United States Government Accountability Office

Report to Congressional Committees

March 2023

SUSTAINABLE AVIATION FUEL

Agencies Should Track Progress toward Ambitious Federal Goals

Revised May 17, 2023. The corrected section in Table 8 on page 27 should read: 'In fiscal year 2022, the Department of Energy announced a $34.5 million funding opportunity to improve the science and infrastructure for converting waste into biofuels and help support the 2050 goal.'

GAO-23-105300

GAO Highlights

Highlights of GAO-23-105300, a report to congressional committees

Why GAO Did This Study

To reduce greenhouse gas emissions from the aviation sector, the White House announced a SAF Grand Challenge in September 2021. The Grand Challenge goal is to supply 3 billion gallons of SAF per year by 2030 and 100 percent of expected domestic commercial jet fuel use by 2050.

GAO was asked to review the federal role in SAF. This report (1) discusses the state of SAF production and use for the U.S. commercial aviation industry and factors shaping this market, and (2) identifies how federal agencies have supported SAF and assesses how they will monitor progress toward Grand Challenge goals.

GAO reviewed data on SAF production and conventional jet fuel use from 2016 to 2022. GAO reviewed Grand Challenge documents and interviewed officials from four agencies selected based on their roles in SAF and interagency efforts. GAO interviewed 43 stakeholders on a range of SAF issues. Selected stakeholders included airlines, SAF producers, airports, industry associations, environmental organizations, and other groups.

What GAO Recommends

GAO recommends that the Departments of Transportation, Energy, and Agriculture develop and incorporate performance measures into the Grand Challenge roadmap. Transportation and Agriculture concurred. Energy indicated the recommendation is completed and that planned roadmap activities will enable progress to be measured. As discussed in the report, GAO disagrees that the recommendation is completed.

View GAO-23-105300. For more information, contact Heather Krause at (202) 512-2834 or KrauseH@gao.gov.

March 2023

SUSTAINABLE AVIATION FUEL

Agencies Should Track Progress toward Ambitious Federal Goals

What GAO Found

Sustainable aviation fuel (SAF) is alternative jet fuel made from renewable and waste feedstocks that can reduce greenhouse gas emissions on a lifecycle basis. SAF production and use in the U.S. has increased in recent years; this fuel is now used by airlines at two major commercial airports in California. While U.S. production reached 15.8 million gallons in 2022, it accounted for less than 0.1 percent of the total jet fuel used by major U.S. airlines (see table). This also falls well below the previous Federal Aviation Administration goal for U.S. airlines to use 1 billion gallons of SAF per year by 2018.

Comparison of Sustainable Aviation Fuel (SAF) Produced and Jet Fuel Consumed by Major U.S. Airlines by year

Millions of gallons

Year	SAF produced	Jet fuel consumed by major U.S. airlines
2016	1.9	17,138
2017	1.7	17,662
2018	1.8	18,325
2019	2.4	18,746
2020	4.6	11,067
2021	5.1	14,617
2022	15.8	17,510

Source: Environmental Protection Agency and Bureau of Transportation Statistics. | GAO-23-105300

Factors driving the SAF market include airlines' interest in reducing their greenhouse gas emissions and federal and California state policy incentives. Airlines have identified SAF as the most promising near-term technology to reduce greenhouse gas emissions and have signaled their interest by entering into agreements for future SAF deliveries. In addition, federal and California policy incentives have helped offset the high cost of SAF according to stakeholders. The high price of SAF compared to conventional jet fuel is a key factor inhibiting increased production and use. Other factors inhibiting market growth include the long time frames and high costs of developing new SAF production facilities. It remains to be seen how the Inflation Reduction Act of 2022, which includes new SAF tax credits, will affect the market.

Since 2007, federal agencies including the U.S. Departments of Transportation, Energy, and Agriculture have sponsored research and provided direct financial support for SAF production. In September 2022, these agencies published a roadmap outlining actions to support the recent White House Grand Challenge goals of producing 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050. However, the roadmap does not establish performance measures to monitor, evaluate, and report the results of these actions. Without performance measures, the agencies are not well positioned to evaluate the effectiveness of federal government actions to meet the Grand Challenge goals. In contrast, establishing and using such measures can identify progress on the extent to which SAF is contributing to emission reductions.

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Abbreviations

ASTM	ASTM International
CAAFI	Commercial Aviation Alternative Fuels Initiative
CO_2	carbon dioxide
COP-26	United Nations Climate Change Conference in Glasgow
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
HEFA	hydroprocessed esters and fatty acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
LCFS	low carbon fuel standard
R&D	research and development
RFS	Renewable Fuel Standard
RIN	renewable identification number
SAF	sustainable aviation fuel
USDA	U.S. Department of Agriculture

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

March 23, 2023

The Honorable Sam Graves
Chair
The Honorable Rick Larsen
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Garret Graves
Chairman
The Honorable Steve Cohen
Ranking Member
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

Absent concerted action, greenhouse gas emissions from the U.S. commercial aviation sector are expected to increase in the coming decades. In 2019, the last full year before the pandemic, U.S. commercial aircraft accounted for 7.2 percent of the transportation sector's—and 2 percent of all—greenhouse gas emissions in the U.S.[1] As air travel grows and other parts of the transportation sector reduce greenhouse gas emissions through technology advances such as electric vehicles, commercial aviation is projected to account for a greater share of total emissions.

Greenhouse gas emissions, such as carbon dioxide (CO_2), result in changes to the climate that can pose risks to many environmental and economic systems and create a significant fiscal risk to the federal government.[2] For example, the impacts and costs of natural disasters are

[1]U.S. Environmental Protection Agency (EPA), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. EPA* 430-R-22-003 (April 2022), accessed November 16, 2022, https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

[2]Greenhouse gases trap heat in the Earth's atmosphere and include CO_2, methane, nitrous oxide, and fluorinated gases such as hydrofluorocarbons. According to the EPA, CO_2 is the primary greenhouse gas emitted by human activities. This report generally uses the term greenhouse gases but at times refers to CO_2 specifically for the sake of accuracy.

projected to increase as extreme weather events become more frequent and intense due to climate change, according to the U.S. Global Change Research Program and the National Academies of Sciences, Engineering, and Medicine.[3]

Sustainable aviation fuel (SAF) is alternative jet fuel that is made from renewable and waste feedstocks and meets sustainability criteria to achieve a net greenhouse gas emissions reduction on a lifecycle basis compared to conventional jet fuel. SAF is a “drop-in” fuel, meaning that, once blended with conventional jet fuel, the fuel blend is fully compatible with existing infrastructure including jet engines and airport fueling infrastructure. SAF can be produced from feedstocks such as municipal solid waste, agricultural residues, and waste lipids.[4] In 2014, we reported that largely because alternative jet fuel was not price competitive relative to jet fuel, it was not being produced commercially in the U.S.[5]

To encourage greater SAF production and use, in September 2021 the White House announced a SAF Grand Challenge. As part of the Grand Challenge, the Biden Administration set a goal to supply 3 billion gallons of SAF per year by 2030 and around 35 billion gallons per year by 2050. The 35 billion gallons annually would meet 100 percent of projected U.S. domestic commercial jet fuel demand. Furthermore, on August 16, 2022, President Biden signed into law the Inflation Reduction Act of 2022, which includes several provisions to support SAF.[6] For example, the law includes 2 years of SAF general business tax credits for fuel sold or used

[3]See U.S. Global Change Research Program, *Climate Science Report: Fourth National Climate Assessment, Volume I* (Washington, D.C.: 2017) https://doi.org/10.7930/J0J964J6 and National Research Council, *Climate Change: Evidence and Causes: Update 2020* (Washington, D.C.: The National Academies Press, 2020) https://doi.org/10.17226/25733.

[4]SAF can also be made from inputs such as captured carbon and green hydrogen. These fuels are called power-to-liquid fuels. This report is primarily focused on SAF made from biomass and waste feedstocks, which are more technologically mature than power-to-liquid fuels.

[5]GAO, *Alternative Jet Fuels: Federal Activities Support Development and Usage, but Long-term Commercial Viability Hinges on Market Factors*, GAO-14-407 (Washington, D.C.: May 7, 2014). We have previously defined alternative jet fuel as a liquid drop-in fuel derived from non-petroleum feedstocks. Since 2018, SAF has become the term preferred by the aviation industry. Other terms that have a similar intended meaning include renewable aviation fuel, biojet fuel, and low carbon jet fuel. For consistency, this report will use the term SAF throughout.

[6]Pub. L. No. 117-169, 136 Stat. 1818.

in 2023 and 2024.[7] After that, the law authorizes the Clean Fuel Production Credit, a tax credit that expires at the end of 2027 and for which SAF is eligible. The law also provides $297 million for the Department of Transportation to award competitive grants to support SAF and to advance the deployment of low-emission aviation technologies. Of that total, approximately $245 million is for projects that produce, transport, blend, or store SAF.[8]

You asked us to assess the federal government's role in facilitating the deployment of SAF as well as identify existing barriers to doing so. This report:

- describes the current state of SAF production and use for the U.S. commercial aviation industry and the factors shaping this market, and
- identifies how federal agencies have supported SAF production and assesses how they will monitor progress toward SAF Grand Challenge production goals.

To describe the current state of SAF production, we reviewed U.S. Environmental Protection Agency (EPA) data on the gallons of SAF produced and Department of Transportation (DOT) Bureau of Transportation Statistics data on the amount of conventional jet fuel used by major U.S. airlines.[9] We assessed the reliability of these data by (1) reviewing existing information about the data and the system that produced them, (2) interviewing knowledgeable officials about the data, and (3) testing the data to check for missing or erroneous values. We

[7]On December 19, 2022, the Treasury Department and Internal Revenue Service issued a notice on the new SAF tax credits; the notice explains requirements and asked for public comments related to the SAF credit to help in developing additional guidance. I.R.S. Notice 2023-06.

[8]More recently, the James M. Inhofe National Defense Authorization Act for Fiscal Year 2023, which passed into law on December 23, 2022, included a pilot program on the use of SAF. Subject to the availability of appropriations, the law directs the Department of Defense to select at least two of its facilities for the program, which is intended to identify logistical challenges of SAF use by the Department of Defense, promote understanding of SAF's technical and performance characteristics in a military setting, and engage nearby commercial airports to explore opportunities to partner on SAF use. Sec. 324, Pub. L. No. 117-263, § 324, 136 Stat. 2395, 2516.

[9]This report is primarily focused on efforts to produce and use SAF for the U.S. commercial aviation market rather than general aviation, which includes corporate and recreational flying.

determined these data were sufficiently reliable for the purpose of describing the state of SAF production.

To determine the factors shaping the market for SAF production and use, we reviewed over 150 academic studies and reports and interviewed 43 stakeholders. We identified academic studies and reports through background research, subject matter expert identification, and a snowball technique.[10] In addition, we reviewed company press releases and other publicly available documentation from company websites on developments in the SAF industry.

We selected 43 stakeholders to capture a range of perspectives based on their role and involvement with SAF, experience with different types of SAF feedstocks, regions of the country, viewpoints, policy positions, and domestic and international experience.[11] Stakeholder views cannot be generalized to represent the views of all SAF stakeholders. See appendix II for a list of the stakeholders we interviewed. We interviewed stakeholders from September 2021 to June 2022. The Inflation Reduction Act of 2022 was subsequently enacted in August 2022.[12]

To identify how federal agencies have supported SAF production and will monitor progress towards production goals, we interviewed officials and gathered information from four federal agencies. We selected these agencies—DOT and its Federal Aviation Administration (FAA); Department of Energy (DOE); U.S. Department of Agriculture (USDA); and EPA—based on their key roles in SAF and interagency efforts. To analyze how agencies will monitor progress towards SAF Grand Challenge goals, we reviewed preliminary presentations on the September 2022 SAF Grand Challenge Roadmap prepared by DOE, DOT, and USDA in collaboration with EPA as well as the final product. We also reviewed the U.S. Aviation Climate Action Plan (2021). We

[10]The snowball technique involved identifying new articles or reports in those a researcher has already found on the topic.

