Sustainable Aviation Fuel Blending and Logistics

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Preface

This report is an update to the 2021 report from the National Renewable Energy Laboratory, *U.S. Airport Infrastructure and Sustainable Aviation Fuel* (www.nrel.gov/docs/fy21osti/78368.pdf). The previous report was prepared at a time when there was a single production facility and provided recommendations for blending. As more production plants have come online, as well as more commitments from the aviation industry, the report was updated to address current market needs. This report is focused on the United States market.

List of Acronyms

ATJ	alcohol-to-jet
COA	certificate of analysis
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FT	Fischer–Tropsch
HEFA	hydroprocessed esters and fatty acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
PADD	Petroleum Administration for Defense District
RCQ	refinery certificate of quality
SAF	sustainable aviation fuel
SKA	synthetic kerosene with aromatics
SPK	synthetic paraffinic kerosene

Executive Summary

Decarbonizing aviation requires a multipronged approach in both alternative fuel use and efficiency to meet emissions reductions and sustainability requirements and goals. In 2022, aviation accounted for 2.1% of human-induced carbon dioxide (CO_2) emissions and 12% of transportation CO_2 emissions (ATAG 2024). About 80% of aviation emissions are from flights longer than about 930 miles (ATAG 2024). Aviation was also responsible for 9% of domestic transportation greenhouse gas emissions in 2022 (EPA 2022). The United States has a significant commercial aviation sector accounting for nearly 28% of global jet fuel use (IATA 2024b, EIA 2024g).

Sustainable aviation fuel (SAF), made from nonpetroleum feedstocks, significantly reduces aviation emissions. SAF must be blended with petroleum-based jet fuel prior to its use in aircraft.[1] SAF is a commercially available fuel in its early stages of production development. There are three domestic plants and one international plant supplying the U.S. market as of mid-2024. Numerous pilot- and demonstration-scale plants in the United States and globally are demonstrating the ability to make SAF from multiple feedstocks and technology pathways. Public data for the Renewable Fuel Standard show significant growth in the domestic market over the past few years, with 26 million gallons in 2023 and nearly 62 million gallons January through July 2024. This report explores background information on jet fuel use, quality standards and practices, and options for blending and delivery to airports.

Jet fuel quality standards and certification documents are essential to fuel performance, operability, and safety (Holladay et al. 2020). All parties involved—including from production, supply chain, the airport, and aircraft—are responsible for maintaining the quality and traceability of jet fuel and SAF. Jet A fuel meets ASTM D1655, *Standard Specification for Aviation Turbine Fuels* (ASTM International 2022).[2] ASTM D7566, *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*, describes the specifications that the various forms of SAF must meet prior to blending with Jet A, as well as requirements for the final blend (ASTM International 2024). After meeting these requirements, the blended fuel is then redesignated as meeting the conventional jet fuel standard ASTM D1655 and can be transported in pipelines and used in aircraft.

Each batch of petroleum jet fuel produced at a refinery generates a batch number and undergoes a full conformity test to generate a refinery certificate of quality (RCQ). A certificate of analysis (COA) is generated for each batch of jet fuel as it moves through the supply chain, requiring retesting of key fuel properties. SAF plants generate a certificate of quality, which documents conformance with the appropriate annex of ASTM D7566. A COA is also generated at the point where Jet A and SAF are blended and for each movement in the supply chain, as a blended fuel may move between multiple terminals.

The method of moving fuels throughout the country depends on the location of production, fuel type, and volume. The modes of transport for fuels include barge/tanker, pipeline, rail, and truck. Jet A moves primarily by pipeline, whereas biofuels produced at stand-alone facilities are moved by rail, barge, or truck (small volumes) and rarely by pipeline. SAF/Jet A blends have moved

[1] SAF in this report refers to the neat fuel/100%. SAF must be blended with Jet A prior to use in aircraft.

[2] Standards are continuously updated; check the ASTM website for the latest version.

through pipelines. SAF co-processed at a petroleum refinery would be certified as ASTM D1655 and would travel by pipeline to terminal(s) and onward to airports by pipeline on truck, depending on the airport fuel receipt infrastructure.[3]

SAF produced at a stand-alone facility or biofuels facility (several plants also produce renewable diesel) require more consideration of where and when to blend with Jet A. The requirements of quality control point toward blending of SAF from a stand-alone facility with Jet A upstream of an airport at a terminal. Terminals are equipped with blending equipment, software, and staff as they are currently designed to blend on-highway transportation fuels. The terminal could be directly connected to an airport via pipeline or thousands of miles away to address the needs of fuel producers, suppliers, and end users. Neat SAF from two different annexes (pathways) cannot be commingled into the same tank for blending with Jet A (ASTM 2024, Energy Institute 2022).

There are a few methods for storing and blending SAF, and the selected method may be determined by fuel handling requirements, terminal operations, and fuel supplier and/or end user preferences. The method in practice today stores SAF and Jet A in separate tanks, where they are both tested for compliance with ASTM D7566 and ASTM D1655, respectively. SAF and Jet A are delivered in the desired ratio to a third blending tank, where the fuel is tested and certified as ASTM D1655. A second option, not in use today, would deliver SAF into a Jet A tank, where the fuel is blended, tested, and certified to ASTM D1655. It is a recommended best practice that SAF use dedicated infrastructure for this blending option (EI 2022). This option may be more economical for small volumes of SAF. Both options result in business as usual at airports, where they receive the SAF/Jet A blend by the same pipeline and trucks as they do today. It is recommended that tank mixing equipment be deployed for either option to ensure homogenous fuel and to account for density differences between batches of fuel.

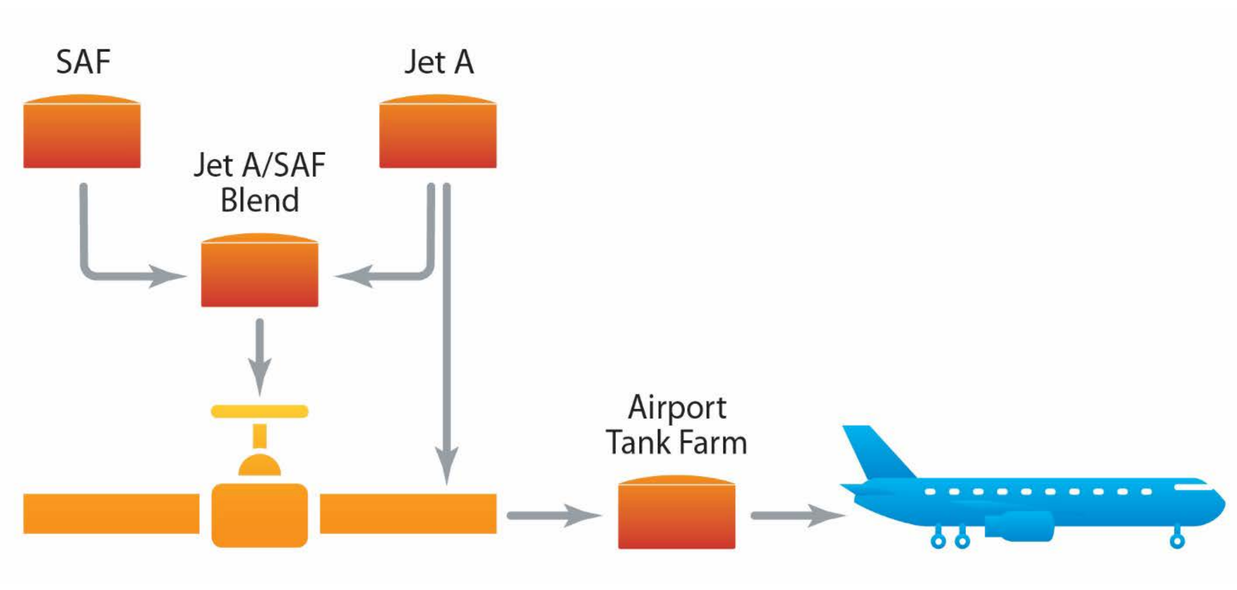

Figure ES-1. Current method of blending Jet A and SAF at a terminal

[3] There are a few domestic airports connected to refineries directly by pipeline; therefore, the coprocessed SAF/Jet A would go from the refinery to the airport via the pipeline.

