# Comparing Biofuels and Hydrogen as Alternatives to Conventional Jet Fuel

Raymond Ye


## Abstract

The aviation industry heavily relies on fossil fuels to power its flights. The significant environmental challenges it creates, along with its unsustainability, intensify global pressure for decarbonization. This paper examines two primary alternatives with the potential to replace Jet A and Jet A-1. The two leading fuel alternatives are biofuels and hydrogen. Biofuels are a quick solution due to their compatibility with existing aircraft infrastructure. Evidenced by their ability to reduce carbon emissions and their highly tested performance in commercial flights. However, high production costs still remain as a major barrier. Hydrogen, on the other hand, whether combusted directly or used in fuel cells, provides a long-term, near zero-carbon option with exceptional energy density by weight. Though poor volumetric density, storage requirements, and infrastructure limitations still hinder large-scale adoption. By comparing the properties, benefits, and limitations of both fuels, this review highlights that while biofuels are the most practical short-term pathway, hydrogen holds the greatest long-term potential for achieving a sustainable and clean aviation future.


## Introduction

The use of fossil fuels has become a popular topic in our society, said to be the cause of our environmental problems, yet, at the same time, the solution to energy. When non-renewable resources like fossil fuels are mentioned, people are reminded of the economic power they hold, in contrast with the ecological damage they create. Current operations in combating the issue of climate change by fossil fuels are through the advancement of technology. However, our current advancements in technology are still unable to account for all climate problems. Huwe and others suggest that “while state support of green industries may accelerate the deployment of green energy and technologies, what ultimately matters for climate stabilization is the timely phase-out of fossil fuels” (Huwe et al., 2024).

The inability to replace fossil fuels completely through technological innovations has caused people to lose hope in going green. This unsettled outrage at the involvement of fossil fuels has led people to strive for new ways to go green, one of these ways being environmentally positive political protests. Embracing the idea of anti-globalization, “The most recent wave of these, since late 2018, has been the school strikes inspired by Greta Thunberg, and Extinction Rebellion” (Paterson, 2020). The topic of fossil fuels not only pollutes our environment but also our societal relationships, bringing urgency in finding the true solution to this complex issue. Fossil fuels are neither sustainable nor great for the environment, so the solution would be to discover new fuel sources that mimic oil in terms of energy density but are sustainable and clean.

To eliminate the issue of fossil fuel usage, we must find a solution that undermines it completely. This would mean that continuous usage of fossil fuels would be deemed as illogical in terms of not only the climate, but the economy as well. Starting small, we can seek new fuel sources that work as efficiently as fossil fuels in select industries. Among the select industries where fossil fuels may be replaced, the aviation industry is a prominent contributor to $CO_2$ emissions globally. In 2023, planes generated about 882 million tons of carbon dioxide

(Quantifying Aviation's Climate Impact 2025). This rapid increase in carbon emissions is linked to development in urban civilizations and the extended use of planes that require fossil fuels for energy (Burkhardt, 2020).

One way we can improve engine efficiency while not changing infrastructure as much is by simply increasing the pressure ratios within the engine. Even so, this leads to the combustor temperatures increasing to a point beyond our current materials' thermocapability, and emitting other pollutants like NOx along with soot (Lee et al., 2009). To add on, improving engine efficiency would not eliminate the use of fossil fuels either, with the potential to still run out in the future.

Seeing as fossil fuels are still a finite resource, simply improving engine efficiency is not much of a viable option. Discovering new, clean, yet energy-dense fuel sources would be a much more viable solution. Before touching on the alternative fuels, we need a clear understanding of our commonly used fuel sources in commercial planes: Jet A and Jet A-1. Jet A and Jet A-1 are both very similar, being refined versions of pure kerosene. Though both these jet fuels differ from kerosene as they have a lower freezing point than kerosene, making them suitable for any weather circumstances.