[11]These stakeholders included: eight SAF producers; four airports; four U.S. commercial airlines and associations; three aviation industry stakeholders and suppliers; four feedstock producers; four conventional jet fuel producers and infrastructure owners; four environmental organizations; four renewable energy investment/ finance organizations; and eight SAF policy, collaboration, or market analysis entities or academics.

[12]We also asked stakeholders about their perspectives on the SAF Grand Challenge and policy options for progress towards the Grand Challenge's production goals. Their perspectives are summarized in appendix I.

interviewed officials from these four agencies and compared these efforts to key or leading practices on achieving government-wide goals based on our prior work.[13] We also analyzed the Inflation Reduction Act of 2022 to describe its provisions related to SAF.

We conducted this performance audit from June 2021 to March 2023 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

SAF Benefits and Specifications

Emissions from a variety of human-generated sources, including commercial aircraft, trap heat in the atmosphere and contribute to climate change.[14] During flight operations, aircraft emit a number of greenhouse gases and other emissions, including CO_2, nitrous oxides, soot, and water vapor. Greenhouse gases such as CO_2 already in the atmosphere will continue altering the climate system for many decades, according to the U.S. Global Change Research Program and the National Academies of Sciences, Engineering, and Medicine.[15] Aircraft emissions other than CO_2 can also affect the climate. For example, condensation trails of small soot and other particles from aircraft exhaust form contrails that appear as line-shaped clouds in the sky. According to the U.S. Aviation Climate

[13]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sep. 27, 2012); and *Managing for Results: Implementation approaches Used to Enhance Collaboration in Interagency Groups*, GAO-14-220 (Washington, D.C.: Feb. 14, 2014). From these sources, we selected practices relevant to developing cross-agency goals and measures.

[14]GAO, *Aviation and Climate Change: Aircraft Emissions Expected to Grow, but Technological and Operational Improvements and Government Policies Can Help Control Emissions*, GAO-09-554 (Washington, D.C.: June 8, 2009).

[15]GAO, *Climate Change: Oversight of Federal Greenhouse Gas Emissions Reduction Efforts*, GAO-22-106062 (Washington, D.C.: Sept. 29, 2022).

Action Plan, persistent contrails produced in the wake of aircraft contribute to net climate warming.[16]

To qualify as SAF, the fuel must meet sustainability criteria to reduce greenhouse gas emissions on a lifecycle basis compared to conventional jet fuel derived from fossil fuels. The extent to which a particular SAF provides climate benefits depends on its emissions profile over the lifecycle of the fuel, taking into account the production, transportation, and combustion of the SAF. When burned by an aircraft engine, SAF still produces levels of CO_2 emissions similar to conventional fuels. However, when considered on a lifecycle basis, net CO_2 emissions from SAF can be significantly lower than conventional jet fuel.[17] In addition to reducing net CO_2 emissions over its lifecycle, preliminary work has shown that SAF burns cleaner, resulting in a 50 to 70 percent reduction in soot and ice formations that produce contrails.[18]

SAF must meet technical specifications to ensure the fuel is compatible with existing aircraft engines and airport fuel infrastructure and can meet the rigorous safety and operational requirements of flight. ASTM International (ASTM) sets standards for both conventional and synthetic

[16]Federal Aviation Administration, U.S. Aviation Climate Action Plan, Nov. 9, 2021. According to the plan, recent estimates indicate that the warming effect of contrail-induced cloudiness could be comparable or even higher than those due to aviation CO_2 although large uncertainties remain. See also Lee, et al. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Atmospheric Environment 244 (2021) 117834. Published online Sept. 3, 2020. https://doi.org/10.1016/j.atmosenv.2020.117834 See also Grobler, et al. Marginal climate and air quality costs of aviation emissions, Environ. Res. Lett. 14 (2019) 114031, Published online Nov. 8, 2019. https://doi.org/10.1088/1748-9326/ab4942.

[17]When incorporating technologies that capture and store carbon into its production, SAF can in principle achieve zero or even negative net CO_2 emission levels. For more information on carbon capture, see GAO, *Decarbonization: Status, Challenges, and Policy Options for Carbon Capture, Utilization, and Storage,* GAO-22-105274 (Washington, D.C.; Sept. 29, 2022).

[18]See Voigt, et al, “Cleaner burning aviation fuels can reduce contrail cloudiness,” *Communications Earth & Environment.* Published online June 17, 2021. https://doi.org/10.1038/s43247-021-00174-y. Federal agencies have noted they will continue efforts to quantify the non-CO_2 environmental impacts of SAF use on air quality and climate change, including the effect of SAF on contrails and aviation-induced cloudiness. See U.S. Department of Energy, U.S. Department of Transportation, and U.S. Department of Agriculture, in collaboration with the U.S. Environmental Protection Agency, *SAF Grand Challenge Roadmap: Flight Plan for Sustainable Aviation Fuel* (September 2022).

jet fuel, the latter of which includes SAF.[19] ASTM approved the first technical pathway that could be employed for producing SAF in 2009. There are currently seven different ASTM-approved technical pathways that could be used to produce SAF, the three most common of which are summarized in table 1.

Table 1: Common Potential Sustainable Aviation Fuel (SAF) Technical Pathways Approved by ASTM International

Technical pathway	Year first approved by ASTM International	Feedstock	Current status in the U.S.
Hydroprocessed esters and fatty acids (HEFA)	2011	Fats, oils, and greases feedstocks such as tallow (animal fat), soybean oil, or used cooking oil	Commercially produced
Fischer-Tropsch	2009	Municipal solid waste, agricultural wastes, and forestry residues	Planned future commercial production
Alcohol to Jet	2016	Sugars, biomass (including from ethanol or isobutanol production), waste gases	Planned future commercial production

Source: GAO analysis of government and industry reports. | GAO-23-105300

Note: The maximum blend limit for SAF varies by technical pathway but is 50 percent SAF/50 percent conventional jet fuel for the three pathways listed.

When discussing SAF, renewable diesel—a fuel that is used by diesel-powered vehicles such as freight trucks and construction equipment to reduce on-road greenhouse gas emissions— often enters the discussion. The chemical composition of the two fuels is similar, and both rely on hydroprocessing to convert esters and fatty acid feedstocks (e.g., fats, oils, and greases) to produce hydrocarbons. Depending on the feedstock, hydroprocessing generally results in around 25 percent of the total fuel product yield in the jet fuel range, with the rest being in the diesel fuel range.[20] The jet-fuel-range hydrocarbons can be and typically are included in the renewable diesel product stream. To produce SAF, those

[19]Formerly known as the American Society for Testing and Materials, ASTM is a globally recognized leader in the development and delivery of international voluntary consensus standards.

[20]Jet fuel and renewable diesel are mostly blended mixtures of several hundred different hydrocarbon molecules. Molecules in the jet fuel range include those containing 8 to 16 carbon atoms, while molecules in the renewable diesel fuel range include those containing 8 to 23 carbon atoms. See U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Bioenergy Technologies Office, *Sustainable Aviation Fuel: Review of Technical Pathways,* DOE/EE-2041 (September 2020).

hydrocarbons must go through an additional distillation step that requires additional processing, energy, and cost. Whether it is economical to undertake this additional step to produce SAF is a function of market conditions for SAF versus renewable diesel and whether any government or other incentives are in place to do so.[21]

SAF Grand Challenge

The September 2021 SAF Grand Challenge is the most recent federal goal related to SAF production. The Grand Challenge goals are to: (1) by 2030, expand SAF production to achieve 3 billion gallons per year of domestic SAF production and (2) by 2050, meet 100 percent of projected domestic jet fuel demand—about 35 billion gallons of annual production.[22] These goals aim to produce SAF that achieves a minimum of a 50 percent reduction in lifecycle greenhouse gas emissions compared to conventional jet fuel. The goals are also intended to put the U.S. aviation industry on a path to full decarbonization by 2050 and are part of the U.S. goal of net-zero greenhouse gas emissions economy-wide by no later than 2050.[23]

DOT, DOE, and USDA signed a memorandum of understanding in September 2021 to work together to accelerate research, development, demonstration, and deployment activities towards achieving the Grand Challenge goals. Each agency has a role in SAF research and development (R&D) and funding. For example, DOT and FAA have assessed if SAF affects aircraft engine performance, and FAA works with ASTM to issue technical pathway specifications that can be used to produce SAF. DOE sponsors a range of biofuel R&D through its Bioenergy Technologies Office and National Laboratories, such as the National Renewable Energy Laboratory. DOE also provides cost-share grants to demonstrate technologies and can offer loan guarantees to qualified SAF and biofuel projects. Last, USDA sponsors R&D on SAF, including feedstocks, and can offer loan guarantees to qualified SAF and biofuel projects.

[21]U.S. Department of Energy, *Sustainable Aviation Fuel: Review of Technical Pathways* (September 2020).

[22]Approved SAF technical pathways are currently subject to a maximum blending limit of 50 percent SAF/ 50 percent conventional jet fuel. For SAF to become 100 percent of jet fuel used by 2050, new SAF pathways would need to be approved that remove the blending limit and allow for 100 percent SAF usage.

[23]U.S. Department of State and Executive Office of the President, *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050* (Washington, D.C.: November 2021).

Key stakeholder groups are also engaged in the Grand Challenge goals and efforts. For example, the Commercial Aviation Alternative Fuels Initiative (CAAFI) is a public-private partnership that has sought to advance SAF since 2006. CAAFI is a coalition of airlines, airports, aircraft and engine manufacturers, energy producers, researchers, international participants, and U.S. government agencies.

Goals and Strategies Related to Aviation Greenhouse Gas Emissions and SAF Production

Similar to the SAF Grand Challenge goals, industry and governments have set goals over the past 15 years to reduce aviation's greenhouse gas emissions and increase SAF production. For instance, in 2012, FAA set a goal for U.S. airlines to use 1 billion gallons of SAF per year starting in 2018. Recently, goals have centered on achieving net zero aviation by 2050 (see table 2).[24] For example, in November 2021, FAA published the U.S. Aviation Climate Action Plan, which describes a whole-of-government approach to put the aviation sector on a path toward net-zero by 2050. More recently, in October 2022, member states of the International Civil Aviation Organization (ICAO) adopted a long-term aspirational goal of net-zero carbon emissions for international aviation by 2050. ICAO is a United Nations Specialized Agency that adopts standards and recommended practices for international aviation. Individual companies such as airlines and conventional jet fuel producers have also adopted their own goals. For example, Alaska Airlines and JetBlue Airways aim to reach net zero by 2040.

Table 2: Timeline of Aviation Greenhouse Gas Emissions Reduction and Sustainable Aviation Fuel (SAF) Production Goals

Year	Entity	Goal
2007	International Air Transport Association (IATA), a trade association for the world's airlines	SAF to account for 10 percent of all jet fuel used by 2017
2009	IATA	Carbon-neutral growth from 2020 and reduce aviation's net carbon dioxide (CO_2) emissions by 50 percent by 2050
2010	International Civil Aviation Organization (ICAO), a United Nations Specialized Agency that adopts standards and recommended practices for international aviation[a]	Aspirational goal of keeping the global net carbon emissions from international aviation from 2020 at the same level
2010	White House	Carbon neutral growth from aviation by 2020
2012	U.S. Federal Aviation Administration (FAA)	U.S. airlines to use 1 billion gallons of SAF per year by 2018
2021	White House, IATA, and Airlines for America (the trade association for U.S. airlines)	Net zero aviation by 2050[b]

[24]Net zero means that the greenhouse gases emitted into the atmosphere are balanced out by greenhouse gases removed from the atmosphere.

