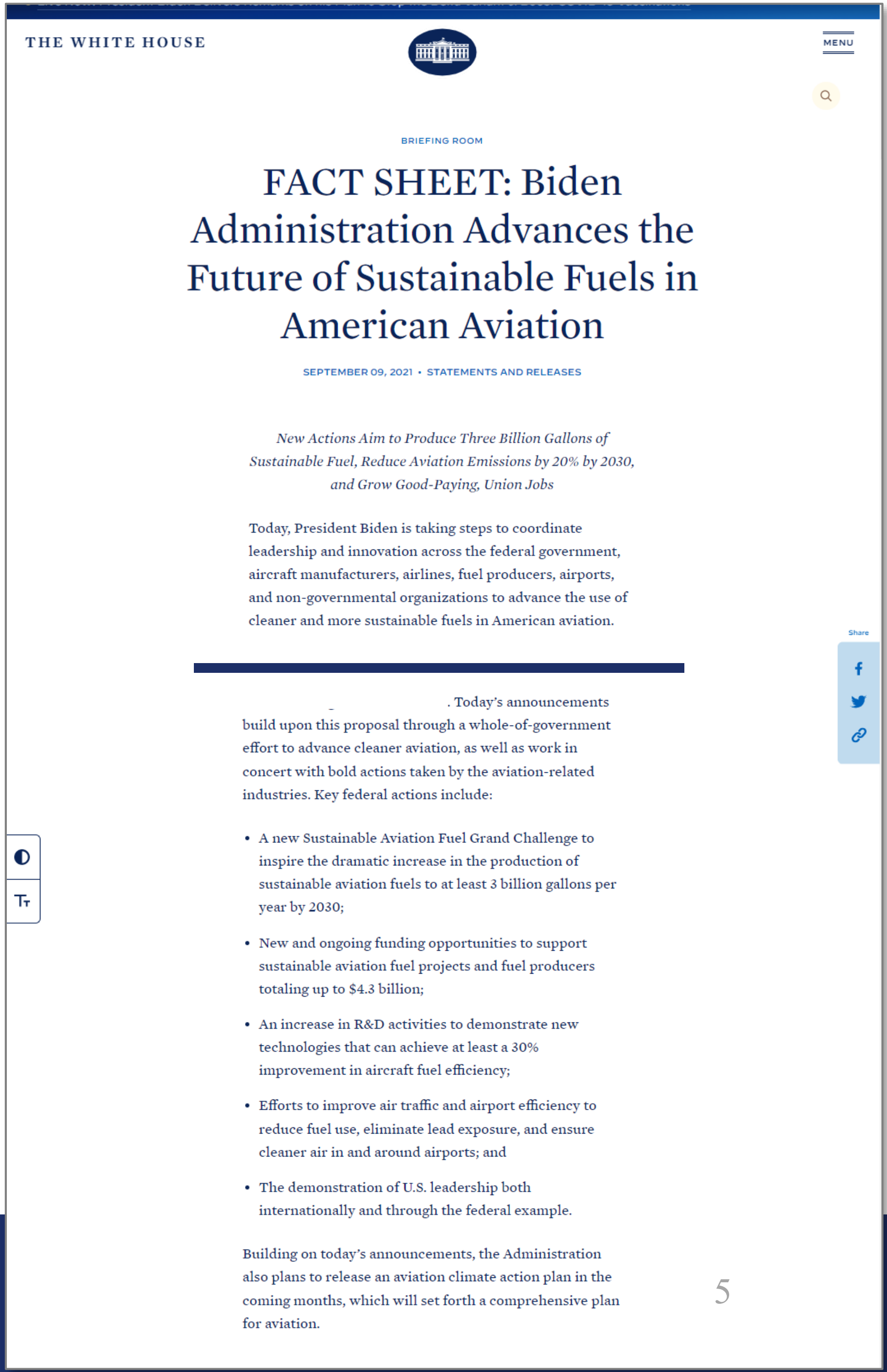
White House Sustainable Aviation Event

On September 9, 2021, government and industry leaders met to discuss actions and make new announcements regarding efforts to address aviation and climate change in the near-term, with a view to long-term ambition.

Key federal actions include:

- A new Sustainable Aviation Fuel Grand Challenge to inspire the dramatic increase in the production of sustainable aviation fuels to at least 3 billion gallons per year by 2030;
- An increase in R&D activities to demonstrate new technologies that can achieve at least a 30% improvement in aircraft fuel efficiency;
- Efforts to improve air traffic and airport efficiency to reduce fuel use, eliminate lead exposure, and ensure cleaner air in and around airports; and
- The demonstration of U.S. leadership both internationally and through the federal example.

"…the Administration also plans to release an <u>aviation climate action plan</u> in the coming months, which will set forth a comprehensive plan for aviation."


THE WHITE HOUSE

MENU

BRIEFING ROOM

FACT SHEET: Biden Administration Advances the Future of Sustainable Fuels in American Aviation

SEPTEMBER 09, 2021 • STATEMENTS AND RELEASES

New Actions Aim to Produce Three Billion Gallons of Sustainable Fuel, Reduce Aviation Emissions by 20% by 2030, and Grow Good-Paying, Union Jobs

Today, President Biden is taking steps to coordinate leadership and innovation across the federal government, aircraft manufacturers, airlines, fuel producers, airports, and non-governmental organizations to advance the use of cleaner and more sustainable fuels in American aviation.

Share

. Today's announcements build upon this proposal through a whole-of-government effort to advance cleaner aviation, as well as work in concert with bold actions taken by the aviation-related industries. Key federal actions include:

- A new Sustainable Aviation Fuel Grand Challenge to inspire the dramatic increase in the production of sustainable aviation fuels to at least 3 billion gallons per year by 2030;
- New and ongoing funding opportunities to support sustainable aviation fuel projects and fuel producers totaling up to $4.3 billion;
- An increase in R&D activities to demonstrate new technologies that can achieve at least a 30% improvement in aircraft fuel efficiency;
- Efforts to improve air traffic and airport efficiency to reduce fuel use, eliminate lead exposure, and ensure cleaner air in and around airports; and
- The demonstration of U.S. leadership both internationally and through the federal example.

Building on today's announcements, the Administration also plans to release an aviation climate action plan in the coming months, which will set forth a comprehensive plan for aviation.

White House Sustainable Aviation Fact Sheet:
https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/09/fact-sheet-biden-administration-advances-the-future-of-sustainable-fuels-in-american-aviation/

Aviation Climate Action Plan

State Action Plan submission to International Civil Aviation Organization (ICAO)

- On November 9, 2021, Secretary of Transportation Pete Buttigieg announced the ***United States Aviation Climate Action Plan***, which describes a whole-of-government approach to put the aviation sector on a path toward achieving net-zero emissions by 2050.

- The plan builds on individual and sector-wide commitments announced by the U.S. aviation industry, and highlights specific actions and policy measures to foster innovation and drive change across the entire U.S. aviation sector.

- Climate Action Plan Press Release:
  https://www.faa.gov/newsroom/us-releases-first-ever-comprehensive-aviation-climate-action-plan-achieve-net-zero

- Climate Action Plan Document:
  https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

U.S. Aviation Climate Goal

To be effective, a goal should be clear, achievable, and ambitious with specific actions that can be taken to achieve it. The goal outlined below contributes to the broader objective to achieve net-zero GHG emissions economy-wide by 2050.

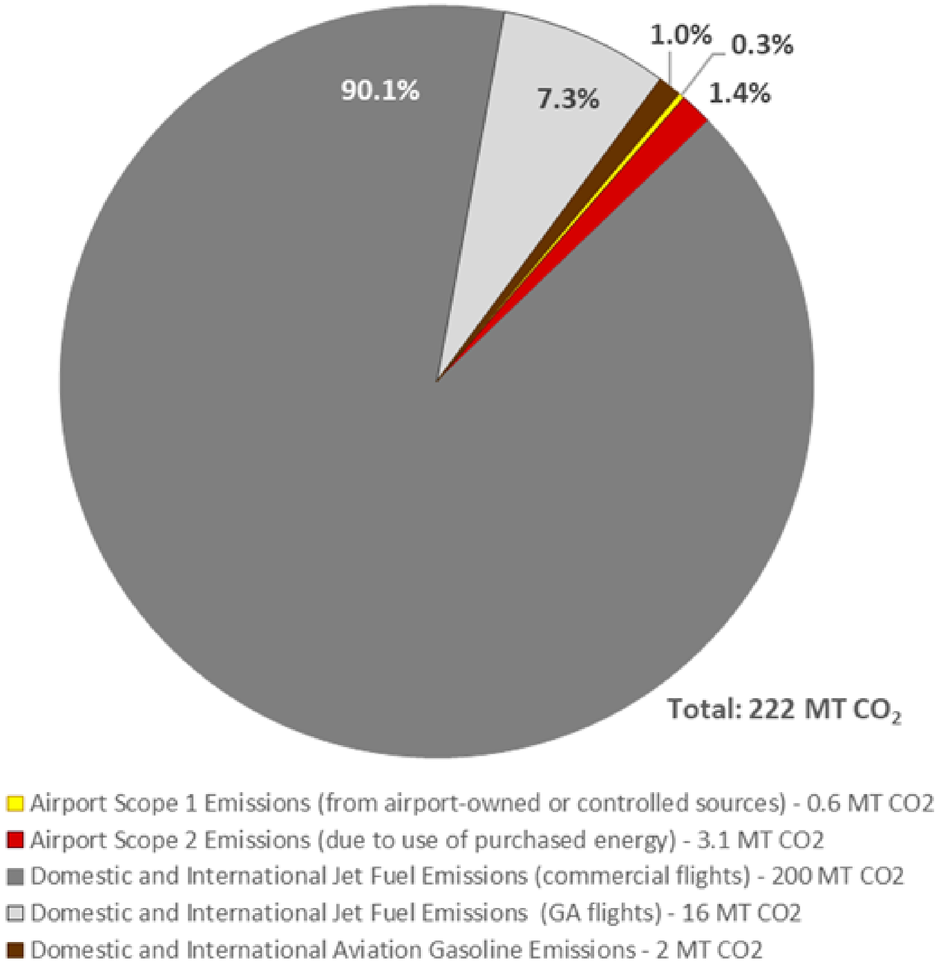
U.S. Aviation Climate Goal:
Net-Zero GHG Emissions* from U.S. Aviation Sector** by 2050

* 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).

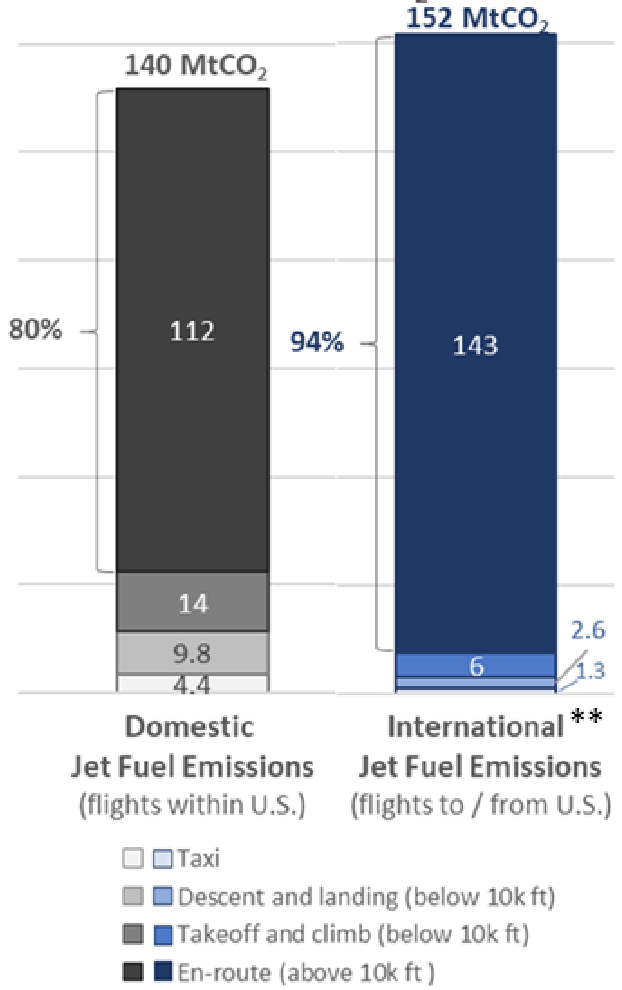
** This U.S. aviation goal encompasses CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators, (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators,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

