Climate-Tech to Watch: Sustainable Aviation Fuel

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Sustainable aviation fuel (SAF) will play the most significant role in meeting President Biden's goal of a zero-carbon aviation sector by 2050, but significant progress must be made to scale up production and bring down costs.

KEY TAKEAWAYS

- Commercial aviation accounted for 2.4 percent of global carbon dioxide (CO_2) emissions in 2018, and emissions are set to triple by 2050 if policies are not adopted to reduce them.
- Few decarbonization options are available for the aviation industry, and they are costly. Technologies such as batteries and liquid hydrogen fuel are far from commercially ready for this application.
- SAF, a type of jet fuel made from sustainable feedstocks, is already available on a limited commercial scale. It can be used in existing aircraft to curb emissions in the near term without significant changes to aircraft design and infrastructure.
- The most widely available type of SAF, made from waste oils and fats, faces significant feedstock constraints. Progress is being made in the United States and globally to demonstrate the commercial viability of other pathways.
- Recently implemented measures such as tax credits for SAF production will encourage scale-up and bring down costs, but ambitious targets remain well out of reach.
- Meeting these targets will require significant increases in research, development, and demonstration (RD&D) investment by the federal government as well as sustained industry leadership and international cooperation.

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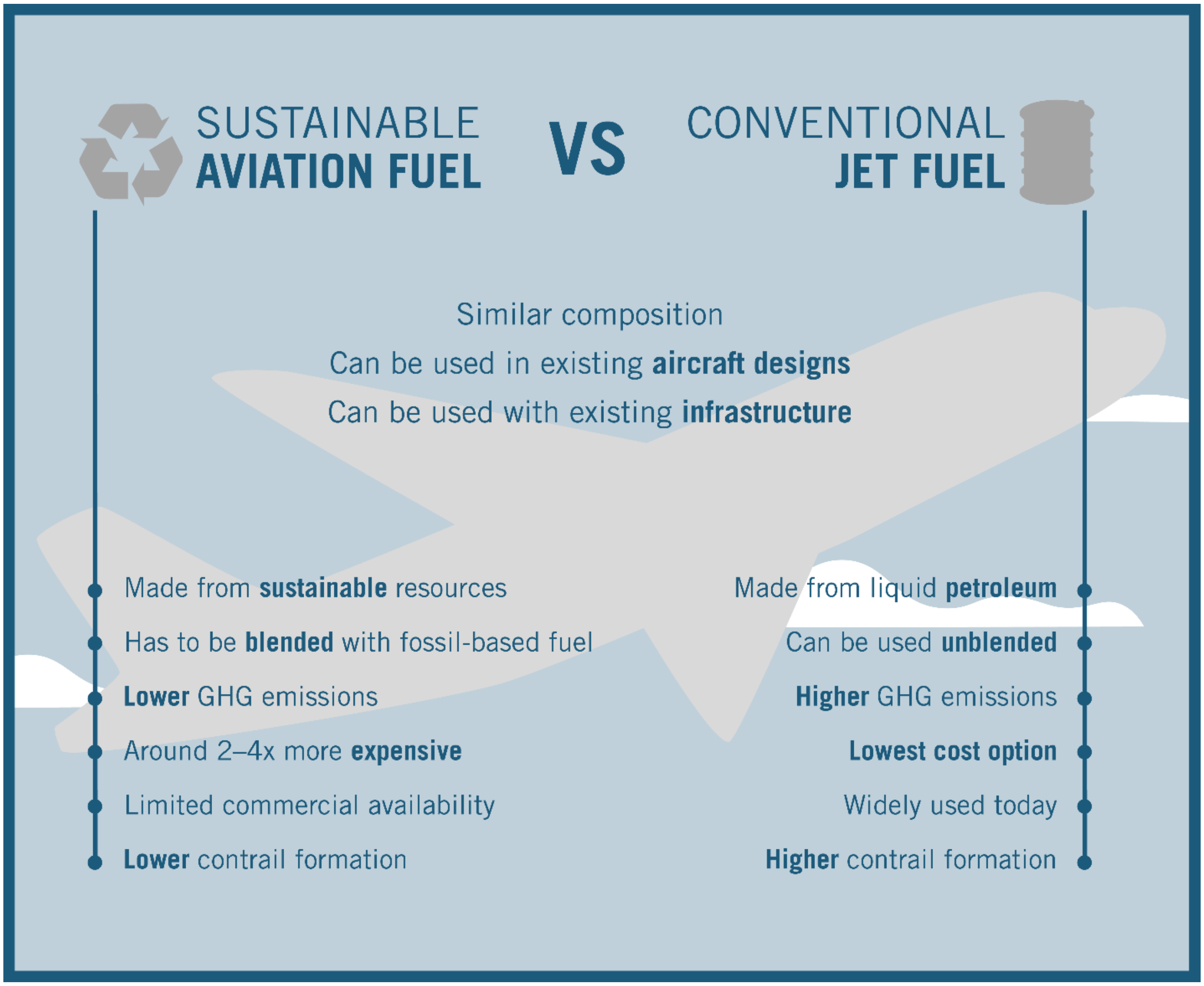