Year	Entity	Goal
	White House	SAF Grand Challenge goals to supply 3 billion gallons of SAF per year by 2030 and by 2050, sufficient SAF to meet 100 percent of U.S. domestic commercial jet fuel demand, around 35 billion gallons
	Airlines for America	In March: make 2 billion gallons of SAF available to U.S. airlines in 2030 In September: increased this goal to 3 billion gallons of SAF in 2030
	60 companies part of World Economic Forum's Clean Skies for Tomorrow Coalition	Produce enough SAF to supply 10 percent of the world's jet fuel by 2030
2022	U.S. Department of Transportation (DOT)	DOT strategic plan FY2022-2026 establishes a key performance indicator to reduce greenhouse gas emissions from aviation to at or below 2019 levels by 2030
	ICAO	Net zero carbon emissions aviation by 2050

Source: GAO analysis of documents and announcements. | GAO-23-105300

[a]ICAO adopts standards and recommended practices in accordance with Article 37 of the Convention on International Civil Aviation (Chicago Convention) in order for all contracting states (including the U.S.) to have the highest practicable degree of uniformity in regulations, standards, and procedures in relation to air navigation and transportation.

[b]Net zero means that greenhouse gases emitted into the atmosphere are balanced out by the removal of such gases.

International, Federal, and State Roles Regarding SAF

In addition to those previously named, several entities and programs at the international, federal, and state levels have a role regarding efforts to reduce greenhouse gas emissions from transportation and aviation and supporting or incentivizing SAF.

International

SAF is one of the principal ways, along with purchasing offsets, that airlines can meet requirements associated with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The General Assembly of ICAO in 2016 decided to implement CORSIA.[25] CORSIA is a market-based measure with the global aspirational goal of keeping the

[25]ICAO Assembly Resolution A39-3 (2016), text available at https://www.icao.int/Meetings/a39/Documents/Resolutions/summary_en.pdf. ICAO Resolutions are adopted by the over 190 member states of the ICAO General Assembly, which includes the United States. A few member states expressed reservations to the resolution adopting CORSIA, which could affect their implementation of CORSIA. All member state participation in CORSIA is voluntary until 2027, with 115 states voluntarily participating in 2023. CORSIA Standards and Recommended Practices are in Annex 16, Volume IV of the Chicago Convention on International Civil Aviation. Convention on International Civil Aviation ("Chicago Convention"), Dec. 7, 1944, 15 U.N.T.S. 295. CORSIA and other ICAO standards and recommended practices are adopted by ICAO's 36-member Executive Council and apply to international (not U.S. domestic) civil aviation.

global net CO_2 emissions from international aviation from 2020 at the same level.[26] To achieve this goal, ICAO established requirements for civil aircraft operators to offset CO_2 emissions from their international (not domestic) flights. To monitor, report, and verify international aviation CO_2 emissions as part of CORSIA, member states, including the U.S., started implementing a system in 2019 to collect emissions information from aircraft operators.[27] ICAO provides guidance for quantifying, on a lifecycle basis, the emissions benefits of a particular fuel.[28] In November 2021, the ICAO Council approved sustainability criteria that SAF must meet to be eligible under CORSIA.[29]

Other international activities regarding SAF include a commitment made at the 2021 United Nations Climate Change Conference in Glasgow (COP-26) to reduce aviation's impact on the environment, including by promoting SAF through national and international measures, which now has 60 signatories, including the United States.[30] The European Union is considering a proposal that would impose a SAF blending mandate for all flights taking off from the European Union, regardless of destination.[31]

[26]ICAO implemented CORSIA with a baseline set at the average of 2019-2020 international aviation emissions. In 2020, during the COVID-19 pandemic, ICAO's Executive Council endorsed a temporary change to CORSIA's baseline for the years 2021-2023, in order that airlines would only need to address emissions above 2019 levels. In practice, that has meant that for these 3 years 2021-2023, airlines have not been required to reduce/offset emissions under CORSIA, as international aviation emissions have remained below 2019 levels. At its General Assembly in October 2022, ICAO Member States agreed to a new CORSIA baseline from 2024 onwards, defined as 85 percent of emissions in 2019.

[27]FAA implements CORSIA in the U.S., including monitoring, reporting, and verifying emissions from international flights from U.S. commercial airlines.

[28]This can be quantified using either a default emissions value or actual emissions value.

[29]We did not evaluate CORSIA's sustainability criteria for SAF or the models used to determine the lifecycle emissions of SAF.

[30]The number of countries is as of December 16, 2022. See https://www.gov.uk/government/publications/cop-26-declaration-international-aviation-climate-ambition-coalition/cop-26-declaration-international-aviation-climate-ambition-coalition for the updated list of countries.

[31]The mandatory minimum share of SAF would increase over time.

Federal

In addition to DOT, DOE, and USDA, the EPA has a role in SAF by administering the Renewable Fuel Standard (RFS) program[32] and issuing emissions standards for commercial aircraft.[33] Since 2006, the RFS has required that transportation fuels—typically gasoline and diesel—sold in the U.S. contain annually increasing amounts of renewable fuels, such as ethanol and biodiesel, to achieve key environmental and energy goals.[34] Stakeholders refer to SAF as an "opt-in" fuel under the RFS program. This means that while there are no specific SAF production and use requirements, refiners and producers required to comply with the program can choose to produce or use SAF to meet the program's overall renewable fuel requirements. Specifically, SAF is eligible to generate a renewable identification number (RIN), which can be used to meet the renewable volume obligations.[35] We reported in November 2016 that it did not appear possible for the RFS program to meet its statutory volume requirements for advanced biofuels due to feedstock limitations and high production costs.[36] In May 2019, we reported that most of the 13 experts we interviewed for that work generally agreed that the RFS had likely had a limited effect, if any, on greenhouse gas emissions.[37]

[32]42 U.S.C. §7545(o). EPA most recently updated regulations issued under this statute in July 2022.

[33]EPA most recently updated these standards for commercial aircraft in 2021 to harmonize U.S. regulations with those set by ICAO in 2017.

[34]The RFS was established by Section 1501 of the Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594, 1067 (2005), and expanded in 2007 by the Energy Independence and Security Act, Pub. L. No. 110-140, § 201 121 Stat. 1492, 1519 (2007) (codified as amended at 42 U.S.C. § 7545(o)).

[35]RINs are unique numbers generated to represent a volume of renewable fuel and work as credits used for compliance with the RFS program requirements. Renewable fuel producers and importers generate RINs for volumes of renewable fuel. Market participants (e.g., renewable fuel producers and exporters) trade those volumes of renewable fuel which come with associated RINs for renewable volume obligation compliance.

[36]GAO, *Renewable Fuel Standard: Low Expected Production Volumes Make it Unlikely That Advanced Biofuels Can Meet Increasing Targets,* GAO-17-108 (Washington, D.C.: Nov. 28, 2016). Due to these challenges, we reported at the time it was unlikely the RFS program would meet its goals to reduce greenhouse gas emissions. See GAO, *Renewable Fuel Standard: Program Unlikely to Meet Its Targets for Reducing Greenhouse Gas Emissions*, GAO-17-94 (Washington, D.C.: Nov. 28, 2016).

[37]GAO, *Renewable Fuel Standard: Information on Likely Program Effects on Gasoline Prices and Greenhouse Gas Emissions,* GAO-19-47 (Washington, D.C.: May 3, 2019).

States

California has been at the forefront of efforts to reduce greenhouse gas emissions since 2006 when its legislature declared global warming a serious threat to the state and established the state's emissions reduction program. The California Air Resources Board is the state agency charged with regulating greenhouse gas emissions, including overseeing the state's low carbon fuel standard (LCFS) program. The program sets carbon intensity benchmarks for transportation fuels that lower over time and that certain entities, such as fuel producers and importers, must meet.[38] Fuels produced above the carbon intensity target generate a deficit, and fuels produced below the carbon intensity target generate a credit. Regulated parties, such as fuels producers and importers, typically will either produce eligible fuels themselves or purchase credits from producers selling their excess credits.

Beyond California, other states have also taken actions to reduce the transportation sector's greenhouse gas emissions and promote SAF production. For example, both Oregon and Washington State have passed clean fuel standard programs that are similar to California's LCFS program and allow SAF to generate credits.[39] In addition, Hawaii has passed several measures related to SAF development, including state tax incentives for renewable fuels and a program to provide matching grants to Hawaii small businesses developing and producing SAF. Some other states have laws to incentivize alternative fuel production, and such laws could include SAF.

SAF Production and Use Have Grown due to Interest from Airlines, but Growth is Limited due to High Costs and Other Factors

SAF production has grown in recent years but remains an extremely small percentage of total jet fuel used by major U.S. commercial airlines. Factors driving the market include airline and other corporate agreements to purchase SAF as well as incentives provided by California and the federal RFS programs. Stakeholders stated that while these incentives have encouraged existing SAF production, the incentives and other factors have favored production of renewable diesel over SAF. Factors inhibiting the market include SAF's lack of price competitiveness with conventional jet fuel and challenges bringing new production online.

[38]Carbon intensity, which is expressed in grams of CO_2 per megajoule of energy, accounts for a fuel's lifecycle greenhouse gas emissions, including those associated with producing, transporting, and consuming the fuel.

[39]SAF is specifically eligible to generate credits under Washington's statutes and Oregon's regulations.

SAF Production Has Grown but Accounted for Less Than 0.1 Percent of Total Jet Fuel Used by Major U.S. Commercial Airlines in 2022

SAF is now used by airlines at two major U.S. commercial airports in California, signifying progress since 2014 when we reported SAF was not being commercially produced or used in the U.S.[40] Two producers, World Energy and Neste, currently supply Los Angeles and San Francisco International Airports with SAF made from hydroprocessed esters and fatty acids (HEFA) (see table 3).[41] Certain airlines purchase the SAF, but once the SAF is delivered, it is distributed into the airport's communal fueling infrastructure and used by all airlines refueling at the airport.

Table 3: Information on Sustainable Aviation Fuel (SAF) Used at Major U.S. Airports, as of 2022

	Los Angeles International Airport	San Francisco International Airport
SAF producer and location	World Energy, LLC (Formerly AltAir, purchased by World Energy in 2018)	Neste, an oil refining company headquartered in Finland
Year SAF started being used at airport	2016	2020[a]
SAF technical pathway used	Hydroprocessed esters and fatty acids (HEFA) technical pathway	HEFA
Feedstocks used	Animal tallow	Used cooking oil and animal tallow
How SAF is produced and transported	Produced in Paramount, California, and trucked to the airport	Renewable diesel is produced at Neste facilities overseas, refined into SAF in Texas, marine shipped to California, and is delivered to the airport via pipeline
Examples of airlines that purchase the SAF	United, KLM, JetBlue, and Amazon (cargo)	Alaska, American, JetBlue, and DHL Express

Source: GAO review of company press releases, stakeholder interviews, and other documentation. | GAO-23-105300

[a]In addition, according to a San Francisco International Airport official, the airport previously received an intermittent supply of SAF from World Energy as early as 2018.

Annual SAF production has increased significantly in the past 6 years but remains miniscule compared to overall jet fuel use (see table 4). SAF production grew from 1.9 million gallons in 2016 to 15.8 million in 2022. By comparison, in 2022, major U.S. airlines consumed over 17 billion gallons of jet fuel, down from a pre-pandemic high of almost 19 billion gallons in 2019.[42] To illustrate the very small amount of SAF relative to

[40]SAF is also provided at several additional airports through fixed based operators that provide fueling service for pilots operating general aviation aircraft. Although general aviation is an important driver of interest in SAF, this report is primarily focused on efforts to produce and use SAF for the U.S. commercial aviation market.

[41]Both producers also produce renewable diesel using the same feedstocks.

[42]DOT considers major passenger and cargo airlines as those with annual operating revenue exceeding $1 billion.

the amount of total jet fuel used by the industry, in January 2022 the CEO of Delta Airlines said that the U.S. SAF supply for a year was enough to fuel Delta's fleet for 1 day before the COVID-19 pandemic. Current use falls well short of previous goals, such as FAA's goal to use 1 billion gallons of SAF per year by 2018.