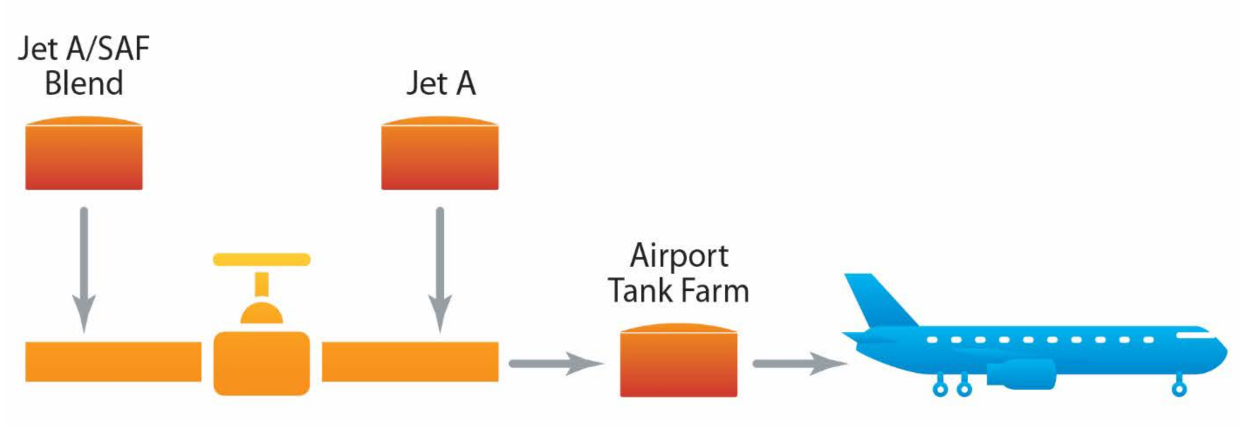

Figure ES-2. Alternative option for blending Jet A and SAF at a terminal

Several other blending locations were evaluated. Each of these options is technically feasible, but there are practical considerations that make them less viable than blending at terminals.

- **Airports:** Blending at an airport is not preferred for several reasons, including that it would be the first instance of certifying the SAF/Jet A blend as ASTM D1655; significant capital investment to add blending equipment, software, and additional off-spec tanks; impacts to airport tank farm insurance; increased truck traffic to airports for SAF delivery; and additional staff and testing/certification of the fuel.
- **Refineries:** In limited instances it may be possible to deliver and blend SAF and Jet A in refinery storage. Each refinery design is unique, and their short-term storage is generally sized for the refinery capacity. A refinery would need off-loading equipment to receive fuel, most likely by truck and less likely by barge and rail. The blended fuel would require recertification before moving by pipeline to terminals and airports.
- **Greenfield/brownfield sites:** Establishing a new blending site near an airport or concentrated SAF production area is possible. It would be more costly than using existing terminals, and permitting a new blending facility and any associated pipelines could take a considerable amount of time. This option would likely only be considered for geographic areas with significant capacity constraints for existing fuel infrastructure.

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1 Sustainable Aviation Fuel Background and Motivation

Airplane manufacturers increase the fuel economy by approximately 20% with each new generation of aircraft; however, that and other increases in efficiency are not sufficient to meet international agreements and individual industry company environmental and sustainability goals. Sustainable aviation fuel (SAF) is a near-term option to help the aviation industry meet requirements and goals. SAF is defined as sustainable fuel made from a feedstock other than petroleum fuels.[4]

The global aviation industry has several initiatives to reduce emissions and SAF is expected to be a significant contributor in meeting these requirements and goals. In 2016, the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations, adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to cap net CO_2 aviation emissions at 2020 levels through 2035. Compliance began in 2019 for airlines exceeding 10,000 tonnes of annual emissions, with a requirement to record fuel usage for the purpose of calculating CO_2 emissions (IATA 2024a). Offsetting requirements, met through a variety of activities, began in 2021 for flights between voluntary countries, and full implementation will occur in 2027.[5] The International Air Transport Association (IATA), a trade association representing 330 airlines, adopted the Fly Net Zero initiative in 2021 to achieve net-zero carbon by 2050 (IATA 2024c).

Figure 1. International flights and offsetting requirements.

Source: ICAO 2023. Note: International flights between participating (green) countries began in 2021 and expand to flights to and from blue countries in 2027. International flights to and from yellow countries are exempt.

[4] SAF is sometimes referred to as "biojet," and the U.S. Environmental Protection Agency (EPA) uses the term "renewable jet fuel."

[5] Many countries volunteered to start implementation early ahead of the 2027 requirement. Lower economic status countries and those with limited air traffic are exempt though many opted to participate (ICAO 2023).

The European Union and several countries have SAF mandates:

- **European Union:** ReFuel EU, the European Union SAF mandate, was passed in October 2023. The requirement escalates over time beginning with 2% in 2025, 6% by 2035, and 70% by 2050 (U.S. International Trade Administration 2024). The regulation allows the European aviation industry to use book-and-claim—a practice of decoupling the fuel credit from where it is used—until 2035, after which SAF must be physically supplied at European Union airports. There are financial penalties for fuel suppliers not meeting the requirement. Sweden and France previously established SAF mandates of 1% in 2021 and 2022, respectively.
- **United Kingdom:** The SAF mandate requires 2% by 2025, 10% by 2030, and 22% in 2040 (UK Parliament 2024). The mandate caps the common hydroprocessed esters and fatty acids (HEFA) production pathway and requires power-to-liquid fuels. There is a buyout price for fuel suppliers unable to secure supply.
- **Norway:** A SAF mandate of 0.5% has been in place since 2020 (Air BP 2019).
- **Singapore:** A SAF mandate of 1% begins in 2026, with plans to increase it over time (S&P Global 2024).

The Sustainable Aviation Fuel Grand Challenge is a joint effort from the U.S. Department of Energy, U.S. Department of Transportation, U.S. Department of Agriculture, and other government agencies working to expand domestic SAF production, reduce costs, and enhance sustainability.[6] The production target of neat SAF is 3 billion gallons by 2030 and 35 billion gallons by 2050. Developing the entire supply chain inclusive of logistics and blending is an activity under this program. While there is not a SAF mandate, there are regulatory motivations and financial incentives to enable the market. SAF qualifies for both the federal Renewable Fuel Standard and various state low-carbon fuel standards, and the compliance and credit mechanisms of those programs help reduce the impacts of higher production costs. The Inflation Reduction Act of 2022 enacted Section 40B, providing a SAF-specific tax credit for both domestic production and imports of up to $1.75/gallon between Dec. 31, 2022, and Jan. 1, 2025 (Alternative Fuels Data Center 2024b). In 2025, the Inflation Reduction Act's 45Z Clean Fuel Production Credit replaces 40B, which provides up to $1.75/gallon for SAF meeting the various requirements (Alternative Fuels Data Center 2024a). Unlike 40B, the 45Z tax credit is not available to imported SAF. There is also the Federal Aviation Administration's (FAA's) Fueling Aviation's Sustainable Transition (FAST) Grant Program, with $244.5 million to support SAF production, transportation, storage, and blending (FAA 2024b).

1.1 Jet Fuel Supply, Consumption, Trade, and Enplanements

U.S. jet fuel consumption exceeded 25.3 billion gallons in 2023, surpassing each of the past 3 years but not reaching levels prior to the COVID-19 pandemic (EIA 2024g). Figure 2 demonstrates that domestic jet fuel production closely aligns with consumption (EIA 2024c, 2024h). In 2023, the United States accounted for nearly 28% of the 92-billion-gallon global jet fuel consumption (IATA 2024b, EIA 2024g). Figure 3 shows consumption by Petroleum

[6] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge.

Administration for Defense District (PADD), with PADD 1 (East Coast) and PADD 5 (West Coast) accounting for 68% of consumption in 2023 (EIA 2024g).[7]

The United States is generally a net exporter of jet fuel (EIA 2024a, EIA 2024h). About 74% of 2023 exports were to other North American countries, while 50% or more of imports came from South Korea the past 5 years (EIA 2024a, 2024h). About 66% of imports arrive to PADD 5 (West Coast), and the remaining 34% to PADD 1 (East Coast), while 83% of exports are from PADD 3 (Gulf Coast) (EIA 2024d, 2024e).

