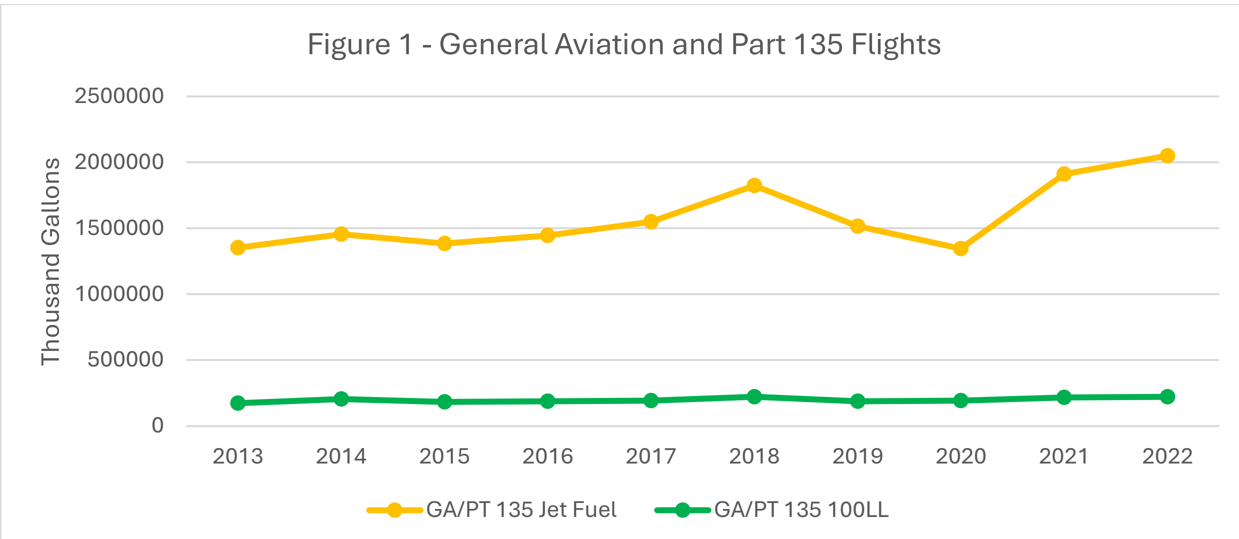
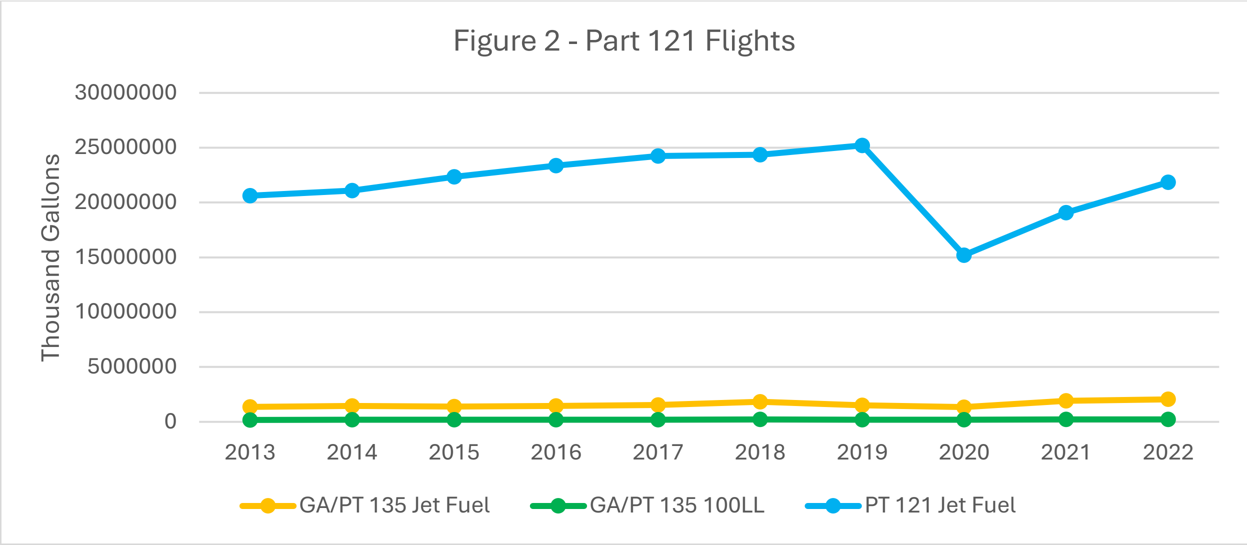
Aviation Fuels and Alternative Power Sources