Table 4: Comparison of Sustainable Aviation Fuel (SAF) Produced and Jet Fuel Consumed by Major U.S. Airlines by Year

Millions of gallons

Year	SAF produced	Jet fuel consumed by major U.S. airlines
2016	1.9	17,138
2017	1.7	17,662
2018	1.8	18,325
2019	2.4	18,746
2020	4.6	11,067
2021	5.1	14,617
2022	15.8	17,510

Source: Environmental Protection Agency and Bureau of Transportation Statistics. | GAO-23-105300

SAF producers such as World Energy and Neste have plans to increase existing facility capacity and bring new facilities on-line to produce SAF and other renewable fuels. In April 2022, World Energy announced it has the necessary permits to renovate its California refinery to expand its capacity to produce SAF and renewable diesel to 340 million gallons a year—an increase of 530 percent from its current rate. According to World Energy, the project is expected to be completed by 2025 and will include new equipment that will enable a broader range of feedstocks, such as used cooking oil, to be used. World Energy also announced its second SAF facility in Houston with an anticipated commissioning before the end of 2025. Meanwhile, Neste announced an expansion of its Singapore facility and expects to have the ability to produce 515 million gallons of SAF annually by the end of 2023, up from its current annual production of 34 million gallons, according to the producer.

Table 5 summarizes examples of new U.S. production facilities under way. These facilities plan to produce SAF using different pathways and feedstocks than the SAF currently commercially produced. SAF producers listed, such as Fulcrum BioEnergy and Gevo, also anticipate constructing future SAF facilities beyond their facilities listed in the table.

Table 5: Examples of Production Facilities Under Way for Sustainable Aviation Fuel (SAF)

Producer	Production facility location	SAF production pathway	Feedstock used	Anticipated total production capacity[a] (millions of gallons per year)	Previous projections and current status
Fulcrum BioEnergy	Sierra facility near Reno, Nevada	Fischer-Tropsch	Municipal solid waste	11	Previously anticipated to start operations in 2018 In May 2022, Fulcrum announced the completion of commissioning and initial operations of producing synthetic gas, which then is converted into liquid fuel
Red Rock Biofuels	Lakeview, Oregon	Fischer-Tropsch	Woody biomass	15	Previously anticipated to start operations in 2017, current anticipated start date unclear
LanzaJet	Freedom Pines Fuels in Soperton, Georgia	Alcohol to Jet	Ethanol	10	Anticipated to complete construction in 2023
Gevo	Lake Preston, South Dakota	Alcohol to Jet	Isobutanol	55	Anticipated to start production in 2025

Source: GAO review of company press releases and other documentation. | GAO-23-105300

[a]Total capacity includes SAF and other products such as renewable diesel.

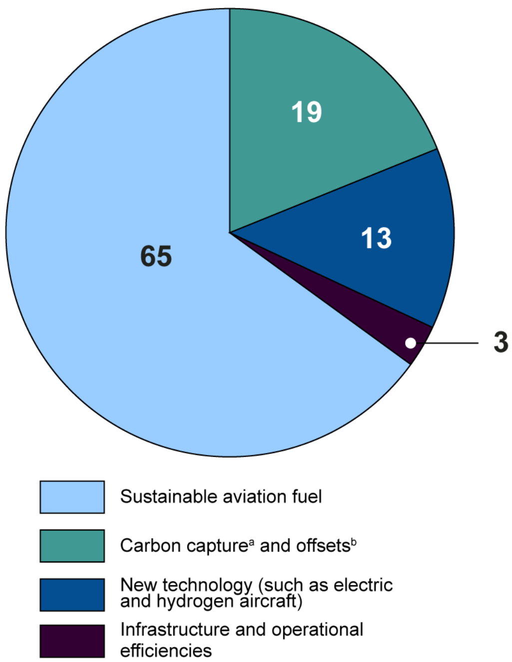
Corporate Agreements to Purchase SAF in the Future Are a Factor Driving the Market

Governments, airlines, and other aviation stakeholders have identified SAF as the most promising technology for the greatest near-term reduction of greenhouse gas emissions within the aviation sector. According to the International Air Transport Association (IATA), to reach net zero aviation in 2050, SAF will need to generate an estimated 65 percent of the CO_2 emissions reductions needed (see figure 1).[43] This estimate reflects the aviation industry's view that other potential avenues to reduce aviation greenhouse gas emissions, such as new electric and hydrogen-powered aircraft, are further in the future. For example, although electric aircraft may become an option for regional flights, long-haul flights will continue to be dependent on liquid fuels for the foreseeable future. In addition, hydrogen technology deployment is

[43]IATA represents some 300 airlines in 120 countries that carry 83 percent of the world's air traffic.

decades into the future given the technology's maturity level and the long operational life of existing aircraft.[44]

Figure 1: The International Air Transport Association's (IATA) Strategy for Achieving Net Zero Aviation by 2050, with the Percentage of Emissions Reduction Contributions Expected to be Made by Each Activity



Source: International Air Transport Association. | GAO-23-105300

[a]Carbon capture is technology that captures CO_2 to recycle it or permanently store it underground

[b]Offsets are activities that reduce emissions in one place in order to compensate for emissions occurring elsewhere.

U.S. airlines have outlined potential risks to the airline industry if it is viewed as not sufficiently reducing its greenhouse gas emissions and other climate impacts. One such risk is that consumers may avoid flying,

[44]The aviation industry also plans to continue to pursue infrastructure and operational efficiencies, such as retiring older, less fuel-efficient aircraft, which it has pursued over the past several decades largely in order to reduce fuel costs. See GAO, *Aviation: Impact of Fuel Price Increases on the Aviation Industry,* GAO-14-331 (Washington, D.C.: Sept. 25, 2014). We reported in August 2020 that the average age of the passenger airplane fleet is approximately 12 years, compared to in 2001 when the average passenger fleet was approximately 26 years old. See GAO, *Aircraft Noise: Information on a Potential Mandated Transition to Quieter Airplanes,* GAO-20-661 (Washington, D.C.: Aug. 20, 2020).

where possible, to reduce their own "carbon footprint." For example, one airline has noted that "flight-shaming"—a term first coined in Sweden in 2017—could grow if the industry is seen as carbon intensive and not doing enough to reduce its climate impacts. Consumers may then start pursuing alternatives to flying, such as shifting to other transportation modes or replacing in-person business meetings to virtual meetings, as many did during the pandemic. One airline also noted that investors, policy groups, and customers may publicly pressure airlines to change airline policies to make more progress on achieving climate change goals. If a recently proposed federal rule change on disclosing climate-related risks is finalized, airlines and other companies would be required to disclose climate-related information that could make it more apparent what progress they have made regarding their climate change goals.[45]

Stakeholders we spoke to also noted that some corporate clients that are seeking to address their own climate risks are a key driver of interest in SAF. Specifically, corporations are increasingly looking for opportunities to reduce their carbon footprint, including in their corporate travel programs. For example, Rocky Mountain Institute and the Environmental Defense Fund launched The Sustainable Aviation Buyers Alliance in April 2021 to bring together aviation customers committed to reducing their air transport emissions through investment in SAF.[46] The alliance states its mission is to accelerate the path to carbon-neutral air transport by driving investment in SAF, catalyzing new and additional SAF production and technological innovation, and supporting member engagement in policymaking. In addition, United Airlines has 30 corporate customers that have agreed to fund the price premium associated with purchasing 7 million gallons of SAF, according to the airline's representatives. Airlines are also exploring whether customers may be willing to voluntarily pay for SAF's price premium.

Airlines have signaled their interest in SAF by signing offtake agreements with producers. Under these agreements, airlines agree to purchase in the future specified amounts of SAF if certain conditions are met, such as the SAF being available at a certain price. Such agreements are

[45]In April 2022, the Securities and Exchange Commission proposed a rule that would require publicly-traded companies to include certain climate-related risks, including a disclosure of greenhouse gas emissions, in their financial statements. *See* The Enhancement and Standardization of Climate-Related Disclosures for Investors, 87 *Fed. Reg.* 21334 (April 11, 2022).

[46]Founding companies include Bank of America, Boston Consulting Group, Boeing, Deloitte, JPMorgan Chase, McKinsey and Company, Microsoft, Netflix, and Salesforce.

commonly used in project finance as a way to demonstrate revenue stream for a project, which allows producers to obtain financing to build or expand facilities. Table 6 provides examples of recently announced agreements between U.S. airlines and SAF producers.

Table 6: Examples of U.S. Airline Offtake Agreements for Sustainable Aviation Fuel (SAF)

Airline	Date of announcement	SAF producer	SAF amount in agreement	SAF pathway	Anticipated delivery
Delta Airlines	March 2022	Gevo	525 million gallons (75 million gallons per year for 7 years)	Alcohol to Jet	Mid-2026
United Airlines	2021	Alder Fuels	1.5 billion gallons	SAF pathway not yet approved by ASTM	As early as 2024
Southwest Airlines	2021	Velocys	219 million gallons at a fixed price over a 15-year term	Fischer-Tropsch	As early as 2026
JetBlue Airways	2021	SG Preston	At least 670 million gallons of blended SAF to New York City area airports	Hydroprocessed esters and fatty acids (HEFA)	2023
American Airlines	2022	Gevo	500 million gallons (100 million gallons per year for 5 years)	Alcohol to Jet	2026

Source: GAO review of company press releases and other documentation. | GAO-23-105300

Previous offtake agreements by airlines, however, have failed to result in actual SAF deliveries within the announced timeframes and have instead been replaced with new offtake agreements. For example, in 2016, JetBlue Airways and SG Preston announced an agreement for more than 33 million gallons of blended SAF per year for at least 10 years, with the first delivery expected in 2019. Although no fuel has yet to be delivered, in 2021 JetBlue Airways announced a new agreement for 670 million gallons with SG Preston. Similarly, in 2019 Delta entered into an offtake agreement with Gevo for 10 million gallons of SAF, which were expected to be available between 2022 and 2023. In 2022, Delta and Gevo announced a new agreement for a total of 525 million gallons of SAF starting in 2026.

Stakeholders Said Policy Incentives Are a Key Factor Shaping the SAF Market

Stakeholders we spoke to before the passage of the Inflation Reduction Act of 2022 noted that SAF production has been encouraged through incentives provided by the California LCFS program and the federal RFS program.[47] Stakeholders noted that a benefit of these incentives is that they are "stackable," meaning they can be combined to help offset the high cost of SAF, which we discuss below.

- *California LCFS*: Over a third of stakeholders (18) identified the California LCFS program as a key driver for existing SAF production. Representatives from a major airline characterized the California LCFS as the most powerful incentive driving alternative fuel development in the world. As mentioned earlier, the program sets carbon intensity benchmarks for transportation fuels—fuels produced above the benchmark generate a deficit, while fuels produced below the benchmark generate a credit. When SAF was added to the program as an eligible fuel in 2019, it could only be an "opt-in" fuel, meaning SAF production can generate credits, but conventional jet fuel production does not generate deficits.[48] This is because, since federal law preempts states from regulating aviation emissions, the California LCFS cannot set a required carbon intensity for jet fuel.[49] The amount of credit depends on the feedstock used to produce the SAF. According to a California Air Resources Board official, SAF produced from used cooking oil receives a credit of about $1 per gallon, although this amount can fluctuate. As mentioned earlier, the only two major U.S. airports where SAF is regularly used are in California. Stakeholders noted because of this program, the production and use of SAF is expected to continue in California for the foreseeable future.
- *Federal RFS program*: Following the statutory inclusion of jet fuel in the RFS in 2007, SAF started generating RIN credits in 2016.[50] To be

[47]We also asked stakeholders about their perspectives on the SAF Grand Challenge and policy options for progress towards the Grand Challenge's production goals. Their perspective are summarized in appendix I.

[48]The SAF producer must also opt-in to the LCFS program and agree to be subject to all the requirements and provisions of the LCFS regulation in order to generate credits for its SAF.

[49]The Clean Air Act preempts states from adopting or attempting to enforce any standard related to emissions of any air pollutant from any aircraft or engine unless any such standard is identical to a standard applicable to such aircraft under Part B (Aircraft Emission Standards) of the Clean Air Act. 42 U.S.C. § 7573.