The FAA reports that enplanements (the number of passengers boarding an aircraft) have grown from 760 million in 2014 to 939 million in 2023 (FAA 2024c).[8] Between 2022 and 2023, enplanements and jet fuel consumption grew by 11% and 5.6%, respectively. The FAA projects enplanement will grow 2.6% per year between 2024 and 2044 (FAA 2024a).

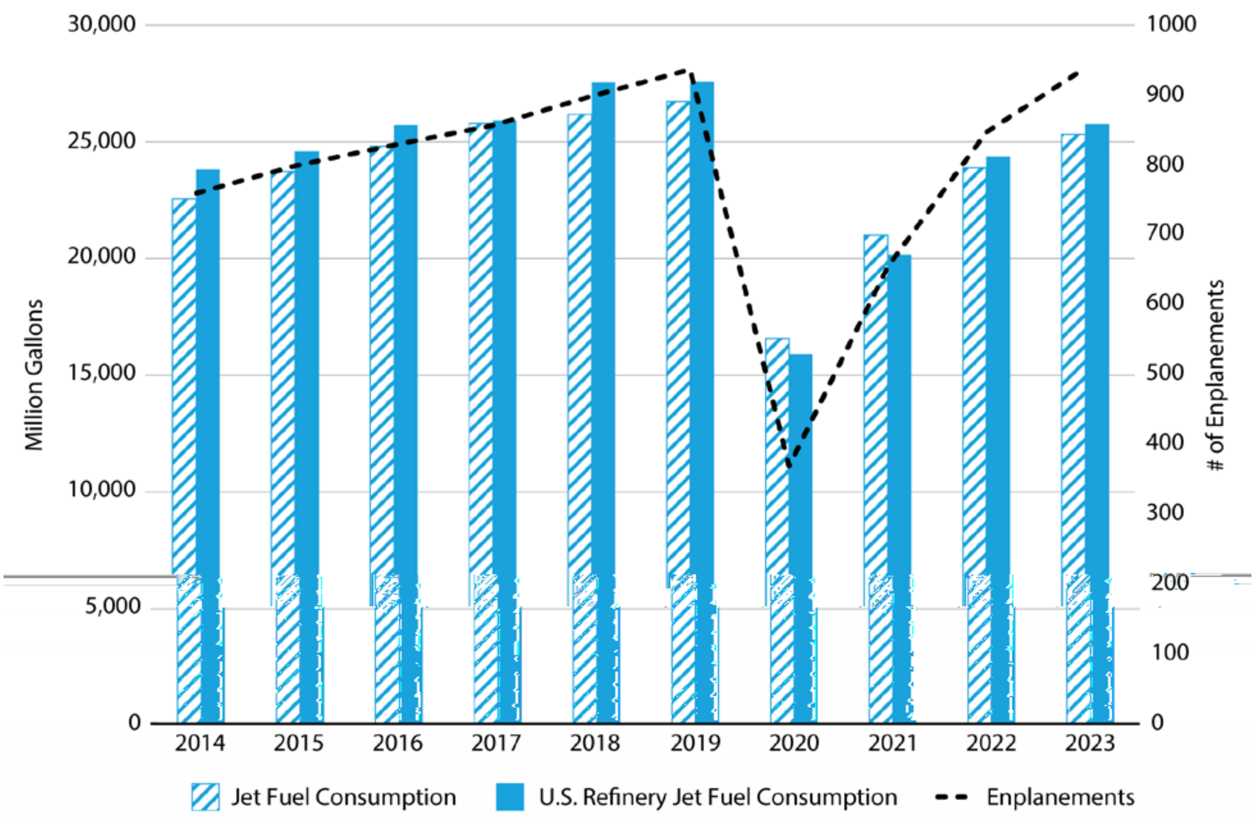

Figure 2. U.S. jet fuel consumption and enplanements.

Sources: EIA 2024c, 2024g; FAA 2024c

[7] PADD 1: CT, DC, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, PA, RI, SC, VA, VT, and WV. PADD 2: IA, IL, IN, KS, KY, MI, MN, MO, NE, ND, OH, OK, SD, TN, and WI. PADD 3: AL, AR, LA, MS, NM, and TX. PADD 4: CO, ID, MT, UT, and WY. PADD 5: AK, AZ, CA, HI, NV, OR, and WA.

[8] Enplanements included in this section are for primary airports, defined as commercial airports with 10,000 or more passengers boarding each year.

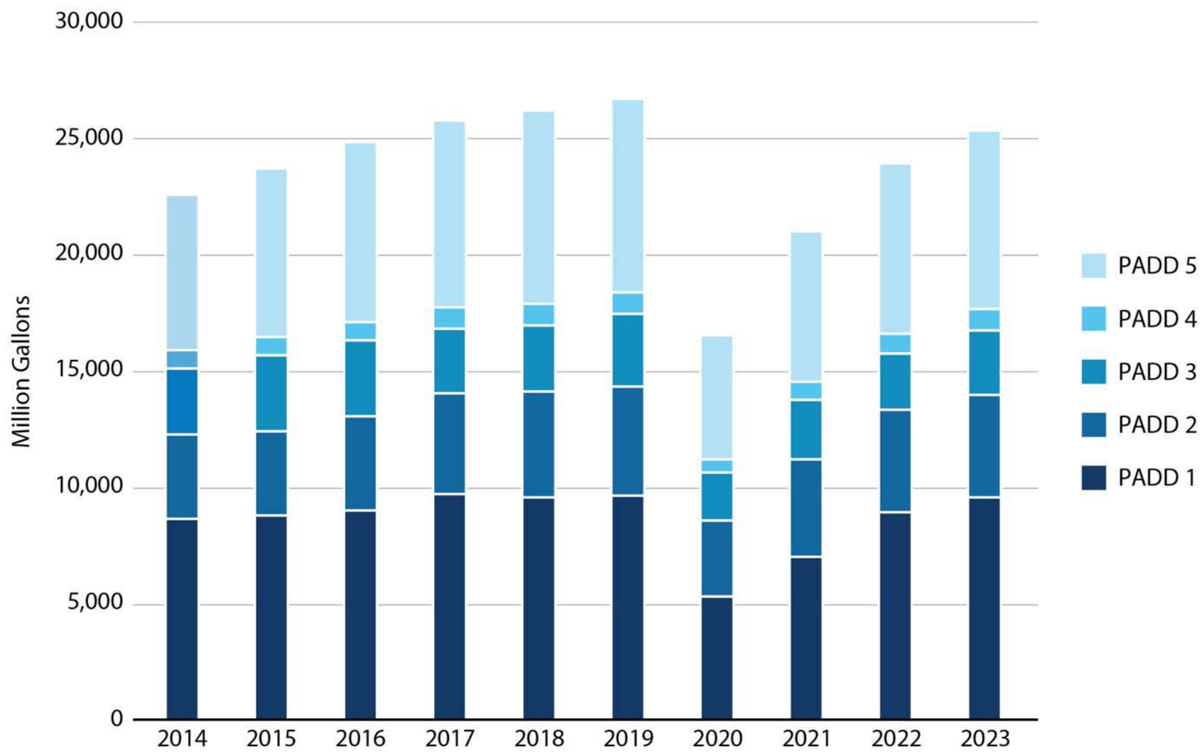

Figure 3. U.S. jet fuel consumption by PADD.

