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Barriers to Sustainable Aviation Fuel Adoption in U.S. Airport Infrastructure: A Systematic Review

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Carbon dioxide (CO_2) emissions from aircraft are a growing concern, as they contribute to global carbon emissions. One of the most prominent approaches to mitigating aviation emissions is transitioning from jet fuel to sustainable alternatives. This study examines the main barriers to adopting Sustainable Aviation Fuels (SAF) in U.S. airport infrastructure. Through a systematic literature review, it identifies the key barriers that hinder SAF adoption in U.S. airport infrastructure. The findings suggest that multiple interrelated factors constrain its large-scale deployment across the U.S. airport system. High production costs and limited fuel availability remain important economic barriers. Many U.S. airports also lack the infrastructure needed to support large-scale SAF storage, blending, and distribution. These infrastructure limitations are linked not only to aging airport facilities but also to regulatory and certification requirements. Fragmented policy frameworks and limited coordination among key stakeholders create additional challenges for SAF implementation. Based on these findings, the study proposes a conceptual framework that groups the main barriers to SAF adoption into four related categories: economic, infrastructural, policy/regulatory, and market/stakeholder. The framework also recognizes collegiate aviation programs as an important but often overlooked stakeholder in SAF adoption. The proposed framework may provide a foundation for future research and policy development for a more sustainable aviation system.

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Introduction

Environmental aspects of the aviation sector have been questioned considerably in recent years (Fichert et al., 2020). According to the Intergovernmental Panel on Climate Change (IPCC, 2022), international shipping and aviation together contribute approximately 2% of global carbon dioxide (CO_2) emissions. Responding to this significant impact, the International Civil Aviation Organization (ICAO) has actively sought measures to mitigate aviation's environmental impacts since the mid-1990s (Fichert et al., 2020).

In light of this, ICAO introduced the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016 as a global market-based measure to reduce CO_2 emissions from international flights (Fichert et al., 2020). It is worth noting that since January 2019, most international airlines have been required to offset any increase in CO_2 emissions above 2020 levels (Maertens et al., 2020).

Due to regulatory pressure imposed by CORSIA, the adoption of *Sustainable Aviation Fuels (SAF*) in the industry has gained momentum (Trejo-Pech et al., 2019). SAF can be defined as biofuels engineered to closely resemble conventional jet fuel in performance while offering a significantly reduced carbon footprint (U.S. Department of Energy [DOE], 2021a). International regulations mandate that SAF be derived from renewable or waste sources and comply with CORSIA sustainability standards (Malina et al., 2022). Over their life cycle, SAF emits substantially less CO_2 than traditional kerosene-based jet fuels (Malina et al., 2022).

Beyond their environmental benefits, understanding production processes is also crucial for evaluating the implementation of SAF. These fuels can be produced from a diverse array of renewable and sustainable feedstocks, such as biomass, waste oils and fats, algae, municipal solid waste (MSW), synthetic paraffinic kerosene (SPK), and hydro-processed esters and fatty acids (HEFAs) (Air Transport Action Group [ATAG], 2017). The main conversion processes include hydroprocessing, gasification, pyrolysis, and fermentation (ATAG, 2017). These flexible methods not only help improve environmental performance but also support job creation and economic growth (ATAG, 2017).

Given this context, examining SAF adoption in major aviation markets could provide valuable insights into its practical implementation. As one of the largest aviation markets in the world, the U.S. is characterized by an extensive network of major airports and airlines that support domestic and international travel. However, this expansion has resulted in significant environmental consequences, particularly the increase in aircraft-related CO_2 emissions (FAA, 2021). Consequently, the U.S. commercial aviation industry has increasingly turned to SAF due to volatile jet fuel prices, concerns about environmental impacts, and the introduction of CORSIA (Trejo-Pech et al., 2019).

In response to these challenges, a growing body of research has examined the potential of SAF to reduce aviation-related emissions. Holladay et al. (2020) emphasized the need for environmentally sustainable and cost-effective aviation fuels to address the sector's escalating carbon emissions. Kittel et al. (2023) proposed that coprocessing sustainable aviation components with alternative petroleum fractions in oil refineries could help mitigate the adverse environmental impacts of jet fuel. It is widely accepted that SAFs play a vital role in creating a sustainable future for both society and the aviation sector (Holladay et al., 2020).

Despite this growing optimism, several barriers continue to hinder the widespread adoption of SAFs. These barriers include high production costs, largely due to limited economies of scale, and supply constraints linked to underdeveloped production and distribution infrastructure. Regulatory and certification requirements further complicate deployment. In addition, competition for feedstocks with other industries, together with technical and integration barriers, continues to hinder large-scale implementation (IATA, 2020; FAA, 2022a; Pate et al., 2022).

Although many barriers to SAF adoption have been identified, the way airport infrastructure interacts with these barriers remains relatively underexamined. Previous studies have shown that most U.S. airports currently lack the infrastructure required to blend SAF on-site (Moriarty & Kvien, 2021; DOE, 2021c). Historically, airport infrastructure in the U.S. has focused on accommodating increased traffic and cargo volume (Airport Council International–North America [ACI–NA], 2023). However, as airports around the world work toward net-zero carbon emissions by 2050, they now need to make significant infrastructure investments (ACI–NA, 2023).