SUSTAINABLE AVIATION FUEL
VS
CONVENTIONAL JET FUEL
Similar composition
Can be used in existing aircraft designs
Can be used with existing infrastructure
Made from sustainable resources
Has to be blended with fossil-based fuel
Lower GHG emissions
Around 2–4x more expensive
Limited commercial availability
Lower contrail formation
Made from liquid petroleum
Can be used unblended
Higher GHG emissions
Lowest cost option
Widely used today
Higher contrail formation

WHAT IS IT?

Sustainable aviation fuel (SAF) is jet fuel produced from sustainable feedstock, usually waste resources, renewable biomass, and captured carbon. It has a much lower carbon footprint than do fossil-based jet fuels and is considered a “drop-in” fuel, meaning it can be blended with other fuel types to reduce emissions from aviation without any changes to aircraft design or existing infrastructure.

ROLE OF SAF IN THE TRANSITION TO CLEAN ENERGY

In 2018, commercial aviation accounted for an estimated 2.4 percent of global CO_2 emissions. As air travel returns to pre-pandemic levels and growth rates, especially in developing nations, emissions from the aviation sector are expected to triple by 2050.[1]

Aviation is one of the hardest-to-abate sectors. Few decarbonization options are available, and they are costly.[2] Technologies such as batteries and liquid hydrogen fuel are far from commercially- ready for this application—due to challenges such as storage of liquid hydrogen on aircraft—and are unlikely ever to be able to power large or long-haul flights. (See table 1.) SAF, which is already available in modest amounts on a commercial scale, may offer a way to curb emissions using existing aircraft designs and infrastructure if costs decline and production capacity increases. The International Air Transport Association (IATA) estimates that as much as 65 percent of the emissions reductions needed to reach net zero by 2050 could come from replacing conventional jet fuel with SAF.[3]

Table 1: Where low- and zero-carbon technologies could be deployed in commercial aviation[4]

	2020	2025	2030	2035	2040	2045	2050
Commuter ▪ 9–19 seats ▪ < 60 minute flights ▪ < 1% of industry CO_2	SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF
Regional ▪ 50–100 seats ▪ 30–90 minute flights ▪ ~3% of industry CO_2	SAF	SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF	Electric or hydrogen fuel cell and/or SAF
Short haul ▪ 100–150 seats ▪ 45–120 minute flights ▪ ~24% of industry CO_2	SAF	SAF	SAF	SAF and possibly some hydrogen	Hydrogen and/or SAF	Hydrogen and/or SAF	Hydrogen and/or SAF
Medium haul ▪ 100–250 seats ▪ 60–150 minute flights ▪ ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF and possibly some hydrogen	SAF and possibly some hydrogen	SAF and possibly some hydrogen
Long haul ▪ 250+ seats ▪ 150 minute + flights ▪ ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

While SAF offers significant emission reductions compared with fossil-based jet fuel, it is not entirely emission-free. It will ultimately need to be paired with other low- and zero-carbon technologies for aviation to reach net zero, or with direct air capture to offset residual emissions.