Even though the differences between the specific Jet fuels, Jet A and Jet A-1, are minimal, they still exist. Jet A-1 has a slightly lower freezing point of −53 °F (−47 °C) while Jet A freezes at −40 °F (−40 °C), making it more suitable for higher altitude, colder international flights (Jet fuel, 2025). Additionally, Jet A-1 contains an anti-static agent to avoid static electricity build-up during flight. Static build-up can occur when fuel is constantly rubbing against internal pipes and hoses; if this continues, it may generate a spark. A spark in the wrong sector of the engine is threatening because it would ignite the fuel, disrupting the flow of the engine, which may cause the engine to malfunction or even explode.

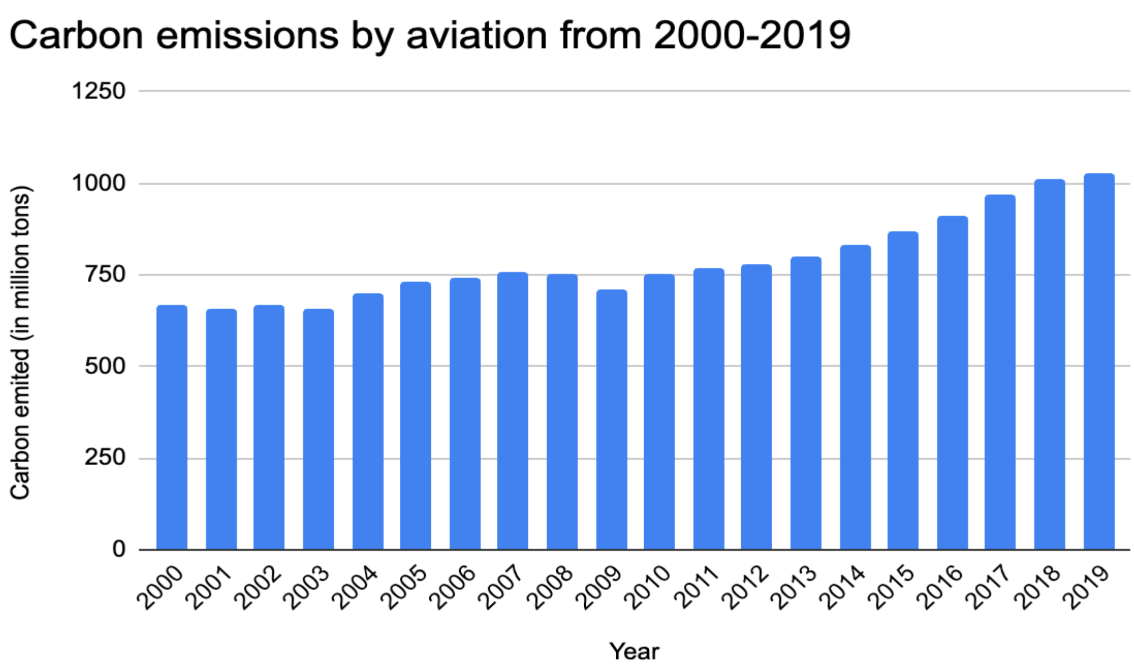


**Figure 1.** Global aviation $CO_2$ emissions from 2000–2019 (Ritchie, 2024).

| Fuel Type | Freezing Point (°C) | Energy Density (MJ/kg) | Additives |
|---|---|---|---|
| Jet A | -40 | ~ 43 | None |
| Jet A-1 | -47 | ~ 43 | Anti-static |

**Figure 2.** Table comparison between Jet A and Jet A-1 (Jet fuel, 2025).

With an understanding of the properties of our current Jet fuels, we seek new fuel sources that meet the same broad requirements of low freezing point and high energy density. These new fuel sources include biofuels and liquid Hydrogen. Both these fuel sources are much cleaner than kerosene, with their unique ways of limiting carbon emission: Biofuels limit carbon by using an agricultural process in manufacturing, taking carbon away from our atmosphere (Cabrera & de Sousa, 2022), Liquid Hydrogen limits carbon due to its chemical compounds involved being only H2 and O2 (Ponater, 2006).