Analysis of U.S. Aviation CO_2 Emissions in 2019

U.S. Domestic & International* Aviation CO_2 Emissions



Detailed Analysis of Commercial Aviation Jet Fuel CO_2 Emissions

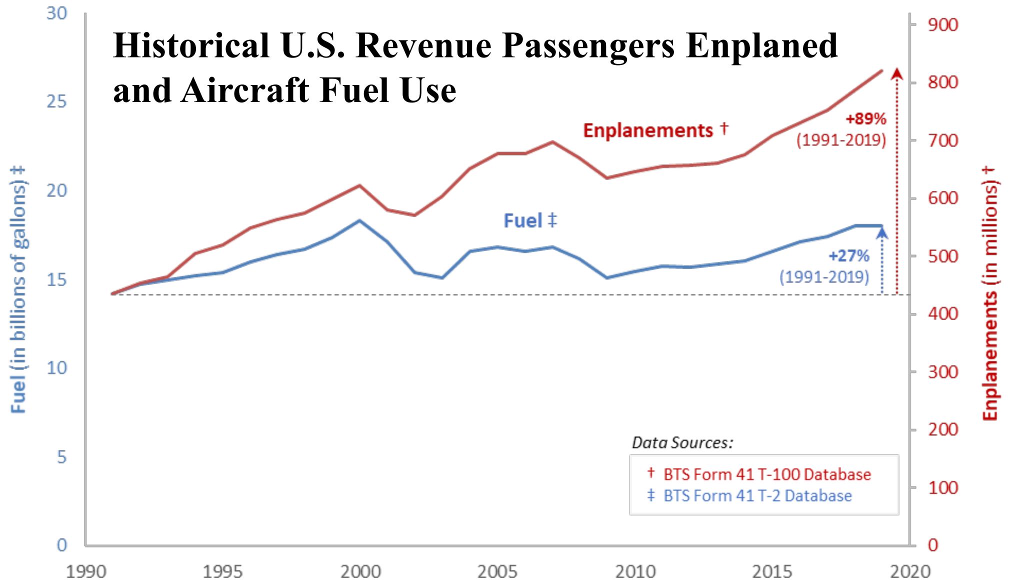


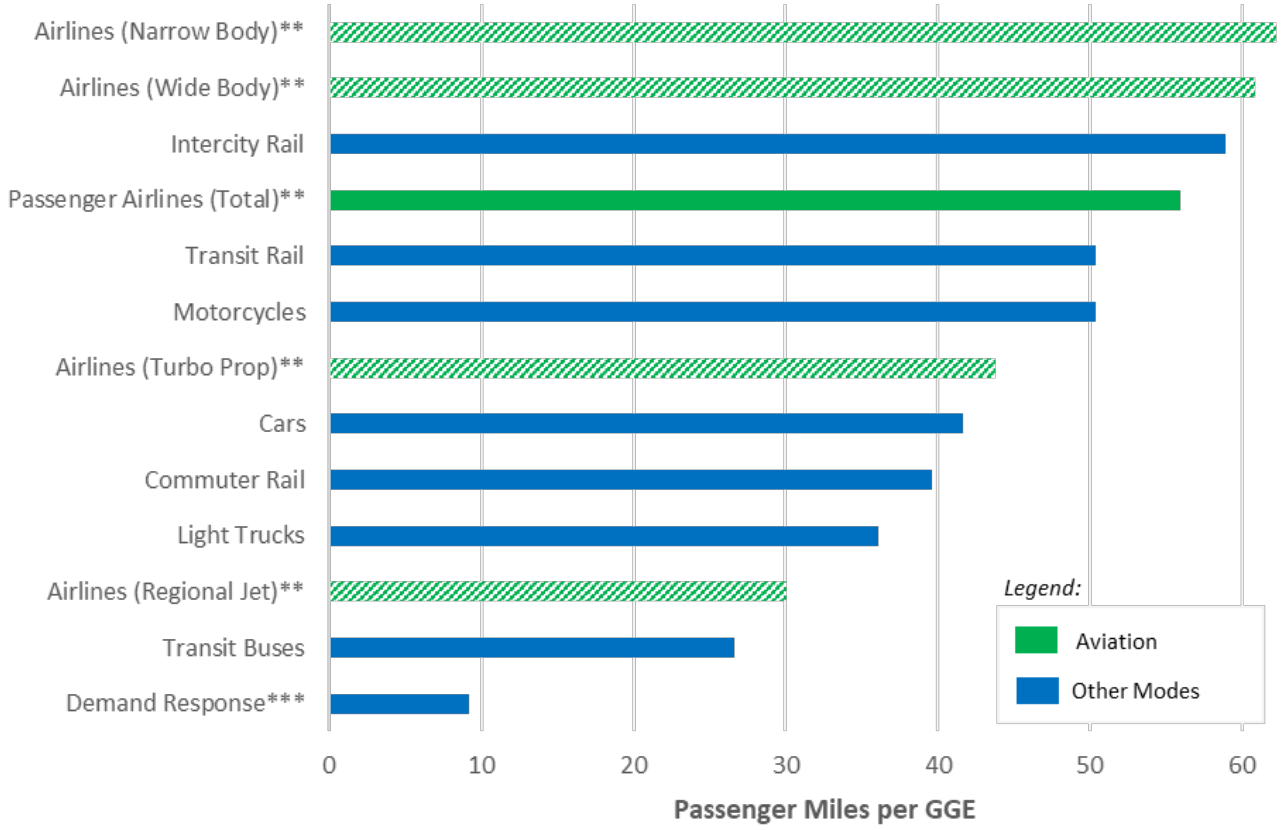
* CO_2 emissions from (1) domestic aviation (i.e., flights departing and arriving within the United States and its territories) from U.S. and foreign operators and (2) international aviation (i.e., flights between two different ICAO Member States) from U.S. operators (only). Airport scopes 1 and 2 added 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.

Domestic Fuel Efficiency

- National Airspace System (NAS) is operating much more efficiently today than 30 years ago - moving more passengers on the same amount of energy.
- Today's fleet of aircraft has an average fuel efficiency of 57.5 passenger-miles per gallon of fuel; for comparison, a modern Toyota Prius hybrid has a fuel economy of 54 miles per gallon (MPG).

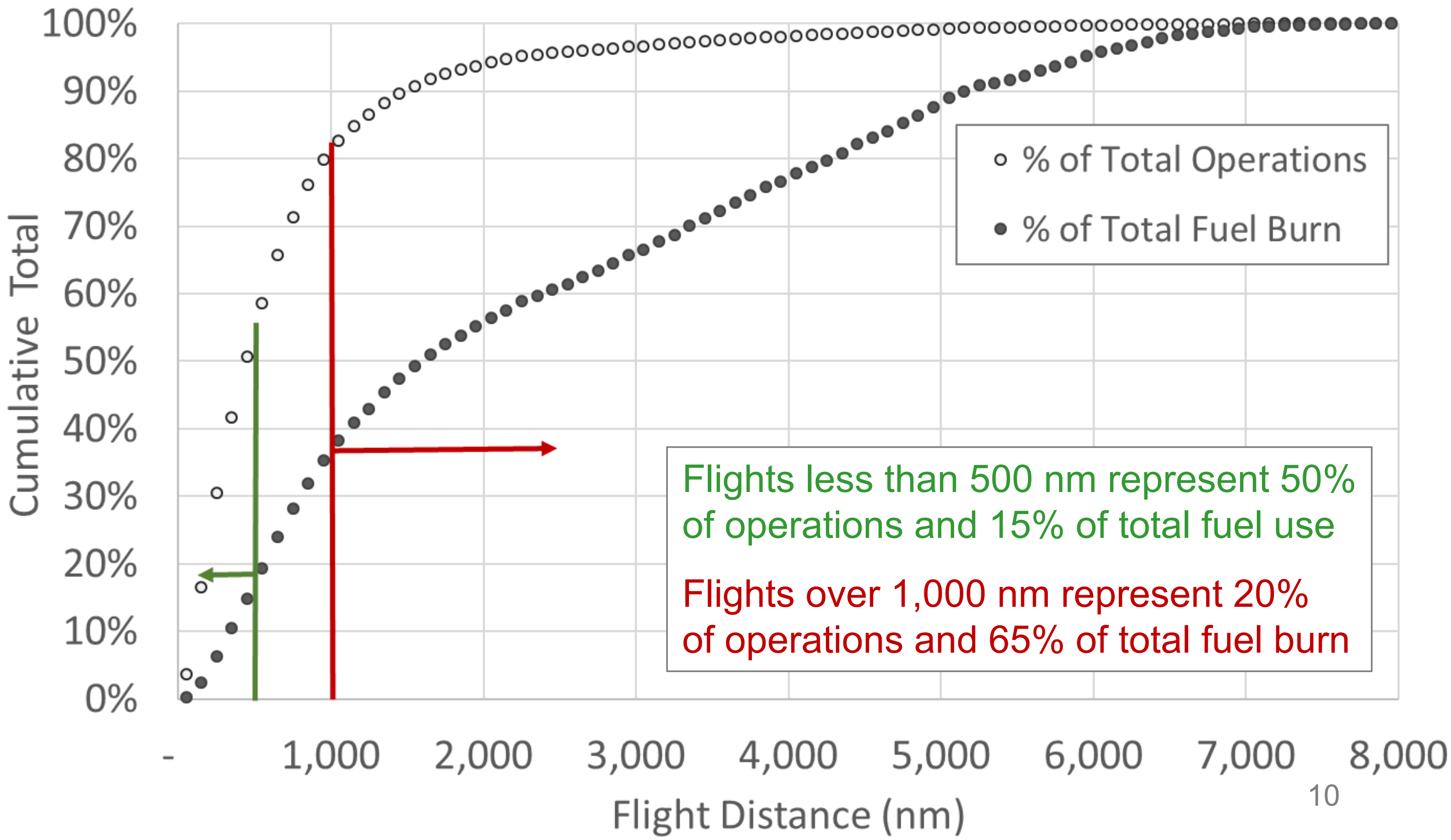




Notes: * Gasoline-Gallon Equivalents (GGE) are used to compare gasoline, diesel, and electricity on a level basis. Alterations to the source data were made to account for the inefficiencies of electricity production. This impacts rail the most because it has the highest level of electric power.
** Domestic flights only. All fuel use is attributed to passengers, none to cargo that might be using the same airplane.
*** Includes passenger cars, vans, and small buses operating in response to calls from passengers to the transit operator who dispatches the vehicle.

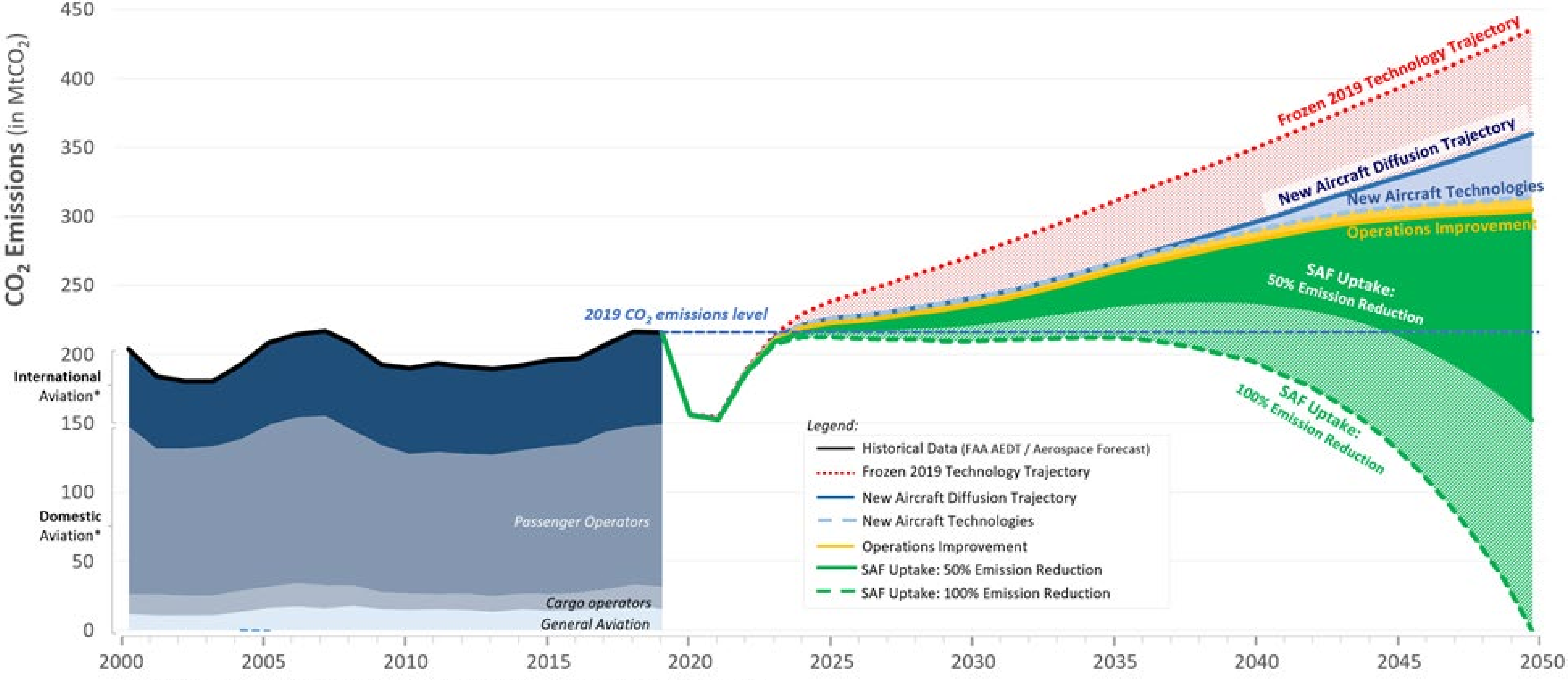
Global Jet Fuel Use

- Global jet fuel use is driven by long-haul aviation
- SAF only option through 2050 for long distances



Data analysis conducted by the U.S. DOT Volpe Center using the Aviation Environmental Design Tool (AEDT)

Domestic and International Aviation CO_2 Emissions



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

NOTE: Analysis conducted by BlueSky leveraging FAA Aerospace Forecast and R&D efforts from the FAA Office of Environment & Energy (AEE) regarding CO2 emissions contributions from aircraft technology, operational improvements, and SAF

Full Report Contents

https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

- Introduction
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- Aircraft and Engine Technology Development
- Operational Improvements
- Sustainable Aviation Fuels
- International Leadership and Initiatives
- Airport Initiatives
- FAA Leadership on Climate, Sustainability and Resilience
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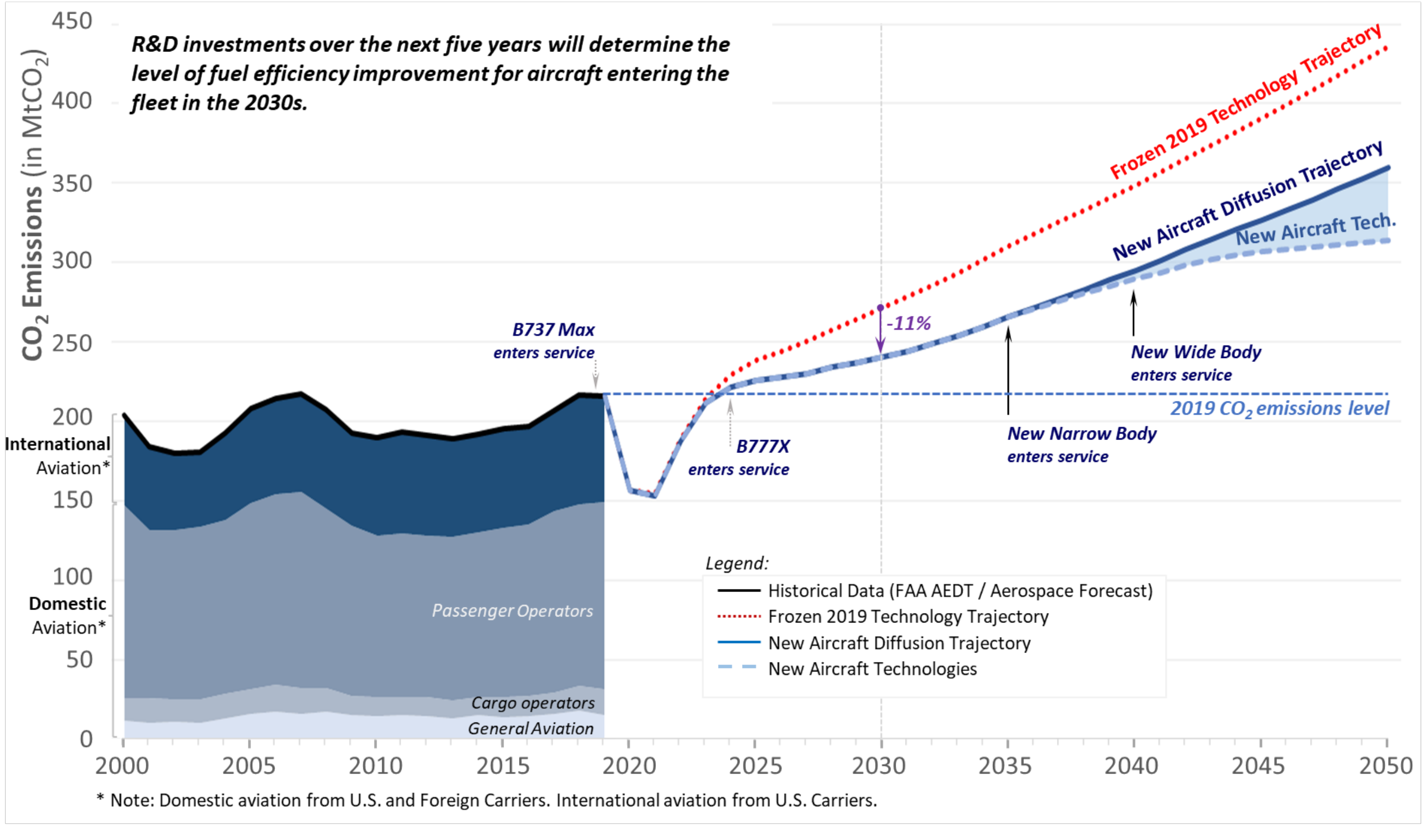
Aircraft and Engine Technology Development

The evolution of modern, more efficient airframes and engines has historically produced the most significant aviation emissions reductions; the Sustainable Flight National Partnership (SFNP) will continue to drive emissions reductions in the future.

Summary of Actions

- Utilize the SFNP to conduct ground and flight tests to demonstrate aircraft and engine technologies and designs that can deliver a step change improvement in environmental performance.
- Pursue ambitious international standards that incentivize the most effective technologies to safely limit the growth of, and ensure reductions in, aircraft emissions.