TYPES OF SAF

A SAF production pathway is defined by the feedstock, production process, and type of fuel that is produced. The American Society of Testing and Materials (ASTM) has approved seven production pathways for drop-in use in aviation, with more on the way. Most pathways are approved for blending up to 50 percent with conventional jet fuel.[5]

1. **Gasification and Fischer-Tropsch (Gas/FT):** The Gas/FT pathway takes a carbon-containing material such as municipal solid waste (MSW) and breaks it into hydrogen and carbon monoxide to form a synthesis gas (syngas). Syngas is then chemically converted (using the well-known set of FT reactions) into a liquid biofuel called synthetic paraffinic kerosene (SPK). SPK differs from conventional jet fuel in that it does not contain aromatics or sulfur compounds that are essential to the fuel performance, so it needs to be blended with other fuel types.[6]

    a. **Power to Liquid (PtL):** Power to liquid, a variation of the Gas/FT pathway, uses water, captured CO_2, and renewable energy to produce liquid fuel. Renewable energy is used to make hydrogen from water via electrolysis, and an FT reaction is used to synthesize the hydrogen and CO_2 into fuel.[7]

2. **Gas/FT plus aromatics:** This pathway is like the first, but the fuel is processed further to produce a hydrocarbon blend containing aromatic compounds. The resulting fuel is known as SPK/A. Unlike SPK produced in the first pathway, SPK/A has a similar composition to that of conventional jet fuel.[8]

3. **Hydroprocessed Esters and Fatty Acids (HEFA):** HEFA-based fuel is made from waste oils and fats that are treated with hydrogen to produce SPK.[9]

4. **Hydrocarbon-HEFA (HC-HEFA):** SAF can also be produced from a species of microalgae in a similar process as the HEFA pathway. It is currently limited to 10 percent blending.[10]

5. **Alcohol-to-jet (AtJ):** In the AtJ pathway, agricultural waste is converted to alcohol and then to jet fuels by dehydration and oligomerization, a chemical process that links molecules together to form a liquid hydrocarbon fuel. Currently, only isobutanol and ethanol are approved feedstocks for AtJ; however, it is also possible to produce jet fuel from methanol.[11]

6. **Catalytic Hydrothermolysis (CHJ):** CHJ uses a catalytic hydrothermal reactor to convert clean free fatty acid (FFA), a product of the processing of waste or energy oils, into hydrocarbons. The hydrocarbons are then treated with hydrogen to produce liquid fuel with a similar composition to fossil-based jet fuel.[12]

7. **Synthesized Iso-Paraffins (SIP):** SIP is a biological process in which yeast is used to ferment sugar into liquid fuel. It is currently limited to 10 percent blending.[13]

COMPARISON OF FEEDSTOCKS AND PRODUCTION PATHWAYS

The costs, emissions reduction potential, maturity, and feedstock availability vary greatly across different types of SAF. The feedstock options and emissions reduction potential for the approved pathways are summarized in table 2.

Table 2: Summary of SAF pathways

Pathway	Feedstock	Cost vs. Historical Average for Fossil Fuel		Emissions Reduction Potential
		2020	2050 Projection	
Gas/FT and Gas/FT plus aromatics	Municipal solid waste, agricultural and forest waste, and lignocellulosic crops	3–4.5x	2–3.5x	85–95%
PtL	Captured CO_2 and hydrogen	3–9x	1–2.5x	Up to 99%[14]
HEFA	Plant and animal fats, oils, and greases	2–3x	2x	33–84%
HC-HEFA	Oils from algae	No data	No data	No data
AtJ	Agricultural and forest waste, lignocellulosic crops, and Industrial gasses	3–4.5x	2–3.5x	26–67%
CHJ	Plant and animal fats, oils, and greases	No data	No data	No data
SIP	Sugar crops	No data	No data	63–64%