These gaps in the literature highlight the need for a more comprehensive understanding of the barriers to SAF adoption within U.S. airport infrastructure. Therefore, this study aims to systematically examine the factors that may hinder the integration of SAF into U.S. airport infrastructure. Beyond identifying the barriers reported in previous studies, it contributes to the literature by proposing an integrated conceptual framework that explains how these barriers interact within U.S. airport infrastructure. The framework provides a more comprehensive understanding of how interrelated barriers influence SAF adoption within the U.S. airport system. Accordingly, the study addresses the following research questions:

- RQ1: What are the main barriers to implementing SAFs within U.S. airport infrastructure?
- RQ2: What strategies or policy measures could help overcome these barriers and promote broader SAF deployment in U.S. airports?

Methodology

This study follows the systematic literature review approach proposed by Tranfield et al. (2003). Systematic reviews use explicit and reproducible procedures to identify, evaluate, and synthesize relevant evidence while minimizing potential sources of bias (Cook et al., 1997; Tranfield et al., 2003). A key feature of this approach is the clear documentation of the search process, including the criteria used to include or exclude sources and the procedures followed to analyze and synthesize the findings (Cook et al., 1997; Tranfield et al., 2003). Given that SAF research covers the fields of engineering, economics, politics, and aviation management, this approach is well-suited to the aim of the present study.

We searched the relevant literature on the following keyword combinations: “sustainable aviation fuel (SAF)”, “U.S. airport infrastructure," “barriers to sustainable aviation fuels," “economic challenges of SAF”, “airport sustainability policy," and “SAF supply chain in the U.S." These keyword combinations were selected to reflect the multidisciplinary nature of SAF research. General terms such as "sustainable aviation fuel" were combined with more specific terms (e.g., infrastructure and cost) to identify studies covering the multiple aspects of SAF adoption. Searches across JSTOR, Taylor & Francis, Scopus, ScienceDirect, and Google Scholar yielded 142 records. After removing duplicates, 103 remained. Following title and abstract screening, 79 articles were reviewed in full text. Finally, 54 studies met the inclusion criteria. In addition to the database search, relevant government and institutional reports were identified through manual keyword searches and included when they addressed the barriers examined in this study.

Sources were included if they: (1) directly discussed the adoption, production, or infrastructure of SAF; (2) focused on economic, infrastructural, political, or stakeholder aspects; (3) were published between 2013 and 2023, with a preference for studies after 2019 to get the most up-to-date information on the market and regulatory shifts; and (4) were peer-reviewed journal articles or trusted institutional reports, such as those from the FAA, ACI, DOE, or IATA. Sources were excluded if they covered only technical fuel chemistry without discussing adoption barriers, or if they did not provide sufficient methodological detail to assess their reliability.

One of the key inclusion criteria concerned the publication period. The review period began in 2013 because that year marked an important stage in the development of SAF research and policy. In 2013, ICAO established the Alternative Fuels Task Force (AFTF) to support research on life-cycle emissions and future SAF deployment (ICAO, 2017). For this reason, the review focused on studies published from 2013 onward.

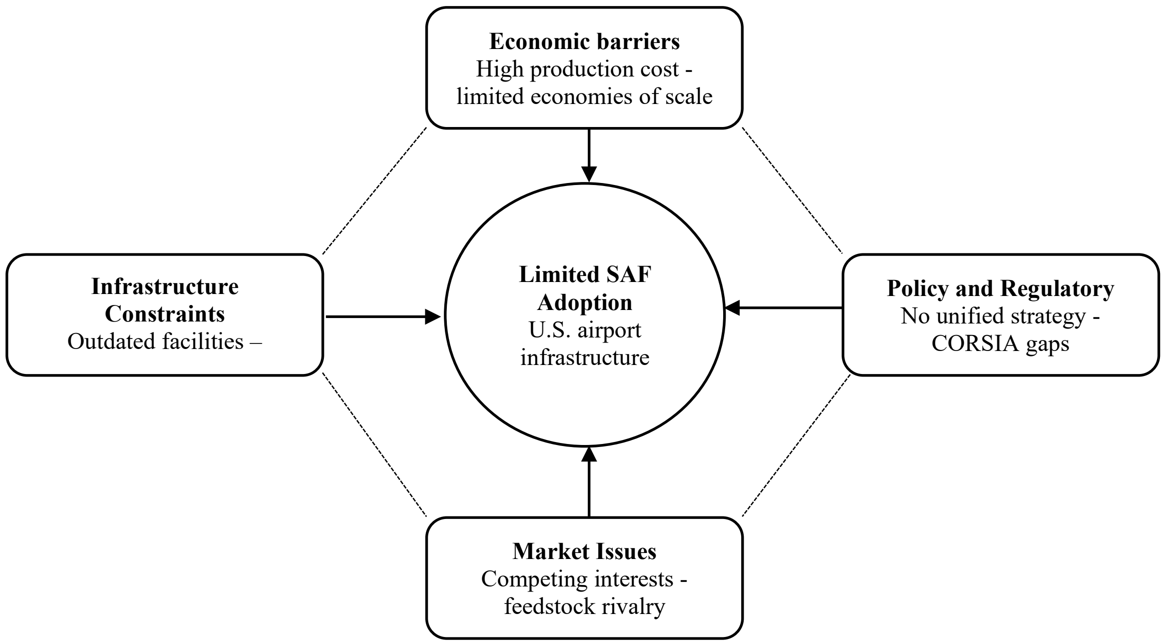
The selected studies were then analyzed using the three-stage thematic synthesis process outlined by Thomas and Harden (2008). In the first stage, findings from individual studies were coded line by line. The second stage involved grouping these coded findings into descriptive themes. In the third stage, the descriptive themes were examined in terms of deeper patterns and tensions to derive new insights from the original studies. This process resulted in four interrelated categories of barriers (namely, *economic, infrastructural, policy and regulatory, and market and stakeholder*), which form the basis of the conceptual framework presented in the following section.