[50]The Energy Independence and Security Act expanded the definition of renewable fuel, which was previously limited to fuel replacing fossil fuel in a motor vehicle, and specifically included jet fuel as an additional renewable fuel. Pub. L. No. 110-140, § 201, 121 Stat. 1492, 1519 (2007) (codified at 42 U.S.C. § 7545(o)(1)(A)). This change was implemented in EPA regulations in 2010. 75 *Fed. Reg.* 14670 (Mar. 26, 2010)(40 C.F.R. Part 80).

an eligible fuel under the RFS, SAF pathways must be approved by EPA. Existing SAF pathways have been approved as advanced biofuels and achieve lifecycle greenhouse gas emissions at least 50 percent lower than those from conventional jet fuel. According to a stakeholder, the value of the RFS credit for SAF was about $2.50 per gallon as of March 2022, although these values fluctuate over time.

Stakeholders also noted that policies such as the RFS program and other factors favor renewable diesel production, making it difficult to incentivize producers to prioritize SAF production.[51] As mentioned earlier, SAF and renewable diesel can be made using the same feedstocks and refineries. Seventeen stakeholders noted that policy incentives give more credits to renewable diesel than SAF. For example, in the RFS program, SAF has a slightly lower equivalency value (1.6), which is the number used to determine how many RINs can be generated for a batch of renewable fuel, than non-ester renewable diesel (1.7), due to SAF's marginally lower energy content per gallon.[52] In addition, as mentioned earlier, SAF requires additional processing and energy, and thus costs more to produce, than renewable diesel. Consequently, for fuel made from the same feedstocks, renewable diesel production far exceeds that of SAF (see table 7). The U.S. Energy Information Administration has predicted production capacity for renewable diesel will grow in the coming years.

Table 7: Sustainable Aviation Fuel (SAF) Production Compared to Renewable Diesel Production

Millions of gallons

Year	SAF produced	Renewable diesel produced
2016	1.9	261.1
2017	1.7	274.5
2018	1.8	317.8
2019	2.4	439.2
2020	4.6	485.6
2021	5.1	619.7

[51]We did not evaluate the extent to which the provisions in the Inflation Reduction Act of 2022 differ between renewable diesel and SAF or how the law will affect incentives for the fuels relative to one another.

[52]When creating the rule, EPA determined the equivalency value for the different renewable fuels based on their energy content in comparison to the energy content of ethanol, and adjusted as necessary for their renewable content. This equivalency was developed when the RFS program was first established.

Year	SAF produced	Renewable diesel produced
2022	15.8	795.8

Source: Environmental Protection Agency. | GAO-23-105300

While the Inflation Reduction Act of 2022 does include provisions for SAF, full implementation of these efforts will take time, and it remains to be seen how the provisions will affect SAF production and price competiveness.

Lack of Price Competiveness with Conventional Jet Fuel and Challenges Bringing New Production Capacity Online Inhibit Market Growth

The high price of SAF relative to conventional jet fuel has been the primary factor inhibiting increased SAF production and use according to stakeholders we interviewed and reports we reviewed prior to the passage of the Inflation Reduction Act of 2022. According to these sources, SAF can cost anywhere from 2 to 8 times the price of conventional jet fuel. Because the aviation industry is highly competitive, key cost inputs such as fuel—which can account for more than a quarter of airlines' costs—affect profitability. Voluntarily purchasing SAF at a premium raises fuel costs for an airline and may make them uncompetitive with other airlines that do not purchase SAF. These additional fuel costs could also translate into higher flight prices that could reduce demand for air travel. We have previously found that past increases in jet fuel prices have contributed to airline industry losses, including the bankruptcy of small airlines.[53]

Stakeholders we spoke to identified other factors that make it challenging to bring new SAF production capacity online:

- **Technology risk for advanced fuels:** Although the technology to produce SAF from fats, oils, and greases using the HEFA pathway is relatively mature, there are no facilities in the U.S. currently commercially producing SAF using other pathways and feedstocks. As a result, there are no commercial projects to learn from in terms of expectations, results, or even design specifications regarding these more advanced SAF pathways. According to a clean energy investment organization we interviewed, certain more-nascent SAF production pathways seem stuck in early stages because the technologies are too expensive or risky to attract traditional investors.

[53]GAO, *Commercial Aviation: Airline Industry Contraction Due to Volatile Fuel Prices and Falling Demand Affects Airports, Passengers, and Federal Government Revenues*, GAO-09-393 (Washington, D.C.: Apr. 21, 2009).

- **Costs and long time frames of new SAF facilities**: SAF production facilities are often new, stand-alone projects that, according to stakeholders, can cost $1 billion to complete and involve a laborious process of development, planning, and construction. One stakeholder noted that this could result in a "Valley of Death" where financing runs out before the project generates revenue. One report we reviewed noted that due to limited engineering and operational experience and immature supply chains, technology risk could result in extended project installation periods and process instability.[54] According to stakeholders, projections for new SAF production facilities are often optimistic, aiming to be complete in a few years. Stakeholders say these facilities in reality take anywhere from 5 to 10 years to complete.
- **Feedstock costs and availability**: Feedstocks are a key cost component of SAF production. Stakeholders we spoke to noted that feedstocks for existing HEFA SAF production, such as soybean oil, are constrained and expensive due to high demand and competition with other uses. For more advanced biofuels, feedstocks such as municipal solid waste and woody biomass are plentiful and inexpensive but can involve expensive transportation, collection, and sorting issues. We have previously reported that the high costs of processing, handling, and transporting feedstocks constrain the production of advanced biofuels.[55]
- **Transportation concerns:** Several airline and airport stakeholders we interviewed expressed concerns about transporting SAF from the refineries—which are often located near the feedstock supply—to airports, which are in major population centers. For example, five stakeholders expressed concern with the ability to access existing transportation infrastructure such as pipelines that transport conventional jet fuel to transport SAF.[56] Seven stakeholders also expressed concern about the additional monetary costs or emissions needed to transport SAF to or from California—where SAF is likely to be sold due to the state's incentives.

[54]International Renewable Energy Agency, *Advanced Biofuels: What Holds them Back?* (Abu Dhabi: November 2019).

[55]GAO-17-108.

[56]On April 18, 2022, Colonial Pipeline announced its ability to accept customer nominations to ship SAF on its system. Colonial is a major pipeline that transports fuel from refineries on the Gulf Coast and directly delivers jet fuel to seven international airports on the east coast.

Federal Actions Have Supported SAF Production, but Agencies Lack Measures to Monitor Progress

Federally Funded R&D and Direct Financial Assistance Have Facilitated SAF Production

Federal agencies have supported SAF by funding R&D and providing direct financial assistance. This federal support has contributed to technology development, demonstration projects, improvements in processes, and the construction of new facilities. More specifically, federal R&D has helped achieve the following:

- **Develop SAF conversion pathways.** The HEFA technical pathway World Energy uses to produce SAF was initially developed under a 2007 Defense Advanced Research Projects Agency (DARPA) contract. In addition, DOE's Pacific Northwest National Laboratory collaborated with LanzaTech to develop an alcohol-to-jet pathway using ethanol as a feedstock. The laboratory licensed the technology to LanzaTech and DOE awarded the company a two-phase $19 million grant starting in fiscal year 2016 to support the construction of the Freedom Pines Fuels production facility in Soperton, Georgia. LanzaJet, a company founded by LanzaTech in 2020, is now the licensor of that alcohol-to-jet technology and operator of the Freedom Pines facility. Several companies have also announced projects using LanzaJet's technology to construct their own alcohol-to-jet SAF production facilities.
- **Demonstrate a SAF supply chain.** USDA awarded a $40 million grant for a collaborative project from 2011 through 2016 involving federal agencies, universities, and private companies that demonstrated a full supply chain for processing SAF from wood waste. This project included collecting the waste from mill and logging sites, processing the waste with USDA-developed techniques, producing isobutanol alcohol from the waste, and converting the isobutanol to SAF using Gevo's technology. Gevo also worked to secure the first ASTM approval for the alcohol-to-jet pathway in 2016. By demonstrating this supply chain and publishing the results, USDA provided future SAF producers with the opportunity to use lessons learned from the project when developing their own supply chains,

potentially reducing their costs.[57] In addition, securing the ASTM approval reduced the barrier to entry for other producers using the alcohol-to-jet pathway.

- **Support the ASTM approval process.** FAA has supported the development of SAF pathways by providing funding for research to improve the approval process of ASTM specifications for new SAF pathways. This includes a "fast track" option that allows fuels to receive ASTM approval with less testing—and therefore less expense to the producer—but is limited to a 10 percent blend. CAAFI, which receives funding from the FAA, also helps interested parties on a wide range of topics associated with research, development, and deployment of SAF. For example, CAAFI is available to consult with fuel producers to help them understand whether they are prepared to proceed with ASTM specification issuance for new fuels. This assistance can help producers avoid the potentially time-consuming and expensive prospect of seeking ASTM specification issuance before they are ready.

The federal government's direct financial assistance has helped support the construction of new SAF production facility projects. In 2014, under the Defense Production Act, the Department of Defense (DOD) awarded $210 million to three companies to construct biofuel production facilities.[58] Two of these companies, Fulcrum BioEnergy and Red Rock Biofuels, were expected to produce SAF and other biofuels.[59] DOE, USDA, and the Navy, in a 2011 memorandum of understanding, expressed doubt that the private sector would assume all of the risk of investing in these facilities because of the unproven technology involved and the competitive barriers posed by the established conventional fuels industry.[60]

[57]Department of Agriculture, *Production of 1,000 Gallons of Certified Biojet Fuel through Biochemical Conversion of Softwood Forest Residues*, FPL-GTR-278 (July 2020).

[58]See GAO, *Defense Energy: Observations on DOD's Investments in Alternative Fuels,* GAO-15-674 (Washington, D.C.: July 27, 2015). Title III of the Act—Expansion of Productive Capacity and Supply—allows military and civilian agencies to provide a variety of financial incentives to domestic firms to invest in production capabilities, so as to ensure that the domestic industrial and technological base is capable of meeting the national defense needs. *See generally* 50 U.S.C. §§ 4531-45344.

[59]The third company, Emerald Biofuels, was expected to produce 83 million gallons per year of renewable diesel and maritime fuels. As of January 2022, the company had not begun construction on its facility.

[60]Memorandum of Understanding between the Department of the Navy and the Department of Energy and the Department of Agriculture, June 2011.

The two companies receiving DOD financial assistance to produce SAF have yet to start commercial SAF production. Fulcrum BioEnergy and Red Rock Biofuels were expected to begin production with fuel available by 2018. As mentioned earlier, the Fulcrum BioEnergy and Red Rock Biofuels facilities anticipate producing 11 and 15 million gallons, respectively, of SAF and other renewable fuel. However, both projects have experienced delays. A Red Rock Biofuels representative told us that challenges included obtaining insurance and financing for the facility's construction, as well as supplier challenges, contributed to the delay. A Fulcrum BioEnergy representative attributed delays to engineering, procurement, and construction challenges, as well as supply chain issues and the COVID-19 pandemic.

Although Fulcrum BioEnergy has completed construction of its production facility, its commercial production of SAF remains several years away. In July 2021, Fulcrum BioEnergy announced the completion of construction of its first facility and in May 2022, announced the facility had successfully performed the first steps of the Fischer-Tropsch pathway, although additional steps are needed to produce SAF. Following this announcement, a Fulcrum BioEnergy representative told us the company would begin producing intermediate products for another company to produce renewable fuels. The representative stated that Fulcrum BioEnergy is aiming to produce its own SAF in 2025 or 2026 at the earliest, on the condition they procure additional equipment. Red Rock Biofuels has not announced when it will complete construction of its facility or begin SAF production.

The Federal Interagency Roadmap Does Not Identify Performance Measures to Monitor Progress toward SAF Grand Challenge Production Goals

In September 2022, DOT, DOE, and USDA, in coordination with EPA, published a SAF Grand Challenge Roadmap. The roadmap outlines a whole-of-government approach with coordinated policies and specific activities to support the Grand Challenge goals to produce 3 billion gallons of SAF per year by 2030 and 35 billion gallons per year by 2050.