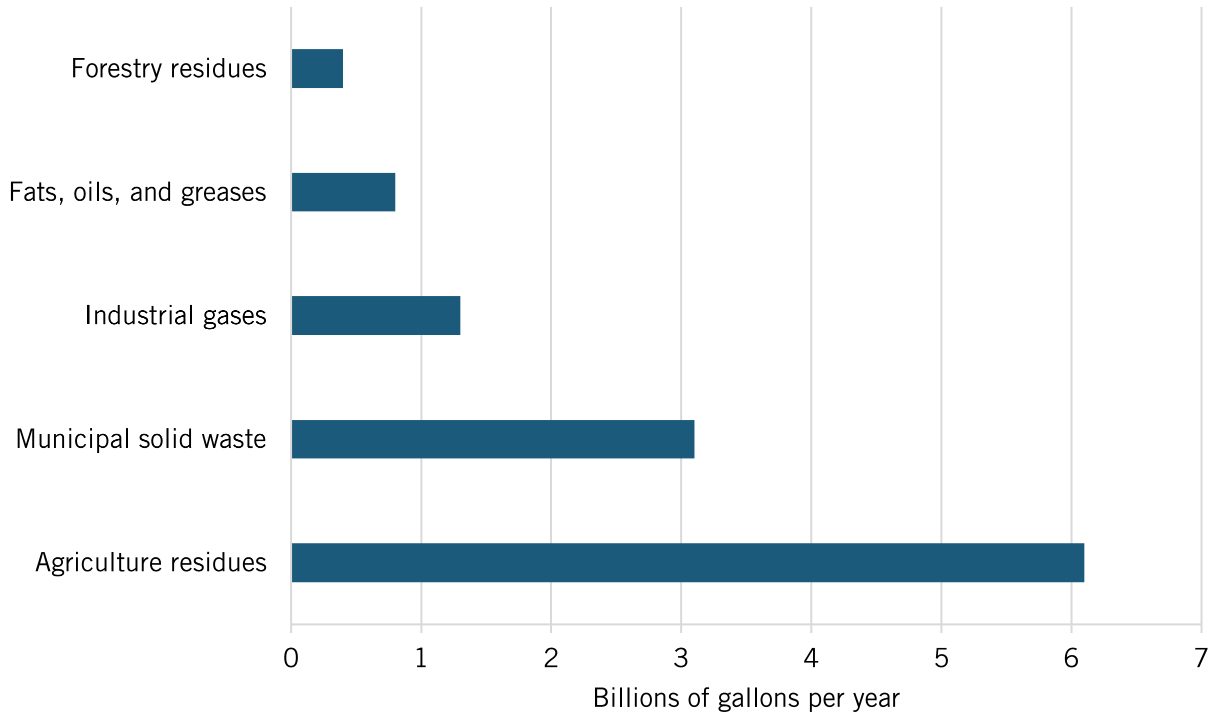
The current and projected costs of SAF depend on the production pathway. HEFA is currently the cheapest pathway, yielding a product that costs about 2 to 3 times as much as conventional jet fuel. However, since it is already being produced at scale, only minor cost reductions are expected in the coming decades. Other pathways currently cost about 3 to 4.5 times as much as conventional fuel, but they should catch up to HEFA by 2050. In fact, PtL, which currently has the highest production cost of all the SAF pathways, may well be the cheapest option by then (if the costs of hydrogen and low-carbon electricity drop rapidly).[15]

The quantity of fuel that can be produced using each pathway depends mainly on the feedstock. HEFA, which is primarily produced using fats, oils, and greases (FOGs) that would otherwise go to waste, faces the greatest constraint. These wastes are limited, and other sectors such as heavy-duty transportation compete with aviation for them. Figure 1 shows that only about 800 million gallons (about 4 percent of the domestic commercial jet fuel market) of SAF can be produced in the United States per year from FOGs.[16]

The feedstocks for other biofuel pathways such as gas/FT and AtJ are less constrained. MSW, agricultural and forestry residue, and industrial gases could be used to produce as much as 10.9 billion gallons of SAF per year, equivalent to about 52 percent of the U.S. aviation fuel market.