Source: EIA 2024g

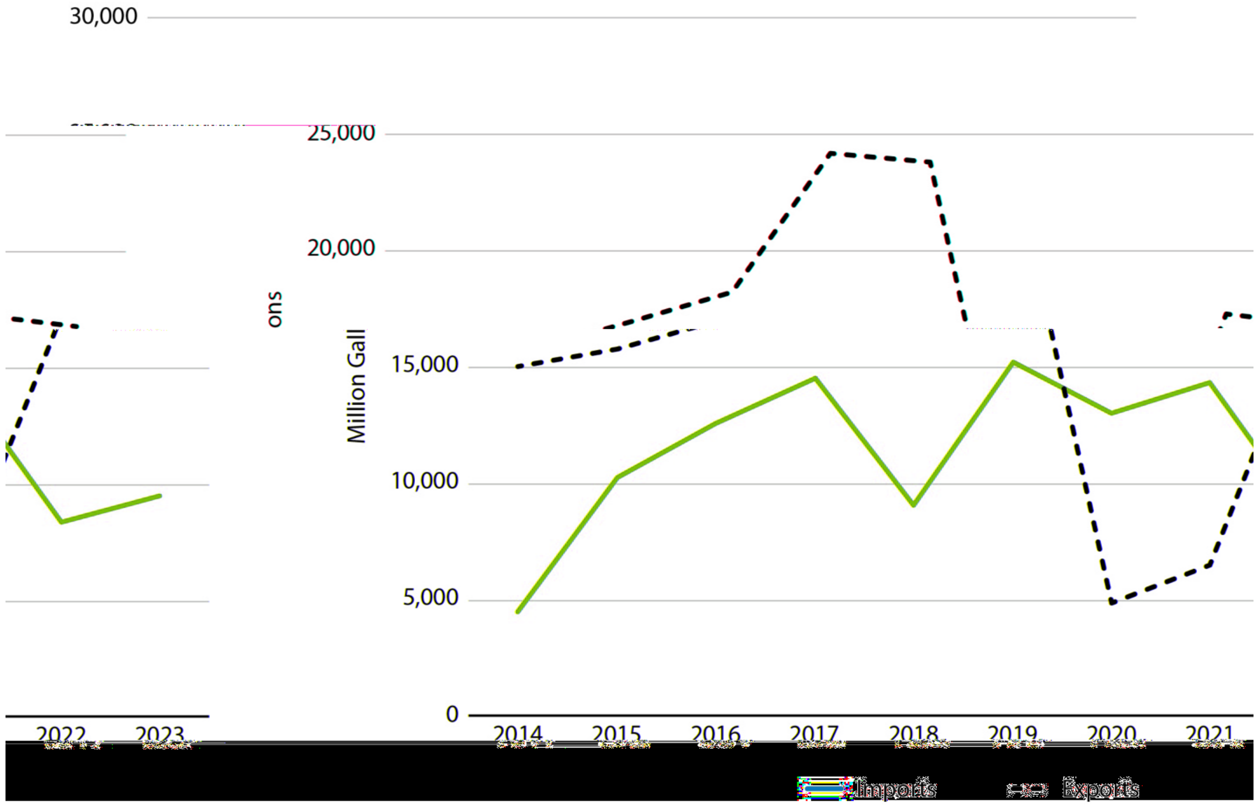

Figure 4. U.S. jet fuel trade.

Source: EIA 2024a, 2024h

1.2 SAF Production and Consumption

SAF production is in an early commercial development phase. There are three domestic plants and an international producer supplying the U.S. market (Table 1). Three plants use the HEFA pathway, and one uses the alcohol-to-jet (ATJ) pathway. All four of these plants also produce renewable diesel and other renewable fuels and products. World Energy was the first domestic conversion of a petroleum refinery to a renewables plant and began producing SAF in 2016. They initially supplied United Airlines at Los Angeles International Airport, later expanding to supply KLM, other airlines, business customers, and airports. Neste began supplying to San Francisco International Airport and to Alaska Airlines, American Airlines, and JetBlue Airways, and later expanded to serve additional airlines, customers, and airports (Neste 2020). Neste exports fuel from their Singapore facility and has also upgraded a biointermediate into SAF at a Houston refinery (Neste 2022). Montana Renewables, a petroleum refinery conversion to a renewable fuels plant, began SAF production in the second quarter of 2023 (Voegele 2023). LanzaJet started up SAF production in 2024 and is the first commercial-scale ATJ plant (LanzaJet 2024). Phillips 66 converted their Rodeo, California, petroleum refinery to produce renewable fuels, and current capacity is 800 million gallons. They announced plans to produce

SAF in 2024 (Phillips 66 2024). There are numerous pilot facilities and other commercial facilities under development worldwide.[9]

Table 1. SAF Plants Supplying the U.S. Market.

Sources: LanzaJet 2024; EIA 2024h; Neste 2023

Plant	Location	Feedstocks	Pathway	Renewable Fuels Capacity (million gallons/yr)[a]	Year SAF Supplied
LanzaJet	Soperton, GA	Ethanol	ATJ	10	2024
Montana Renewables	Great Falls, MT	Waste fats, oils, and greases; vegetable oil	HEFA	184	2023
Singapore	Waste fats, oils, and greases; vegetable oil	HEFA	850	2020	Neste
42	2016	World Energy	Paramount, CA	Waste fats, oils, and greases; vegetable oil	HEFA

[a] Total renewable fuel capacity is shown; plants produce renewable diesel, SAF, and other biofuels/chemicals.

SAF domestic production and consumption volumes are not published. The best approximation is derived from the Renewable Fuel Standard's compliance mechanism, renewable identification numbers. SAF supply has increased each year since its introduction in 2016 (Figure 5; EPA 2023). The first 7 months of 2024 are higher than 2023, with increased imports, and it is anticipated to grow at a faster pace with the startup of both the LanzaJet and Phillips 66 plants. (EPA 2023). Figure 6 shows the high variability of monthly SAF renewable identification number generation, which may represent market dynamics of plants producing both SAF and renewable diesel and potentially competition for foreign SAF or imported biointermediates processed into SAF in the United States (Neste 2022). The demand for SAF exceeds supply, with a significant number of offtake agreements for both airlines and business/private aviation. Many businesses see the use of SAF as essential to meeting their corporate goals. While increased SAF supply is a positive sign, it represented approximately 0.1% of domestic jet fuel consumption. Worldwide SAF production was about 165 million gallons in 2023, with U.S. consumption accounting for about 16% (IATA 2023; EPA 2023).

[9] The International Energy Agency's Bioenergy Technology Collaboration Programme maintains a global database of biomass conversion plants: www.ieabioenergy.com/installations/.

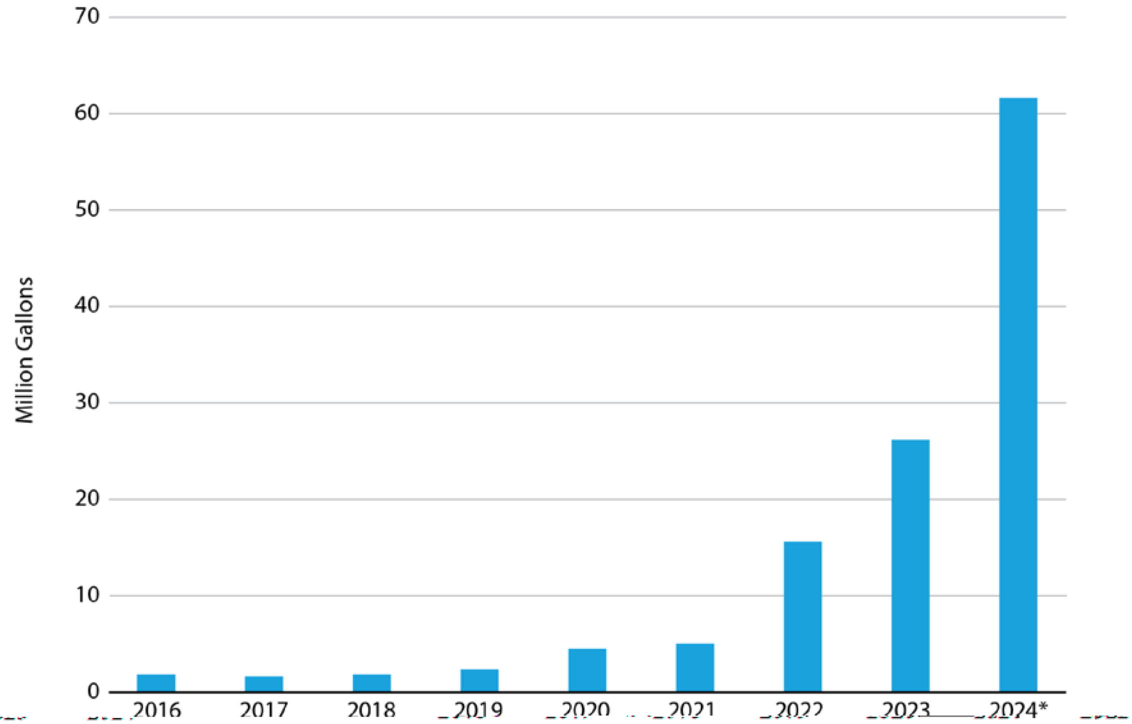

Figure 5. Estimated domestic SAF supply.