Conceptual Framework

The barriers to SAF adoption in U.S. airport infrastructure do not operate independently of one another. This study proposes a conceptual framework that identifies four interrelated barrier categories and examines the feedback dynamics that emerge between them (see Figure 1).

As shown in Figure 1, four categories (i.e., economic barriers, infrastructure constraints, policy and regulatory issues, and market and stakeholder issues) put significant pressure on the pace of SAF adoption. More importantly, these barriers reinforce each other through a series of cycles. For example, high production costs tend to discourage private-sector investment in the infrastructure improvements necessary for the wider-scale deployment of SAF. This, in turn, prevents the formation of economies of scale that would lower costs. A similar cycle exists between policy and market behavior: fragmented regulations undermine investor confidence, weakening market incentives.

Figure 1.
Conceptual Framework: SAF Adoption Barriers in U.S. Airport Infrastructure



The main theoretical contribution of this study is to show how these barriers are interconnected. Earlier research has mostly addressed each barrier separately (e.g., economic viability in Roth, 2020; infrastructure limitations in Moriarty and Kvien, 2021; regulatory challenges in Korkut and Fowler, 2021). The framework in this paper brings these ideas together and suggests that solving just one barrier is not enough. Real progress in adopting SAF needs coordinated efforts across all four areas. The next sections examine each category in detail before returning to the implications of this integrated framework in the Discussion.

Sustainable Aviation Fuel: Economic Aspects

Purchasing aircraft fuel accounts for a substantial portion of the operational expenses of airlines (Roth, 2020). The average price U.S. airlines paid for jet fuel increased from approximately $0.81 per gallon in 2000 to $2.35 per gallon in 2025 (Airlines for America [A4A], 2026). In nominal terms, this is just under a threefold increase. However, after adjusting the 2000 price for inflation, it is equivalent to approximately $1.51 in 2025 dollars. This means that the real increase is about 56%. Consequently, increasing environmental concerns and the significant variability in fuel prices have led airlines to prefer alternative fuel sources (Liu et al., 2013).

Nevertheless, the strict quality requirements for commercial aviation fuel limit the use of alternative fuels in all existing aircraft (Liu et al., 2013).

As mentioned previously, the primary factor impeding airlines' widespread adoption of SAFs is the significantly higher production cost of renewable jet fuel compared to conventional jet fuel (Roth, 2020). Several studies also supported the notion that the cost of converting biomass and residual waste into aviation fuel is a significant obstacle to the widespread adoption of sustainable aviation fuel (SAF) by airlines (Trejo-Pech et al., 2019; Shahabuddin et al., 2020; Bauen et al., 2020; Brandt et al., 2022).

According to Roth (2020), renewable jet fuel will continue to be more expensive than conventional jet fuel in the short to medium term. Nevertheless, US airlines remain committed to advancing the commercialization and adoption of SAF, as it will help the aviation sector accomplish its goals of decreasing emissions, increasing energy diversity, and improving energy efficiency (Airlines for America [A4A], 2020). Three primary conditions must be satisfied before airlines may use SAF (A4A, 2020): As a first step, the SAF has to be as efficient and safe as conventional jet fuel. Second, it has to show that it is more eco-friendly than jet fuel made from petroleum. Finally, it should be practically profitable (A4A, 2020).

Although SAF needs to be safe, efficient, and ecologically sustainable, its financial viability depends on the effective coordination of many elements along the supply chain (A4A, 2020). For SAF to be economically viable, each stage of the supply chain needs to be reliable and affordable (A4A, 2020). This includes having a sustainable source of feedstocks that can meet fuel production demands, efficient transport and processing of feedstocks, facilities for converting feedstock into SAF, facilities for blending SAF with petroleum-based jet fuel, verification of fuel quality and environmental standards, transportation of purchased SAF to airports, and receipt and application of blended SAF at airports (A4A, 2020).

Furthermore, the aviation sector should ensure that SAFs have the same favorable regulations as ground-based alternative fuels (A4A, 2020). The International Air Transport Association (IATA) has requested that governments provide incentives to increase the use of SAFs because the aviation industry aims for net-zero carbon emissions by 2050 (IATA, 2022). To achieve this goal, SAF should contribute 65% of aviation's carbon reduction by 2050 and require an annual production capacity of 449 billion liters (IATA, 2022). Reaching the aim would require increasing the SAF's present yearly output capacity of 125 million liters to 449 billion liters (IATA, 2022).

In addition to addressing the economic competitiveness of SAF and regulatory measures, the adoption of SAFs requires significant investment, collaboration, and innovation across the aviation industry (Roth, 2020). These challenges must be addressed to ensure the long-term success of SAF and the aviation industry's shift towards greater sustainability (A4A, 2020).