In the roadmap, the agencies outline their plans across six action areas to support the SAF industry and stakeholders in achieving the Grand Challenge goals. Table 8 summarizes the six action areas and provides examples of agency activities within each action area, which are planned or ongoing. Several of the activities noted in the table, such as R&D and funding demonstration projects, are continuations of activities the agencies have engaged in for a number of years. In addition, the Inflation Reduction Act of 2022 included a DOT grant program that includes $245 million for projects that produce, transport, blend, or store SAF, which could cover several action areas below.

Table 8: The Six Action Areas in the Sustainable Aviation Fuel (SAF) Grand Challenge Roadmap and Examples of Agency Activities

Action area	Description	Examples of associated agency activities
Feedstock Innovation	Support and conduct feedstock R&D to reduce the cost, technology uncertainty, and risk of producing SAF; increase yield and sustainability; and optimize SAF precursors (i.e. ethanol and isobutanol)	In fiscal year 2022, the U.S. Department of Agriculture announced a $1 billion investment in Partnerships for Climate-Smart Commodities, and provided funding in 2022 to producers of agricultural and forestry products that use climate-smart practices
Conversion Technology Innovation	Support and conduct R&D on SAF through pilot scale to achieve technology improvements and carbon intensity reductions	In fiscal year 2022, the Department of Energy announced a $34.5 million funding opportunity to improve the science and infrastructure for converting waste into biofuels and help support the 2050 goal
Building Supply Chains	Support SAF production expansion both through R&D transitions from pilot to large-scale demonstration projects, and validating supply chain logistics, as well as through public-private partnerships and collaboration with regional, state, and local stakeholders	In fiscal year 2021, the Department of Energy awarded $64 million to 22 SAF and other biofuel producers, and in fiscal year 2022, announced it would award another $59 million to accelerate the production of biofuels, including SAF
Policy and Valuation Analysis	Provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF	According to the roadmap, the Department of Energy will update their study on the availability of potential feedstocks and continue to improve environmental models and data for SAF to evaluate scenarios and provide direction for greater SAF production
Enabling End Use	Facilitate SAF end use by supporting SAF R&D that addresses barriers to greater SAF deployment, such as more efficient testing, expansion of blending limits, and integrating SAF into existing infrastructure	The Federal Aviation Administration is funding research as part of its ongoing efforts to enable neat unblended SAF and SAF blends up to 100 percent
Communicating Progress and Building Support	Monitor and measure progress against SAF goals and communicate to the public the environmental, climate, and economic benefits of SAF	According to the roadmap, agencies will create a public database to track SAF facilities, production, and use

Source: GAO review of the Grand Challenge Roadmap and other agency documentation, as of December 2022. | GAO-23-105300

As stated in the roadmap, the agencies will form public-private implementation teams around the action areas to further develop and refine activities and timelines. This is intended to be the beginning of an evolving, collaborative, and dynamic process, according to the roadmap. Within each of the six action areas, the roadmap identifies workstreams that define critical topics to be addressed.

Agency officials note that multiple areas of the roadmap will involve monitoring progress of the Grand Challenge. For example, under the policy and valuation analysis action area, the roadmap identifies a workstream that will develop data and analytical tools to evaluate scenarios necessary to meet SAF Grand Challenge goals. In addition, as part of its action area to communicate progress and build support for SAF, the roadmap states the agencies will take a coordinated interagency approach to develop a publicly-available database that provides information on SAF production facilities, production volume, and end use. The roadmap also indicates methodology will be developed to estimate total SAF production, lifecycle CO_2 reductions, and other sustainability characteristics. However, the roadmap does not state how the agencies will determine whether they are making the progress needed over time to ensure they can meet the 2030 and 2050 production goals. Specifically, the roadmap does not identify performance measures that relate to the long-term Grand Challenge goals or the associated information the agencies would need to collect to be able to regularly measure performance.

According to agency officials from DOT, DOE, and USDA, the roadmap includes plans that are not yet fully developed, such as how they intend to develop a database to track and communicate progress on the SAF Grand Challenge goals. The roadmap indicates that refining the database to track Grand Challenge progress will be ongoing until 2024 and that agencies will update the roadmap approximately every two years. As we have previously reported, performance measures enable ongoing monitoring and reporting of progress toward pre-established goals and in this case should address the outcomes of the Grand Challenge goals.[61]

When we interviewed stakeholders about potential types of performance measures that could track the progress of SAF Grand Challenge goals, they said the goals were ambitious and to meet them would require significant and sustained progress. They identified different areas of focus for the agencies to consider for potential performance measures:

- **Planned production capacity measures**. Six stakeholders stated that it would be helpful to track planned SAF production capacity by monitoring the construction of new SAF facilities. Given the history of SAF producers failing to begin production by their announced targets, to the extent agencies were to simply compile publicized accounts, it would likely result in the collection of inconsistent information and optimistic projections of future SAF production. For example, some announcements give SAF capacity projections by the amount of blended fuel, which differ in blending ratios, while others give the amount in "neat," or unblended, SAF. Likewise, some announcements

[61]GAO, *Performance Measurement and Evaluation: Definitions and Relationships*, GAO-11-646SP (Washington, D.C.: May 2011).

give total capacity, which could include renewable diesel, while others are specific to SAF. In addition, since announcements are often optimistic, projections based on these announcements are also likely to be inaccurate. To better gauge when production capacity can be realistically expected, one renewable fuel investor stakeholder suggested that agencies could track when facilities achieve specific milestones, such as securing investment partnerships and completing construction. Meanwhile a SAF producer noted the agencies could weigh the veracity of SAF production announcements by examining the track record of the producer and the state of the technology being deployed. By developing measures to forecast future SAF production capacity, the agencies could have a clearer picture of whether progress towards production capacity increases are on track to meet the Grand Challenge goals.

- **Characteristics of SAF produced, such as feedstock used and lifecycle emissions reduction.** Three stakeholders suggested that the agencies could track SAF's progress by characteristics of SAF produced, such as emissions reductions achieved, in addition to gallons of SAF produced. One stakeholder told us that information similar to what California collects for its LCFS, including production facility location, feedstock type, and location where fuel is consumed, could help federal agencies and the public better understand the state of SAF production. Several federal agencies collect information on SAF production and use. For example, the Energy Information Administration collects production volume information from SAF producers but combines the amount of SAF produced with other renewable fuels for reporting purposes.[62] In addition, the EPA reports SAF production volumes, including the feedstocks used. When we spoke to DOT officials, they told us that they may consider data sources such as EPA SAF production data and voluntary data on SAF usage reported by airlines and others, but did not indicate whether performance measures would be used to track the information. By developing measures about the characteristics of SAF produced and used, the agencies could link developments in the SAF market to the progress they have made in the other roadmap activities.
- **SAF price relative to conventional jet fuel.** Eight stakeholders said that greater availability of market information such as SAF prices, feedstock prices, or information on the overall economics, including the value of different incentives, could help better understand where

[62]The Energy Information Administration collects more detailed information about petroleum-based fuels, including regional prices, production, transportation, and consumption. Authority for the Administration's data collection is under 15 U.S.C. § 772.

SAF stands in terms of potential greater production and use. The Bureau of Transportation Statistics collects information from airlines on their fuel costs and consumption, but this does not include information about SAF. In addition, five stakeholders told us that it can be difficult to obtain information on the SAF market since it is small and information may be business proprietary. By developing measures that publicly report such information, the agencies could track the extent to which the key barrier to greater SAF production—the higher price of SAF relative to conventional jet fuel and other renewable fuels—remains.

We have previously reported that interagency collaborative efforts can benefit from creating performance measures to monitor, evaluate, and report on the results of their efforts. Doing so allows for identifying areas for improvement; failing to do so may place these efforts at risk of failing to achieve their desired outcomes.[63] Monitoring and reporting on agencies' performance is needed to improve their efforts and hold them accountable to their joint goals. For performance measures to be of most use, they should be developed early in the life of the Grand Challenge to allow regular progress to be monitored over the coming decades. Once the measures are established, the agencies can then determine what information sources are best suited to track the measures over time.

Without first establishing performance measures, it is not clear how the efforts the agencies plan to pursue as part of the roadmap, such as the database, will enable the agencies to accurately monitor progress relative to the Grand Challenge goals or identify areas where more progress may need to be made. Therefore, agencies run the risk of repeating history by not achieving their goals, given that the federal government did not achieve or track progress toward its prior—and far less ambitious—SAF goal. As noted earlier, in 2012, FAA set a goal for U.S. airlines to use 1 billion gallons of SAF per year by 2018. In 2016, the federal government published an interagency strategy for increasing production of SAF, but the strategy did not include any means for tracking the agencies' progress.[64] The 1-billion gallon goal was not achieved and has been replaced by the SAF Grand Challenge to produce 3 billion gallons of SAF by 2030 and 35 billion gallons of SAF by 2050, suggesting that better

[63]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sep. 27, 2012); and *Managing for Results: Implementation approaches Used to Enhance Collaboration in Interagency Groups*, GAO-14-220 (Washington, D.C.: Feb. 14, 2014).

[64]National Science and Technology Council, *Federal Alternative Jet Fuels Research and Development Strategy* (June 2016).

performance measurement will be needed to better track progress towards achieving the Grand Challenge goals.

In addition to helping track and report on progress towards the Grand Challenge goals, establishing performance measures can provide several benefits. For example:

- **Evaluating agency actions and policy impact.** By developing performance measures now, the agencies have an opportunity to track SAF commercial development progress in the intervening years before 2030 and 2050, and if needed, adjust their activities and efforts to best match the needs of the market and industry. The agencies would also have information with which to inform the aviation industry, policymakers, and the public if SAF progress is off track. In addition, with the new SAF provisions contained in the Inflation Reduction Act of 2022, the agencies can better track the effect of these provisions on SAF production. Doing so could help policymakers make better informed decisions when allocating resources among efforts to reduce overall greenhouse gas emissions.
- **Gauging the extent to which SAF is poised to play a role in reducing aviation greenhouse gas emissions**. Developing and reporting on measures could help Congress and the public understand the role that SAF can play in achieving the aviation industry's SAF and emissions goals. As mentioned earlier, according to IATA, an estimated 65 percent of the aviation sector's emissions reductions will need to come from SAF to achieve reach net zero aviation by 2050. If SAF production is not on a path to reach the Grand Challenge's targets, the aviation industry and the public can use this information to better evaluate whether it is realistic to expect the aviation sector to reach net zero by 2050.
- **Holding the agencies and aviation industry accountable**. Reporting progress on measures also helps the public hold agencies and the aviation industry accountable to their goals. The federal government has not met its previous goal of 1 billion gallons of SAF by 2018. In addition, as mentioned earlier, several aviation industry stakeholders and airlines have made SAF use and emissions reductions goals and offtake agreements with SAF producers for over 2 billion gallons of SAF. However, federal agencies and the aviation industry have not regularly reported on the progress they have made towards these goals and agreements. Furthermore, industry estimates for future SAF production have been routinely optimistic and have often failed to materialize. This situation has raised concerns regarding "greenwashing," or unsubstantiated and exaggerated

corporate sustainability claims. Establishing performance measures and reporting on SAF progress could arm the public with better information with which to evaluate government and corporate claims regarding the extent to which SAF is positioned to provide emissions reductions benefits to the aviation sector.

Conclusions

Greater use of SAF is the cornerstone of the aviation industry's planned efforts to reduce its greenhouse gas emissions and reach its goal of net zero aviation by 2050. DOT, DOE, and USDA have published a roadmap to guide their efforts to increase SAF production and achieve the SAF Grand Challenge goals. However, these agencies have not yet established performance measures to track progress towards these federal goals. Developing performance measures now will allow the agencies to evaluate their efforts to meet Grand Challenge goals, including the effect of the SAF provisions of the Inflation Reduction Act of 2022, and make adjustments needed to meet the desired outcomes. Performance measures will also enable the agencies to communicate to Congress and the public on the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals.

Recommendations for Executive Action

We are making three recommendations—one to each of the three agencies responsible for the Grand Challenge Roadmap—DOT, DOE, and USDA.