Source: EPA 2023; * 2024 data are January through July

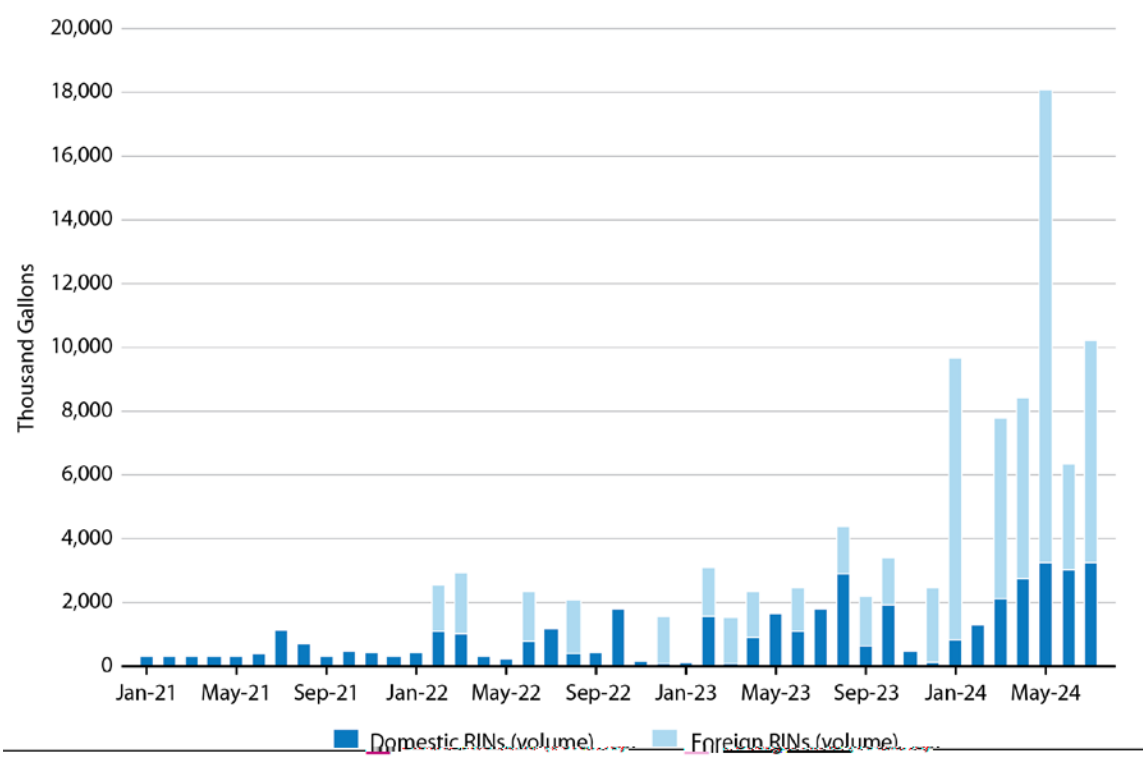

Figure 6. Estimated monthly SAF supply.

Source: EPA 2023

2 Jet Fuel Quality Standards

Jet fuel quality is carefully controlled through multiple harmonious standards adopted throughout the world. The approval for SAF and technology pathways is rigorous to ensure the quality and safety of the fuel. The FAA funded a report that provides detailed information on jet fuel quality and associated test methods, and quality control throughout the supply chain (Miller et al. 2014).

Several entities, including the Energy Institute, the Joint Inspection Group, the American Petroleum Institute, and SAE International, develop best practices to safeguard fuel quality through the supply chain. The Energy Institute developed EI 1533, *Quality assurance requirements for semi-synthetic jet fuel and synthetic blending components (SBC)*, to define quality control of SAF from the point of production to blending with Jet A, as well as required and recommended practices throughout the entire supply chain (Energy Institute 2022).[10]

ICAO, in collaboration with IATA, Airports Council International, and Airlines for America, summarizes best practices in the *Manual on Civil Aviation Jet Fuel Supply* (ICAO 2012). This document covers the entire supply chain including production, distribution, airport storage/hydrant systems, and delivery to aircraft. It describes roles and responsibilities, required documentation, lab sampling test methods, and requirements.

2.1 Jet Fuel ASTM Standards and Other Standards

As described by Rumizen (2021), the FAA establishes "airworthiness standards" for the design and operation of aircraft. The fuel is considered an operating limitation for aircraft and engines, rather than a physical part of the product. This means that the aviation fuels permitted for use are identified by the engine and aircraft manufacturer, typically using an industry standard such as from ASTM. ASTM International is a voluntary consensus standards organization composed of aviation industry experts including airplane and engine manufacturers; fuel system equipment manufacturers; fuel producers, suppliers, and users; and other interested parties. Industry experts meet regularly to create, maintain, and continuously update fuel quality specifications and test methods.

Jet fuel must meet ASTM D1655, *Standard Specification for Aviation Turbine Fuels* (ASTM International 2022).[11] Aircraft and engine manufactures around the globe very commonly use ASTM D1655 to define the fuels that can be used in their products. Jet A is the fuel type used in the United States, and Jet A-1 in the rest of the world. The fuels are nearly identical, with the primary difference in the freezing point: Jet A at a maximum of −40°C and Jet A-1 at a maximum of −47°C.

ASTM D4054, *Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives* describes the process and guidelines for obtaining approval of a new fuel by the engine and aircraft manufacturers. Currently, approval for blending up to 50 vol% is allowed. Once approved, the new fuel (or fuel blending component) is added to ASTM D7566 *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons.*

[10] This is a supplement to *EI/JIG Standard 1530: Quality assurance requirements for the manufacture, storage, and distribution of aviation fuel to airports (A4)*, publishing.energyinst.org/featured/1530.
[11] Standards are continuously updated; check the ASTM website for the latest version.

In 2009, ASTM D7566 was amended to allow Fischer–Tropsch (FT) fuels, which can be made from biomass (ASTM International 2024). Synthesized hydrocarbons, synthetic fuels, or synthetic blending components are all terms used to describe jet fuels or jet fuel blending components that are not made from petroleum. All forms of SAF that have been approved to date are synthetic blending components. ASTM D7566 contains all the requirements of ASTM D1655, plus additional requirements that must be met by so-called semi-synthetic fuels that are made by blending Jet A with a synthetic blending component listed in ASTM D7566. ASTM D7566 fuel, when blended with Jet A in percentages outlined in D7566, also meets D1655 requirements and can be considered a D1655-complaint aviation fuel. Once a is D1655-compliant, it can be used in in the fungible fuel distribution system. Approved SAF production technology pathways are available in the D7566 specification annex, as are the specific testing requirements for that pathway. ASTM imposes blending limits for each pathway, based on the fuel molecule families produced by the pathway. At the time of this writing, the current version of D7566 (D7566-24a) approves eight pathways (also referred to as annexes):

- FT fuels with synthetic paraffinic kerosene (FT-SPK), 50% maximum blend. Coprocessing with petroleum feedstock is allowed at a 5% limit.
- HEFA fuels (HEFA-SPK), 50% maximum blend. Coprocessing with petroleum feedstock is allowed at a 5% limit.
- FT fuels with synthetic kerosene with aromatics (FT-SKA), 50% maximum blend.
- Synthetic isoparaffin from fermented hydroprocessed sugar, formerly known as direct-sugar-to-hydrocarbon fuels (SIP-SPK), 10% maximum blend.
- ATJ fuels (ATJ-SPK) produced from isobutanol and ethanol, 50% maximum blend.
- Catalytic hydrothermolysis jet (CHJ) produced from esters and fatty acids at a 50% maximum blend concentration.
- Hydrocarbon HEFA (HC-HEFA) produced from esters and fatty acids at a 10% maximum blend concentration.
- ATJ-SPK with aromatics (ATJ-SKA) from C2–C5 alcohols, 50% limit.