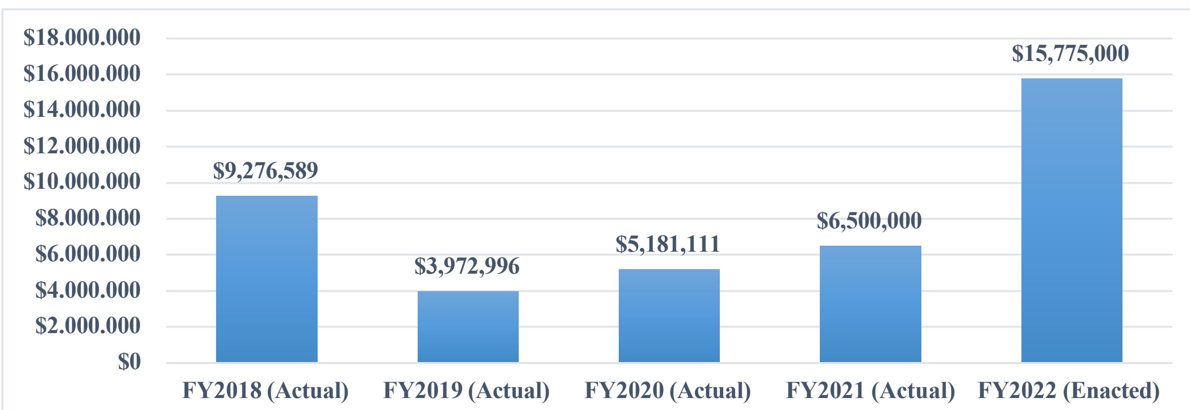
U.S. Airport Infrastructure and SAF Integration

The United States is often viewed as a leader in SAF development due to its extensive network of industry participants, certification specialists, and researchers working in the field

(Holladay et al., 2020). Recognizing the potential of SAF to reduce aviation emissions, the Federal Aviation Administration (FAA) established a target of one billion gallons of renewable jet fuel consumption per year for the U.S. aviation sector beginning in 2018 (Winchester et al., 2013). Figure 2 presents FAA funding allocated to SAF-related initiatives between 2018 and 2022, highlighting continued federal efforts to support SAF development and deployment.

The FAA's policy commitment has been accompanied by a number of federal programs designed to support SAF research, production, and deployment across the aviation sector. These include the Center of Excellence for Alternative Jet Fuels and Environment (ASCENT) and the Fueling Aviation's Sustainable Transition (FAST) grant program. ASCENT brings together universities, government agencies, and industry partners to conduct research on alternative aviation fuels and their environmental impacts (FAA, 2022f). The FAST program, established under Section 40007 of the Inflation Reduction Act of 2022, provides $244.5 million in funding for projects involving the production, transportation, blending, and storage of sustainable aviation fuel (United States Congress, 2022). Likewise, the U.S. Department of Energy (DOE) announced $64 million in funding in 2020 to support research and development of SAF production technologies (DOE, 2021b).

Figure 2
SAF Funding Levels



Source: Adapted from FAA (2022a)

In addition to SAF-specific programs, the FAA has also implemented a variety of initiatives aimed at improving the environmental sustainability of airport operations. These include the Airport Sustainability Planning (ASP) Program, the Zero Emission Vehicle (ZEV) Program, and the Voluntary Airport Low Emissions (VALE) Program (FAA, 2022b). The ASP program supports the development of airport sustainability plans, while ZEV and VALE encourage the adoption of low-emission technologies and the electrification of airport ground vehicles and equipment (FAA, 2022c, 2022d, 2022e). Consistent with these objectives, Greer et al. (2020) noted that airports can achieve short-term emissions reductions through the electrification of ground transportation and gate equipment. However, it should be emphasized that these programs primarily support broader airport sustainability and decarbonization efforts rather than SAF-specific infrastructure development.

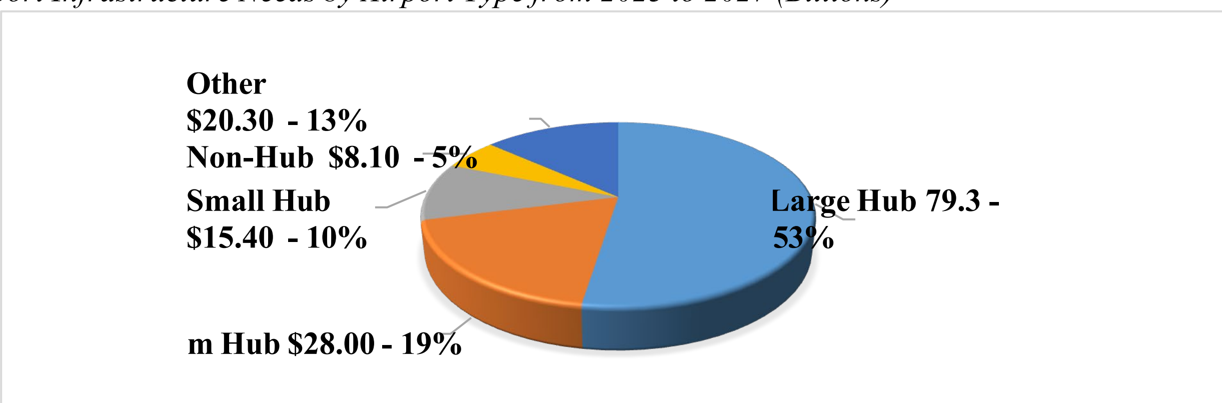
Despite the FAA's initiatives, the current state of U.S. airport infrastructure presents significant limitations for large-scale SAF integration. In the U.S., there are 3,304 public-use airports identified by the National Plan of Integrated Airport Systems (NPIAS), with approximately 520 of them being commercial service airports (American Society of Civil Engineers [ASCE], 2021). The majority of these NPIAS airports, which are more than 2,500, are classified as general aviation airports and mainly serve the purpose of supporting flight training and emergency services (ASCE, 2021).