All commercial passenger and general aviation aircraft rely on a motive force for propulsion to maintain flight. This has been historically achieved through the combustion of hydrocarbon based fossil fuels such as jet fuel (Jet-A) and aviation gasoline (Avgas or 100LL). In 2021, an estimated 5,791 commercial and 205,870 general aviation aircraft performed over 94 million operations at airports in the United States.[1] Jet fuel consumption is forecast to continue to increase, while Avgas use is expected to remain level.

Aircraft fuel consumption is documented based on aircraft operational type as outlined by Federal Aviation Regulations (FAR). General Aviation is governed by FAR Part 91 regulations and covers non-commercial operations. These are typically small aircraft flown for recreation and personal travel. Non-scheduled commercial flights, such as business and charter operations fall under Part 135 regulations. Scheduled commercial passenger and airline service is regulated under Part 121. Annual fuel usage estimates for Part 91 and 135 operators are shown in **Figure 1**[2], and fuel usage estimates for Part 121 operators are included in **Figure 2**.[3]



1 National Plan of Integrated Airport Systems (NPIAS) 2023-2027, Federal Aviation Administration, U.S. Department of Transportation
2 General Aviation and Part 135 Activity Surveys, Federal Aviation Administration, U.S. Department of Transportation
3 U.S. Product Supplied of Kerosene-Type Jet Fuel (Thousand Barrels), U.S. Energy Information Administration



A growing focus on environmental sustainability and stewardship, coupled with advancements in alternative fuels and power sources, have begun to change the future landscape of aviation propulsion. These include sustainably sourced jet fuel, lead free aviation gasoline, hybrid and all-electric systems, and hydrogen technology.

Sustainable Aviation Fuel

Passenger, business, and freight aircraft are powered primarily by jet fuel, a refined kerosene-type fuel. Jet-A and Jet-A1 are the two primary fuels used in jet, turboprop, and reciprocating piston diesel engine aircraft.[4] These fuels are derived from crude oil and contribute to greenhouse gas (GHG) emissions. Aircraft account for 10 percent of U.S. transportation sector GHG emissions, and 3 percent of total GHG emissions.[5] The U.S. consumed nearly 24 billion gallons in 2022.[6] 250 million gallons of the fuel is used by Delta Airlines annually at MSP alone.[7]

In an effort to reduce GHG emissions from jet fuel use, government and industry initiatives are being implemented to expand the use of Sustainable Aviation Fuel (SAF). SAF can be produced from a variety of feedstocks including renewable biomass and waste oils. Traditional crude oil-based fuels release carbon to the atmosphere when burned. In theory, carbon emissions from the combustion of SAF would equal the amount of carbon absorbed by the growth and production of the feedstock, resulting in a closed carbon loop, and a net zero increase in carbon emissions. According to a study referenced by the Department of Energy, using 100% SAF has the potential to cut CO2 emissions from jet fuel related aviation by up to 94%.[8]

To that end, the U.S. Departments of Energy (DOE), Transportation (DOT), and Agriculture (USDA) created the Sustainable Aviation Fuel Grand Challenge in 2021 with the goal of expanding domestic consumption of SAF to 3 billion gallons by 2030, 35 billion gallons by 2050,