Aircraft Evolution – 1947 to Today

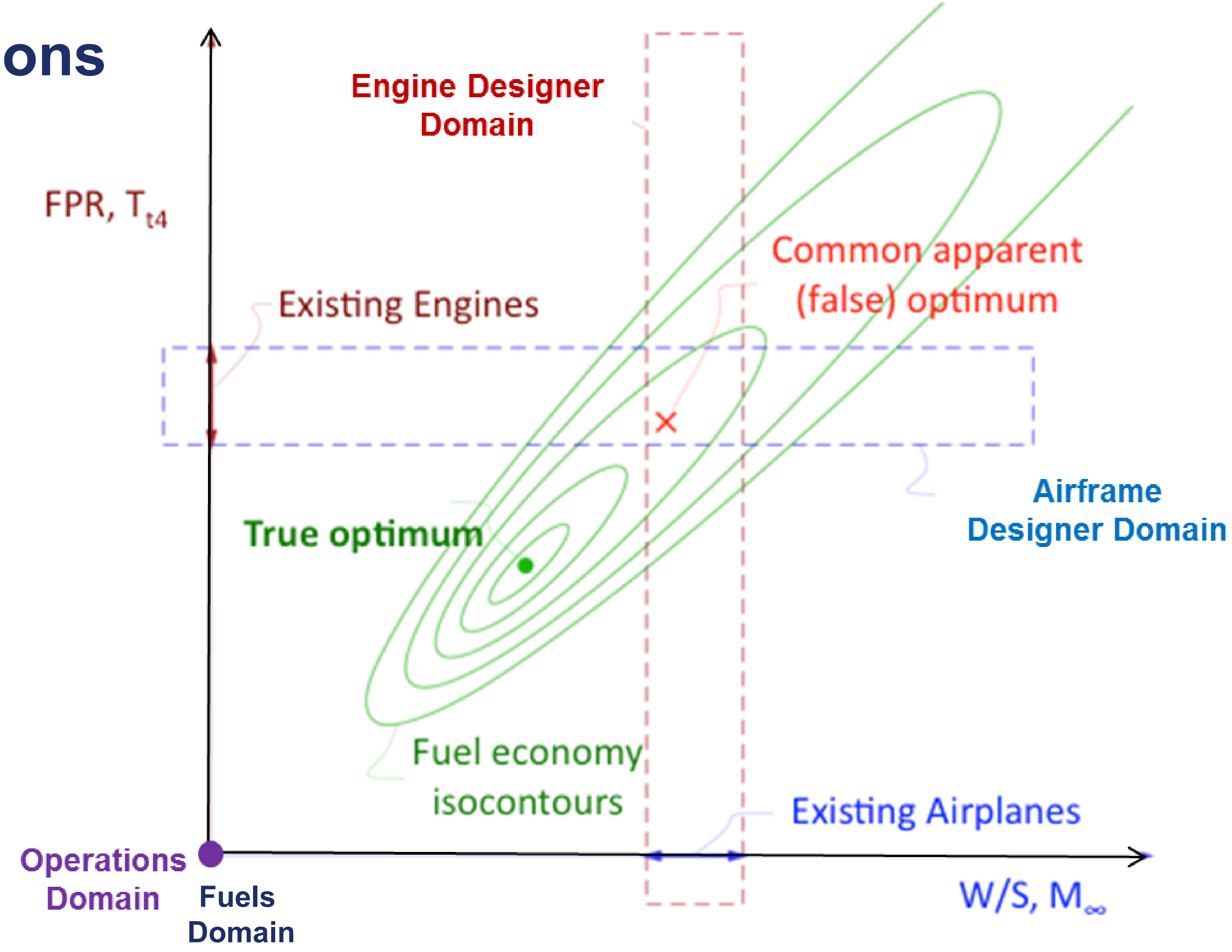
Every large jet aircraft today is a descendant of Boeing B-47[1]

The Jet as Art by Jeffrey Milstein[2]

Source:
1. http://www.boeing.com/history/products/b-47-stratojet.page
2. http://www.jeffreymilstein.com/index/aircraft.html#grid

Integrated Design Solutions

Need globally-optimized airframe / engine / operations to get a step change in environmental performance relative to today while ensuring safe operation



Original graphic courtesy of Mark Drela, MIT (modified here)

Sustainable Flight National Partnership

A sustained major technology development initiative, under which NASA and FAA will work with industry, to accelerate the maturation of aircraft and engine technologies that enable a step-change reduction in fuel burn, emissions, and noise, (i.e., 25-30% lower fuel burn and 10-15 dB noise reduction relative to best-in-class aircraft).

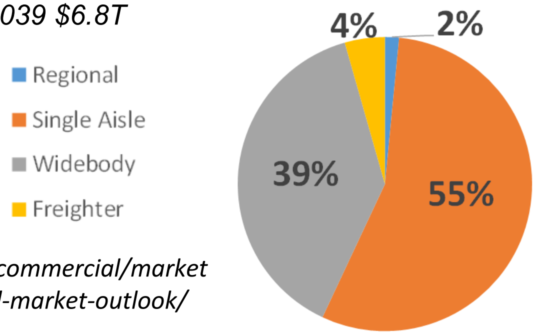
SFNP will build upon successful cooperation among FAA, NASA, and industry:

- NASA's investments under the SFNP include a suite of integrated, large-scale aircraft and propulsion flight and ground technology demonstrations, including ultra-efficient wings (such as transonic truss-braced wings), small-core gas turbines, electrified and hybrid electric aircraft propulsion system(s), and new manufacturing techniques such as high-rate composite manufacturing to enable rapid production of such new aircraft.
- FAA R&D is focused on engine technologies, low-emissions combustion, and aircraft technologies that enable future operational concepts. At the FAA, these technology development efforts will be executed primarily under the CLEEN Program and the ASCENT Center of Excellence.

Initially target narrow-body aircraft family as it accounts 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.

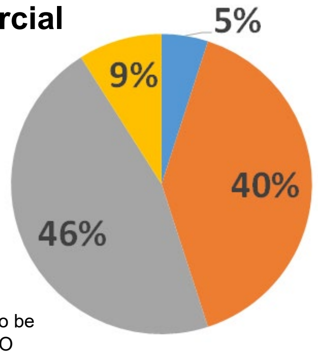
Global Market Value*

2020-2039 $6.8T



**boeing.com/commercial/market /commercial-market-outlook/*

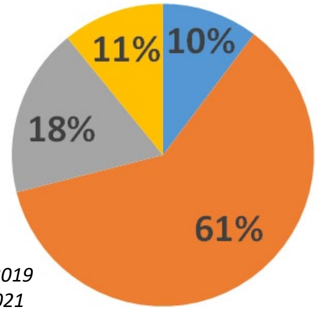
Estimated CO_2 Emissions from Global Commercial Operators** *(2018)*



****Volpe Preliminary Data – used with permission** final data to be published in Chapter 1 of 2022 ICAO Environmental Report

Population Exposed to Significant Noise ***

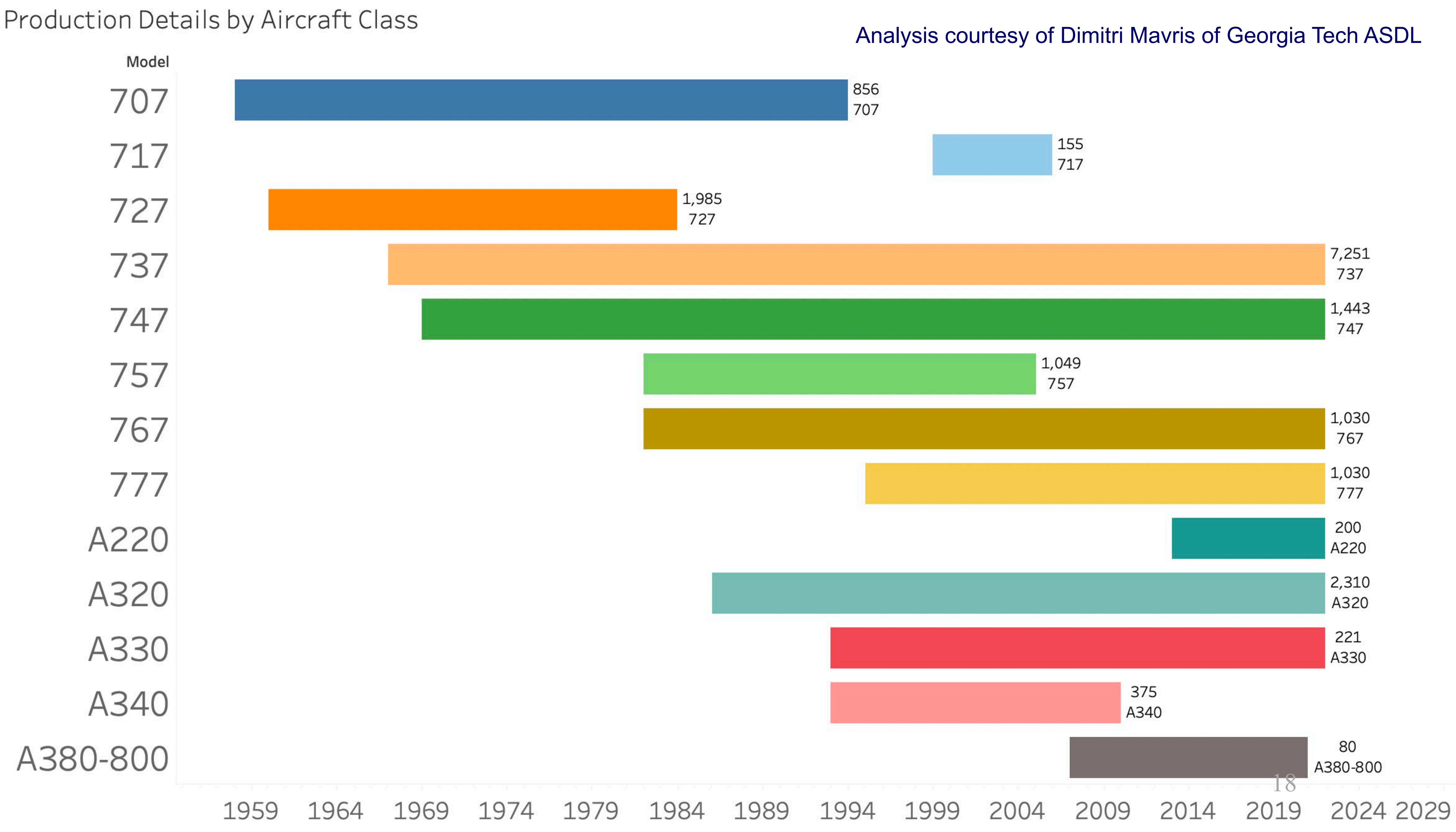
65 DNL, U.S. CY 2019



**** F. Grandi, AEDT3c, CY 2019 U.S. inventory, 18 March 2021*

Aircraft Assembly Line History

Assembly lines remain in use for decades – choices in new aircraft classes could have long impacts

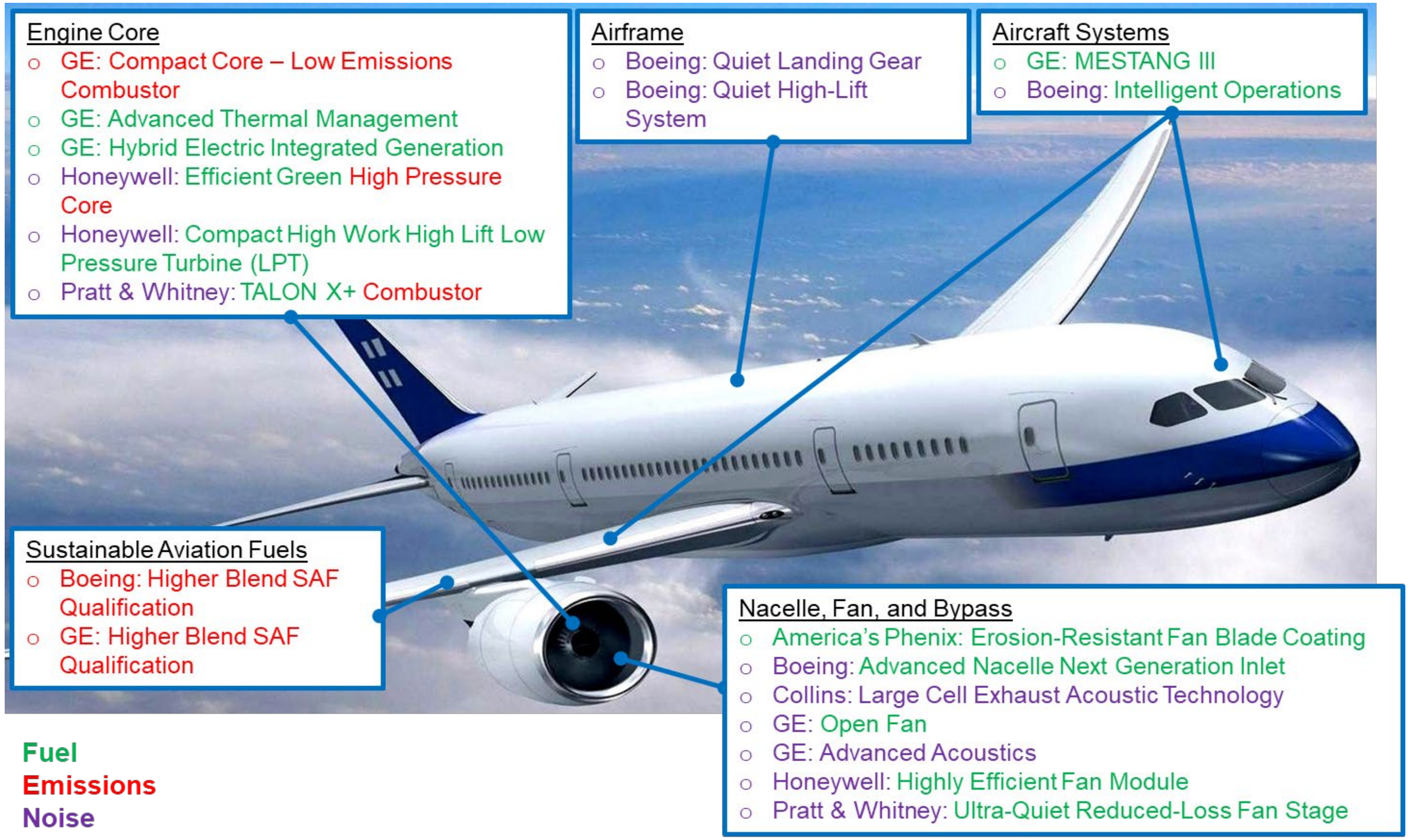


Aircraft Technology

Through the Continuous Lower Energy, Emissions, and Noise (CLEEN) Program, FAA are working in a public-private partnership with industry to accelerate maturation of certifiable aircraft and engine technologies.

- Technological innovation will be essential to enable environmentally sustainable growth and maintain U.S. global leadership.
- FAA have been operating CLEEN Program since 2010 (initially set up during Bush administration).
- FAA announced CLEEN Phase III on Sept 9, 2021. Currently expanding program and setting up Phase IV.
- Summary of CLEEN accomplishments over first two phases (10+ years) available online.