The most recent report from ACI–NA (2023) indicates that by 2040, passenger traffic in the U.S. will have increased to 158% of its level in fiscal year 2019, while cargo traffic is anticipated to reach 167% of its level in the same time frame. In this context, the report notes that much of the existing U.S. airport infrastructure is not adequate to support projected growth in passenger and cargo traffic. It therefore highlights the need to modernize aging facilities and expand airport capacity.

Furthermore, ACI–NA estimates that American airports will need $151 billion in infrastructure projects between 2023 and 2027 (ACI–NA, 2023). Figure 3, adapted from ACI–NA (2023), presents the estimated infrastructure requirements by airport type during this period.

Figure 3

Airport Infrastructure Needs by Airport Type from 2023 to 2027 (Billions)



Source: Adapted from ACI–NA (2023)

As shown in Figure 3, regardless of size, almost all airports in the U.S. require additional funding to maintain or improve their facilities for aircraft and passengers. Large hub airports account for 53% of all airport construction needs, totaling $79.3 billion. Medium hub airports account for 19% of the overall need for airport facilities, totaling approximately $28 billion. Small hub airports account for 10% of all airport needs, totaling $15.4 billion. Non-hub airports account for 5% of total airport needs, which equals $8.1 billion (ACI–NA, 2023).

Table 1 shows the overall costs of U.S. airport infrastructure requirements by project type from 2023 to 2027. For major hub airports, terminal construction projects account for the largest share of all project expenditures over this period, totaling $43.3 billion. Terminal and capacity upgrades are worth $11.4 billion and $6.3 billion, respectively. For medium-sized hub airports, terminal construction projects also account for the highest cost, totaling $12.7 billion, followed by access to terminal projects at $3.3 billion. For small hub airports, terminal construction projects are the most important at $5.1 billion, followed by capacity expansions at $2.84 billion.

Table 1
The Costs of Airport Infrastructure Needs by Project Type (Millions of Current Year Dollars)

Airport Category	Safety	Security	Recons. Needs	Standards	Environ.	Capacity Needs	Terminal Building	Access to Terminal	New Airports	Other	Total
Large hub	2,547	897	4,291	1,973	1,740	6,322	43,268	11,360	2,335	4,536	79,269
Medium hub	726	438	2,572	948	278	1,781	12,727	3,327	1,884	3,299	27,980
Small hub	705	306	1,597	868	83	2,834	5,123	1,344	6	2,564	15,429
Non-hub	364	62	3,372	2,248	141	369	1,260	145	-	100	8,061
Other	959	27	8,961	6,763	56	914	822	424	357	1,014	20,296
Total	5,301	1,730	20,792	12,800	2,298	12,220	63,200	16,601	4,581	11,512	151,036
Percent	3.51%	1.15%	13.77%	8.48%	1.52%	8.09%	41.84%	10.99%	3.03%	7.62%	100.00%

Source: Adapted from ACI–NA (2023, p.39)

Previous studies have identified several infrastructure challenges at U.S. airports, including aging facilities, capacity limitations, outdated technologies, and funding shortages (Birenbaum, 2021; Miketa & Radin, 2021; ASCE, 2021; ACI–NA, 2023). These challenges can make it difficult for airports to maintain and upgrade existing infrastructure while also meeting future operational needs.

Many U.S. airports were built several decades ago and now require significant modernization. Miketa and Radin (2021) reported that the average U.S. airport is about 40 years old. In addition to aging facilities, limited capacity remains a major challenge. According to ACI–NA (2023), existing airport infrastructure is unable to accommodate projected long-term traffic growth without significant modernization and capacity expansion.

Technology modernization also remains a challenge. Airports increasingly need investments in digital systems, passenger-processing technologies, and operational improvements to meet evolving passenger expectations and improve efficiency. Meeting these modernization needs requires substantial financial resources. ACI–NA (2023) estimates that U.S. airports will require approximately $151 billion in infrastructure investment between 2023 and 2027, while existing funding sources remain insufficient to meet these needs.

These concerns are also reflected in the American Society of Civil Engineers' assessment of U.S. aviation infrastructure. The ASCE gave the U.S. aviation sector a grade of D+, suggesting that much of the existing airport infrastructure is in poor condition and needs major repairs, upgrades, or replacement (ASCE, 2021).

Although these challenges are not specific to SAF, they can influence airports' ability to invest in the additional infrastructure required for SAF storage, blending, distribution, and fuel-handling operations.

Challenges and Opportunities Associated with SAFs in the Existing U.S Airport Infrastructure

Although SAFs are widely recognized as one of the most promising options for reducing aviation-related emissions, their large-scale deployment remains dependent on overcoming a range of interconnected economic, infrastructural, regulatory, market, and stakeholder-related challenges (van Dyk & Saddler, 2021; Oakleaf et al., 2022; Detsios et al., 2023). From this perspective, the challenges associated with SAF adoption in U.S. airport infrastructure can be grouped into four categories: (1) economic barriers, (2) infrastructure constraints, (3) policy and regulatory challenges, and (4) market and stakeholder-related issues.

