U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

SAF must meet the same fuel quality requirements as conventional jet fuel, making it compatible with existing airplanes and airport infrastructure. However, many emerging SAFs provide better performance in addition to reduced GHG emissions.
Photo from iStock 980044756

Sustainable Aviation Fuel: Decoupling Carbon from Commercial Flight

Demand for jet fuel is expected to balloon over the next three decades, which adds to the aviation industry's challenge of meeting goals for cutting aviation greenhouse gas (GHG) emissions in half by midcentury.[1] Sustainable aviation fuels (SAFs) made from renewable biomass and waste resources have the potential to deliver the performance of petroleum-based jet fuel but with a fraction of its carbon footprint, giving airlines solid footing for decoupling GHG emissions from flight.

The U.S. Department of Energy (DOE) is working with the U.S. Department of Agriculture, the U.S. Department of Transportation, and other federal agencies to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale. The strategy will highlight needs in research and development, scale-up, policy and financing, state and local involvement, and workforce development.

SAF Support from the Bioenergy Technologies Office

DOE's Bioenergy Technologies Office (BETO) empowers energy companies and aviation stakeholders by supporting advances in research, development, and demonstration (RD&D) to overcome barriers for widespread deployment of SAF. With targeted efforts to lower feedstock costs and scale SAF production technologies, BETO harnesses American innovation to:

- Create jobs in green industries
- Invest in farming communities
- Achieve lasting carbon reductions across the U.S. economy.

Sustainable Aviation Fuel: Safe, Reliable, Low Carbon

SAF is a biofuel used to power aircraft that has similar properties to conventional jet fuel but with a smaller carbon footprint. Depending on the feedstock and technologies used to produce it, SAF can reduce life cycle GHG emissions dramatically compared to conventional jet fuel (see "Life Cycle Greenhouse Gas Emissions of SAFs in GREET"). Some emerging SAF pathways even have a net-negative GHG footprint (see "SAF in Action"). This makes SAF an important solution for lowering GHGs from the aviation sector, which comprise 9%–12% of U.S. transportation GHG emissions.[2]

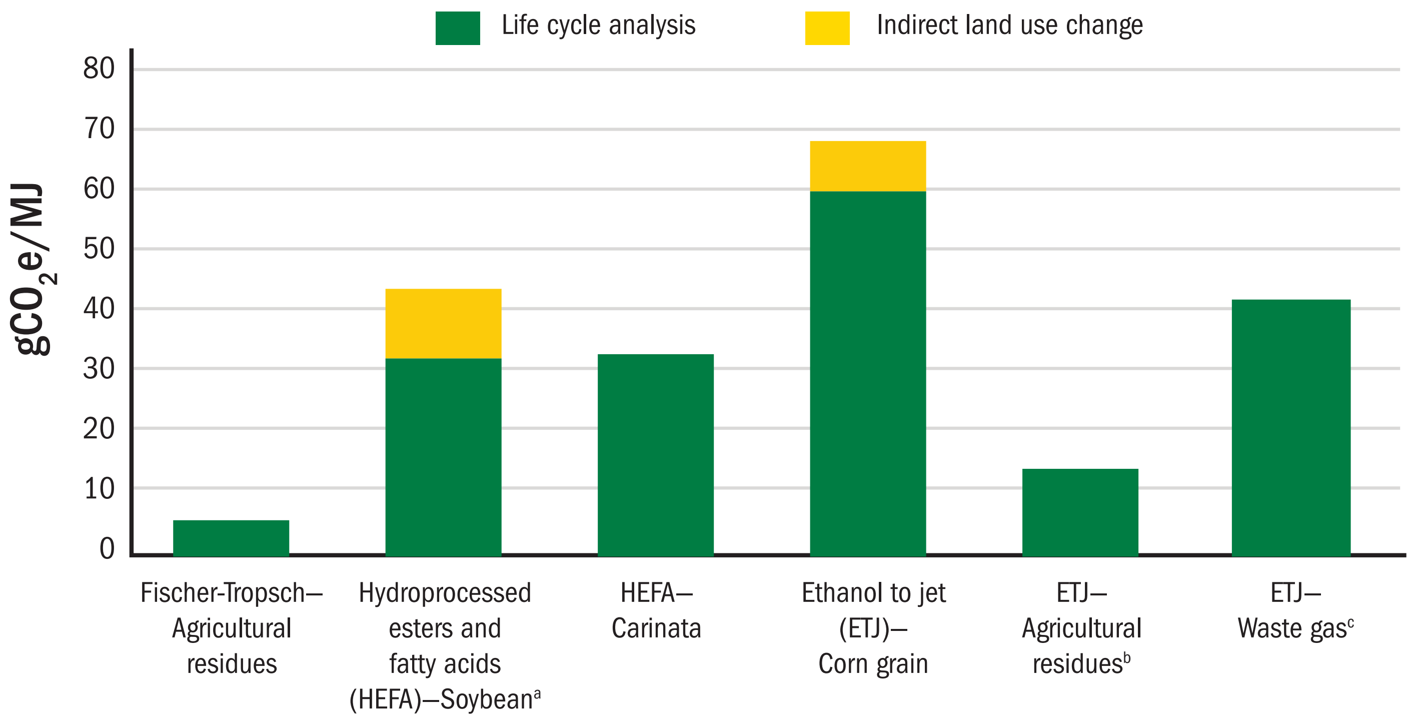
SAF can be made with a variety of feedstocks and technologies, which use physical, biological, and chemical reactions to break down biomass and waste resources and recombine them into energy-dense hydrocarbons. Like conventional jet fuel, the blend of hydrocarbons in SAF must be tuned to achieve key properties needed to support safe, reliable aircraft operation.