It is important to note that the blend percentages given are the maximum allowable, but D7566 fuel property requirements may limit blending to a lower level for a specific batch of synthetic blending component. Multiple additional pathways are currently under review by ASTM. There is future potential for a 100% SAF fuel, but there are no anticipated impacts on infrastructure, as it will contain a minimum of 8% aromatics, which is within the range of Jet A aromatic content.

The U.K. Ministry of Defense maintains another commonly used jet fuel quality standard outside of the United States, Defense Standard 91-091 (Def Stan 91-091), *Turbine Fuel, Kerosene Type, Jet A-1*. The standard is nearly identical to ASTM D1655, with minimal differences for test limits for acidity level and naphthalene content. Def Stan 91-091 includes a fuel traceability requirement for semi-synthetic jet fuel such as SAF.

2.2 Certification of Quality

Jet fuel and SAF travel by multiple modes of transportation including pipeline (neat SAF blendstock not currently shipped by pipeline), truck, barge, and rail (uncommon for Jet A). If the tested fuel falls outside any ASTM limits at the refinery, SAF plant, or along the supply chain, the batch must be segregated from other fuel and retested to determine if the fuel can be used. Refinery certificates of quality (RCQs), certificates of quality, certificates of analysis (COAs), and recertification test certificates are used for quality control in contracts between buyers and sellers.

- An RCQ is generated at a refinery for each batch of petroleum jet fuel produced. The document includes batch number, quantity of the batch, refinery name, date, documentation that the tested fuel meets ASTM D1655 (Jet A), and type and volumes of additives.[12]
- A certificate of quality is generated at a SAF facility and includes the same information as an RCQ but tests to the appropriate annex of ASTM D7566.
- A COA is generated by a certified and accredited third-party laboratory downstream from production at each transition point. COA documentation includes documentation that the tested fuel meets ASTM D1655 or D7655, and related annex tables.
    - A COA typically includes results from Airlines for America's ATA Specification 103, *Standard for Jet Fuel Quality Control at Airports*.[13]
    - A COA is generated when SAF and Jet A are blended, certifying it as ASTM D1655.
- A recertification test certificate is generated in instances where there is risk of fuel contamination, such as after the jet fuel travels through a multiproduct pipeline or ocean vessel or in other instances where this is a risk of contamination. Its documentation is like an RCQ, though not as many fuel parameters are tested. The testing makes sure specification limits are met and that there are no significant changes noted for each property in the test certificate.

SAF is blended with Jet A at the percentage determined by the end user or up to the allowable maximum percentage based on the technology pathway. A COA is generated based on testing that demonstrates the fuel is compliant with ASTM D7566 Annex 1 Tables 1 and 2. Once confirmed, the fuel is designated as ASTM D1655.

Best practices and standards differ in how to determine batch number and necessary fuel testing when fuels are blended. The American Petroleum Institute's Recommended Practice 1543, *Documentation, Monitoring and Laboratory Testing of Aviation Fuel During Shipment from Refinery to Airport*, states that if two batches of jet fuel are commingled at a storage facility, the batch identity is lost. The pipeline industry has addressed this by generating batch numbers for volumetric accounting, but this does not carry over the COA from the original batches that were commingled, and the fuel is tested against ATA 103, which does not require full conformity testing after commingling of batches (Miller et al. 2014).

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[12] RCQ and COA are similar documents. The RCQ may include additional information such as type and quantity of additives, and potentially the percentage of non-hydroprocessed, mildly hydroprocessed, or severely hydroprocessed components. The refiner typically generates the RCQ but is allowed to use an independent laboratory to generate an RCQ; the refiner is ultimately responsible for the laboratory results.

[13] Airlines for America, formerly Air Transport Association, provides airlines with the ATA 103 standard, which requires the following eight tests: visual appearance in a white bucket, gravity, distillation (10%, 50%, 90%, final boiling point, residue, and loss), flash point, freezing point, water separation, copper corrosion, and existent gum. If an airline incorporates ATA 103 into their maintenance/operating manuals, the airline must adhere to it under FAA regulations.

3 SAF Logistics and Blending

Multiple modes of transit are used to move imported and domestically produced Jet A and SAF (Figure 7). The modes or transport depend on where the fuel was produced or imported, volumes, and infrastructure availability. It is more common for Jet A and SAF to arrive at terminals where they are blended, certified to ASTM D1655, and delivered to an airport by pipeline or truck for airports without pipelines. In limited instances, refineries are directly connected to an airport by pipeline. There is future potential to produce SAF containing fuel by coprocessing bio-derived components alongside petroleum feedstock at existing refineries and limited future potential to deliver third-party-produced SAF to refinery storage for blending and certification. Industry discussions have considered connecting SAF production facilities by pipeline to terminals. Jet fuel quality is tested at every point it moves through the supply chain. Figure 8 shows movements of petroleum jet fuel between PADDs by both pipeline and tanker/barge.