CLEEN Phase III Technologies



Fuel
Emissions
Noise

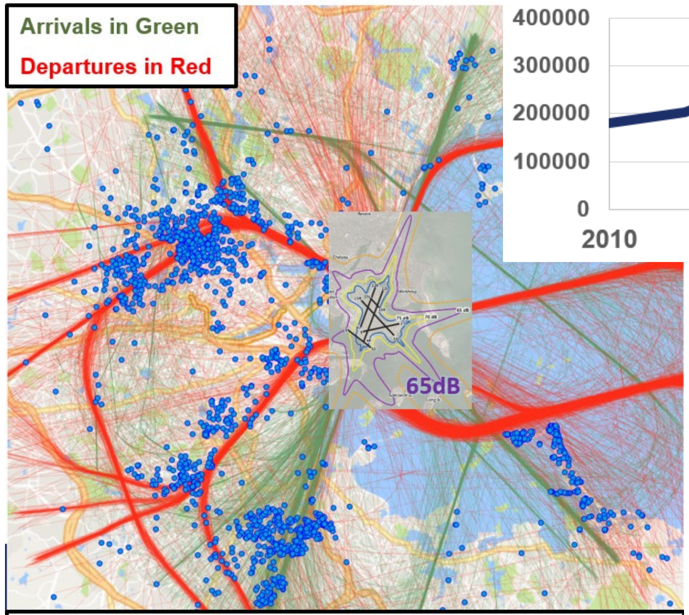
For more information on CLEEN program: http://www.faa.gov/go/cleen

For the CLEEN Phase 3 Press Release:
https://www.faa.gov/newsroom/faa-awards-100m-develop-next-generation-sustainable-aircraft-technology

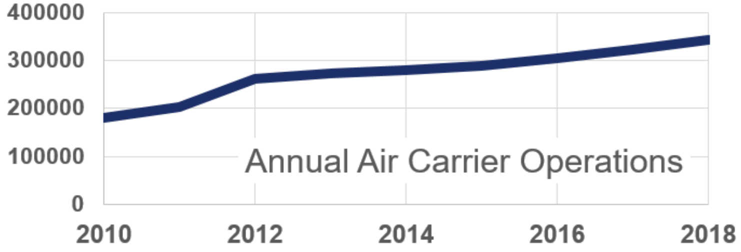
For a summary of CLEEN Accomplishment:
https://www.faa.gov/newsroom/continuous-lower-energy-emissions-and-noise-cleen-program?newsId=22534

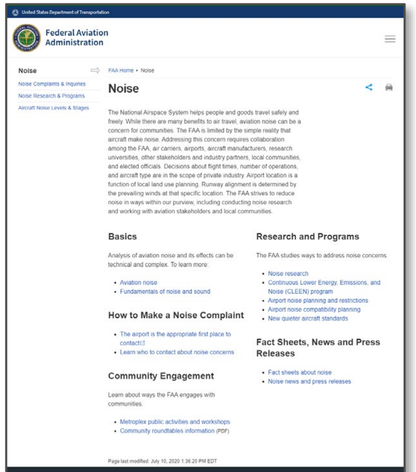
Aircraft Noise

- Recent efforts to modernize the national air transportation system have required changes in aircraft operational patterns leading to increased concern about aircraft noise
- While air space redesigns have been taking place, operations by air carriers have also increased
- Airport communities that are outside the DNL 65 dB contour are expressing concerns about aircraft noise
- New noise website, Federal Register Notice, and extensive outreach have been used to communicate and receive input on aircraft noise policy



Each marker represents a unique complaint address





United States Department of Transportation

Federal Aviation Administration

Noise

Noise Complaints & Inquiries

Noise Research & Programs

Aircraft Noise Levels & Stages

FAA Home • Noise

Noise

The National Airspace System helps people and goods travel safely and freely. While there are many benefits to air travel, aviation noise can be a concern for communities. The FAA is limited by the simple reality that aircraft make noise. Addressing this concern requires collaboration among the FAA, air carriers, airports, aircraft manufacturers, research universities, other stakeholders and industry partners, local communities, and elected officials. Decisions about flight times, number of operations, and aircraft type are in the scope of private industry. Airport location is a function of local land use planning. Runway alignment is determined by the prevailing winds at that specific location. The FAA strives to reduce noise in ways within our purview, including conducting noise research and working with aviation stakeholders and local communities.

Basics

Analysis of aviation noise and its effects can be technical and complex. To learn more:

- Aviation noise
- Fundamentals of noise and sound

How to Make a Noise Complaint

- The airport is the appropriate first place to contact
- Learn who to contact about noise concerns

Community Engagement

Learn about ways the FAA engages with communities.

- Metroplex public activities and workshops
- Community roundtables information (PDF)

Research and Programs

The FAA studies ways to address noise concerns.

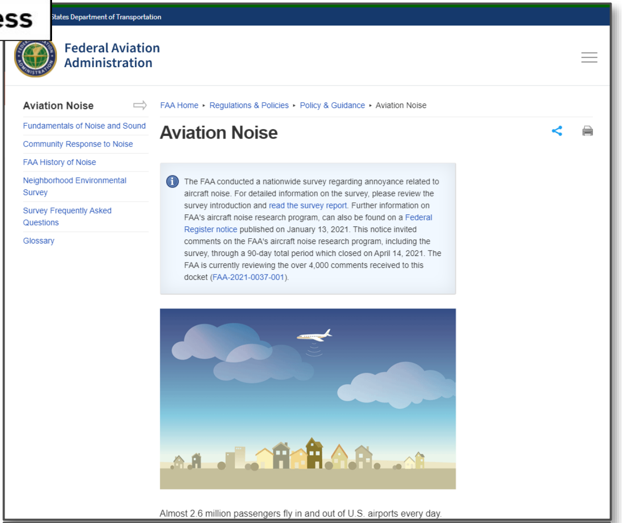
- Noise research
- Continuous Lower Energy, Emissions, and Noise (CLEEN) program
- Airport noise planning and restrictions
- Airport noise compatibility planning
- New quieter aircraft standards

Fact Sheets, News and Press Releases

- Fact sheets about noise
- Noise news and press releases

Page last modified: July 10, 2020 1:36:20 PM EDT

www.faa.gov/noise



States Department of Transportation

Federal Aviation Administration

Aviation Noise

Fundamentals of Noise and Sound

Community Response to Noise

FAA History of Noise

Neighborhood Environmental Survey

Survey Frequently Asked Questions

Glossary

FAA Home ▸ Regulations & Policies ▸ Policy & Guidance ▸ Aviation Noise

Aviation Noise

The FAA conducted a nationwide survey regarding annoyance related to aircraft noise. For detailed information on the survey, please review the survey introduction and read the survey report. Further information on FAA's aircraft noise research program, can also be found on a Federal Register notice published on January 13, 2021. This notice invited comments on the FAA's aircraft noise research program, including the survey, through a 90-day total period which closed on April 14, 2021. The FAA is currently reviewing the over 4,000 comments received to this docket (FAA-2021-0037-001).

Almost 2.6 million passengers fly in and out of U.S. airports every day.

www.faa.gov/go/aviationnoise

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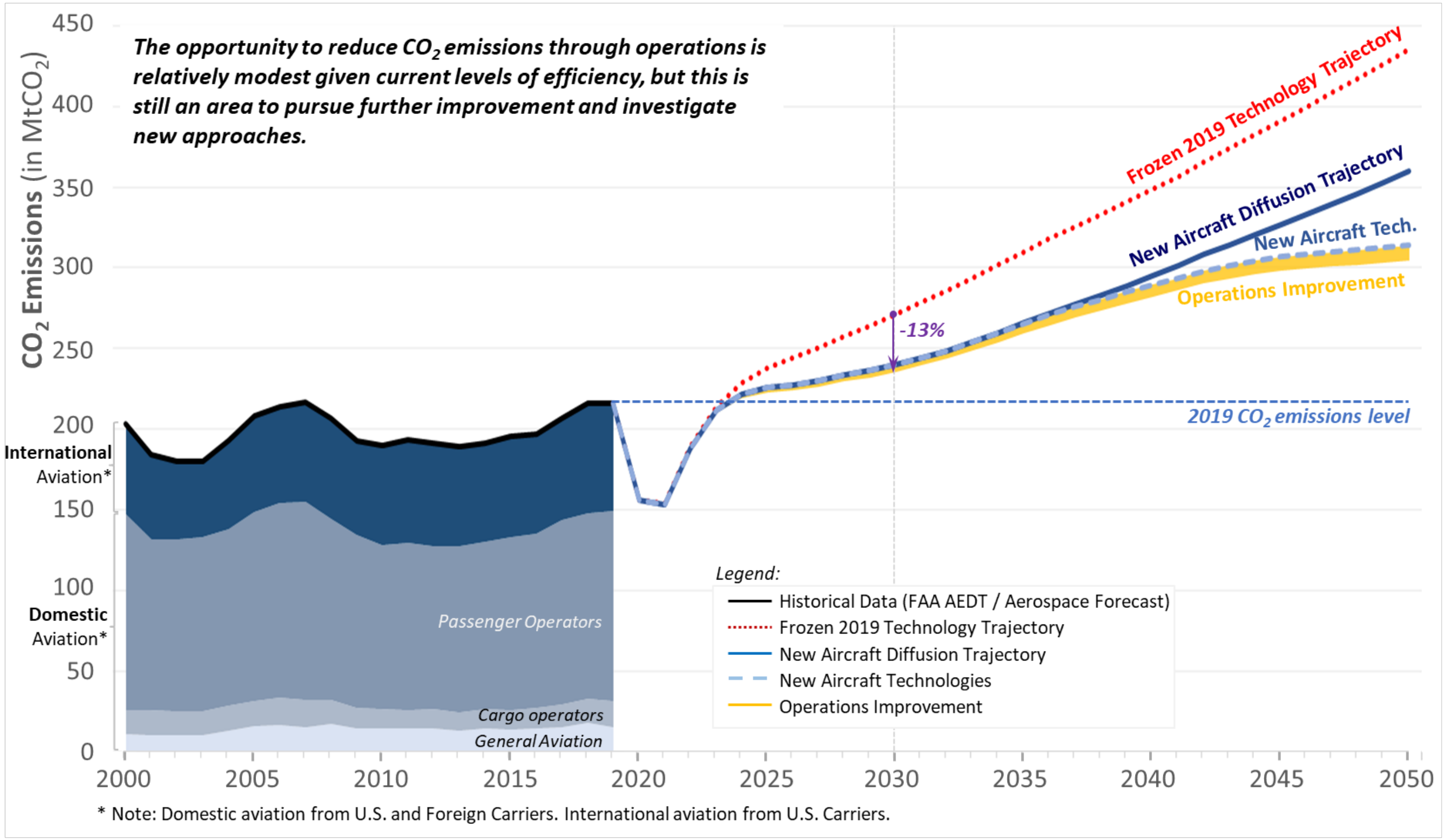
Operational Improvements

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.

Summary of Actions

- Continue to operationalize 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 and information distribution to enable operators to fly more fuel-efficient trajectories, especially during the cruise phase of flight, in U.S.-controlled airspace.



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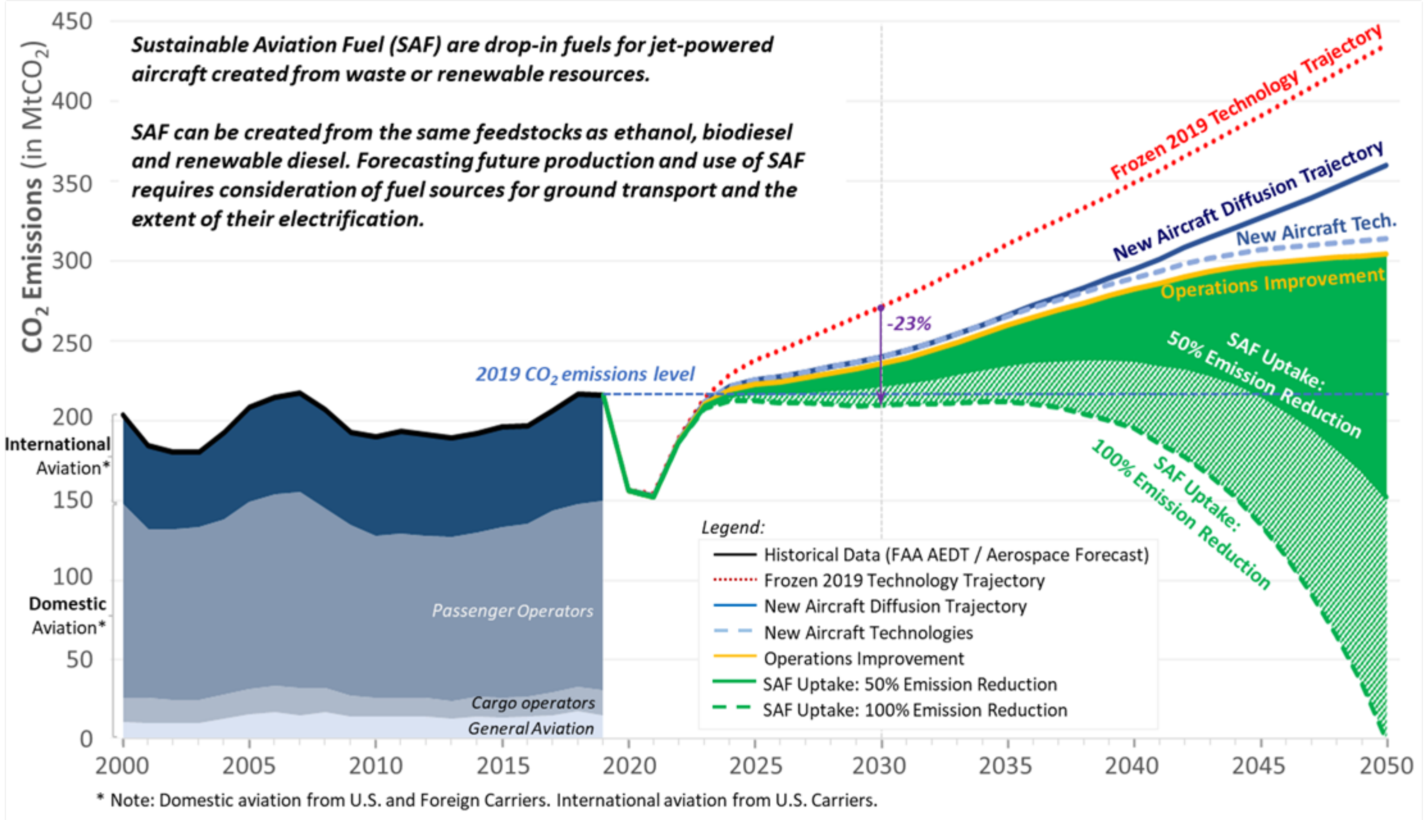
Sustainable Aviation Fuels

Sustainable Aviation Fuels (SAF) will be critical to the long-term decarbonization of aviation. Through a range of policy instruments, including the SAF Grand Challenge, the USG will work with industry to rapidly scale up SAF production with the goal of meeting the fuel needs of U.S. aviation by 2050.

Summary of Actions

- Support critical USG efforts on research, development, demonstration, and deployment of feedstock systems, conversion, testing, analysis, and coordination of SAF activities.
- Develop multi-agency roadmap to implement SAF Grand Challenge.
- Sustainable Aviation Fuel tax credit.
- Catalyze bulk purchases of SAF by military and other end users.