### Biofuels

Sustainable Aviation Fuels (SAF), specifically biofuels, are the most researched and studied fossil fuel replacement in the aircraft industry. Biofuel is a direct drop-in substitute or even complete replacement for kerosene, being derived by processing feedstocks (Cabrera & de Sousa, 2022). In order to reduce carbon emissions, biofuels are made from feedstocks coming from a variety of bases, oilseed plants, agricultural/forestry residue, fats/oils from cooking waste, and even algae (Overton, 2022). One method that can limit carbon from our atmosphere is by growing crops such as corn for the sole purpose of biofuel production. This method ensures a closed cycle: when we use the biofuels, they release carbon into the atmosphere, but then we can reduce that carbon by growing these feedstocks, relying on their photosynthesis to absorb it. The main limitation with growing feedstocks for biofuels would be high production costs. To battle this, another method of producing biofuels would be to reuse green waste for production. Specifically, waste such as lignocellulosic biomass, corn grain, sawdust, forest residue, wood residue, sugarcane bagasse, straw, and agricultural wastes (Zahid, 2024). Although this second method is more economically viable than the first, it removes the purpose of limiting carbon emissions. As evidenced, there are still limitations in the biofuel industry. In the following sections discuss the positives and negatives of the use of sustainable aviation fuel.

### Viability of Biofuels

Biofuels are known as the “drop-in” fuel due to their great compatibility in our current airport infrastructure; without any need for modifications, we can implement this change instantly (Wandelt et al., 2025). This similarity also means that it can be mixed into our current Jet-A fuel. This is also the reason it's among the most researched and tested alternative fuels, with currently over 350,000 flights flown using this specialized biofuel (Sustainable aviation fuel).

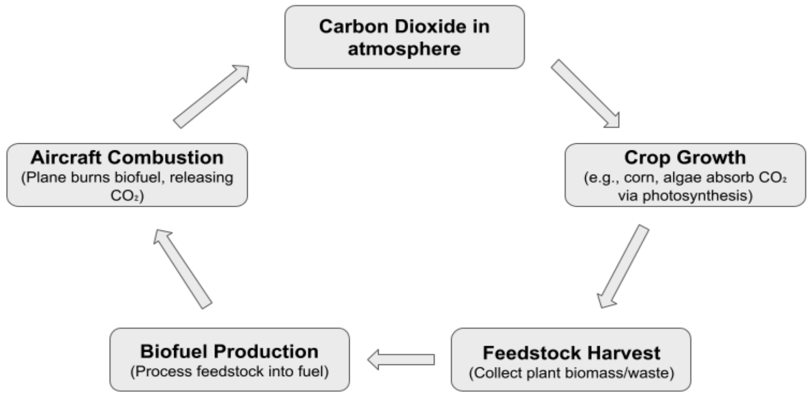


**Figure 3.** Simplified carbon lifecycle of sustainable aviation biofuels (Conceptual model based on Cabrera & de Sousa, 2022; Overton, 2022).

If we were to switch over to biofuels and replace jet fuel completely, we could lower carbon emissions in the aviation sector by 94% (Teoh et al., 2022). Besides the diminished production of carbon due to the closed cycle of regrowing feedstocks, another result in this cleaner production process is that biofuels, as a fuel, contain fewer pollutants when burned. Production of compounds like sulfur oxides, carbon monoxide, and unburned hydrocarbons is decreased in the combustion of biofuels as compared to crude oil-derived jet fuel. Due to this reduction in particulate production, another surprising benefit occurs: plane contrail formation can be lowered. Excessive Plane contrails are an issue because these contrails can form huge cirrus clouds that trap heat, resulting in an even greater global warming effect than that of carbon (Overton, 2022). These are some reasons why sustainable aviation fuel production doubled from 300 million liters in 2022 to 600 million liters in 2023 (Developing Sustainable Aviation Fuel (SAF)).