A Menu of Sustainable Feedstocks for Producing SAF

An estimated 1 billion dry tons of biomass can be collected sustainably each year in the United States, enough to produce 50–60 billion gallons of low-carbon biofuels. These resources include corn grain; oil seeds; algae; other fats, oils, and greases; agricultural residues; forest harvesting residues;

1 iata.org/en/programs/environment/climate-change
2 epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

Life Cycle Greenhouse Gas Emissions of SAFs in GREET



All SAFs are less carbon-intensive than conventional jet fuel, though some pathways and feedstocks have a greater net-emissions benefit. Both indirect and direct land use change, such as cultivating new land for feedstocks or converting natural vegetation into other land types, also impact life cycle emissions.

a. Indirect land use change of soybean biodiesel in the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model is 9.28 gCO2e/MJ. This has been converted into per MJ jet considering soybean biodiesel and jet yields.
b. Heat integration between ethanol and jet fuel production is considered.
c. Evaluated using GREET 2017 with datasets provided by LanzaTech, assuming standalone ETJ for the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation.

wood mill waste; municipal solid waste streams; wet wastes (manures, wastewater treatment sludge); and dedicated energy crops.[3] This vast resource is able to meet the projected fuel demand of the U.S. aviation industry, as well as provide additional volumes of drop-in low-carbon fuels for use in other modes of transportation, and produce high-value bioproducts and renewable chemicals.

SAF feedstocks unlock benefits beyond lowering GHG emissions. Growing, sourcing, and producing fuel from these renewable and waste resources can create new economic opportunities in farming communities, improve the environment, and even boost aircraft performance.[4]

- **Extra revenue for farmers:** By growing biomass crops for SAF production, American farmers can earn more money during off-seasons by providing feedstocks to this new market, while also securing benefits for their farms like reducing nutrient losses and improving soil quality.

- **Environmental services:** Biomass crops can control erosion, improve water quality and quantity, increase biodiversity, and store carbon in the soil, which can deliver on-farm benefits and environmental benefits across the country. Producing SAF from wet wastes, like manure and sewage sludge, reduces pollution pressure on watersheds, while also keeping potent methane gas—a key contributor to climate change—out of the atmosphere.

- **Improved aircraft performance:** Many SAFs contain fewer aromatic components, which enables them to burn cleaner in aircraft engines. This means lower local emissions of harmful compounds around airports during take-off and landing. Aromatic compounds are also precursors to contrails, which can exacerbate the impacts of climate change.

Biofuels Production Supports American Jobs

The United States is the largest producer of biofuels in the world, which contributes to its domestic economy,

[3] energy.gov/eere/bioenergy/2016-billion-ton-report
[4] energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

creates jobs, and reduces GHG emissions. U.S. ethanol production grew from 1.6 billion gallons in 2000 to more than 15 billion gallons in 2019.[5] In 2019, the U.S. ethanol industry employed over 68,000 workers, with a production capacity of nearly 17 billion gallons per year.[6] The increasing production of ethanol and its use as a blend in motor gasoline helped reduce GHG emissions by 544 million metric tonnes of CO_2 equivalent between 2005 and 2019.[7] This is comparable to offsetting the annual emissions from nine coal-fired power plants or 7.8 million passenger cars, on average, each year over this 15-year period.[8]

Expanding domestic SAF production can help sustain the benefits of the U.S. biofuel industry and forge new economic benefits, creating and securing employment opportunities across the country. These include jobs in:

- Feedstock production in farming communities
- Construction for building cutting-edge biorefineries
- Manufacturing for operating SAF biorefineries and infrastructure
- Aviation, including countless pilots, crew members, maintenance workers, and other industry professionals.