[4] Kerosene and Jet Fuel Spills, Office of Response & Restoration, National Oceanic and Atmospheric Administration (NOAA)
[5] EPA Finalizes Airplane Greenhouse Gas Emission Standards, Office of Transportation and Air Quality, U.S. Environmental Protection Agency
[6] Jet Fuel Consumption, Price, and Expenditure Estimates, 2022, U.S. Energy Information Administration
[7] Minnesota SAF Hub Launches First-of its-Kind Coalition to Scale Sustainable Aviation Fuel, GreaterMSP, Aug. 29, 2023
[8] CORSIA, The First Internationally Adopted Approach to Calculate Life-Cycle GHG Emissions of Aviation Fuels, Renewable and Sustainable Energy Reviews, Volume 150, Oct. 2021

and at least a 50% reduction on lifecycle greenhouse gas emissions.[9] In August 2023, the Minneapolis Saint Paul Regional Economic Development Partnership (GreaterMSP), Bank of America, Delta Air Lines, Ecolab, and Xcel Energy announced a coalition to develop, scale production, and establish a SAF hub at MSP. By 2027, Delta hopes to replace 10% of its fuel use with SAF, growing to 50% by 2035.[10]

In a boost to the development of the Minnesota SAF hub, the FAA announced a $16.8 million grant to Gevo Inc. to convert the existing ethanol and isobutanol production plant into an alcohol-to-jet fuel SAF facility.[11] This project is part of the larger $291 million allotted for SAF technology development and production initiatives as a part of the Inflation Reduction Act of 2022. In addition, Flint Hills Resources is collaborating with Delta in developing a blending facility at its Pine Bend refinery in Rosemount, MN, to be completed by the end of 2025, to blend SAF with existing jet fuel production.[12] This will then be delivered to MSP through the existing jet fuel pipelines between the plant and airport. To further incentivize SAF production and usage in Minnesota, a sustainable aviation fuel tax credit was passed in 2023. This provides a credit of $1.50 per gallon of SAF produced or blended in Minnesota and used in an aircraft departing the state.[13]

Existing SAF production consists of an ASTM International (formerly known as the American Society for Testing and Materials) approved 50% blend of traditional jet fuel and SAF. Boeing, Airbus, Rolls Royce, Virgin Atlantic, SAF producer Neste, and others have begun flight testing large commercial aircraft using 100% unblended SAF. Signature Aviation, the world's largest global Fixed-based Operator (FBO) network, with facilities at MSP, has begun offering 30% blended SAF at some of their larger airports, including Los Angeles (LAX) and San Fransisco (SFO). Currently, SAF is more expensive per gallon than traditional jet fuel. Signature has created a program to offset this existing price differential. Global customers interested in receiving environmental sustainability credit may choose to pay the higher price for SAF at an airport not yet equipped to dispense it. At those airports supplied with SAF, the fuel will then be dispensed at the price of traditional jet fuel for customers that do not choose to pay the price delta.[14]

Concern exists over whether SAF production can ramp up to meet the lofty goals of replacing traditionally produced jet fuel. 15.8 million gallons of SAF were produced in 2022.[15] This equates to only a small fraction of the amount of jet fuel used by just one of the major commercial airlines annually. The Government Accountability Office (GAO), in review of the federal role in SAF implementation, published a report in 2023 highlighting ongoing issues in the transition to SAF future.

- While some technology to produce SAF and similarly related products (biodiesel) are mature, nascent technologies are expensive and risky to develop and lack investors.

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[9] Sustainable Aviation Fuel Grand Challenge, Bioenergy Technologies Office, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy
[10] Soy Powered Planes? Minnesota Hopes to be a Hub for Sustainable Aviation Fuels, MPR News, Aug. 29, 2023
[11] Biden-Harris Administration Announces Nearly $300 Million in Awards for Sustainable Aviation Fuels and Technologies as part of Investing in America Agenda, Federal Aviation Administration (FAA), Aug. 16, 2024
[12] Plan for Minnesota's First Sustainable Aviation Fuel (SAF) Blending Facility Revealed by GREATER MSP Partnership-Led Coalition, Sept. 10, 2024
[13] Minn Stat 41A.30, Sustainable Aviation Fuel; Tax Credit
[14] Signature Goes All in on SAF at KLAX, Aviation International News, May 14, 2024
[15] Sustainable Aviation Fuel, Agencies Should Track Progress Toward Ambitious Goals, Mar. 23, 2023, U.S. Government Accountability Office