Jet Fuel

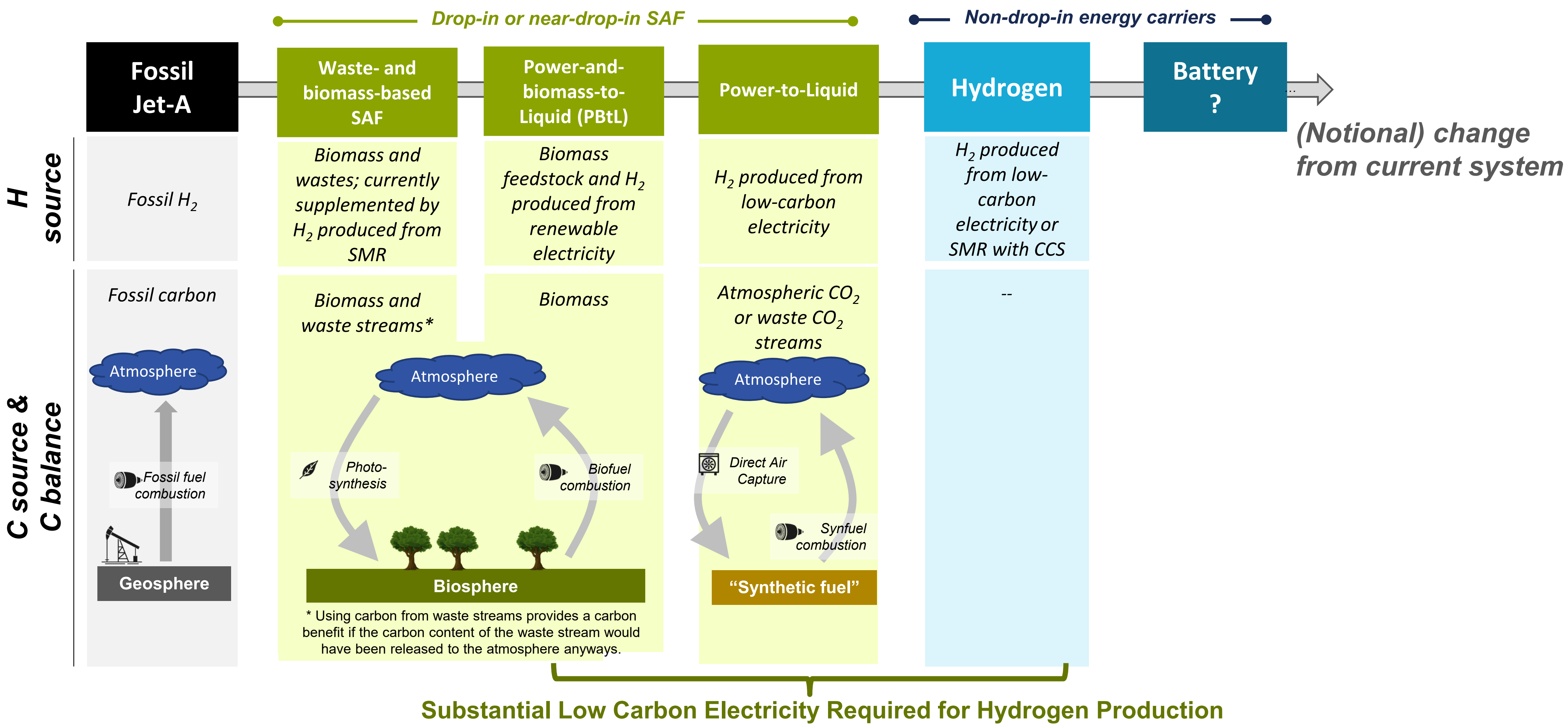
- Jet fuel is a critical component of the safe, reliable, and efficient global air transportation system
- Jet fuel provides a unique combination of properties that enable aircraft to safely carry hundreds of passengers and tons of freight for thousands of miles at high speed
  - Remains a liquid at very low temperatures of flight
  - Does not vaporize at low atmospheric pressures experienced in the upper atmosphere during cruise flight
  - Tolerates relatively high engine temperatures without breaking down and clogging fuel lines
  - Provides considerable energy both in terms of energy per unit mass and per unit volume
- While these properties play a key role in enabling today's aviation system, they also make it a difficult sector to decarbonize because they are hard to replace

Aircraft Fueling Options

- Utilizing R&D program to understand full range of options for powering aircraft
  - ASCENT Project 1 Alternative Jet Fuel Supply Chain Analysis
  - ASCENT Project 52 Comparative Assessment of Electrification Strategies for Aviation
  - ASCENT Project 80 Hydrogen and Power to Liquid (PtL) Concepts for SAF Production

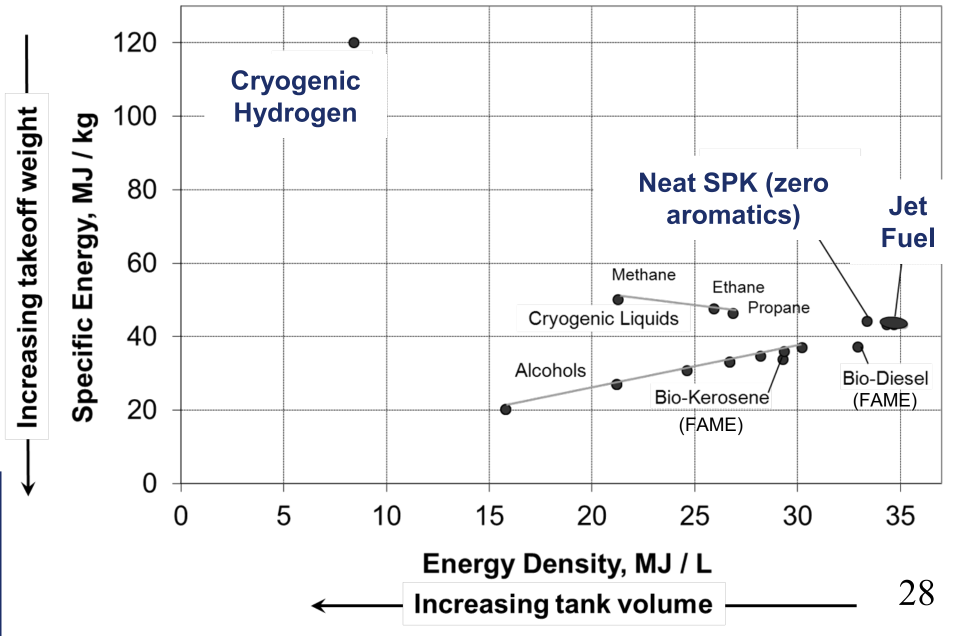
- Looking both at near term and much further into future
- Carefully considering electricity, cryogenic hydrogen, and power-to-liquid fuels – in addition to SAF
- Ensuring that research findings are shared broadly with aerospace and energy communities

Energy Carriers for Aviation – A Typology



Aircraft Energy

- To enable long distance transport, aircraft need considerable energy storage while also producing considerable power
- To produce this power, an aviation fuel needs large energy per unit mass and volume
- Aviation has stringent safety requirements – see ASTM D1655 & D7566 for jet fuel



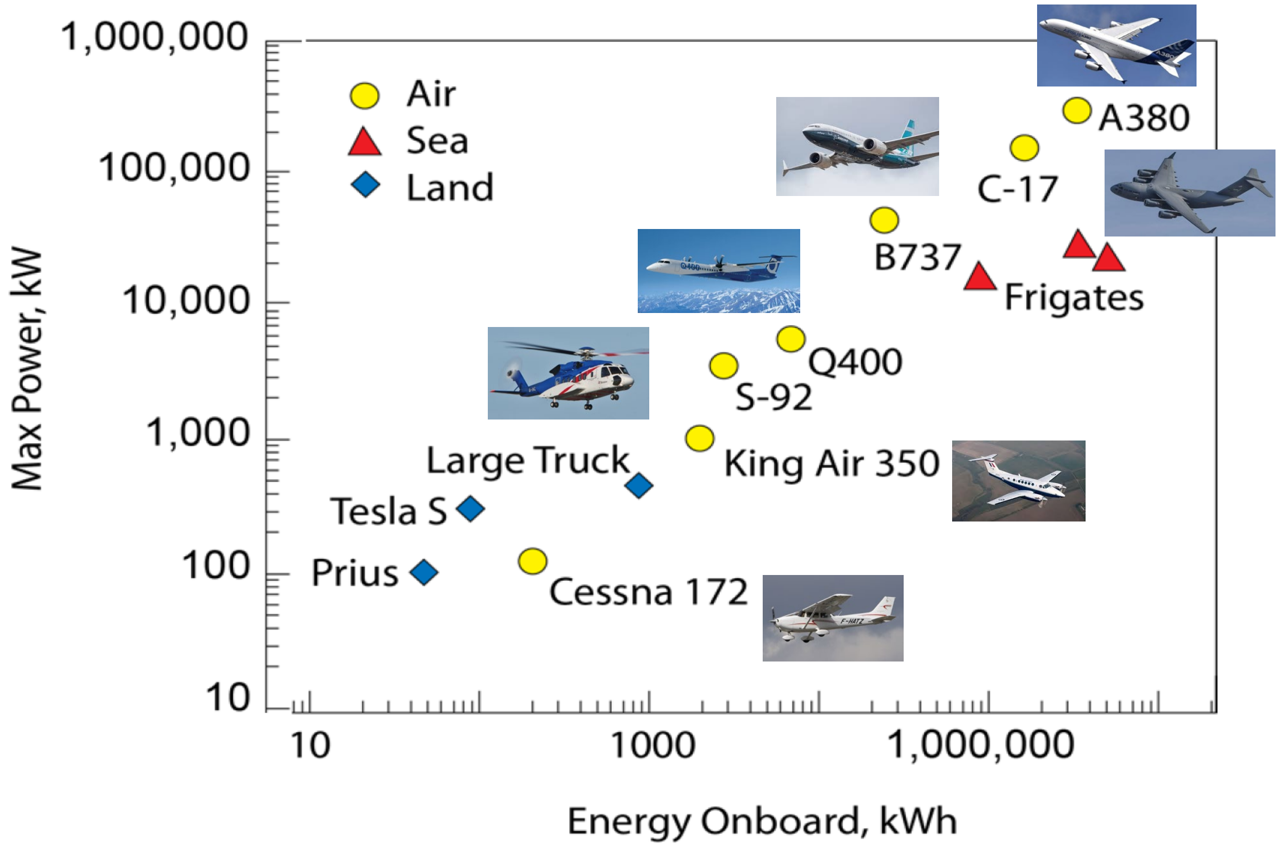


FIGURE 2.1 Power and energy required for vehicles ranging from small cars to large commercial aircraft. SOURCE: A.H. Epstein, 2014, Aeropropulsion for commercial aviation in the twenty-first century and research directions needed, *AIAA Journal* 52(5):901-911, doi:10.2514/1.J052713. Reproduced by permission of United Technologies Corporation, Pratt & Whitney.

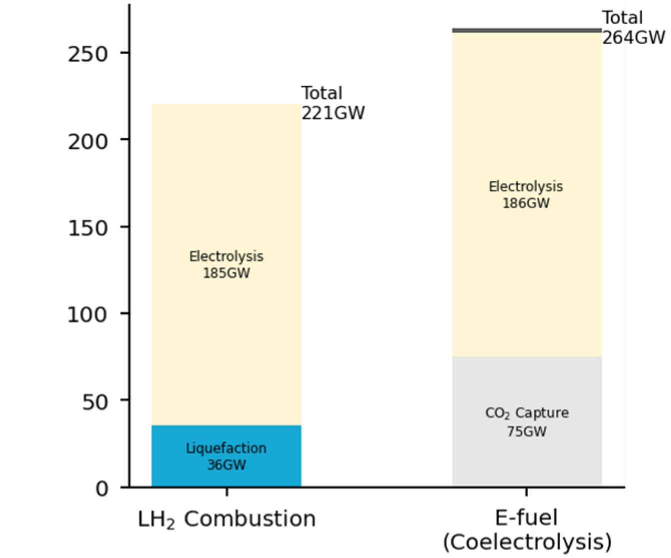
Graphic from 2016 National Academies report, "Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions."

Airports as Energy Hubs: Global picture

- Replacing jet fuel with cryogenic hydrogen would require considerable electricity to electrolyze water and compress it to a cryogenic state
- Power-to-liquids would require comparable energy as cryogenic hydrogen, but without requiring infrastructure changes

Electric power consumption of fuel production [1]

broken down by process step, in GW

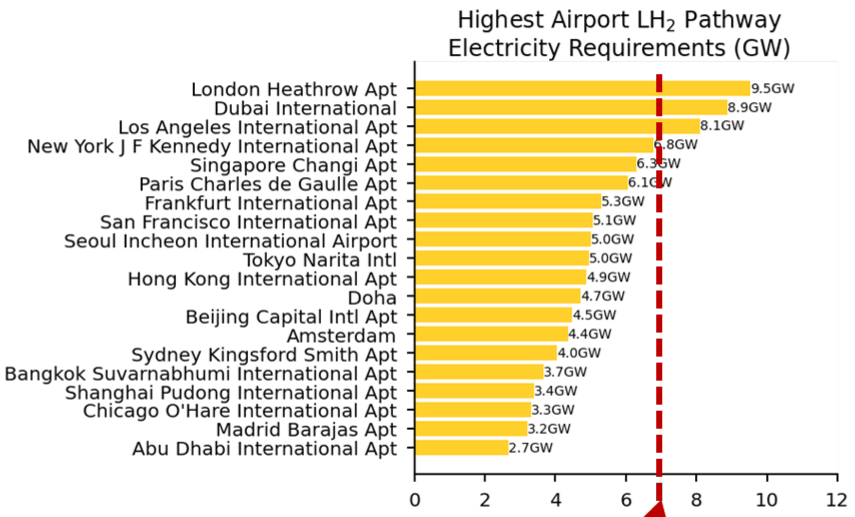


[1] Values are annual average power demand.

For comparison:
U.S. power generation capacity (2019): 1.2 TW
Cumulative global PV capacity (2019): 627 GW

Electric energy consumption of fuel production

in GW, by airport



Capacity of largest existing nuclear power station

Preliminary Results from Ongoing Research in ASCENT Project 52 for flights greater than 1,000 km

Aircraft Energy Sources – Multiple Fuel Option

Fundamental question: how to do we replace petroleum with low carbon energy sources?

Energy Source
- Petroleum

Conversion
- Refining

Finished Fuel
- **Hydrocarbons (aka jet fuel)**

Energy Source
- Biomass
- Residues
- Wastes

Conversion
- Chemical, biological, and thermochemical processes

Finished Fuel
- **Hydrocarbons (aka SAF)**

Today's Infrastructure and Fleet of Aircraft

Energy Source
- Solar
- Wind
- Hydro
- Nuclear

Conversion
- Electricity generation
- Electrolysis

Finished Fuel
- **Electricity for Batteries**
- **Hydrogen**

New Infrastructure and Future Aircraft

Aircraft Energy Sources – Single Fuel Option

Fundamental question: how to do we replace petroleum with low carbon energy sources?