BETO RD&D Brings More SAF to the Market

To meet U.S. and aviation climate goals, more production pathways and feedstocks are needed to meet growing demand for SAF. In partnership with biorefiners, aviation companies, and farmers, BETO-funded researchers are developing novel pathways for producing SAFs from renewable and waste feedstocks that meet strict fuel specifications for use in existing airplanes and infrastructure. BETO is working with laboratory and industry partners to develop new SAF pathways and fuel formulations in order to enable testing and certification required to ensure these fuels are fully compatible with existing aircraft and infrastructure. A few examples include:

SAF from wet waste: Drawing on stores of carbon energy in cheap, widely available food waste, animal manure, and other wastes with high water content, SAF from wet waste is a carbon-negative fuel (see “SAF in Action”).

Bio-based polycyclic alkane SAF: If upgraded with ultraviolet light and catalysts, bio-acetone made from a range of biomass resources, like corn stover or bioenergy crops, can yield SAF with 12% more energy than conventional jet fuel.[9]

SAF from carbon-rich waste gases: Waste carbon monoxide from industrial processes can be captured and upgraded with bacteria into ethanol for easy conversion into “alcohol-to-jet” SAF.[10] ■

BETO-funded researchers are developing novel pathways for producing SAFs from renewable and waste feedstocks that meet strict fuel specifications for use in existing airplanes and infrastructure. *Photo from iStock 868922846*

5 eia.gov/totalenergy/data/monthly/index.php
6 ethanolrfa.org/wp-content/uploads/2020/02/2020-Outlook-Final-for-Website.pdf
7 onlinelibrary.wiley.com/doi/10.1002/bbb.2225
8 epa.gov/energy/greenhouse-gas-equivalencies-calculator
9 energy.gov/eere/bioenergy/articles/taking-cleaner-skies-lanl-research
10 pnnl.gov/news/release.aspx?id=4527

SAF in Action: Carbon-Negative Jet Fuel Made from Manure and More[11]

Wet waste—including food waste, manure, sewage, and inedible fats, oils, and greases—is a large source of methane emissions, a pollutant 20 times more potent than carbon dioxide. Scientists at the National Renewable Energy Laboratory (NREL) have created a biorefining process that reinvents methane-forming wet waste as a powerful tool for decarbonizing aviation.

NREL's SAF from wet waste is produced using catalysts that build energy-dense hydrocarbons out of volatile fatty acids (VFAs)—made by fermenting wet waste in anaerobic digesters. The resulting SAF is compatible with existing jet engines and has a carbon footprint as much as 165% lower than conventional jet fuel. Producing the fuel diverts more GHGs from the atmosphere than are released by using the fuel in aircraft. If blended with conventional jet fuel, that emissions reduction enables net-zero-carbon flight.

It is one BETO-funded project among many that mobilizes national lab expertise, industry insight, and domestic resources to accelerate the deployment of climate-friendly SAF.

About the Bioenergy Technologies Office

BETO supports research, development, and demonstration to enable the sustainable use of domestic biomass and waste resources for the production of biofuels and bioproducts. BETO's overall goals are designed to:

- Lower costs and reduce technology risks for production of biofuels and bioproducts
- Improve environmental benefits of bioenergy production
- Reduce greenhouse gas emissions from the transportation, industrial, and agricultural sectors to address the climate crisis
- Support the scale-up of sustainable, low-carbon biofuel production technologies
- Create economic opportunities and good-paying jobs in agriculture and manufacturing sectors.

Meeting these goals requires significant and rapid advances in technology development and innovation across the entire biomass-to-bioenergy supply chain.

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
BIOENERGY TECHNOLOGIES OFFICE

For more information, visit:
energy.gov/eere/bioenergy

DOE/EE-2365 · September 2021

[11] nrel.gov/news/program/2021/from-wet-waste-to-flight-scientists-announce-fast-track-solution-for-net-zero-carbon-sustainable-aviation-fuel.html