HYDROGEN FOR AVIATION

Prospects

GOOD

This fact sheet is part of an Energy Innovation paper assessing clean hydrogen's value for cutting climate pollution from 12 end uses. The full report includes context, analysis, policy recommendations, and citations—see QR code or link at bottom.

Hydrogen can be used to make sustainable aviation fuels needed for long-distance flights.

NOTE: *We rate long-haul aviation as "good" but short-haul aviation as "uncertain."*

CONTEXT: The conventional approach to reducing aviation emissions has been via sustainable aviation fuel (SAF), defined as "liquid hydrocarbon jet fuel produced from renewable or waste resources that is compatible with existing aircraft and engines." SAF uptake to date has been negligible, but the U.S. SAF Grand Challenge aims to rapidly scale its use by 2050.

Hydrogen could play several roles in decarbonizing aviation. Fuel cell-powered aircraft have high efficiencies but low range, while hydrogen combustion aircraft can achieve greater range but are still limited to about a third of the passenger market. Ultimately, aviation requires high energy densities to support more passengers or cargo and travel longer distances.

Hydrogen-derived SAF ("e-fuels") therefore holds the greatest potential for most of the aviation sector. The Fischer-Tropsch process converts hydrogen and carbon into liquid e-fuels. Carbon can initially be sourced from fossil fuel combustion (albeit with half the climate benefit) but must eventually come from a net-zero source (e.g., biomass or the air). The most promising path may be power-and-biomass-to-liquids (PBtL), in which hydrogen boosts SAF output per unit biomass by a factor of 2.4-3.75 relative to conventional, hydrogen-free biomass routes.

INFRASTRUCTURE NEEDS: The direct use of hydrogen requires new or retrofitted aircraft, in part to accommodate extra space for liquid hydrogen storage. These aircraft would need to meet specific design standards to ensure compatibility with the same airports as today's jets. Airports would also need hydrogen delivery, storage, and refueling infrastructure.

E-fuels can be used in existing aircraft with up to a 50 percent mix with conventional fuel—though work is underway to allow for 100 percent. This limits the need for changes to jets or airports. Instead, e-fuels require carbon sources (e.g., carbon capture equipment, biomass) and SAF production facilities. One study finds PBtL production could be cost-effective in much of the U.S. Midwest and Great Plains by using off-grid renewables to power electrolyzers (avoiding grid interconnection costs), steel tanks to store hydrogen, and local biomass production—with e-fuels able to use existing jet fuel infrastructure rather than requiring hydrogen pipelines.

SOCIAL IMPACTS: Jet fuel combustion worsens local air quality by releasing smog-forming compounds, toxins, and particulate matter, raising airport workers' and adjacent communities' risk of respiratory issues, cardiovascular disease, and cancer. E-fuels can improve air quality because of their lower sulfur content and fewer impurities. Hydrogen fuel cell aircraft would cause no pollution, but hydrogen combustion aircraft would still emit harmful nitrogen oxides.

Jet fuel combustion also creates contrails—created by water vapor attaching to particulate matter and freezing—that could be responsible for as much as two-thirds of aviation's climate impact. E-fuels can only partially mitigate this problem (from emitting fewer particulates). Hydrogen fuel cell and combustion aircraft do not emit particulates, but they do emit relatively more water vapor, which can attach to naturally present aerosols—so their impact on contrail formation and their climate warming effects are currently unclear.

COMPETING TECHS: The top competitor to hydrogen for SAF production is **biomass**, with most SAF made today (and expected in the near future) coming from fats, oils, and greases—though some hydrogen is often used to treat biomass to produce SAF. The U.S. Department of Energy finds there is more than enough potential biofuel supply in the U.S. to replace all jet fuel "without impacting agriculture, trade, or current uses of biomass." However, other studies find this wouldn't be sufficient to also support other sectors' biofuel needs for their decarbonization or would strain land use. Thus, while biomass has momentum and greater technological maturity, hydrogen-based PBtL's ability to cut biomass needs—along with its cost and emission advantages—may give it an edge to serve much of the market.

The top competitor to hydrogen fuel cell and combustion aircraft for short-haul aviation is **battery electric technologies**. These aircraft have a substantial energy efficiency advantage over hydrogen alternatives but suffer from the relatively high weight of batteries, which will need dramatic improvements in energy density to access more than a tiny share of the market. For example, current technologies can only achieve up to 400 miles with fewer than 10 seats. By comparison, fuel cell aircraft can achieve similar ranges but with roughly five times more seats, and hydrogen combustion aircraft can reach ranges of several thousand miles and far greater capacity. However, new aircraft design concepts (optimized for batteries rather than jet fuel) may be able to achieve much more range or capacity. If battery aircraft find success for more short-haul trips and SAF scales quickly for long-haul trips, there may be less appetite to build infrastructure to enable a shrinking market for hydrogen aircraft.

TAKEAWAY: Hydrogen-based e-fuels hold great potential to reduce biofuel demands for cleaning up long-haul aviation, and hydrogen fuel cell and combustion aircraft will compete with battery aircraft for shorter-range trips. However, SAF does little to solve local air pollution and climate-warming contrail issues. Thus, barring a breakthrough, it will still be important to take other measures to mitigate aviation's harms—including reducing air travel.

FURTHER READING:

- Amol Phadke, Jose Luis Dominguez Bennett, Natalie Popovich, and Umed Paliwal, "Inflation Reduction Act incentives increase cost-competitiveness of lower-footprint clean hydrogen-based sustainable aviation fuel," Lawrence Berkeley National Laboratory, June 11, 2024, https://doi.org/10.21203/rs.3.rs-4530317/v1
- Thomas K. Walker III, Marika Tatsutani, and Jonathan Lewis, "Decarbonizing Aviation: Enabling Technologies for a Net-Zero Future," Clean Air Task Force, April 2024, https://cdn.catf.us/wp-content/uploads/2024/04/03083920/decarbonizing-aviation-technologies-net-zero-future.pdf
- Eric G. O'Rear et al., "Sustainable Aviation Fuels: The Key to Decarbonizing Aviation," Rhodium Group, December 7, 2022, https://rhg.com/research/sustainable-aviation-fuels/
- **Featured story:** Sean Mowbray, "Sustainable aviation fuels: Potential lagging behind reality," Mongabay, July 18, 2023, https://news.mongabay.com/2023/07/sustainable-aviation-fuels-potential-lagging-behind-reality/
- **Full report:** https://energyinnovation.org/publication/hydrogen-policys-narrow-path-delusions-and-solutions