Economic Barriers

A key challenge to the adoption of SAF is its economic viability. Earlier U.S. studies pointed to several factors that limited the commercialization of alternative aviation fuels. For example, a U.S. Government Accountability Office (GAO) report identified high capital investment requirements, feedstock costs, and uncertainty surrounding future federal policies as major obstacles to private investment in commercial-scale alternative jet fuel production facilities (GAO, 2014). More recent studies indicate that many of these concerns remain relevant, with high production costs and limited economies of scale continuing to hinder the widespread adoption of SAF (Smith et al., 2017; Mueller et al., 2019). In addition, airport-level analyses in the U.S. suggest that factors such as renewable fuel subsidies, material costs, and operational conditions play an important role in shaping SAF production costs and adoption outcomes (Bhatt et al., 2023).

Several techno-economic studies provide quantitative evidence of the cost challenges associated with SAF production. Trejo-Pech et al. (2019) found that feedstock production and harvesting account for 55–66% of total delivered cost and reported that producers earn a margin of no more than 6.1 ¢/kg above the estimated break-even cost of 17.7 ¢/kg. At the supply-chain level, Sharma et al. (2021) indicated that the break-even price of SAF produced from switchgrass for Memphis International Airport exceeds $7.50 per gallon without renewable-fuel credits. The authors further added that this price is much higher than that of conventional jet fuel. Similar results have been reported for other SAF production pathways. Wang et al. (2021) found that none of the six ASTM-certified SAF pathways were financially viable without policy support. They estimated that policy costs of $35–337 million per facility would be required to make these pathways competitive with conventional jet fuel.

Although production costs are a major barrier to SAF adoption, the economic challenges are not limited to fuel production. Woodward et al. (2022) argued that substantial financial investments are required to upgrade existing airport infrastructure to accommodate SAF storage, blending, and distribution systems. Furthermore, broader assessments of SAF adoption indicate that ongoing technological and logistical challenges continue to prevent large-scale implementation (Cabrera & De Sousa, 2022). Overall, this review has demonstrated that high costs across the SAF value chain remain a major barrier to the widespread adoption of SAF in the U.S.

Infrastructure Constraints

Infrastructure limitations represent another significant barrier to SAF adoption. As explained in Sections 4 and 5, many U.S. airports were developed to support conventional aviation fuel systems and are not fully equipped to accommodate SAF-related operations. These limitations are particularly important because airports serve as key interfaces between fuel production, distribution, and aircraft operations.

NASEM (2016) identified airports as critical points where conventional and alternative fuel supply chains converge and emphasized the importance of airport-based fuel logistics and tracking systems for the future commercialization of SAF. Consistent with this view, DOE (2021c) reported that many U.S. airports currently lack the infrastructure required to support large-scale SAF handling and blending operations. Similarly, Moriarty and Kvien (2021) argued that integrating SAF into existing U.S. airport fuel infrastructure may require significant investments in storage, blending, and fuel-handling equipment.

In addition to airport facilities, SAF transportation creates further infrastructure challenges. Most large U.S. airports receive jet fuel through pipeline systems. However, current U.S. regulations do not allow neat (unblended) SAF to be transported through shared pipelines. Instead, SAF must first be blended with conventional Jet A fuel and certified to meet ASTM fuel standards before it can enter these systems (Moriarty & Kvien, 2021). San Francisco International Airport provides a practical example of this process. Woodward et al. (2022) reported that neat SAF is transported to an off-airport terminal, where it is blended and certified before being delivered to the airport through the Kinder Morgan pipeline network. SAF is usually delivered twice each month in batches ranging from 630,000 to 1.89 million gallons. As a result, blending is often carried out at fuel terminals rather than at airports, adding complexity to the fuel supply chain. This example shows how regulations, fuel certification requirements, and existing infrastructure affect SAF distribution practices in the U.S.

The literature reviewed in this study suggests that SAF infrastructure challenges extend beyond airport facilities. Successful SAF deployment depends not only on airport storage and blending capacity but also on the wider logistics network connecting production facilities, fuel terminals, pipelines, and airports. As a result, integrating SAF into existing airport systems requires substantial investment as well as operational and logistical changes.

Policy and Regulatory Challenges

Uncertainty in policies and regulations makes it harder to adopt SAF in the U.S. aviation sector. Several studies have noted that the U.S. lacks a clear, unified federal strategy for developing SAF (Mueller et al., 2019; Korkut & Fowler, 2021; CRS, 2022).

International programs like CORSIA are designed to lower aviation emissions, yet putting them into practice at the national level is still complicated and inconsistent (Chao et al., 2019). Policy-focused studies, such as Ghatala (2020), also emphasize the importance of financial incentives and investment frameworks to support SAF development.

Researchers (e.g., Mueller et al., 2019) therefore emphasize the importance of coordinated policy measures, including tax incentives, subsidies, and sustainability certification standards. Without strong policy support, the transition toward SAF is likely to remain slow and fragmented.

Market and Stakeholder-Related Issues

Market dynamics and stakeholder interactions further complicate the adoption of SAF. The SAF ecosystem includes airlines, airport operators, fuel producers, policymakers, and feedstock suppliers (CRS, 2022). Each group has its own priorities and economic interests, which can make it hard for them to work together. For example, airlines often have narrow profit margins and may hesitate to take on the extra costs of SAF (Klauber et al., 2017). Meanwhile, investing in infrastructure needs long-term planning, which can clash with the focus on short-term operations instead of long-term sustainability.

Infrastructure challenges are not limited to airport facilities. Lewis et al. (2018) argued that the successful deployment of alternative jet fuels depends not only on production capacity but also on efficient feedstock transportation networks and fuel distribution systems linking production facilities to airports.