Energy Source
- Petroleum

Conversion
- Refining

Finished Fuel
- **Hydrocarbons (aka jet fuel)**

Energy Source
- Biomass
- Residues
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Conversion
- Chemical, biological, and thermochemical processes

Finished Fuel
- **Hydrocarbons (aka SAF)**

Energy Source
- Solar
- Wind
- Hydro
- Nuclear

Conversion
- Electricity generation
- Electrolysis
- Chemical, biological, and thermochemical processes

Today's Infrastructure and Fleet of Aircraft

Sustainable Aviation Fuels (SAF)

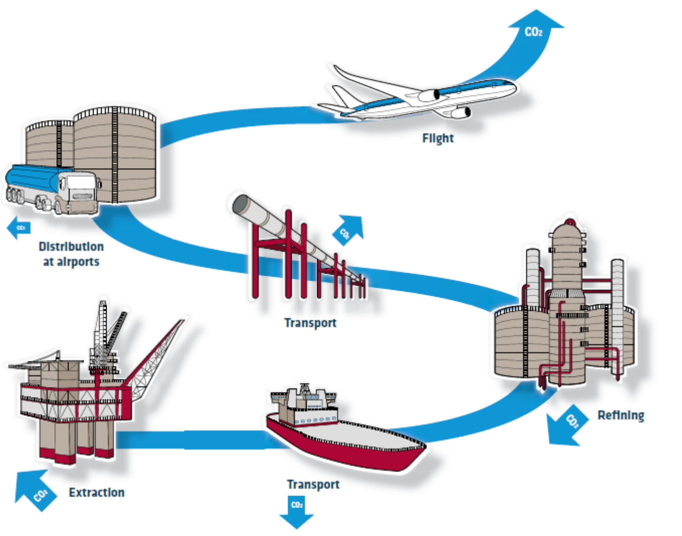
- SAF are "drop-in" liquid hydrocarbon fuels with the same performance and safety as conventional jet fuels produced from petroleum
- SAF are fully fungible with the existing fuel supply and can be used in the same infrastructure, engines, and aircraft
- SAF can be produced from renewable feedstocks, waste materials, and industrial waste gases
- Some types of SAF reduce emissions that impact air quality and contrail formation, which also impacts climate change

Image courtesy of Anna Oldani from Frankfurt Intl Airport

Sustainable Aviation Fuels – Life Cycle Benefit

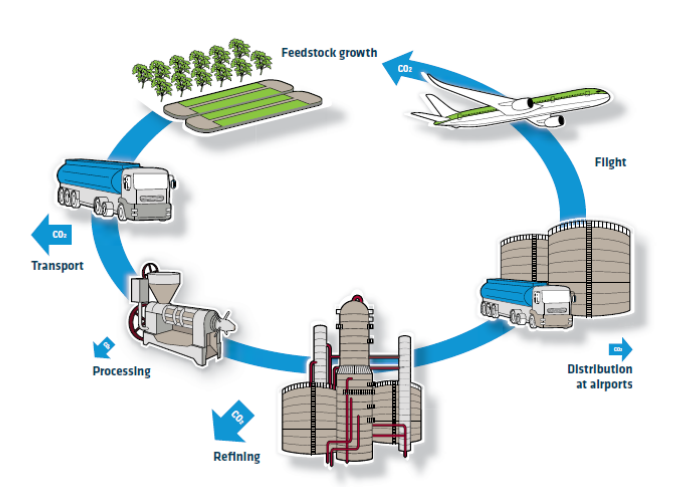
The extent to which any particular SAF provides a climate benefit depends on the life cycle of the fuel, taking into account the production, transportation, and combustion of the SAF, as well as indirect effects.

Carbon lifecycle diagram: fossil fuels



At each stage in the distribution chain, carbon dioxide is emitted through energy use by extraction, transport, etc.

Carbon lifecycle diagram: Sustainable aviation fuel



Carbon dioxide will be reabsorbed as the next generation of feedstock is grown.
Note: *the diagram above does not demonstrate the lifecycle process of SAF derived from municipal waste.*

FAA have extensive research that have supported development of rigorous life cycle accounting methods over the last decade:

- Argonne National Labs GREET Model
- ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
- SAF Blenders Tax Credit (I.R.A. Sections 13203 and 13704)

Diagram from ATAG Beginner's Guide to SAF, which is available at:
https://aviationbenefits.org/downloads/beginners-guide-to-sustainable-aviation-fuel/

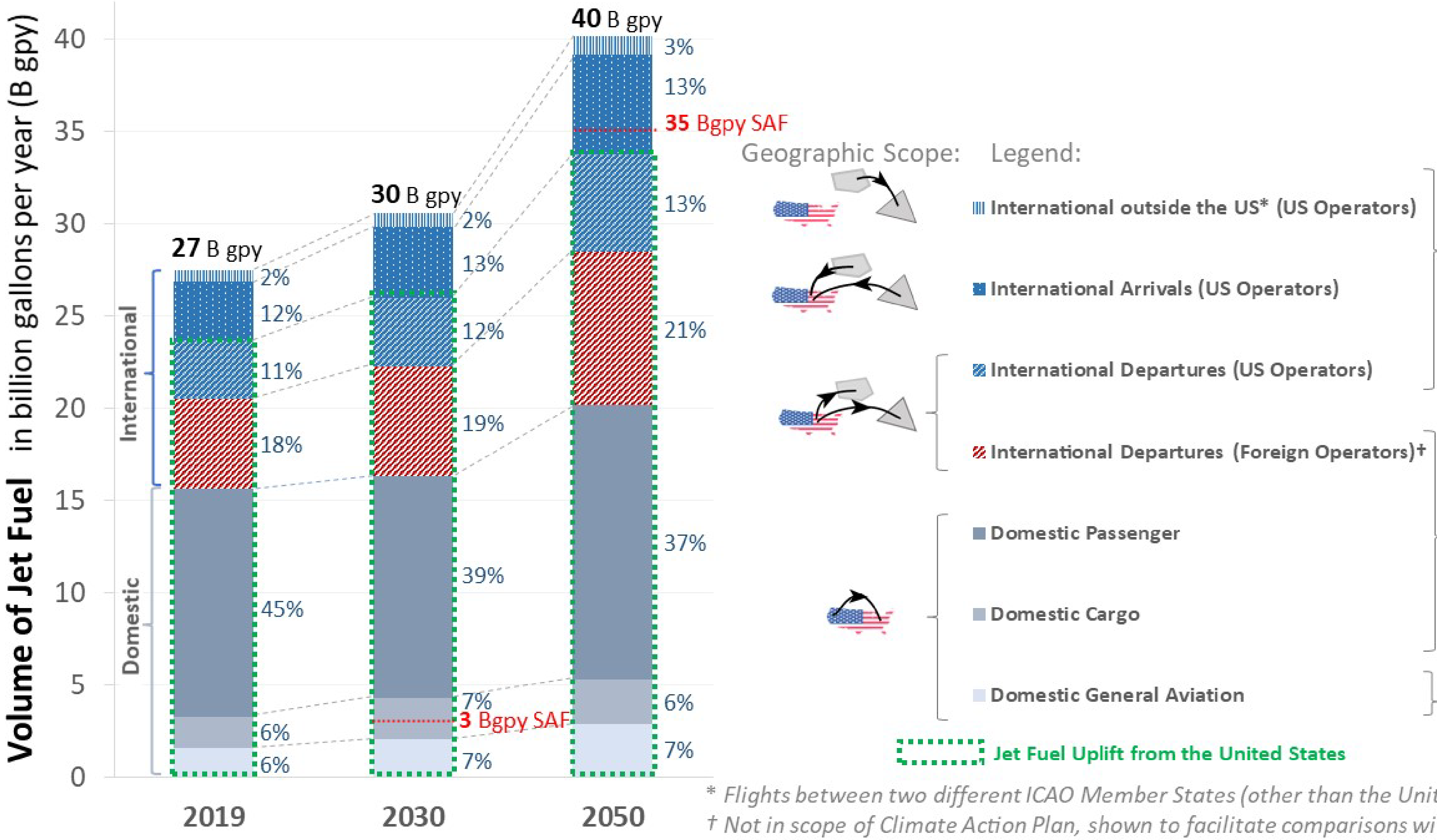
SAF Grand Challenge

https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

Sustainable Aviation Fuel Grand Challenge

The US Government has identified the development and deployment of SAF as a key aviation climate priority. The USG has established a multi-agency effort led by the DOT, DOE, and USDA to implement the "SAF Grand Challenge" to reduce cost, enhance sustainability, and expand production and use of SAF that achieves a minimum of a 50% reduction in life cycle GHGs compared to conventional fuel.

Potential demand for jet fuel in gallons per year (gpy) across domestic operations (by U.S. and Foreign Carriers).



Data Sources and Assumptions:

2019: BTS T-2 (International operations reported by US carriers).

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 2019 CORSIA breakdown).

2019: EPA GHG Inventory, international departures by foreign operators scaled based on 2019 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.

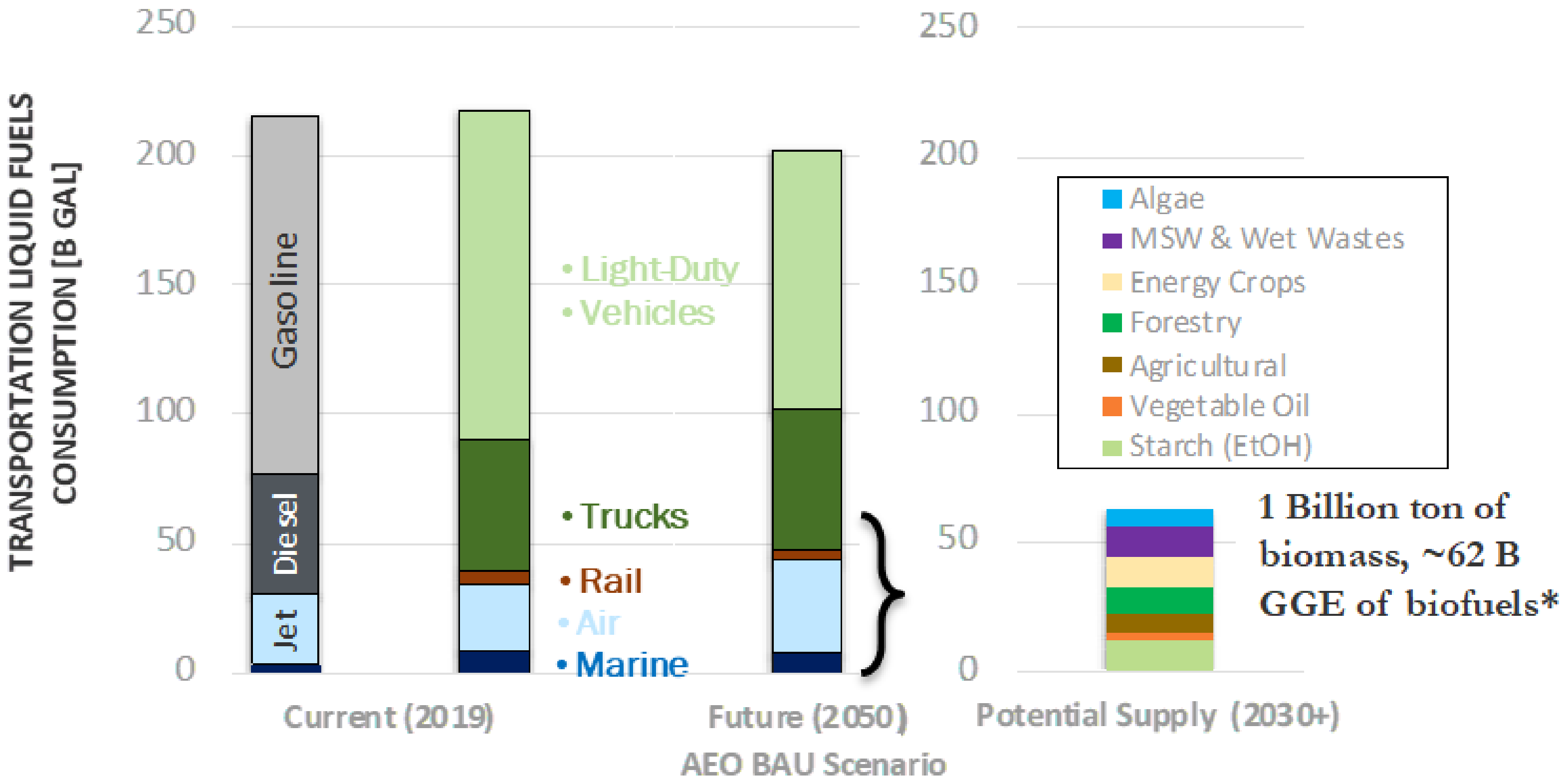
2019-2050: General Aviation from FAA Aerospace Forecast (2021-2041).

** 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.

Total Available Biomass for Renewable Fuels

- Biomass can fully **supply future Aviation/ Maritime/Rail** (requires 75% of all feedstocks)
- Biggest market pull is **in sustainable aviation fuels** (SAF)
- Provides market for **current ethanol** (~17B gal, ~40% of corn production)
- Supports decarbonization of chemicals via **bioproducts**, and decarbonization of agriculture through healthy forests and sustainable agriculture
- **CO_2-to-fuels** remains to be explored



SAF Grand Challenge Roadmap

Multi-agency plan to define needs for the next decade to enable SAF GC Goals

- Six Action Areas
  1. Feedstock Innovation (FI)
  2. Conversion Technology Innovation (CT)
  3. Building Supply Chains (SC)
  4. Policy and Valuation Analysis (PA)
  5. Enabling End Use (EU)
  6. Communicating Progress and Building Support (CP)
- 26 Workstreams with 139 Activities
- 2022-2030 & 2030-2050 timeframes
- Released at the Global Clean Energy Action Forum on September 23, 2022

https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuel-grand-challenge-roadmap-flight-plan-sustainable

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- **International Leadership and Initiatives**
- Airport Initiatives
- FAA Leadership on Climate, Sustainability and Resilience
- Non-CO_2 Impacts of Aviation on Climate
- Policy and Measures to Close the Gap

U.N. International Civil Aviation Organization (ICAO)

- ICAO sets standards and recommended practices for civil aircraft to enable our global aviation system
- General Assembly of 193 ICAO Member States
  - Meets every three years (this cycle sets the pace of ICAO work)
  - Assembly approves/endorses work conducted in the previous three years and sets forth commitments and future work by ICAO
  - Resolution – method by which the Assembly makes policy and commitments
- ICAO Council
  - 36 member states with permanent representatives
  - ICAO Council conducts day-to-day oversight of ICAO work program; meets for two week voting sessions four times per year
- ICAO five Strategic Objectives:
  1. Safety
  2. Air Navigation Capacity and Efficiency
  3. Security & Facilitation
  4. Economic Development of Air Transport
  5. Environmental Protection
- ICAO Committee on Aviation Environmental Protection (CAEP)
  - Standing Committee of the Council to conduct environmental technical work

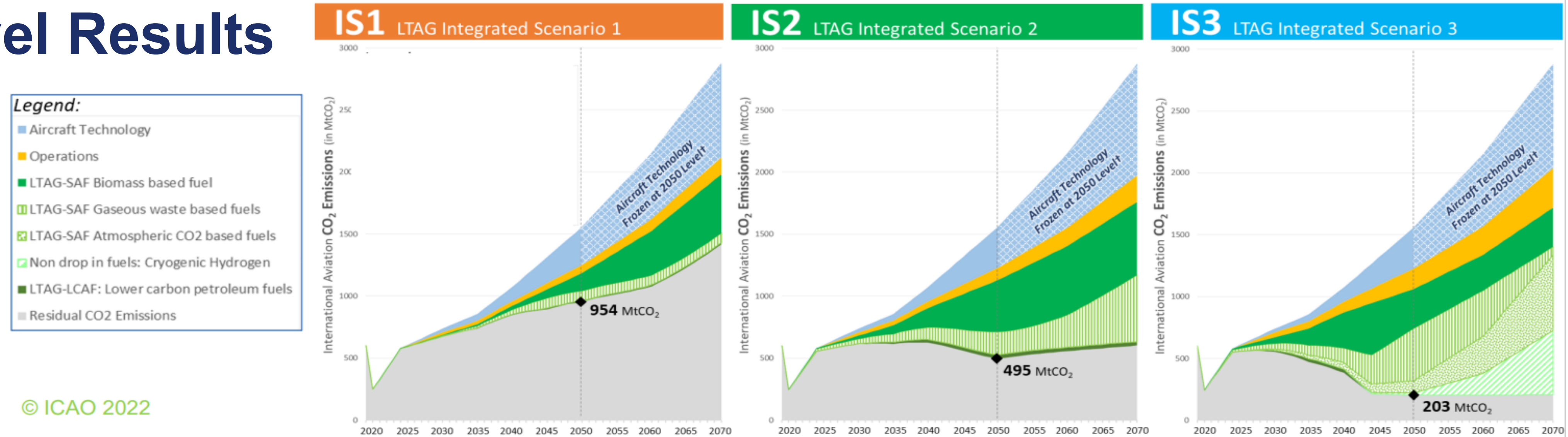
For additional information on ICAO:
https://www.icao.int/about-icao/Pages/default.aspx