PtL offers an even more robust solution to feedstock constraints, since the supply of low-carbon electricity and captured CO_2 could far exceed SAF demand.[17]

Figure 1: U.S. SAF production potential[18]



The emissions reductions that could be achieved with SAF are also dependent on which feedstock is used. HEFA has the greatest range of emissions reduction potential; fuel produced from FOGs can reduce emissions by as much as 84 percent compared with conventional jet fuel; while palm oil or soybean oil-based fuel only reduces emissions by 33 to 55 percent. SAF produced using the gas/FT pathway provides 85 to 95 percent greenhouse gas (GHG) savings.[19] A full life cycle assessment has not yet been conducted for PtL fuels, but some initial estimates suggest they could reduce emissions by up to 99 percent.[20]

AtJ fuels generally have higher life cycle emissions than do the other SAF pathways, with emissions reductions falling somewhere between 26 and 67 percent. The SIP pathway provides about 63 percent GHG savings; however, the main feedstocks for this pathway are edible crops such as sugar cane, which could interfere with local food security and result in additional indirect emissions.[21]

Contrails from the combustion of jet fuel are another way aviation impacts the climate. At the low temperatures found at airplane cruising altitudes, water vapor interacts with soot particles from jet engine exhaust to form trails of condensation. According to NASA modeling, SAF can reduce contrail formation by 50 to 70 percent.[22]

GLOBAL PROGRESS

Aviation is a global industry, and international cooperation will be needed to achieve net zero. The International Civil Aviation Organization (ICAO) took a first step in this direction in 2016, introducing a global system that seeks to stabilize net CO_2 emissions from the industry. Currently participating in this system, which offsets emissions from international flights, are 107 countries.[23]

SAF qualifies as an offset under the ICAO system. While SAF currently accounts for only about 0.05 percent of global jet fuel consumption, this share should grow.[24] In 2021 alone, buyers announced 20 new offtake agreements, bringing the global total to 53.[25] These agreements represent more than 5.5 billion gallons of sustainable fuel over their lifetime, more than 2,000 times the amount produced in 2021 (roughly 26 million gallons).[26]

Almost all the demand for SAF is currently met through the HEFA production pathway. The Finnish biofuel company Neste is set to become the largest global producer of HEFA-based SAF by 2023 with the expansion of its refineries in Rotterdam and Singapore. Once completed, this expansion will increase Neste's annual production capacity from 34 million gallons (0.03 percent of the global commercial jet fuel market) to 515 million gallons (0.5 percent of the global market).[27]

RD&D investment has also increased for other pathways, particularly PtL. In 2021, Airbus announced that it is partnering with SAF+ Consortium to produce PtL using green hydrogen at commercial scale in Canada. The group's pilot plant began production in 2021, and a full-scale demonstration project is planned for 2025.[28] The Dutch company SkyNRG plans to complete a PtL facility in Amsterdam by 2027 as well.[29]

PROGRESS IN THE UNITED STATES

In 2021, the White House launched the Sustainable Aviation Fuel Grand Challenge, a government-wide commitment to accelerating the production of SAF to 3 billion gallons per year by 2030 and meeting 100 percent of demand by 2050. The Grand Challenge was formalized in a Memorandum of Understanding (MOU) between the Department of Energy (DOE), Department of Transportation (DOT), and Department of Agriculture (USDA) and is supported by about $4.3 billion in new and existing funding.[30]