The Secretary of Transportation should coordinate with DOE and USDA to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals. (Recommendation 1)

The Secretary of Energy should coordinate with DOT and USDA to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals. (Recommendation 2)

The Secretary of Agriculture should coordinate with DOT and DOE to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which

SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals. (Recommendation 3)

Agency Comments and Our Evaluation

We provided a draft of this product to DOT, DOE, USDA, and EPA for comment. In comments reproduced in appendixes III and V, DOT and USDA concurred with our recommendations. DOT noted that successful implementation of the Grand Challenge is of critical importance to meeting national and industry goals and stated it will provide a more detailed response to the recommendation within 180 days of the final report issuance. USDA said it anticipates working with DOE and DOT to develop and communicate performance measures with the next planned roadmap progress report.

DOE, in comments reproduced in appendix IV, agreed that tracking progress is important for the successful management of the Grand Challenge. It added that existing performance measurement activities currently specified in the roadmap will meet the intent of the recommendation. DOE also indicated the recommendation was currently completed. DOE stated initial activities included in roadmap will provide data collection and analytical capability to enable the agencies to measure progress. As DOT and USDA's letters also mentioned, DOE identified areas of the roadmap that will be relevant for measuring and reporting progress. DOE noted that it will continue to coordinate with USDA and DOT on the implementation of the roadmap and intends to release annual progress reports in September of each year.

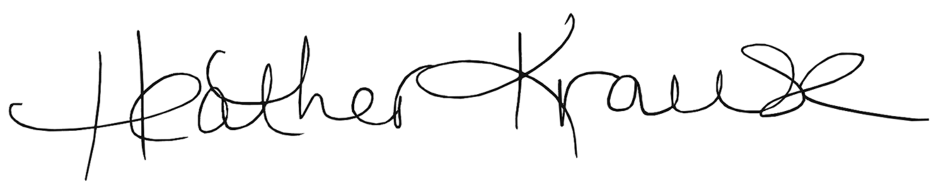
The actions DOE describes in its letter are initial steps to developing performance measures but are not sufficient to close the recommendation at this time since they do not specify such measures or incorporate them into the roadmap. In our report, we acknowledge the actions DOE describes in its letter. For example, we report that agency officials said that multiple areas of the roadmap will involve monitoring progress of the Grand Challenge. We also note that according to agency officials, the roadmap includes plans that are not fully developed and that agencies will provide updates to the roadmap. However, we also state that the current roadmap does not indicate how the agencies will determine whether they are making the progress needed over time to ensure they can meet the 2030 and 2050 production goals. Specifically, the roadmap does not identify performance measures that relate to the Grand Challenge long-term goals or the associated information the agencies would need to collect to be able to measure performance regularly.

For performance measures to be of most use, they should be developed early in the life of the Grand Challenge to allow regular progress to be monitored over the coming decades. Without performance measures, it is not clear how the efforts the agencies plan to pursue as part of the roadmap will enable the agencies to accurately monitor progress relative to the Grand Challenge goals or identify areas where more progress may need to be made.

The EPA provided a technical comment that we incorporated as appropriate.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 4 days from the report date. At that time, we will send copies to the appropriate congressional committees and other interested parties. In addition, this report is available at no charge on our website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or KrauseH@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix VI.



Heather Krause
Director, Physical Infrastructure

Appendix I: Stakeholder Views on Potential SAF Policy

We spoke to 43 stakeholders representing a range of vantage points of the sustainable aviation fuel (SAF) industry before the passage of the Inflation Reduction Act of 2022 on August 16, 2022.[1] We asked stakeholders about their perspectives on the SAF Grand Challenge goals and policy options that could spur SAF production to meet these goals.[2] Twenty-six stakeholders noted that the production volumes of the Grand Challenge goals were ambitious, but could be achieved with policy support. Stakeholders said that to be effective, policy support would need to address the barriers to greater SAF production, such as lowering the cost of SAF to be competitive with other biofuels and more cost-effective for airlines to purchase and mitigating investment risk in new SAF production. Stakeholders also said that to achieve the Grand Challenge goals, likely more than one policy option would need to be implemented.

Nearly all stakeholders (42/43) we interviewed identified a SAF tax credit as an effective policy option, noting it could offset the higher cost of SAF and spur production in the short-term.[3] Stakeholders noted advantages and disadvantages of a SAF tax credit in the following areas:

- **Targeted to SAF.** Stakeholders said that a benefit to a tax credit is that it can complement existing policies and incentives such as the RFS and California LCFS programs to help offset the high cost of SAF. According to stakeholders, a tax credit could be useful to initiate increased production, and we previously reported that there is a precedent to using tax credits to encourage renewable energy such as wind and solar.[4] For example, we found that the long-term ethanol tax credit was important in creating a profitable ethanol industry when

[1]Pub. L. No. 117-169, 136 Stat. 1818. See appendix II for a list of these stakeholders, which included SAF producers; airports; U.S. commercial airlines and associations; aviation industry stakeholders and suppliers; feedstock producers; conventional jet fuel producers and infrastructure owners; environmental organizations; renewable energy investment/ finance organizations; and SAF policy, collaboration, or market analysis entities or academics.

[2]When we spoke to stakeholders, policy for SAF was proposed in various legislation, such as a SAF tax credit in the Build Back Better Act, H.R. 5376, 117th Cong. § 136203 (2021).

[3]One stakeholder, an environmental organization, did not support federal policy that encouraged SAF production because they said that many feedstocks being considered would cause significant climate or environmental harm if devoted to fuel production, and because EPA should more stringently regulate aircraft emissions instead.

[4]GAO-14-407.

the industry had to invest in production facilities.[5] However, the purchase of SAF by airlines would still be voluntary and may not reach desired levels of use industry-wide, according to two stakeholders. In addition, five organizations from the U.S. trucking industry wrote a letter to Congress expressing concern over a SAF-specific tax credit, stating that it would create competition over feedstocks and would achieve emissions reductions at a higher cost to the taxpayer than renewable diesel.[6] Similarly, the International Council on Clean Transportation has noted the climate benefits of low-carbon fuel are the same whether that fuel is used in the road or aviation sectors. As a result, the organization has suggested policies that promote low-carbon fuel regardless of the end-use sector will be the most effective at developing the advanced fuel industry.[7]

- **Impact on the commercial aviation industry and emissions.** A tax credit could help airlines purchase SAF without raising ticket prices or adding economic hardship to the aviation industry, according to stakeholders. Because a SAF tax credit would be subsidized by the government in the form of forgone tax revenue, taxpayers, some of whom may not fly, would bear the cost to help the aviation industry reduce its greenhouse gas emissions. Because a tax credit could help keep the cost of flying down, demand for flying could increase, which could undercut emissions reductions gained from using SAF. In addition, we have previously reported that tax credits may result in government funds subsidizing production that would have happened anyway rather than spurring new production.[8]
- **Encourage innovation.** According to stakeholders, a tax credit could encourage SAF innovation and improvements in greenhouse gas emissions reductions over time if designed as performance-based,

[5]We noted the tax credit was less important after capital investments were made, the industry was mature, and ethanol could be profitable. See GAO, *Biofuels: Potential Effects and Challenges of Required Increases in Production and Use*, GAO-09-446 (Washington, D.C.: Aug. 25, 2009).

[6]Five organizations, including the American Trucking Associations, National Association of Convenience Stores, National Association of Truckstop Operators, SIGMA: America's Leading Fuel Marketers, and Truckload Carriers Association, wrote a letter to Congress in September 2021.

[7]The International Council on Clean Transportation, *Long-term aviation fuel decarbonization.*

[8]GAO, *Tax Expenditures: Background and Evaluation Criteria and Questions*, GAO-13-167SP (Washington, D.C.: Nov 29, 2012). And also see, Congressional Budget Office, *Federal Support for the Development, Production, and Use of Fuels and Energy Technologies* (November 2015).

such as establishing an emissions threshold and providing an additional incentive for each percentage above the threshold. A performance-based requirement could also encourage the SAF market to determine the best technologies and feedstocks to reduce greenhouse gas emissions.

- **Provide long-term policy certainty.** If a tax credit is not authorized for a sufficiently long duration, it may not provide the policy certainty that investors and producers need to increase SAF production, according to stakeholders. Stakeholders noted that a tax credit should provide policy certainty, such as for 10 years. As noted previously, stakeholders said SAF production facilities can take anywhere from 5 to 10 years to complete. We previously reported that stakeholders pointed out that traditionally, tax credits have frequently expired and been reinstated, which leads to uncertainty and makes the incentive less effective in spurring production long-term.[9]

Although stakeholders generally expressed support for tax credits to spur SAF production, fourteen (14/43) also noted that more than one policy would likely be needed to achieve the widespread use of SAF envisioned by the Grand Challenge. A tax credit was commonly referred to as a “carrot” by stakeholders, because it provides an incentive to producers to voluntarily produce and airlines to voluntarily buy SAF, and it helps lower the cost of SAF. Other policies— such as a SAF mandate, a national low carbon fuel standard (LCFS), or a carbon tax— are commonly referred to as policies with a “stick” by stakeholders, because they involve requirements for using or producing low carbon fuels such as SAF or penalties for using or producing fossil fuels, or both (see table 9).

Table 9: Policies Other Than Tax Credits Stakeholders Mentioned that Could Encourage Sustainable Aviation Fuel (SAF) Use or Achieve Broader Greenhouse Gas Emissions

Policy Option	Definition
SAF Mandate	Requires airlines to use a certain volume of SAF, such as a mandated percentage of total jet fuel use.
National Low Carbon Fuel Standard (LCFS)	Sets a carbon intensity threshold for fuels—fuels above that threshold receive deficits, while fuels below the threshold receive credits. The carbon intensity threshold can be lowered over time to incentivize continual improvement in greenhouse gas emissions.
Carbon Tax	Puts a price on carbon and requires the emitters of greenhouse gases to pay for the damage of those emissions.

Source: GAO analysis of interviews and other documents. | GAO-23-105300

[9]GAO-14-407.

SAF Mandate

Almost a third of stakeholders (13/43) said that a mandate requiring airlines to use a certain volume of SAF could also be an effective policy option to spur SAF production. Stakeholders noted a mandate provides a guaranteed demand signal to SAF producers and investors. As noted previously, the European Union is considering a proposal that would impose a SAF blending mandate.

Eight stakeholders said that a SAF tax credit and mandate to airlines could work together to provide a strong demand signal to the market by providing an incentive to help with cost and a requirement for a greater number of airlines to use SAF. Recent reports on SAF also suggested that policies directed at mandating SAF use should first be preceded by policy to increase SAF production.[10] At the time we spoke to stakeholders, 10 of them pointed out that the U.S. SAF market was not ready for a mandate. According to four stakeholders, if a mandate were imposed before the market was ready, it could further increase the cost of SAF.

Another possible advantage of implementing a mandate along with a tax credit is that the tax credit can help incentivize innovation in fuels, thus making better quality fuels available to the market if a mandate is imposed. Stakeholders noted that a downside to a SAF mandate on its own is that it is typically volumetric, therefore the focus is on volume required rather than greater greenhouse gas emissions reduction. A report from the International Council on Clean Transportation stated that a SAF mandate will likely result in the production of the type of SAF most commercially available (currently, HEFA) without encouraging greater production and use of feedstocks and technology that could lead to greater greenhouse gas reductions.[11] However, one stakeholder said that by introducing a mandate along with a tax credit that encourages innovation, this approach could incentivize the production of higher quality fuels for airlines to purchase to meet the mandate.

According to stakeholders, a mandate could increase the cost of flying, as airlines would be required to purchase SAF, which is currently more

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[10]See International Air Transport Association, *Fact Sheet: EU and US policy approaches to advance SAF production*, (2021); and Atlantic Council, *Sustainable Aviation Fuel Policy*.

[11]The International Council on Clean Transportation, *Long-term aviation fuel decarbonization*.

expensive than conventional jet fuel. Three stakeholders pointed out that while airlines may pass the increased cost on in the form of raised ticket prices, it would be evenly applicable across U.S. airlines, thus removing the competitive disadvantage of using SAF. Although a decreased demand for flying from higher ticket prices could contribute to greater greenhouse gas emissions reductions, it could also affect the economic health of the U.S. aviation industry.