In addition, competition for feedstocks and uncertainties in the supply chain make SAF deployment more difficult. Limited feedstock availability and high production costs also continue to slow the wider adoption of SAF (Holladay et al., 2020; Pate et al., 2022). Addressing these challenges will require closer cooperation among governments, fuel producers, airlines, airports, and researchers.

Opportunities for SAF Integration

Despite these challenges, SAF adoption also creates important opportunities for the U.S. aviation sector. In addition to reducing carbon emissions, it can stimulate technological innovation and support the development of new energy supply chains. U.S.-based studies suggest that airports may become increasingly important within future SAF supply chains by supporting fuel storage, distribution, and coordination among producers, airlines, and regional transportation networks (Oakleaf et al., 2022; Seiple et al., 2023). According to Oakleaf et al. (2022), future airport infrastructure may be designed to accommodate a wider range of sustainable energy solutions and low-carbon technologies alongside SAF storage and distribution activities.

The expansion of SAF production pathways in the U.S. may also help diversify fuel supplies, strengthen long-term energy security, and improve the resilience of aviation fuel supply chains (Airlines for America, 2019). One pathway that has received increasing attention is power-to-liquids (PtL), which uses captured carbon dioxide and renewable electricity to produce sustainable fuels. Such technologies may not only increase fuel availability but also contribute to wider decarbonization efforts across the energy sector (Grim et al., 2022).

In addition, supportive policies, financial incentives, and coordinated stakeholder action can accelerate SAF deployment and encourage private-sector investment (Ghatala, 2020). As SAF production expands, it may create new economic opportunities across the aviation sector and support the growth of domestic SAF markets (Seiple et al., 2023). Overall, these opportunities suggest that SAF can contribute not only to the environmental sustainability of aviation but also to the long-term development of the U.S. aviation fuel system.

Role of Academic Institutions in SAF Transition

As a conceptual contribution of the present study, this section extends the discussion by considering the potential role of collegiate aviation programs in advancing SAF adoption. Although previous research has highlighted the contributions of disciplines such as agricultural economics, environmental engineering, and public policy to SAF development (e.g., Trejo-Pech et al., 2019; Sharma et al., 2021; Wang et al., 2021), the role of collegiate aviation programs has received relatively little attention. Given their close connections with aviation education, industry partnerships, and applied research, these programs are well-positioned to support the transition toward SAF. Their potential contribution can be grouped into three main areas: research and knowledge generation, workforce development, and policy support.

Research and knowledge generation. Academic research centers can fill the critical knowledge gaps that are currently hindering the widespread adoption of SAF. For example, university researchers can provide empirical data to guide industry stakeholders by focusing on the economic modeling of local supply chains. Similarly, they can conduct life-cycle assessments for new types of feedstock and carry out feasibility studies at airports. In fact, the FAA's Alternative Jet Fuels and Environmental Excellence Center (ASCENT) has already demonstrated the value of academia-industry-government collaboration in advancing SAF-related research (FAA, 2022f). Expanding such partnerships, particularly by involving collegiate aviation institutions, would strengthen the evidence base needed to justify large-scale infrastructure investment.

Workforce development. According to IATA, increasing SAF production remains difficult because current production levels are still very low, making SAF considerably more expensive than conventional jet fuel. High feedstock costs, developing production technologies, limited infrastructure, and large upfront investment needs continue to slow its wider adoption (IATA, 2026). Although technological and financial investments are essential, they may not be sufficient on their own to overcome these barriers. The transition to SAF also requires professionals who understand its technical, economic, logistical, and regulatory aspects. In this respect, collegiate aviation programs can make an important contribution. By integrating topics such as SAF technologies, supply chain management, sustainability policies, and industry case studies into their curricula, these programs can better prepare graduates for the changing needs of the aviation industry.

Policy advocacy and stakeholder bridging. This study has repeatedly identified fragmented policies as a structural barrier to the adoption of SAF. In this context, academic institutions can also serve as neutral intermediaries among the fragmented stakeholder groups. This is not a role that industry actors or government agencies can easily fill. Whilst private companies operate under pressures that prioritize profit, public bodies are often constrained by political cycles. In contrast, universities possess a more long-term institutional perspective. Additionally, peer-reviewed research conducted by academic institutions across these disciplines provides credibility to policy suggestions and may assist in translating technical results into meaningful advice for airport operators and regulators. Consequently, universities may become valuable actors that facilitate dialogue between sectors that do not coordinate with one another. As our review has shown that policies do not work in harmony with one another (Mueller et al., 2019; Korkut & Fowler, 2021), this bridging role is particularly important.

In sum, the successful integration of SAF into U.S. aviation infrastructure is not solely an engineering or financial challenge but also an educational one. Collegiate aviation programs that actively engage with SAF-related research, curriculum development, and stakeholder collaboration will be better positioned to contribute to the sustainability transition that the sector is undergoing.

Discussion

This study thoroughly examined the economic, infrastructure, policy, and market challenges encountered in the adoption of SAFs at U.S. airports. In response to the first research question, the findings clearly demonstrate that many large airports in the U.S. are operating at or near capacity. In particular, the current facilities' inability to meet SAF storage, blending, or distribution requirements stands out as a significant issue. These findings vividly support the view that the transition to SAF is not merely a matter of adopting a new technology, but also involves significant challenges that require extensive infrastructure upgrades. Importantly, this challenge is not caused by aging infrastructure alone. As discussed earlier, regulatory and fuel-certification requirements limit how SAF can be transported and blended (Moriarty & Kvien, 2021; Woodward et al., 2022).