As part of the Grand Challenge, the Bioenergy Technologies Office (BETO) of DOE has awarded $64.7 million in funding to support biofuel RD&D to reduce transportation emissions. The awards include $3 million to Alder Energy for developing advanced pyrolysis technology to convert biomass to SAF and $2.8 million to the National Renewable Energy Laboratory for lowering the cost and emissions from producing fermentable sugar from corn stover.[31]

The Biden administration's effort to advance SAF has been backed by strong industry support; every major U.S. airline has already made commitments to purchase SAF. United Airlines is leading the way, with offtake agreements totaling about 2.3 percent of global jet fuel demand.[32] The airline announced the largest purchase agreement to date in 2021, for 1.5 billion gallons (or 1.4 percent of the global market) from DC-based Alder Fuels.[33] United also became the first airline to successfully operate a fully SAF-powered flight with passengers onboard, establishing the feasibility of going beyond the current 50 percent blending limit.[34]

American Airlines has agreed to purchase 131 million gallons of SAF, and Delta has 260 million gallons of SAF under offtake agreements, equivalent to 0.1 percent and 0.2 percent of global jet fuel demand, respectively. In addition to offtake agreements, American Airlines has invested $100 million in Breakthrough Energy's Catalyst program, an initiative designed to facilitate public-private partnerships to advance sustainable aviation.[35]

KEY POLICY ISSUES

One of the biggest barriers to achieving the Biden administration's ambitious goals for SAF is cost. SAF today carries a hefty "green premium"—up to nine times the price of conventional jet fuel. Significant support for innovation will be needed to reduce this differential. An estimated 35 billion gallons of alternative fuel will be needed to meet 100 percent of the demand for jet fuel in 2050, an unsustainable level at today's cost.[36]

The Inflation Reduction Act of 2022 took a first step by including a $1.25 to $1.74 per gallon production tax credit for SAF.[37] These incentives are anticipated to expand capacity, reduce cost, and increase availability of U.S.-made SAF. SAF produced using captured carbon may also be able to benefit from the 45Q tax credits for carbon capture, utilization, and storage projects. However, tax credits provide a subsidy that does not necessarily reduce production costs. The policy's aim is to drive cost reductions indirectly through learning by doing as production scales. Other policies that complement tax credits, such as public RD&D funding and regulation, are likely to be necessary to achieve this outcome.[38] SAF tax credits have also drawn criticism from fuel retailers who worry that they will divert feedstock from renewable diesel production.[39]

Federal RD&D investments are more important at this stage than tax credits aimed at cost reduction because they expand the scale of production. Many federal departments and programs are involved in the effort. BETO plays a significant role, funding research and development efforts aimed at both creating new pathways for producing SAF and improving existing pathways. USDA is responsible for continuing investments and building expertise in sustainable biomass production systems. It is also responsible for decarbonizing supply chains and investing in biomanufacturing capability.[40]

The Federal Aviation Administration (FAA) is essential for certifying new SAF production pathways. Under the Continuous Lower Energy, Emissions, and Noise (CLEEN) program, the FAA can act as a cost-sharing partner with industry, enabling the private sector to test and evaluate new sustainable fuels. The Aviation Sustainability Center (ASCENT), a consortium of research institutions, industry, and federal agencies, assesses the impact of new SAF pathways on emissions and performance. The work of these two programs has enabled the certification of the seven existing SAF pathways.[41]

Even with all this policy support, it is unlikely SAF will become cost competitive with regular jet fuel before 2050. Getting airlines to adopt SAF will therefore be a challenge and require a permanent suite of policies to ensure global adoption. Fuel costs make up a large share of airline expenses, so opting to use SAF will result in higher ticket prices and reduce airline travel, especially for lower-income customers.

LOOKING FORWARD

SAF will almost certainly play a role in decarbonizing the aviation sector. Meeting the ambitious targets set by the Biden administration and other governments will require significant RD&D investment by the public sector worldwide, backed by complementary policies as well as sustained industry leadership and international cooperation. Given the feedstock constraints and technological uncertainty associated with SAF, a wide range of pathways must be explored on a commercial scale.

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