ICAO CAEP Long Term Aspirational Goal

- FAA have long worked with NASA, EPA, Volpe Center, and ASCENT Center of Excellence universities to develop tools and conduct analysis of a wide range of economic and environmental impacts that could result from changes to aviation noise, emissions, and energy policy.
- In 2020, the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) undertook an effort to assess the feasibility of a long term aspirational goal (LTAG) for CO2 emissions from international aviation.
- In March 2022, the final report of the LTAG task group was approved for release by the ICAO Council for use in informing decision making leading up to the 41st ICAO Assembly
- In October 2022, the 41st ICAO Assembly agreed to a long term aspirational goal of net zero CO_2 emissions for international aviation by 2050

Full report: https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

High Level Results

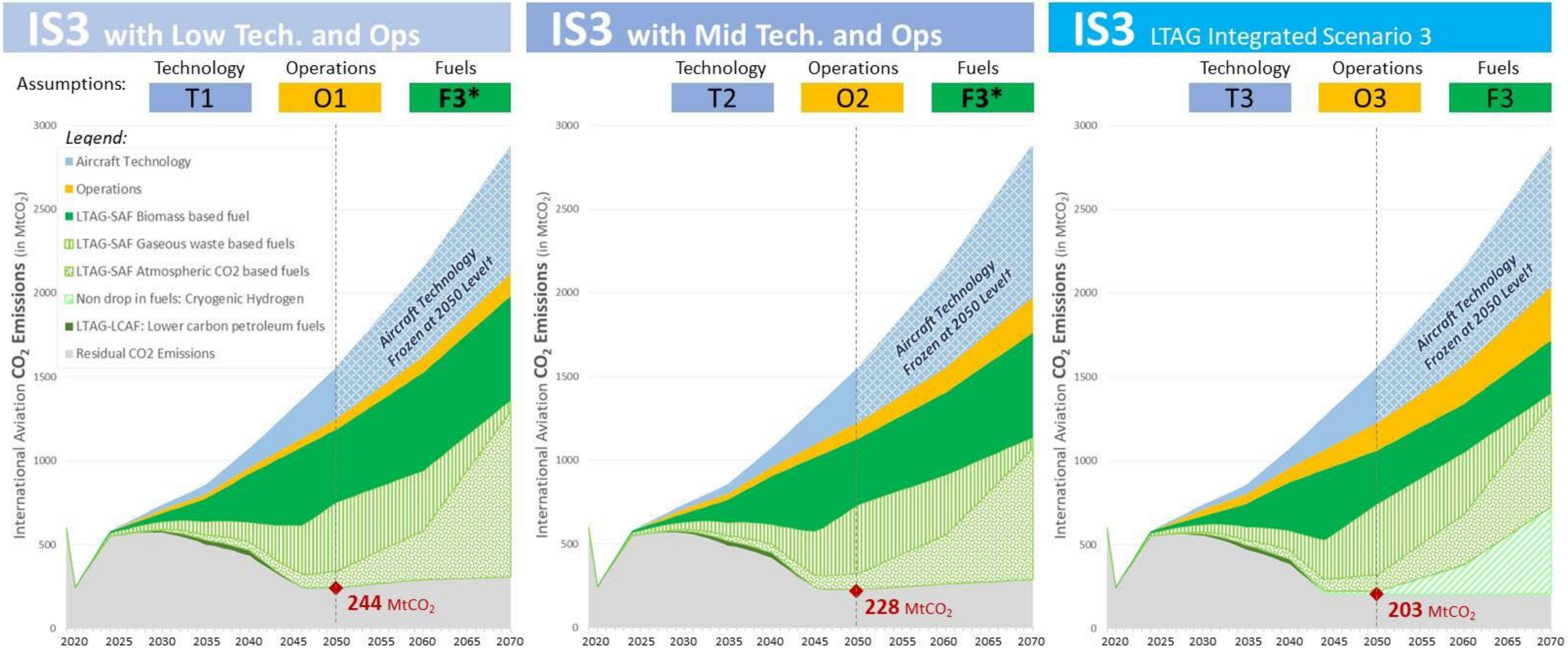


Metrics	IS1	IS2	IS3
CO_2 Emissions in 2050 after Reductions	**≈950 $MtCO_2$** in 2050 *(**160%** of 2019 CO_2 emissions)*	**≈500 $MtCO_2$** in 2050 *(**80%** of 2019 CO_2 emissions)*	**≈200 $MtCO_2$** in 2050 *(**35%** of 2019 CO_2 emissions)*
Reduction in 2050 from the Baseline	**39% total** through: Technologies - 20%, Operations - 4%, Fuels - 15%	**68% total** through: Technologies - 21%, Operations - 6%, Fuels - 41%)	**87% total** through: Technologies - 21%, Operations - 11%, Fuels - 55%
Cumulative residual Emissions from 2020 to 2070	23 $GtCO_2$ (2020 to 2050) 23 $GtCO_2$ (2051 to 2070)	17 $GtCO_2$ (2020 to 2050) 11 $GtCO_2$ (2051 to 2070)	12 $GtCO_2$ (2020 to 2050) 4 $GtCO_2$ (2051 to 2070)

15

- Scenarios show potential for substantial CO_2 reductions
- Drop-in fuel, and SAF in particular, plays largest role in reducing CO_2 for in-sector measures considered, followed by aircraft technology, and operations
- Will need CCS w/SAF, DAC, and/or out of sector offsets to get to zero

Sensitivity Study – Potential of SAF under Varied Scenarios



* Amended Fuel Scenario (F3) to align with Aircraft Technology scenarios associated with IS1 and IS2 (i.e., no ACA-T3 hydrogen powered aircraft included in IS1 and IS2) and adjusted to meet fuel volume constraints. Note. – Under a F3* (IS1 Hybrid) scenario LTAG-SAF Atmospheric CO_2 fuel volumes scaled by 1.68 in 2070 (no changes in 2060). Similarly, under a F3* (IS2 Hybrid) scenario LTAG-SAF Atm. CO_2 fuel volumes scaled by 1.33 in 2070 (no changes in 2060).

† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

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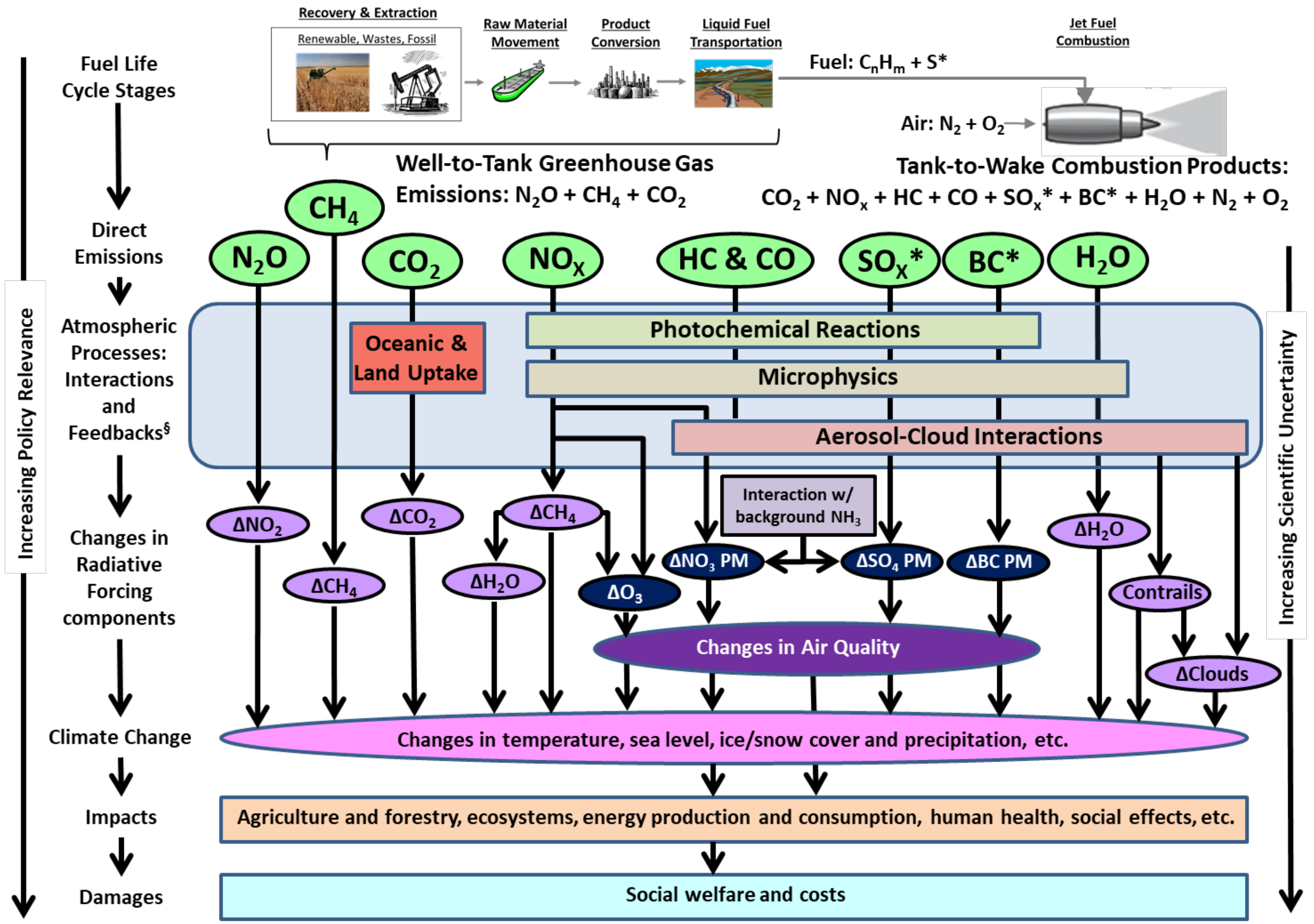
- Policy and Measures to Close the Gap

Non-CO_2 Impacts of Aviation on Climate

Aircraft combustion emissions also have non-CO_2 impacts on the climate. Primary concern is the impact of aviation induced cloudiness.

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 industry to cost-effectively mitigate the overall climate impacts of aviation via contrail mitigation.



§Account for radiative, chemical, microphysical and dynamical couplings along with dependence on changing climatic conditions and background atmosphere
*Sustainable aviation fuels can be produced with zero sulfur related emissions and reduced black carbon emissions

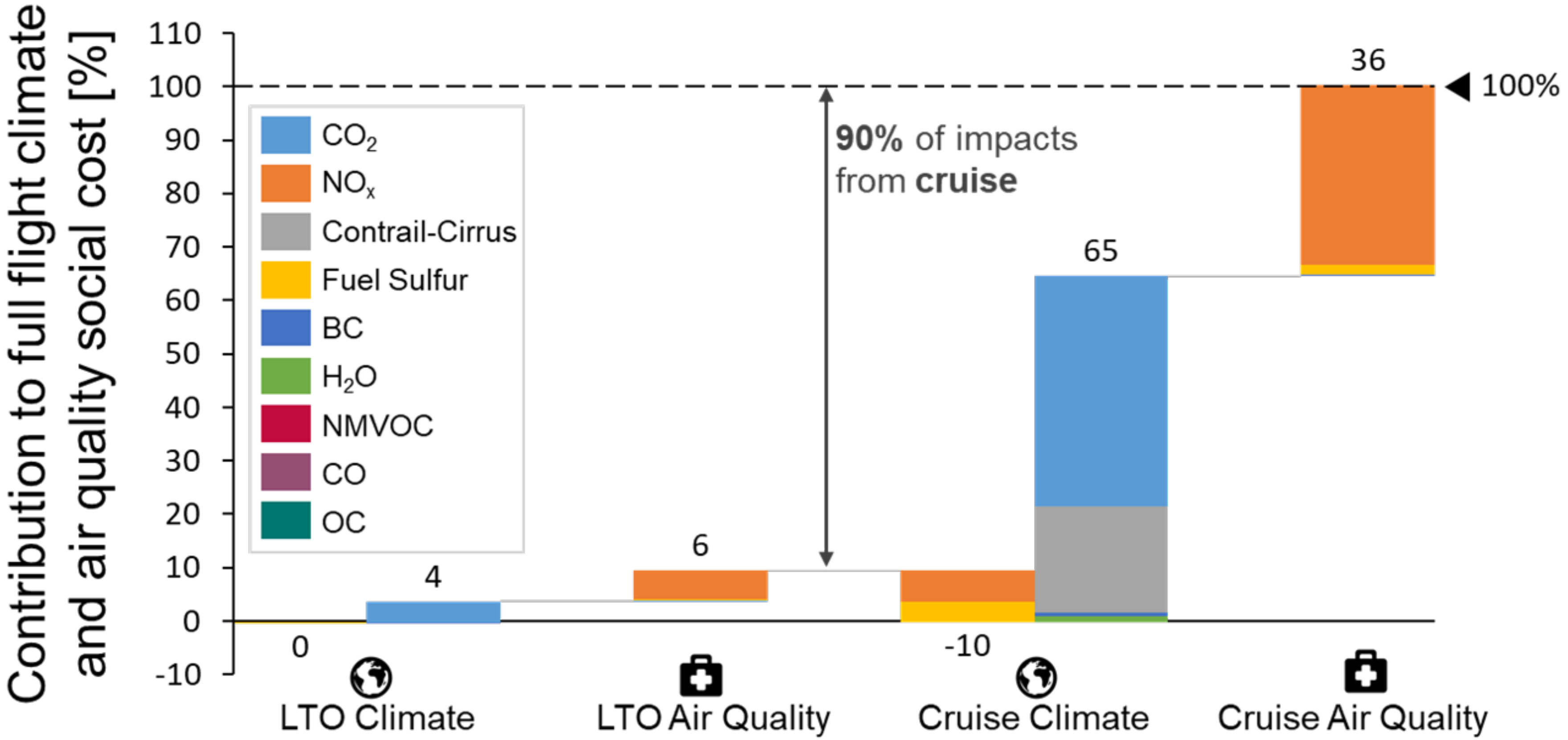
Modified from Brassuer et al 2016

ASCENT Project 58:

Impacts of Aviation Emissions

Impacts of Full Flight Emissions on Air Quality, Climate, and Ozone

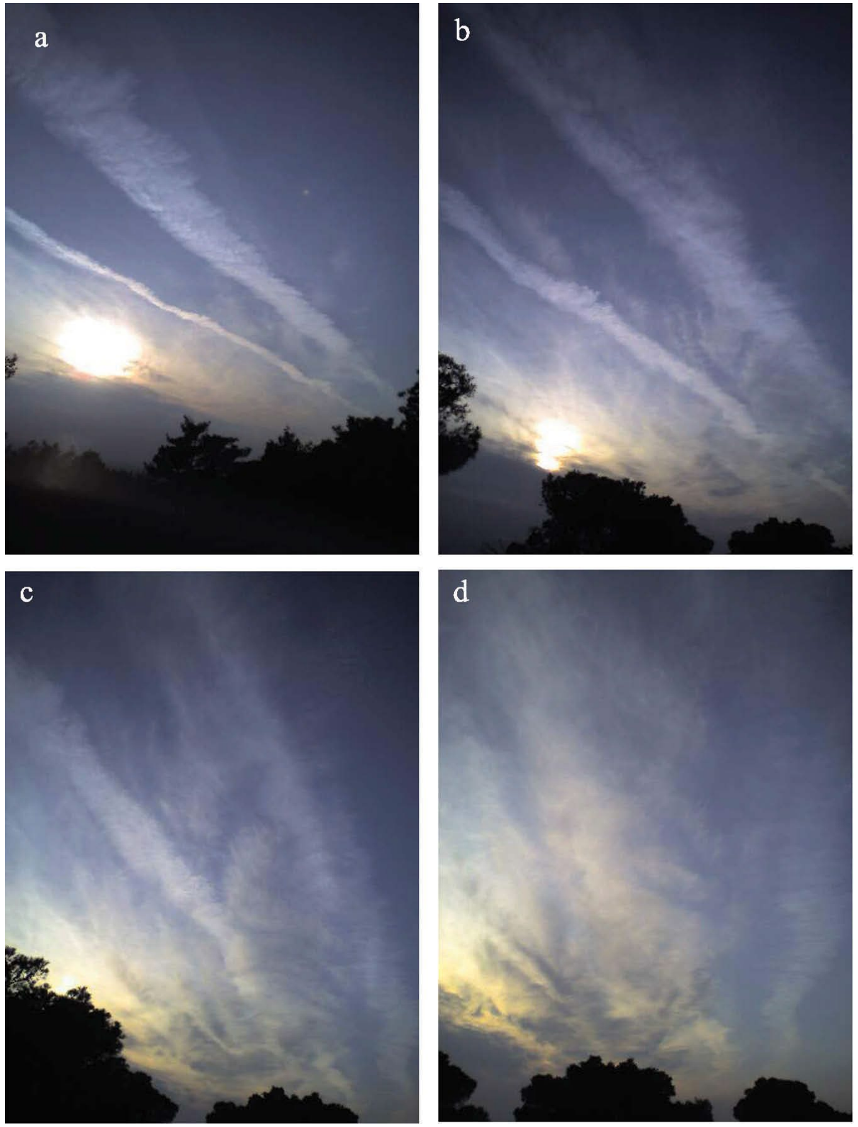
- Project continues long-standing FAA-funded effort at MIT to use analytical tools to model global movement and transformation of aircraft emissions as well as their impacts on surface air quality, global climate change, and the ozone layer
- Team have found that globally, impacts of cruise emissions on surface air quality are larger than those attributed to landing and takeoff (~16,000 premature mortalities[1] or 0.2% of the 9 million premature mortalities from combustion emissions globally[2])
- However, the results have considerable uncertainty and we continue to do work to better understand the impacts of cruise emissions on surface air quality



1. Grobler et al, Environmental Research Letters 2019. Data updated with more recent social cost of carbon, 3% discount rate; Country specific VSL.
2. Landrigan et al., The Lancet 2017

Aviation Induced Cloudiness

From: Heymsfield et al. BAMS 2010

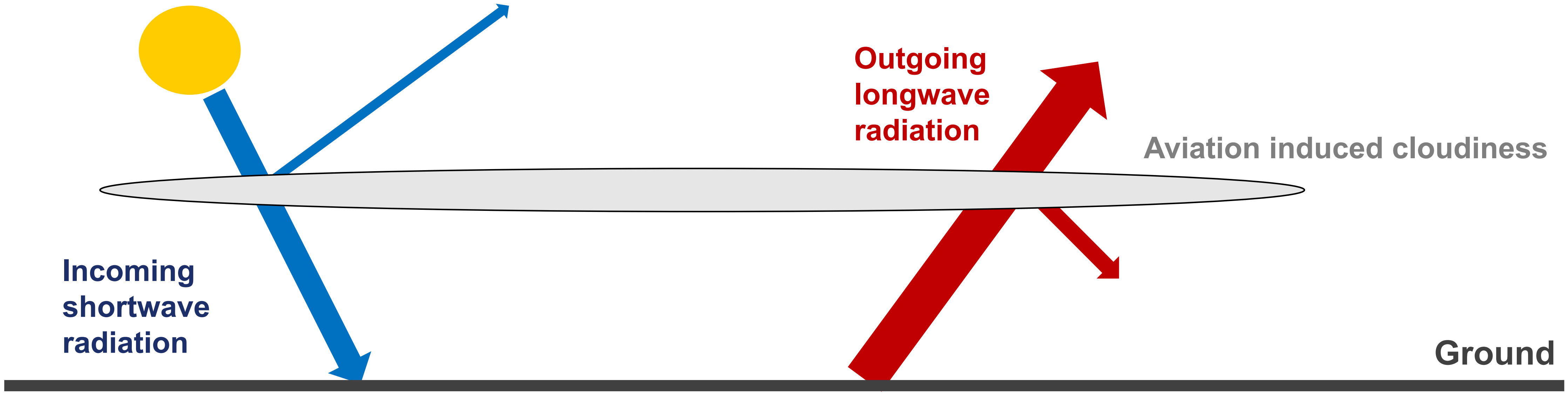


Photographs of contrail spreading into cirrus taken from Athens, Greece, on 14 Apr 2007 at 1900, 1909, 1913, and 1920 local time (from top left to bottom right). Courtesy of Kostas Eleftheratos, University of Athens, Greece.

Joint EPA-FAA fact sheet on contrails from September 2000:
https://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/contrails.pdf

Aviation Induced Cloudiness – Some Basics

- Contrail formation and aviation induced cloudiness <u>determined by atmospheric conditions</u> – contrails can form and disappear, or can form and persist, depending on temperature and humidity where the aircraft is flying
- Climate impact of aviation induced cloudiness is due to small differences in the amount of incident solar radiation and outgoing heat from the planet
- <u>Magnitude and sign</u> of climate impact is determined by season, time of day, and presence of other clouds underneath the aviation induced cloudiness
- Impact is <u>measured in minutes to hours</u> - if aviation activity were to stop, the impact of aviation induced cloudiness would cease within a day



Potential Mitigation Measures for Aviation Induced Cloudiness

- Changing flight altitude / horizontal flight track (need to avoid / minimize increased fuel burn)
- Developing engines with changes in engine exhaust temperature / non-volatile particulate matter within exhaust
- Changing fuel composition with modifications to fuel sulfur content and fuel aromatic content

Caution with contrail mitigation measures

- Need to weigh any changes in fuel burn carefully – time scales of impacts are very different
- Not all aviation induced cloudiness is climate warming and some is actually climate cooling

FAA Efforts Related to Aviation Induced Cloudiness (AIC)

FAA supporting research on multiple fronts to examine measures that *could* mitigate aviation's impact on climate change through modification to contrails and aviation induced cloudiness

Potential means of modifying aviation induced cloudiness

- Modify current jet fuel specification
- Sustainable Aviation Fuels (SAF)
- New engines and combustor technology
- Change lateral flight path or flight altitude

Sensor Development

No current FAA-funded effort

Operational Procedure Modification

No current FAA-funded effort

Decision Support Tools

Contrail Avoidance Decision Support and Evaluation (ASCENT Project 78)

Cost Benefit Analyses of Changing Fuel Composition (ASCENT Project 39 and PARTNER Project 27)

Fuel Composition Impacts on NVPM and Contrails

In-flight Measurement Campaigns (NASA, DLR, NRC-Canada, and FAA efforts)

Ground Measurement Campaigns (ASCENT Projects 2, 69, 81, 87)

Analyses on NVPM (Aerodyne Research Inc. efforts and ASCENT Projects 24, 39, 48, 70, 71)

Improved Climate Knowledge and Modeling Capabilities

ASCENT Projects 21, 22, and 58

Combustor Technology Development

CLEEN Program

Full Report Contents

https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

Policies and Measures to Close the Gap

The Aviation sector is a challenge to decarbonize. The use of robust offsets including carbon capture can support the sector's goals by leveraging emissions reductions elsewhere.

Summary of Actions

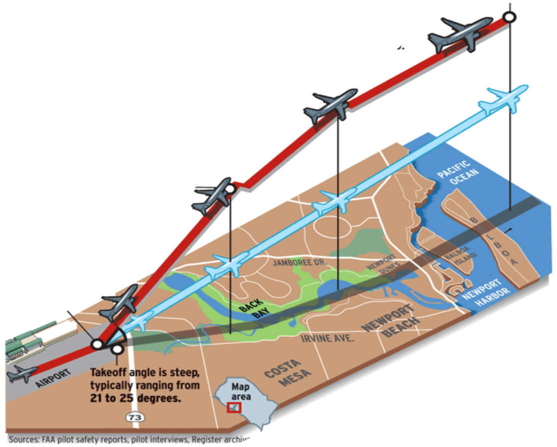
- Examine policy options that incentivize innovations in lower-emitting aviation.
- Examine policy options that help close the gap for emissions from domestic flights, by providing access to and use of emission reductions that come from outside the sector.

ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

In 2016, ICAO Member States reached agreement on CORSIA, a global market-based measure to address international aviation's CO_2 emissions. In the simplest terms, CORSIA requires aircraft operators purchase emissions offsets or use CORSIA Eligible Fuels (CEF) to reduce international CO_2 emissions above a defined baseline. There are two types of CORSIA Eligible Fuels, Sustainable Aviation Fuels created from renewable or waste feedstocks, and Lower Carbon Aviation Fuels, created from fossil feedstocks. As an international program, CORSIA enables the development of harmonized standards for both emissions offsets and CEF to ensure their robustness and sustainability and creates a marketplace for their use. This harmonization establishes global certainty for all stakeholders involved. The USG has played a leadership role in the development of all aspects of CORSIA and continues work ensuring CORSIA's environmental integrity.

Our Direction

- Utilizing a comprehensive approach to address environmental challenges
- Working with a broad range of stakeholders to understand issues and develop solutions through technology, fuels, operations, and policy
- Developed ambitious, yet achievable aviation climate action plan to guide our efforts
- Overcoming these challenges will not be easy, but the aerospace industry has a long history of overcoming incredible challenges



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Office of Environment and Energy

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SAF Grand Challenge Roles

Sustainable Aviation Fuel Grand Challenge

DOE

- Continue investments and develop expertise in sustainable technologies to develop cost effective low carbon liquid fuels and enabling coproducts from renewable biomass and waste feedstocks
- Continue a significant multi-year SAF scale-up strategy committed to in FY21
- R&D aimed at creating new pathways toward higher SAF production
- Advance environmental analysis of SAF
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

DOT/FAA

- Develop overall strategy to decarbonize aviation
- Coordinate ongoing SAF testing and analysis
- Work with standards organizations to ensure safety and sustainability of SAF
- Continue International technical leadership
- Promote end use of SAF
- Support infrastructure and transportation systems that connect SAF feedstock producers, SAF refiners, and aviation end users
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

USDA

- Continue investments and build expertise in sustainable biomass production systems
- Decarbonize supply chains
- Invest in bio-manufacturing capability & workforce development
- Community and individual education
- Provide outreach & technology transfer to producers, processors and communities to accelerate adoption and participation
- Commercialization support
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

https://www.energy.gov/sites/default/files/2021-09/S1-Signed-SAF-MOU-9-08-21_0.pdf

SAF GC Roadmap – Action Areas

1. **(FI) Feedstock Innovation** – Support and conduct R&D on sustainable feedstock supply that enables system innovations across the range of SAF-relevant feedstocks and identify optimization to reduce cost, technology uncertainty, and risk; increase yield and sustainability; and optimize SAF precursors (e.g., ethanol and isobutanol).
2. **(CT) Conversion Technology Innovation** – Support and conduct R&D, through pilot scale for technology improvements/carbon intensity reductions for both processes that are already commercial, or nearing commercialization and processes that will be ready for commercialization beyond 2030 but need to be developed now.
3. **(SC) Building Supply Chains** – Support SAF production expansion through supply chains, ensuring R&D transitions from pilot to large scale and field validation and demonstration projects, validating supply chain logistics, enabling public–private partnerships, supporting development of bankable business models, and collaborating with regional, state, and local stakeholders.
4. **(EU) Enabling End Use** – Facilitate the end use of SAF by civil and military users by addressing critical barriers, including efficient evaluation of fuel engine and aircraft performance and safety, advancement of certification and qualification processes, expansion of existing blend limits, and integration of SAF into fuel distribution infrastructure.
5. **(PA) Policy and Valuation Analysis** – Provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF, including evaluation of existing and new policies.
6. **(CP) Communicating Progress & Building Support** – Engage stakeholder organizations, monitor and measure progress against SAF Grand Challenge goals, provide public information resources, and communicate benefits of the SAF Grand Challenge.

Support for 2030 & 2050 production

Sustainable Aviation Fuel
Grand Challenge

Workstreams Supporting Near-Term Production and Mid to Long-Term Innovation

Workstreams Supporting Near-Term SAF Production Impactful to 2030 Goals

- **Build and support stakeholder coalitions through outreach, extension, and education** (Workstream SC.1) to set the stage for SAF supply chains to develop and sustain themselves and replicate with continuous improvement.
- **Maximize sustainable lipid supply for 2030** (Workstream FI.2) through a coordinated approach to lipid feedstock RDD&D to support rapid buildout of lipid pathway production.
- **Decarbonize, diversify, and scale current fermentation-based fuel industry** (Workstream CT.1) to address barriers to expansion of SAF supply via alcohol pathways.
- **Invest in SAF infrastructure** to support industry deployment (Workstream SC.4) and to allow industry to attract investment into production capacity.
- **Develop improved environmental models and data for SAF** (Workstream PA.1) to support optimization of existing policies and implementation of new policies that could be enacted.
- **Inform SAF policy development** (Workstream PA.3) with analysis of gaps and impacts of policies under consideration.
- **Stakeholder outreach and engagement on sustainability** (Workstream CP.1) to exchange data and information about best practices to reduce life cycle GHG emissions from agricultural and forest-derived feedstocks and optimize other environmental and social impacts.
- **Enable use of drop-in unblended SAF and SAF blends up to 100%** (Workstream EU.2) to simplify blending requirements, reduce cost of logistics, and facilitate supply.
- **Integrate SAF into fuel distribution infrastructure** (Workstream EU.4), including conducting infrastructure analysis to identify and address barriers to SAF supply to airports.

Workstreams Supporting Midterm and Long-Term Innovation Impactful to 2050 Goals

- **Conduct RD&D on scaling and sustainability of biomass, waste, and residue feedstocks** (Workstreams FI.3 and FI.6) to enable innovations in technologies and strategies that increase the availability of biomass and waste resources at reduced CI and cost. This includes addressing the social, environmental, and economic sustainability aspects of feedstock supply chains.
- **Conduct RD&D on feedstock logistics and handling reliability** (Workstreams FI.4 and FI.5) to increase efficiencies and decrease cost and CI of supply logistics from the producer's field to the conversion facility door.
- **De-risk scale-up through R&D and integrated piloting of critical pathways by 2030** (Workstreams CT.1–CT.4) to accelerate fuel conversion technology scale-up and improve financeability of critical conversion pathways that utilize the full potential of an expanded feedstock supply.
- **Build and support regional stakeholder coalitions through outreach, extension, and education** (Workstream SC.1) to continue to expand an SAF industry that improves environmental and economic performance while supporting job creation and social equity in multiple regions of the country.
- **Model and demonstrate sustainable regional supply chains for critical pathways by 2035** (Workstreams SC.2 and SC.3) to promote commercialization of SAF supply chains through process validation and risk reduction via access to critical data and tools that empower rapid, informed decision-making when evaluating SAF supply chain options.
- **Continue to invest in industry deployment** (Workstream SC.4) to help overcome barriers to project financing through creative financing, government loans and loan guarantees, and outreach.
- **Continue to inform SAF policy development** (Workstream PA.3) to enable aligned policy incentives that will support long-term SAF deployment.
- **Support SAF qualification** (Workstream EU.1) to accelerate fuel safety testing, evaluation, and specification activity; reduce the cost and time for new approvals; and expand the range of qualified fuels to include new critical pathways that will enable expansion of SAF supply.