- SAF production facilities using existing technologies, are often built as new, stand-alone facilities that are expensive and take a long time to plan, design, and build, extending the period between project initiation and initial profit.
- Feedstock is a major cost component in SAF production. Soybean oil is already in high demand for other uses (biodiesel, etc.). feedstocks using municipal waste, woody biomass, and others may be plentiful and relatively cheap, but involve the expense and carbon footprint of processing and transporting to SAF production facilities.
- Once produced, SAF needs to be distributed to airports. SAF production would likely occur near the feedstock source, while large scale SAF powered operations would occur at airports in populated areas. Major airports may have dedicated traditionally derived jet fuel pipelines to supply operations. Until production increases to the point of replacing traditional jet fuel, SAF would likely need to be trucked to airports across the country, decreasing the sustainability of the fuel.
- Fuel cost is a major component to the thin operating margins of air carriers. The existing cost differential of SAF compared to traditional jet fuel is likely uneconomical for airlines at consumption levels planned for. Tax incentives to offset cost should exist for longer periods of time (10 years) to solidify economic assessments and encourage SAF investment, production, and expansion.

Finding solutions to these issues will be vital to replacing traditionally derived jet fuel with SAF while continuing to foster an expanding commercial aviation sector.

Unleaded Aviation Gasoline

Early internal combustion piston engine designers faced difficulty in increasing the horsepower and mechanical reliability of gasoline fueled engines. Premature detonation, also known as knock, due to the low quality, low octane gasoline of the time, resulted in engine wear and failure. Efforts to discover an antiknock additive for gasoline culminated in the introduction of Tetraethyllead (TEL) in the 1920s. Leaded gasoline increased the octane rating and allows for higher engine compression, substantially increasing both horsepower and economy. Traditional aviation piston engines operate at higher power and rpm settings. This required high quality/octane gasoline with great antiknock properties, ultimately culminating in today’s 100 octane low lead gasoline (100LL).

With the discovery that TEL causes lead poisoning, the U.S. began phasing out leaded automotive fuels in the 1970s. Automobile engines do not require fuel with an octane rating as high as that of aircraft and operate under a different performance regime. Additionally, the cost and effort in research and development for changes in engine design to account for the absence of lead in fuel can be spread over the vast quantities of cars and trucks sold annually. The numbers of GA aircraft represent a tiny fraction of number of vehicles on American roads. In 2023 alone, Ford sold more than 700,000 F-Series pickup trucks. The entire GA fleet that relies on 100LL, totals roughly 170,000 aircraft. Due to the cost of owning and operating an airplane, many legacy aircraft are maintained and upgraded rather than regularly replaced. This means many are powered by older, highly reliable engine designs that were not originally developed or certified to operate on unleaded Avgas. The leaded Avgas powered fleet consumes between 150 and 175 million gallons of 100LL annually. This is roughly one-tenth of one percent of the gasoline sold for automobiles in the U.S.[16]

[16] When Will We See Unleaded AvGas?, Flying Magazine, Nov. 9, 2021

Industry and regulatory motion in developing a high quality 100LL replacement that is guaranteed to work reliably in all legacy aircraft with varying types of piston engines, with no adverse performance or mechanical effects, for a significantly small share in the gasoline market, has been slow. By 2014, however, the FAA and industry formed the Piston Aviation Fuels Initiative (PAFI) to identify suitable 100LL replacements through a traditional ASTM testing and verification process. This has transitioned to the Eliminate Aviation Gasoline Lead Emission (EAGLE) program which has narrowed the search to two fuel candidates that are undergoing further suitability testing. General Aviation Modifications Inc. (GAMI) pursued a different route in developing their Avgas replacement. G100UL (unleaded) was certified by the FAA for the entire piston engine fleet in September 2022. To use G100UL, an aircraft owner must acquire a Supplemental Type Certificate (STC) from GAMI. By the spring of 2024, 1.2 million gallons of G100UL had been produced by aviation fuel supplier Vitol.[17]