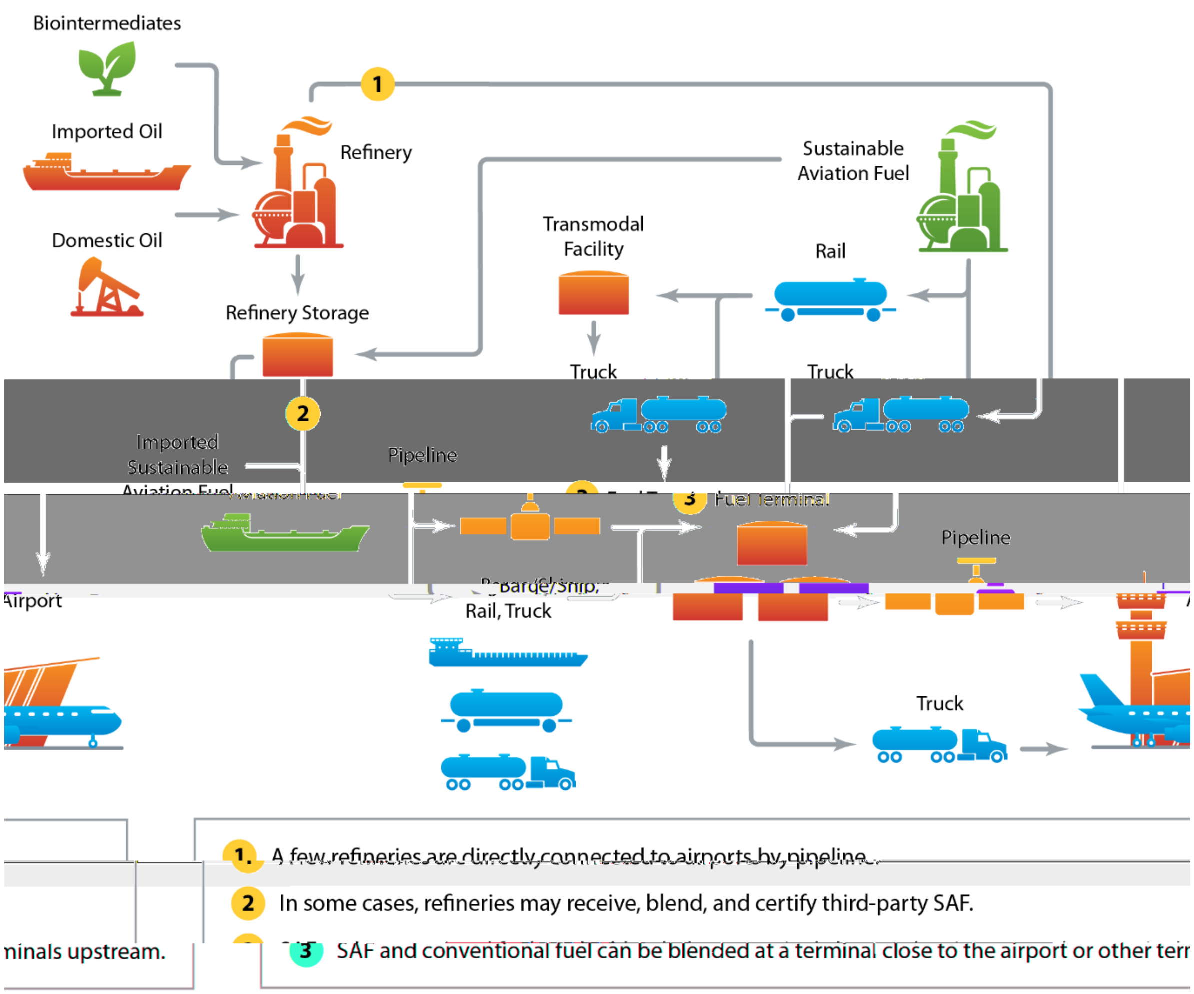

Figure 7. SAF and jet fuel supply chain

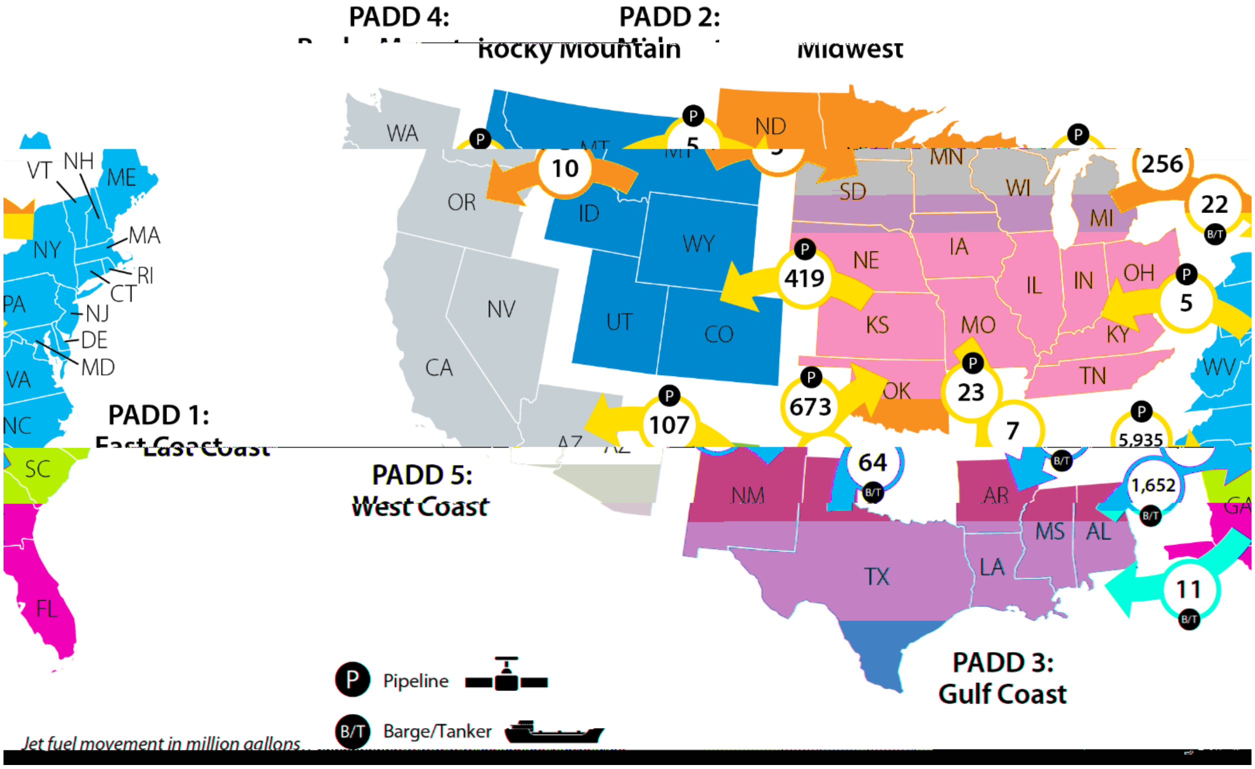

Figure 8. Petroleum jet fuel movements between PADDs (2023).[14]

Source: EIA 2024c

3.1 Jet A and SAF Logistics

Jet A is moved primarily by pipeline, whereas biofuels produced at stand-alone facilities are moved by rail or barge/tanker (large volumes) or truck (small volumes). Dedicated railcars and trucks are strongly encouraged (Energy Institute 2022). Pipelines are multiproduct, and tanker and barge vessels generally carry different fuels over time. In the future, if SAF containing fuel is produced by coprocessing bio-derived components with conventional refinery streams to produce Jet A at an existing refinery, an RCQ would be generated at the refinery, and the fuel would flow through the supply chain in a business-as-usual model via pipeline directly to an airport or, more commonly, by pipeline to a terminal and then by pipeline to an airport.

SAF produced at a domestic stand-alone facility currently travels by rail or truck to a fuel terminal for blending with Jet A. As volumes grow, there is the expectation that SAF will move by barge/tanker. There is the potential in the future to connect SAF production facilities to terminals by pipeline. SAF imported from other countries would be delivered by tanker (a ship designed for bulk petroleum transport) to a terminal. SAF movements from existing domestic plants vary based on available infrastructure. Existing plants are using several shipping methods, and these are shared as examples on how available infrastructure and location impact fuel movements. The Montana Renewables plant ships SAF by rail to a Southern California terminal, where it is blended and delivered to airports. LanzaJet's SAF will be delivered by truck to terminal(s) in the Savanah, Georgia, area; their facility does not have rail. World Energy moves

[14] The arrows represent the movements from one PADD to another PADD; not between specific states.

SAF/Jet A blends by truck to airports. Neste's imported fuel is delivered by tanker to California water-based terminals or a nearly finished product is sent to a Houston area refinery where it is upgraded to SAF and sent by rail to California (Schwanz 2023, Neste 2022). There are different considerations for various transit methods.

There are constraints in the Jet A supply chain in some geographical areas, where demand for pipeline shipments outstrips available space and growth in the number of flights at airports results in fuel demand higher than an airport's pipeline can accommodate. Airports without pipelines have experienced issues with the availability of qualified truck drivers to deliver Jet A. These same constraints could impact SAF movements.

3.1.1 Jet Fuel Movements: Pipeline, Rail, Barge, Tanker, and Truck

Pipelines are the preferred method for moving any fuel due to lower costs and less impacts from weather events. Major multiproduct refined petroleum product pipelines transporting jet fuel are shown in Figure 9.[15] Domestically produced and imported jet fuel is commonly moved throughout the country by pipeline, passing through one or more terminals before delivery to an airport by pipeline or by truck. Pipelines batch fuels based on fuel properties, and if dissimilar fuels come into contact, a transmix or interface is delivered to a separate tank for reprocessing. Fuel is batched through pipelines, and customers receive the specified volume of fuel; however, they are not receiving fuel from a particular terminal or refinery. For example, an energy company may ship their jet fuel on a pipeline to a terminal thousands of miles away and receive the volume of fuel ordered, but it is not necessarily the fuel from their refinery. Fuels from different producers all meet the same ASTM standards and once on the pipeline system are considered fungible (or interchangeable). While possible, it is uncommon to use unique batch identifiers to move specific fuels to a customer; this results in higher costs and administrative burden. Jet fuel competes with other refined petroleum products for pipeline capacity to move fuel long distances and in some markets, there are pipeline constraints where demand outstrips available capacity. Further, there are airports where the pipeline into the airport operates at capacity and demand is met by truck deliveries and tankering—a practice of loading more fuel than necessary at the airport of origin.

SAF/Jet A blends have been delivered by pipeline after being recertified as meeting ASTM D1655. A demonstration was done with imported SAF blended at a Houston-area terminal and moved via two pipeline systems to LaGuardia International Airport (Delta 2022). This shipment was done using a unique batch identifier for the pipeline shipment. The Federal Energy Regulatory Commission regulates fuels carried by pipeline, and their requirement for new fuels is to publish rules in a pipeline's tariff or shipper manual, where the pipeline company must specify fuel requirements. Several pipeline companies have notified the Federal Energy Regulatory Commission and provided information in their tariff or shipper manual for SAF/Jet A blends meeting ASTM D1655. At this time, neat SAF blendstock is not being transported by pipeline, but updates to pipeline company manuals with specific fuel quality requirements could enable those shipments.