National Low Carbon Fuel Standard or Carbon Tax

A quarter of stakeholders (11/43) identified an LCFS program or a carbon tax as broader policy options designed to let the market determine the most cost-effective methods to reduce overall greenhouse gas emissions and could potentially affect SAF production. We previously reported that, according to several stakeholders, either an LCFS or a carbon tax was a better policy framework alternative to the RFS to encourage greater greenhouse gas emissions reductions.[12] According to stakeholders, either policy options could help reduce the cost advantage that jet fuel currently has over SAF by raising the cost of conventional jet fuel. However, both policy options raise the potential for broad economic impact by increasing the costs of all transportation fuels.[13] In the case of air travel, airlines and passengers could pay for “the true costs of flying,” which would be reflected in higher ticket costs. This approach in turn could make the cost of flying more expensive, potentially reducing demand for flying, therefore reducing aviation greenhouse gas emissions.

[12]GAO-17-94.

[13]See Congressional Research Service, *A Low Carbon Fuel Standard: In Brief*, (July 2021); Congressional Research Service, *Attaching a Price to Greenhouse Gas Emissions with a Carbon Tax or Emissions Fee: Considerations and Potential Impacts*, (March 2019); and Gilbert E. Metcalf, Annual Review of Resource Economics, *Carbon Taxes in Theory and Practice* (June 2021).

Appendix II: List of Stakeholders GAO Interviewed, by Category

Table 10: List of Stakeholders GAO Interviewed by Category

Category	Stakeholder
SAF producers	Advanced Biofuels Association (ABFA)
	Neste
	World Energy, LLC
	Fulcrum BioEnergy
	Gevo
	Alder Fuels
	LanzaTech and LanzaJet
	Red Rock Biofuels
Airports	Port of Seattle/ Seattle-Tacoma International Airport
	Dallas/Fort Worth International Airport
	Los Angeles International Airport
	San Francisco International Airport
U.S. commercial airlines and associations	Airlines for America
	United Airlines
	Alaska Airlines
	JetBlue Airways
Aviation industry stakeholders and suppliers	Aerospace Industries Association
	National Business Aviation Association
	Honeywell
Feedstock producers	Waste Management
	American Soybean Association
	National Corn Growers Association
	National Alliance of Forest Owners
Conventional jet fuel producers and infrastructure owners (pipelines, fueling)	Shell Aviation
	Chevron
	World Fuel Services
	Kinder Morgan
Environmental organizations	Environmental Defense Fund
	National Wildlife Federation
	Center for Biological Diversity
	The International Council on Clean Energy (ICCT)
Renewable energy investment/ finance organizations	Breakthrough Energy
	US Renewables Group
	New Energy Risk
	Goldman Sachs

Category	Stakeholder
SAF policy, collaboration, or market analysis entities or academics	Commercial Aviation Alternative Fuels Initiative (CAAFI)
	The Aviation Sustainability Center (ASCENT)
	California Air Resources Board (CARB)
	Mike McCurdy, ICF
	Fred Ghatala, Advanced Biofuels Canada
	Gilbert E. Metcalf, Tufts University
	James Stock, Harvard University
	Madhu Khanna, University of Illinois

Source: GAO. | GAO-23-105300

Appendix III: Comments from the Department of Transportation

U.S. Department of Transportation
Office of the Secretary of Transportation

Assistant Secretary for Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

February 16, 2023

Heather Krause
Director, Physical Infrastructure Issues
U.S. Government Accountability Office
441 G Street NW
Washington, DC 20548

The Federal Aviation Administration is committed to the safe, efficient, and environmentally sound operation of the nation's air transportation system. The Department has worked closely with industry and stakeholders for more than a decade to investigate and facilitate the development and safe integration of sustainable aviation fuel (SAF). In combination with efficiencies from new technology and operations, SAF represents the best near-term technology to rapidly reduce greenhouse gas emissions from aviation. Successful implementation of the SAF Grand Challenge in partnership with the United States Departments of Energy (DOE) and Agriculture (USDA) is of critical importance to meeting national and industry goals. DOT, DOE, and USDA have published a roadmap to guide efforts to increase SAF production and achieve the SAF Grand Challenge goals. Initial activities included in the roadmap will provide data collection and analytical capability to enable the agencies to measure progress and impact. Areas of the roadmap that will successfully measure, guide and report progress include:

- Workstream **PA.2. Conduct Techno-Economic and Production Potential Analysis** coordinates, expands, and refines modeling capabilities across multiple agencies to evaluate opportunities and scenarios necessary to meet the SAF Grand Challenge goals.

- Workstream **CP.3. Measure Progress of the SAF Grand Challenge** focuses on a coordinated interagency approach to monitoring and publicly reporting progress toward the SAF Grand Challenge goals.

Upon review of GAO's draft report, the Department concurs with GAO's recommendation to coordinate with DOE and USDA to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals. We will provide a detailed response to the recommendation within 180 days of the final report issuance.

We appreciate the opportunity to respond to the GAO draft report. Please contact Gary Middleton, Audit Relations and Program Improvement, at (202) 366-6512 with any questions or requests for additional information.

Philip A. McNamara
Assistant Secretary for Administration

Appendix IV: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

March 10, 2023

Ms. Heather Krause
Director, Physical Infrastructure
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Ms. Krause:

The Department of Energy (DOE) welcomes the opportunity to respond to the action recommended by the U.S. Government Accountability Office (GAO) in the draft report titled, "*Sustainable Aviation Fuel: Agencies Should Track Progress Toward Ambitious Federal Goals* (GAO-23-105300)." DOE's Office of Energy Efficiency and Renewable Energy (EERE), Bioenergy Technologies Office (BETO) has reviewed the report and the recommendation to DOE. DOE appreciates GAO's analysis relating to the implementation of the Sustainable Aviation Fuel Grand Challenge (SAF-GC). DOE agrees that performance measurement is important for the success of the SAF-GC and, as described in the enclosure, has already taken steps to define performance measure in the Grand Challenge Roadmap.

GAO should direct any questions concerning DOE's response to Valerie Reed, Director, Bioenergy Technologies Office, at (202) 586-8014.

Sincerely,

FRANCISCO MORENO Digitally signed by FRANCISCO MORENO
Date: 2023.03.10 17:50:24 -05'00'

Alejandro Moreno
Acting Assistant Secretary
Deputy Assistant Secretary for
Renewable Power
Energy Efficiency and Renewable Energy

Enclosure

ENCLOSURE

GAO Recommendation:

The Secretary of Energy should coordinate with DOT and USDA to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals (Recommendation 2).

Management Response:

DOE agrees that accurate tracking of our progress is important for the successful management of the Grand Challenge and considers that existing performance measurement activities currently specified in the roadmap will meet the intent of this recommendation. DOE has and will continue to coordinate with USDA and FAA on implementation of the roadmap and intends to release annual progress reports with USDA and FAA in September of each year. Initial activities included in the roadmap will provide data collection and analytical capability to enable the agencies to measure progress and impact. Two areas of the roadmap will be relevant for successfully measuring, guiding, and reporting progress:

- Workstream **PA.2. Conduct Techno-Economic and Production Potential Analysis** will coordinate, expand, and refine modeling capabilities across multiple agencies to evaluate opportunities and scenarios necessary to meet the SAF Grand Challenge goals. Results from these activities will be available to guide decision makers on expanding SAF production in a manner that carefully considers GHG reductions, cost of production, and policy needs.
- Workstream **CP.3. Measure Progress of the SAF Grand Challenge** will focus on a coordinated interagency approach to monitoring and publicly reporting progress toward the SAF Grand Challenge goals. This will include tracking feedstock to SAF production and use, estimating total SAF production, life cycle CO2 reductions, and other characteristics. The information-sharing system will prioritize ease of use for public accessibility.

Estimated Completion Date: Completed

Appendix V: Comments from the Department of Agriculture

USDA United States Department of Agriculture | Research Education Economics | Office of the Under Secretary | Room 216W Jamie L. Whitten Building Washington, DC 20250-0110

February 28, 2023

Dr. Heather Krause
Director, Physical Infrastructure Issues
U.S. Government Accountability Office
441 G Street NW
Washington, DC 20548

Dear Ms. Krause:

The U.S. Department of Agriculture (USDA) appreciates the opportunity to respond to the U.S. Government Accountability Office (GAO) draft report "Sustainable Aviation Fuel GAO-23-105300" dated March 2023. The Department of Agriculture (USDA) has worked closely with industry and stakeholders for more than a decade to investigate and facilitate the development and safe integration of sustainable aviation fuel (SAF). In combination with efficiencies from new technology and operations, SAF represent the best near-term technology to rapidly reduce greenhouse gas emissions from aviation. Successful implementation of the SAF Grand Challenge in partnership with Department of Energy (DOE) and Department of Transportation (DOT) Federal Aviation Administration (FAA) is of critical importance to meeting national and industry goals.

USDA generally agrees with the findings in the GAO draft report. The GAO report recommends that the agencies implementing the Grand Challenge work together to establish performance measures to track progress toward the ambitious goals of the Grand Challenge. The General Accounting Office (GAO) recommended and included feedback from stakeholders that the agencies track measures focused on 1) planned production capacity, 2) characteristics of SAF including feedstocks and lifecycle emissions reductions and, 3) information on SAF price relative to conventional jet fuel, feedstock prices and impact of incentives. Accurate tracking of our progress is indeed fundamental to the successful management of the Grand Challenge.

The GAO report recommendation is aligned with the intent and thinking on the part of the agencies responsible for implementing the roadmap. Initial activities included in the roadmap will provide data collection and analytical capability to enable the agencies to measure progress and impact. Two areas of the roadmap will be relevant for successfully measuring, guiding, and reporting progress:

- Workstream **PA.2. Conduct Techno-Economic and Production Potential Analysis** will coordinate, expand, and refine modeling capabilities across multiple agencies to evaluate opportunities and scenarios necessary to meet the SAF Grand Challenge goals. Results from these activities will be available to guide decision makers on expanding SAF production in a manner that carefully considers greenhouse gas (GHG) reductions, cost of production, and policy needs.

- Workstream **CP.3. Measure Progress of the SAF Grand Challenge** will focus on a coordinated interagency approach to monitoring and publically reporting progress toward the SAF Grand Challenge goals. This will include tracking feedstock to SAF production and use, estimating total SAF production, life cycle CO2 reductions, and other characteristics. The information-sharing system will prioritize ease of use for public accessibility.

Upon review of GAO's draft report, the Department concurs with the recommendation directed to the Secretary of Agriculture to coordinate with DOE and DOT-FAA to develop and incorporate into the Grand Challenge Roadmap performance measures that enable the agencies to evaluate their actions and the effect of policy on SAF production and communicate the extent to which SAF is poised to contribute to larger aviation greenhouse gas emissions reduction goals. Working with DOE and DOT-FAA we anticipate development and communication of these measures with the next planned roadmap progress report.

We appreciate the opportunity to review and respond to the GAO draft report. Please contact Dr. William Goldner at (202) 360-0916 with any questions or if GAO would like to obtain additional details about these comments.

Sincerely,

Chavonda Jacobs-Young

Chavonda Jacobs-Young, Ph.D.
Under Secretary, Research, Education, and Economics
USDA Chief Scientist

Appendix VI: GAO Contact and Staff Acknowledgments

GAO Contacts

Heather Krause, (202) 512-2834 or KrauseH@gao.gov

Staff Acknowledgments

In addition to the contact named above, Jonathan Carver (Assistant Director), Emily Larson (Analyst in Charge), Paul Aussendorf, Melanie Maralit Diemel, Jaci Evans, Quindi Franco, Josh Garties, Delwen Jones, Jessica Lucas Judy, Chi L. Mai, Amanda B. Parker, Kristin Petroff, Kelly Rubin, Frank Rusco, MaryLynn Sergent, Gretchen Snoey, Karla Springer, Jennifer Stratton, Janet Temko-Blinder, Joseph Thompson, Sarah Veale, Jack Wang, and Alicia Wilson made key contributions to this report.

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