In October 2023, the Environmental Protection Agency (EPA) released their final determination on lead emissions from aircraft.[18] The study concluded that aircraft burning leaded fuel contribute to health risks from lead in communities which are near general aviation airports. This followed several years of study and counter study on the health effects due to GA aircraft operations. This has led to proposals to ban the sale of 100LL in several states and municipalities. GA industry advocacy groups have cautioned that a ban on 100LL before a viable alternative is in place would have negative safety consequences. Of note, the 2024 FAA reauthorization Act, passed in May 2024, requires those airports that sold 100LL in 2022 to continue to make the fuel available through 2030, or when a replacement is ready. On the heels of this legislation, the California legislature passed a law banning the sale and distribution of 100LL statewide, beginning in 2031.[19]

As unleaded Avgas alternatives are developed and made available for sale, the major contributing factor in aircraft owner adoption and transition will be price. It is anticipated that the cost of unleaded Avgas alternatives will exceed 100LL until production and distribution reach levels of economy commensurate with those of traditional Avgas. Some airport sponsors have begun to explore ways in which they can incentivize the use of more expensive unleaded fuel in the meantime, including novel fuel subsidy and STC reimbursement programs. In May of 2023, the City of Naples, Florida began subsidizing the cost of unleaded fuel alternatives, providing $180,000 in funding.[20] This initiative also included a $250 refund for the owners of aircraft based at the airport that receive an STC for the use of unleaded fuel. Similarly, Long Beach, California has appropriated $200,000 toward unleaded fuel subsidies and are reimbursing STCs up to $300.[21] Following this trend, the Colorado Aeronautical Board (CAB) of the Colorado Department of Transportation, approved a $300,000 grant to the Centennial Airport outside of Englewood to subsidize the transition to unleaded Avgas.[22] Should these new incentive programs succeed in converting GA airport operations to unleaded fuel usage in these larger markets, they may be a viable way of transitioning GA fleets to lead free gas to protect the health of residents living near airports.

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[17] More Than 1 million Gallons of G100UL Unleaded Fuel Now Available, General Aviation News, May 1, 2024
[18] EPA Determines That Led Emissions from Aircraft Engines Cause or Contribute to Air Pollution, U.S. Environmental Protection Agency (EPA), Oct. 18, 2023
[19] California Legislature Passes Leaded Avgas Ban, General Aviation News, Aug. 31, 2024
[20] Florida Airport Offers Incentives For Pilots To Buy UL94 Fuel, General Aviation News, Jun. 13, 2023
[21] KLGB Launches Unleaded Fuel Subsidy Program, General Aviation News, Jan. 30, 2024
[22] Colorado's Centennial Airport Leads Unleaded Aviation Fuel Initiative with $300,000 Grant Approval, Avweb, Jun 14, 2024

Electric and Hybrid Aircraft

In an industry highly reliant on fossil fuels, the push to increase sustainability and decrease the environmental footprint of aviation has led to new electric and hybrid power alternatives. Small, lightweight GA aircraft are suitable platforms for existing all-electric conversion. As battery technology improves, becomes more power dense, and lighter in weight, electric propulsion may be able to replace many fossil fuel powered light aircraft applications. For larger aircraft, a combination of sustainability technologies are being explored to augment or replace jet engines. These include hybrid electric and hydrogen systems in place of, or in addition to, traditional propulsion systems.

General Aviation

Several manufacturers have begun producing or developing small electric GA aircraft. The Pipistrel Alpha Electro is the first all-electric aircraft allowed by the FAA to operate under Light Sport Aircraft (LSA) regulations.[23] Other manufacturers are working on electric aircraft of their own. Many of these are based on existing aircraft models that use an electric motor and batteries for propulsion.

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This nascent technology lacks the range and payload of traditional piston engine powered aircraft. Existing battery technology is heavier than the fuel required to power a traditional combustion engine. The Alpha Electro can fly for one hour with a 30-minute reserve. This negates the ability to fly any great distance away from an airport today.

Flight school training fleets are considered the most likely early adopters of electric aircraft. Anticipated lower operating costs due to reduced mechanical complexity, the lack of engine controls/monitoring easing pilot workload, relatively short flight needs and the elimination of AVGAS fuel costs, make an electric aircraft ideal for initial pilot training.