In discussing the viability of using biofuels, examining their limitations and practicality is crucial. To start off with the first limitation, biofuels may differ slightly from conventional Jet-A fuel due to their varied feedstock and production methods; characteristics like density, viscosity, and volatility may change as a result. This hinders their full compatibility with our current jet engines, requiring small engine modifications still yet to be made (Mane, 2025). Another troublesome limitation would be the cost. The process of manufacturing biofuels is extremely extensive, with steps that require an absurd amount of money: growing the feedstock, sacrificing money for both land and resources, then harvesting and processing, which requires a lot of energy. On top of this, due to feedstocks having slightly differing properties, a higher production cost will be required to maintain consistent quality. In summary, production cost is by far the limiting factor that discourages airlines from switching over to biofuels. The production cost of biofuel is 3-5 times more expensive compared to standard Jet fuel (Hundt & Antonenko, 2024). According to King & Spalding, in order for us to combat production costs for the long term, “these costs will need to be passed through to customers or benefit from other cost recovery mechanisms.” Cost recovery mechanisms, such as subsidies. Signifying that discovering new and efficient production techniques will be the breakthrough to this financial obstacle.

### Hydrogen (Combustion and Fuel Cells)

By weight, combusting hydrogen produces more energy than any other fuel, which is the reason that it's one of the main fuels used in rockets today. Hydrogen's characteristics, such as its high energy capacity and light weight, make it a viable fuel for commercial airplanes. Hydrogen can be used in two ways: either directly combusted (similar to our current engine infrastructure), or the hydrogen can be fed into a fuel cell, producing electrical energy instead. Both methods of energy production are extremely clean, with no carbon dioxide and limited NOx emissions (Gopalasingam et al., 2025).

How direct hydrogen combustion works is in its name; we would inject liquid hydrogen into the engine, then directly combust the hydrogen like we would for standard Jet A fuel. Though major engine modifications will need to be made since hydrogen diffuses much quicker and is much more flammable, bringing safety precautions into play (Gopalasingam et al., 2025). Direct combustion of hydrogen has been tested by numerous companies; for example, Lockheed's 1956 liquid hydrogen aircraft by Pratt Whitney, built to run on liquid hydrogen for direct combustion (Brewer, 2017). Even though hydrogen combustion engines are not commercialized yet, major aircraft engine manufacturers such as Rolls-Royce, Safran, GE, and P&W are working to bring future hydrogen-powered turbine engines into the long-range aviation market (Gopalasingam et al., 2025).

Direct hydrogen combustion may be great in terms of its dense energy capacity; however, another valid competing method, the hydrogen fuel cell, is feasible as well. Hydrogen fuel cells are highly energy efficient. A hydrogen fuel cell is made up of an anode, a cathode, and an electrolyte membrane. These three components work in a constant cycle to produce energy through the electrochemical process of splitting the hydrogen, passing the lone electron through the electrolyte membrane, towards the cathode, then sending it back to the anode, repeating the process (Felseghi et al., 2019). The use of hydrogen fuel cells produces three times more energy with the same amount of hydrogen used compared to direct combustion. To put into perspective, standard diesel has an energy efficiency of 35%, direct hydrogen combustion has an efficiency of 25%, while hydrogen fuel cells have an energy efficiency of 60% (Bloom Energy, 2025). Hydrogen fuel cells may seem like the ideal aircraft fuel, but they're riddled with flaws. Hydrogen fuel cells are extremely heavy, and their odd shapes require a new plane design that's much broader than our traditional planes, both factors which hinder their energy efficiency during flight. Due to the nature of these flaws, hydrogen fuel cells are more likely to be only viable in small aircraft, while with the focus of this paper being on huge international commercial planes, direct hydrogen combustion is a more ideal long-term solution.

### Viability of Hydrogen Combustion

Since known, hydrogen is extremely energy dense by weight. By weight, kerosene has an energy density of 40 MJ/KG, whereas hydrogen is at 120 MJ/KG. Weight is a key component when it comes to the balance of a plane. If we were to switch to hydrogen as the fuel, 1kg of hydrogen produces the same amount of energy as 2.8kg of kerosene (Felseghi et al., 2019). Besides the energy density of hydrogen, burning hydrogen is extremely clean compared to Jet fuel as well. Hydrogen is a clean fuel that does not release any carbon dioxide, therefore lowering $CO_2$ emissions (Yilmaz & Taştan, 2018). Additionally, hazardous chemicals are not produced from combusting hydrogen; this is the reason why multiple studies have been done on using hydrogen as fuel in vehicles in the last 30 years (Shadidi et al., 2021).