From an economic perspective, one of the biggest obstacles to the widespread adoption of SAFs remains high production costs. This challenge is made even greater by the significant investment required to upgrade existing infrastructure for SAF use, which limits opportunities to achieve economies of scale in the short term. As an illustrative example, the 2023 report from ACI–NA estimates that U.S. airports collectively require more than $ 151 billion in infrastructure investment for 2023 - 2027. Consequently, fuel producers, airport operators, and investors are struggling to take action due to these financial barriers, which are significantly slowing down the pace and scope of SAF adoption.

Crucially, the financial barriers are deeply intertwined with infrastructure constraints. This complex interplay could significantly delay the adoption of SAF. Weak or inadequate infrastructure acts as a natural deterrent for businesses seeking to enter new markets. Particularly, when demand is low, companies are understandably reluctant to invest in improving infrastructure. Another challenge to the adoption of SAF is that different stakeholders have conflicting objectives. For example, while airlines aim to reduce costs in the short term, building new infrastructure requires a long-term investment, which makes it difficult to find common ground. These findings are also supported by a recent meta-review conducted by Wandelt et al. (2025), which identified feedstock availability, scalability, and production costs as continuing barriers to SAF development. This suggests that the challenges identified in studies published between 2013 and 2023 still remain.

Addressing the second research question, the findings highlight that these complex challenges can only be overcome through industry-wide collaboration and fundamental changes to the regulatory framework. It is essential for policymakers to reduce the current uncertainty by both offering financial incentives and establishing clear, long-term regulatory commitments. Indeed, without such alignment at the government level, it seems inevitable that private-sector investments will remain limited.

Despite these challenges, several federal programs support SAF-related objectives. The FAA's ASP and VALE programs contribute to broader airport sustainability and decarbonization efforts, although they are not specifically designed to fund SAF production, blending, or distribution infrastructure. Other initiatives, such as the FAA's ASCENT center and FAST program, are more directly focused on supporting SAF development and infrastructure. These programs provide funding for activities related to SAF production, transportation, blending, and storage (FAA, 2022f). Although these initiatives represent important steps toward expanding SAF adoption, the literature suggests that substantial economic and infrastructure barriers remain.

Overall, the findings suggest that successful SAF adoption in U.S. airport infrastructure requires addressing several economic, infrastructural, regulatory, and stakeholder-related challenges. Although SAF offers important environmental and strategic benefits, its widespread adoption will depend on reducing financial barriers and modernizing airport infrastructure. This study also highlights the potential role of collegiate aviation programs, which have received limited attention in previous research. Through research, education, and collaboration with industry and policymakers, these programs can support the transition to SAF. Therefore, closer cooperation among government agencies, industry stakeholders, collegiate aviation institutions, and research centers will be important for advancing SAF adoption and supporting a more sustainable aviation system.

Conclusion and Recommendations

In this study, we examined the main barriers associated with the adoption of Sustainable Aviation Fuels (SAF) in U.S. airport infrastructure. The findings provide a comprehensive understanding of the key barriers and how they interact to constrain SAF adoption in U.S. airport infrastructure.

The most important finding of this study is that the primary barrier to SAF adoption is the limited ability of U.S. airport infrastructure to support large-scale SAF storage, blending, and distribution. This constraint reflects not only the age of existing facilities but also regulatory and certification requirements and persistent underinvestment. Consequently, large-scale SAF deployment will require both infrastructure investment and continued regulatory clarity. In addition to this structural challenge, fragmented policy approaches and a lack of sufficient coordination among key stakeholders are also seriously hindering progress. When all these factors come together, they impede the widespread adoption of SAF and highlight the complexity involved in transitioning to a more sustainable aviation system.

The study also shows how financial difficulties and infrastructure deficiencies feed into one another, and how this cycle is further complicated by confusing policies and conflicts of interest among stakeholders. This holistic perspective helps us better understand why the adoption of SAF remains limited despite its well-known environmental benefits. By integrating these barriers within a single conceptual framework, the study demonstrates that successful SAF adoption requires coordinated efforts to address economic, infrastructural, regulatory, and stakeholder-related challenges.

The research findings also have significant implications for policymakers and administrators. Overcoming barriers to the widespread adoption of SAF will require coordinated efforts and strategic, long-term planning. For example, policymakers should prioritize large-scale infrastructure investment programs. In addition, it is essential to establish stable, long-term incentives to support SAF production and adoption.

Although these findings offer useful implications for policy and practice, this study has some limitations that should be considered when interpreting the results. The proposed conceptual framework is grounded in a systematic review of the literature. However, it has not yet been empirically tested in real airport settings. In addition, the findings are specific to the U.S. airport system and may not be directly applicable to countries operating under different regulatory, institutional, and infrastructure conditions.

Future research can build upon these findings. By adding empirical data, such as stakeholder interviews or airport-level case studies, researchers could examine the operational and financial aspects of SAF deployment in more depth. Such studies would help the aviation sector make more informed decisions as it moves toward sustainability. Ultimately, the proposed conceptual framework may serve as a foundation for future research examining SAF adoption in different airport settings and national contexts.

Declarations

I acknowledge the use of Grammarly [https://app.grammarly.com/]to improve my writing and edit grammatical issues.
All authors declare that they have no conflicts of interest.

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