Electric aircraft will require a charging infrastructure that does not currently exist at airports. Like electric automobiles, existing charging technology requires aircraft to be connected to charging infrastructure significantly longer than it takes to fuel an ICE powered aircraft. Future airport planning may require dedicated areas with space and infrastructure for charging aircraft. As

[23] Pipistrel Gains FAA Exemption for Velis Electro, Aviation International News (AIN), Mar. 5, 2023
[24] Why Electric Airplanes are Taking Off at Flight Schools, CNN.com, Sept. 8, 2022

battery electric technology improves and matures, constructed charging infrastructure may need to be upgraded and/or replaced at shorter intervals than legacy fueling facilities.

To that end, MnDOT Aeronautics has begun to evaluate the challenges and opportunities of incorporating electric charging infrastructure into the existing state aviation system. The Minnesota Electric Aviation Network (MEAN) Plan will be kicking off in 2025. With an eye toward the integration of electric aircraft, the study will include:

- Which airports in the state have the electrical grid capacity/infrastructure, particularly 3-phase power, to support Direct Current Fast Charging (DCFC)
- What is required in developing a state network of electric aircraft charging stations to provide cross-country re-charging similar to legacy aircraft re-fueling capability
- Where is there existing demand for electric aviation

Commercial Aviation

To meet sustainability goals in larger commercial passenger, business, and freight aircraft, hybrid propulsion systems are being explored. These include the incorporation of battery electric technology with traditional combustion engines, the use of hydrogen fuel cells to produce electricity in place of batteries, and hydrogen combustion in traditional engine designs in place of jet fuel.

Benefits of hybridization during typical commercial flight include.[25]

- Electric taxiing to runway – Aircraft engines off or at low idle until the aircraft reached the runway
- Take-off assist – Electric assistance providing additional power during take-off and climb
- Cruise Charging – Use a portion of engine power to charge batteries during high altitude cruise when traditional jet engines are in most efficient power regime
- Descent and landing – Engines in low power setting, electric components provide significant portion of needed thrust
- Electric taxiing to gate – Engines shut down, taxing on electric power
- Charging at gate – Aircraft connected to charging infrastructure during the loading and unloading of passengers and/or freight
- Reduced fuel burn would result in lower emissions at airports, which would benefit airport surrounding communities

Preliminary study of the efficiency gains possible with hybridization have predicted a reduction in fuel burn by up to 5%.[26] Importantly, this study was based on existing battery and hybridization technologies. Advancing battery storage and capacity may increase the efficiency of hybrid aircraft further.

Several manufacturers have already begun testing aircraft using hybrid systems. Ampaire, ZeroAvia, Daher/Airbus, and others have flight tested models that incorporate new hybrid electric technology in smaller, existing turboprop-based airframes such as the Cessna Caravan, Dornier 228, and Daher TBM.[27] As technology demonstrators, these aircraft have been

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[25] Hybrid and Electric Flight, Airbus.com
[26] Sizing and Operational Analysis for Hybrid Electric Aircraft: A feasibility Study for the Regional Market, American Institute of Aeronautics and Astronautics (AIAA), Jun. 8, 2023
[27] Ampaire's Hybrid-Electric Caravan Runs on SAF, AOPA.com, Feb. 28, 2024, Ampaire's Hybrid-Electric Caravan Runs on SAF, AOPA.com, Feb. 28, 2024, Maiden Flight for Hybrid Dornier 228, Pilot, Mar. 9, 2023

developed to explore the benefits of hybridization while promoting the development and design of dedicated hybrid aircraft.

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In addition to battery storage, electricity can be generated in a hydrogen fuel cell. A fuel cell consists of two electrodes, the negative anode and positive cathode, that react hydrogen and oxygen through an electrolyte to produce electricity and water vapor.[29] Hydrogen can also be used as the fuel source in a combustion engine. While the specific energy of hydrogen is significantly greater than that of traditional liquid fuels, the energy density of gaseous hydrogen is thousands of times lower.[30] This requires the hydrogen to be stored under great pressure and cryogenic temperatures to achieve maximum energy density. These properties require new aircraft fuel storage designs in place of existing liquid fuel systems. Hydrogen storage technology on a scale large enough to serve existing aviation does not yet exist, requiring new, likely expensive, development initiatives to solve this difficult issue.