Hydrogen is truly energy dense in terms of weight, but by volume, hydrogen's density is undoubtedly small. Standard Jet fuel has an energy density by volume of roughly 32 MJ/L, whereas liquified hydrogen has an energy density of only 8 MJ/L (Hydrogen factsheet). This means that in terms of size, a hydrogen plane's fuel tank would be more than three times larger in size compared to our current fuel tanks while generating the same amount of energy. This lack of density by volume will require the use of bigger fuel tank sizes that will not fit in our current plane designs, meaning a completely new design solution will be required.

| **Fuel Type** | **Energy Density (MJ/Kg)** | **Energy Density (MJ/L)** |
|---|---|---|
| Jet Fuel | 40 | 32 |
| Hydrogen | 120 | 8 |

**Figure 4.** Energy density comparison of Jet fuel and hydrogen by weight and volume, highlighting hydrogen's high energy per kilogram but low energy per liter (Data from Felseghi et al., 2019; Hydrogen Factsheet, 2025).

Besides its poor energy density by volume, another limitation of using hydrogen is its accessibility and the weight of storage. Currently, liquified hydrogen is not an easy source to get since we do not mass-produce it like Jet fuel. The process of liquifying hydrogen requires extreme temperatures down to 423°F at standard atmospheric pressure (Felseghi et al., 2019). On top of that, storing liquified hydrogen requires massive cryogenic tanks that not only hinder plane size but also weight as well. Despite these limiting factors, an Aerospace company, Airbus, has been working on a hydrogen combustion aircraft that is capable of flying for four hours, aiming to reach markets by 2035 (Airbus, 2021).

**Summary of Key Findings**

| **Fuel Type** | **Adoption Timeframe** | **Aircraft Compatibility** | **Advantages** | **Limitations** |
|---|---|---|---|---|
| Biofuel | -short to medium term (already in limited commercial use; scalable this decade) | -Fully compatible with existing jet engines when blended with conventional Jet-A fuel<br><br>-No major aircraft or engine redesign required | - Drop-in fuel, compatible with existing engines and infrastructure<br><br>- Reduces $CO_2$ emissions up to 94%<br><br>- Fewer pollutants like sulfur oxides and contrails | - Production 3–5× more expensive than Jet fuel<br><br>- Small variations in feedstock affect fuel consistency<br><br>- Scaling up may compete with food |

| Fuel Type | Adoption Timeframe | Aircraft Compatibility | Advantages | Limitations |
|---|---|---|---|---|
| | | | | production if crops are used |
| Hydrogen (combusted) | -Long term (post-2035, still in experimental and prototype stages) | -Not compatible with current commercial aircraft designs<br><br>-Requires redesigned airframes, fuel tanks, and modified combustion engines | - near zero carbon emissions<br><br>- Very high energy density by weight (3× Jet fuel)<br><br>- Abundant and sustainable long-term fuel | - Poor energy density by volume (larger tanks needed)<br><br>- Requires major engine and plane design modifications<br><br>- Storage and infrastructure challenges (cryogenic tanks) |

**Figure 5.** Summarized evaluation between sustainable aviation biofuels and Direct Hydrogen Combustion compared to conventional Jet fuel (Data from Wandelt et al., 2025; Teoh et al., 2022; Hundt & Antonenko, 2024; Overton, 2022; Felseghi et al., 2019; Yilmaz & Taştan, 2018; Hydrogen factsheet).

Discussions

These findings suggest that we should focus on a short-term adoption of biofuels while advancing in the development of long-term hydrogen use. This transition can be supported by governments through targeted tax credits and subsidies based on each fuel's ability to reduce CO2 emissions. Both Biofuels and hydrogen combustion limit carbon emissions, with hydrogen specifically presenting near-zero carbon results. As evidenced by subsidies provided for electric vehicles, the government's efforts to go green are clear. In 2021, the Sustainable Aviation Fuel Grand Challenge, led by the U.S. Department of Energy (DOE), the U.S. Department of Transportation (DOT), and the U.S. The Department of Agriculture (USDA), was created in hopes of reducing the cost, enhancing energy security, and expanding the production of SAF (Sustainable aviation fuel). Even with minor government support for financing the production and use of Sustainable aviation fuels is available, the high cost of biofuel production still outweighs this support. This suggests that a greater amount of subsidies is possible and should be placed, further encouraging the adoption of biofuels. Similar to biofuels, hydrogen's clean nature should allow it to qualify for subsidies as well. Hydrogen has the potential to become a long-term sustainable energy for the future; what we require now, is the funding to keep researching and developing new implementations for hydrogen.