As with all-electric aircraft designs mentioned above, plug-in hybrid and hydrogen propulsion systems will require the development and integration of charging/alternative fueling infrastructure lacking at existing airports. Individual charging stations at each airport terminal gate will be required for aircraft with battery electric propulsion. Accommodating hydrogen fueling, either to augment or replace the existing airport fueling networks designed to move and dispense jet fuel, may require large scale infrastructure improvements. Additionally, hydrogen powered aircraft will require large-scale production of hydrogen far beyond the levels of existing industrial capacity.

There are several ways to produce hydrogen, each with different environmental impacts and production efficiencies. The cheapest and most common method of producing hydrogen currently breaks down natural gas using pressure and heat to produce hydrogen and a great deal of carbon dioxide.[31] Using biomass-derived liquid (ethanol) increases the sustainability of the feedstock, but both of these methods require a carbon capture and storage method to

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[28] ZeroAvia secures US$150m in Series C Financing, AviTrader.com, Sept. 13, 2024
[29] Fuel Cells, Hydrogen and Fuel Cell Technologies Office, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy
[30] Hydrogen Fuel Cell Engines and Related Technologies, Energy Technology Training Center, College of the Desert, Palm Desert, CA, 2001
[31] Hydrogen Production and Distribution, Alternative Fuels Data Center, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy

mitigate effects of carbon release to the atmosphere. Electrolysis uses electricity to separate hydrogen and oxygen atoms within water molecules. This method of hydrogen production may have a lower carbon footprint if the source of electricity is generated through renewable energy sources. If the electricity and/or heat source to produce hydrogen is generated via fossil fuels (coal, gas, and oil), the associated carbon footprint of production may negate the advantages of using hydrogen as an aviation fuel or energy source.

Distribution is a significant challenge facing wide-scale adoption of hydrogen technologies. Unlike existing liquid fuels, hydrogen requires high-pressure cryogenic infrastructure in transit from producer to airport user. As such, most hydrogen is produced in close proximity to the end consumer. The existing hydrogen pipeline network is limited in size and serves petrochemical refineries in Illinois, California, and the Gulf Coast. Transporting hydrogen by truck or rail requires high pressure heavily insulated tanks that are susceptible to leakage and evaporation if not consumed quickly enough and increase the cost and reduce the efficiency of a hydrogen infrastructure.

Conclusion

The aviation industry is undergoing many major transformation changes, none more so than the very fuels powering existing aircraft. As the last remaining user of leaded gasoline, long sought replacements within GA are finally nearing full-scale adoption in line with agency regulation. The growing push to reduce greenhouse gas emissions from both outside and within the aviation industry has led to major government initiatives and commercial investment in sustainably sourced, lower life cycle GHG jet fuels. Longer-term advancements in technology envisage an industry transformed by electrification, hybridization, and hydrogen integration. These are nascent technologies with major potential to reduce the environmental footprint of aviation yet carry significant technological and economic challenges that have yet to be solved.

The Council does not directly fund aviation facilities to aid with transitions to alternative fuels but opportunities for partnerships exist with regional partners working on establishing new technologies or protecting the health and safety of aviation users and residents. Areas where Metropolitan Council authority and planning goals intersect with aviation regulatory and industry trends are detailed below:

1. **Region is Equitable and Inclusive** – Support a diverse field in the development of new fuels and alternative power sources while advocating for the continued availability of legacy fuels for existing users until safe replacements are available.

2. **Communities are Healthy and Safe –** The elimination of lead and reduction in GHGs in traditional fuels should be supported, reducing harmful emissions, and enhancing air quality.

3. **Region is Dynamic and Resilient –** Development and integration of SAF hub and novel electric/hydrogen power technologies to advance and promote regional innovation and job creation.

4. **Lead on Addressing Climate Change** – Support industry transition to more sustainably sourced jet fuels that lead to reduced GHG emissions with the ultimate integration of future electrification and alternative fueling initiatives.

5. **Protect and Restore Natural Systems** – Require airport development projects to prioritize adoption of unleaded AVGAS, eliminating the remaining source of

environmental lead exposure, and plan for future integration of electric charging and alternative fuels facilities.

The Metropolitan Council will continue to monitor aviation industry trends in relation to our regional planning goals.