## Conclusion

This review looked into potential alternative fuel sources for commercial planes specifically. Evaluating the pros and cons of biofuels, hydrogen Combustion, and the brief mention of hydrogen fuel cells. Among the fuels mentioned, each has the possibility of replacing or supplementing Jet A fuel in the future. In terms of a short-term quick solution, biofuels would be the answer, with their similar properties, minor modifications required, and heavily tested statistics, it seems like it's the best replacement for our current Jet A fuel. Though a quick replacement, the cost of these biofuels is a major hindering factor that worries companies. Biofuels are 5 times more expensive than Jet fuel, and fuel costs account for 30% of a plane ticket. Meaning an airline company that adopted biofuels would have to sell its tickets at 2.2 times that of its competitors. Contrastingly, with biofuel being a quick replacement, in search of long-term options, hydrogen would be the fuel to look into. Hydrogen currently has its flaws, such as its inefficient storage size and lack of infrastructure for production, but these characteristics can be altered through innovation. Hydrogen's selling point would be its abundance and sustainability, allowing us to mass-produce it and build a civilization run on hydrogen. While both fuels have their own challenges, the continued development of biofuels and hydrogen shows that a sustainable, low-carbon future for aviation is not only possible, but already underway.

## References

Bloom Energy. (2025, February 13). *What are the advantages of hydrogen fuel cells?* https://www.bloomenergy.com/blog/what-are-the-advantages-of-hydrogen-fuel-cells/#:~:text=Hydrogen%20fuel%20cells%20outshine%20traditional,the%20same%20amount%20of%20fuel.

Brewer, G. D. (2017). *Hydrogen Aircraft Technology*. CRC Press.

Burkhardt, U. (2020, November 11). *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*. Science Direct. https://www.sciencedirect.com/science/article/pii/S1352231020305689?pes=vor&utm_source=tfo&getft_integrator=tfo#bib91

Cabrera, E., & de Sousa, J. M. M. (2022, March 26). *Use of sustainable fuels in aviation-A Review*. MDPI. https://www.mdpi.com/1996-1073/15/7/2440

*Developing sustainable aviation fuel (SAF).* IATA. (n.d.). https://www.iata.org/en/programs/sustainability/sustainable-aviation-fuels/#:~:text=What%20is%20SAF?,fully%20compatible%20with%20modern%20aircraft.

Felseghi, R.-A., Carcadea, E., Raboaca, M. S., TRUFIN, C. N., & Filote, C. (2019, December 3). *Hydrogen fuel cell technology for the Sustainable Future of stationary applications*. MDPI. https://www.mdpi.com/1996-1073/12/23/4593#Considerations_Regarding_Hydrogen_Fuel_Cell_Technology

Gopalasingam, D., Rakhshani, B., & Rodriguez, C. (2025a, October 20). *Hydrogen Propulsion Technologies for Aviation: A review of fuel cell and direct combustion systems towards decarbonising medium-haul aircraft*. MDPI. https://www.mdpi.com/2673-4141/6/4/92#B8-hydrogen-06-00092

Gopalasingam, D., Rakhshani, B., & Rodriguez, C. (2025b, October 20). *Hydrogen Propulsion Technologies for Aviation: A review of fuel cell and direct combustion systems towards decarbonising medium-haul aircraft*. MDPI. https://www.mdpi.com/2673-4141/6/4/92#B105-hydrogen-06-00092

Hundt, B., & Antonenko, A. (2024, May 30). *Challenges and opportunities in the scale-up of SAF production*. Sustainable Aviation Futures. https://www.sustainableaviationfutures.com/saf-spotlight/scale-up-saf-king-and-spalding#:~:text=The%20second%20hurdle%20is%20particularly,used%20in%20PtL%20SAF%20production.

Huwe, V., Hopkins, D., & Mattioli, G. (2024). Aviation exceptionalism, fossil fuels and the State. *Review of International Political Economy*, *32*(1), 76–100. https://doi.org/10.1080/09692290.2024.2384925

*Hydrogen combustion, explained*. Airbus. (2021, September 2). https://www.airbus.com/en/newsroom/stories/2020-11-hydrogen-combustion-explained

Lee, D., Fahey, D., Forster, P., Sausen, R., Owen, B., Lim, L., Wit, R., & Newton, P. (2009, April 19). *Aviation and global climate change in the 21st century*. Science Direct. https://www.sciencedirect.com/science/article/pii/S1352231009003574?ref=pdf_download&fr=RR-2&rr=9997bb51a99d67bf

Mane, S. (2025, March). *Sustainable Aviation Fuel: Prospects and Limitation*. Research Gate. https://www.researchgate.net/profile/Shreya-Mane-2/publication/389952181_Sustainable_Aviation_Fuel_Prospects_and_Limitations/links/67da682de62c604a0dde2925/Sustainable-Aviation-Fuel-Prospects-and-Limitations.pdf?__cf_chl_tk=FGTQF7WBTyQObIXXXFvn_j3zXcwfc7b8FbFJLT_cZDs-1764111508-1.0.1.1-VBD9eLy11CYCBQB6kkXQ32a0MTJX7TRP_kDJNy3HwWY

Overton, J. (2022, February 1). *An introduction to sustainable aviation fuels*. EESI. https://www.eesi.org/articles/view/an-introduction-to-sustainable-aviation-fuels#:~:text=The%20strategy%20with%20the%20most,renewable%20electricity%20for%20the%20electrolysis.

Paterson, M. (2020). Climate change and international political economy: Between collapse and transformation. *Review of International Political Economy*, *28*(2), 394–405. https://doi.org/10.1080/09692290.2020.1830829

Ponater, M. (2006, August 22). *Potential of the cryoplane technology to reduce aircraft climate impact: A state-of-the-art assessment*. Science Direct. https://www.sciencedirect.com/science/article/abs/pii/S1352231006006686

*Quantifying aviation's climate impact*. Aviation. (n.d.). https://aviationbenefits.org/other-environmental-challenges/quantifying-aviations-climate-impact/

#:~:text=SHARE&text=Air%20transport%20generated%20882%20million,to%20limit%20greenhouse%20gas%20emissions.

Ritchie, H. (2024, April 8). What share of global $co_2$ emissions come from aviation?. Our World in Data. https://ourworldindata.org/global-aviation-emissions

Shadidi, B., Najafi, G., & Yusaf, T. (2021, September 29). *A review of hydrogen as a fuel in internal combustion engines*. MDPI. https://www.mdpi.com/1996-1073/14/19/6209#B94-energies-14-06209

*Sustainable aviation fuel*. Alternative Fuels Data Center: Sustainable Aviation Fuel. (n.d.). https://afdc.energy.gov/fuels/sustainable-aviation-fuel

Umichigan. (n.d.). *Hydrogen factsheet*. Center for Sustainable Systems. https://css.umich.edu/publications/factsheets/energy/hydrogen-factsheet#:~:text=electrification%20are%20problematic.-,2,Image

Wandelt, S., Zhang, Y., & Sun, X. (2025, January 20). *Sustainable aviation fuels: A meta-review of surveys and key challenges*. Science Direct. https://www.sciencedirect.com/science/article/pii/S2941198X24000678#sec2

Wikimedia Foundation. (2025, December 2). Jet fuel. Wikipedia. https://en.wikipedia.org/wiki/Jet_fuel

Yilmaz, İ., & Taştan, M. (2018, November 1). *Investigation of hydrogen addition to methanol-gasoline blends in an SI engine*. Science Direct. https://www.sciencedirect.com/science/article/abs/pii/S0360319918322420

Zahid, I. (2024, July 17). *Current outlook on sustainable feedstocks and processes for sustainable aviation fuel production*. Science Direct. https://www.sciencedirect.com/science/article/pii/S2452223624000804#sec2