[15] This graphic does not show smaller regional pipelines that carry jet fuel nor pipelines from terminals to airports.

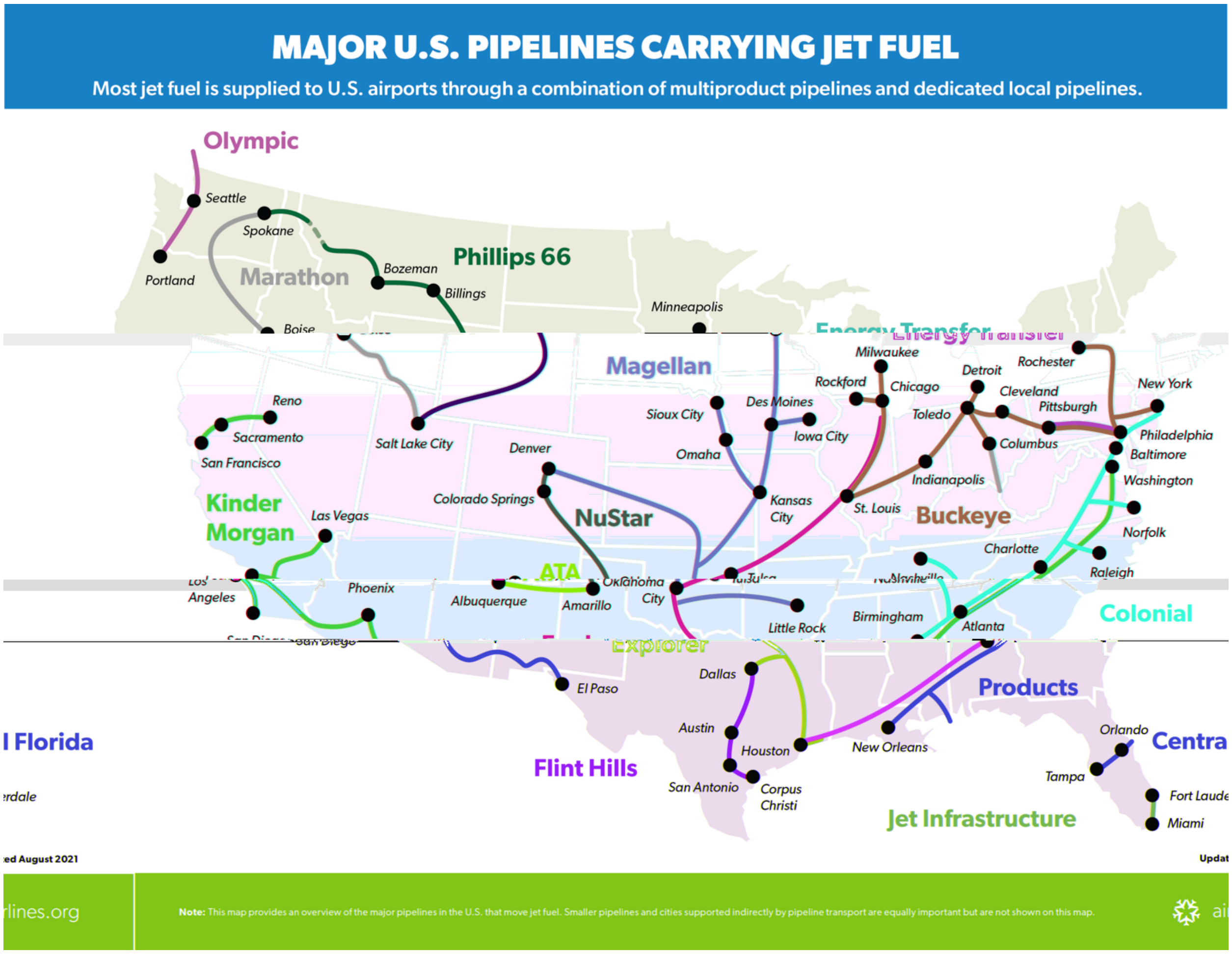

Figure 9. Major U.S. Pipelines Carrying Jet Fuel.

Source: Airlines for America 2021; used with permission

Rail is a common mode to move biofuels from production locations to population centers. Railcars dedicated to SAF movements are strongly encouraged (Energy Institute 2022). Not all terminals have rail facilities, and in those instances the biofuels are received at a transmodal facility and delivered to nearby terminals by truck. Railcars are typically leased by fuel producers and distributors and hold about 30,000 gallons each. Costs for shipping by rail vary based on distance, competition, and whether it is a single car rate for trains with multiple commodities or unit car rates for trains with about 100 railcars of the same commodity. As an example, 2021 rail rates to move ethanol from multiple Midwest cities to Houston and Fort Worth, Texas, averaged \$0.29/gallon and \$0.23/gallon for single car and unit car, respectively (U.S. Department of Agriculture 2021).

Barges are used to move fuels along rivers and inland waterways and along the costal United States. Moving fuels by barge generally costs more than pipeline but less than rail or truck. The Jones Act, a federal code, requires that all goods transported in U.S. waters be carried on U.S. vessels. Tug or tow boats move multiple barges (fat-bottomed vessels) via inland waterways. Capacity varies widely, with an inland tank barge ranging from 400,000 to 1.2 million gallons and an oceangoing tank barge between 7 and 14 million gallons (National Oceanic and Atmospheric Administration 2016).

Tankers, a type of ship designed for bulk transport of oil and petroleum products, are used to move large volumes of fuel. Tankers are used for both international trade and to move fuel between domestic PADD regions. Capacity varies based on vessel size and distance it is designed to travel for refined petroleum products, with a range of 22–227 million gallons (EIA 2014).[16] If non-dedicated tanks are used to transport SAF or Jet A, individual tank history must be recorded for last three products contained prior to loading and reviewed for any risks prior to storing SAF or a SAF blend (Energy Institute 2022). Costs to move jet fuel by tanker will be determined by distance, volume, and petroleum market dynamics. Rates show a high degree of variability over time, from less than $10/barrel to more than $55/barrel between 2018 and 2022 (EIA 2022).

Trucks are used to move Jet A from terminals and refineries to airport tank farms where a pipeline is unavailable. Trucks also move fuel from airport tank farms to aircraft if the airport does not have a fuel hydrant system. Jet A trucks in the United States are dedicated and do not transport other fuels to reduce any risk of contamination. Jet A truck capacities range from 3,000 to 10,000 gallons (Seidenman 2023). It is expected that the same trucks that transport Jet A today will be used to transport SAF and SAF/Jet A blends. Ideally, trucks are used to move fuels short distances.

3.1.2 Airport Infrastructure and Fuel Management

All commercial airports have on-site fuel storage—an area called the tank farm. A tank farm comprises multiple interconnected pieces of equipment designed to safely receive, store, and dispense fuel to a hydrant system or truck delivery to aircraft. Although not an all-inclusive list, a tank farm consists of tanks; pipeline interconnection; equipment to control the flow of fuel and vapors; meters to measure the volume of fuels into the tank farm and out to aircraft; filters to remove contaminants; pumps to move fuel throughout the system; safety equipment to prevent, detect, and contain leaks throughout the system; off-loading racks to fill fuel trucks; and hydrant systems—underground pipes and hydrants. Generally, airports own the tank farm and lease it to an airline fuel consortium or fixed based operator who manage it. Smaller airports may operate under a different scheme in which the airport either operates the fuel system or hires a third party to do so. Fuel is delivered to airplanes via a fuel hydrant system (underground pipes to each gate) or by fuel truck. All airlines agree to allow the use of ASTM D1655 compliant jet fuel containing SAF at an airport, as specific SAF blends would not be delivered to a particular flight or airline. However, airlines and other aviation customers buying SAF would receive any benefits associated with purchasing the fuel.

Airport tank farms size their fuel infrastructure to accommodate their peak week of the year and allow for future growth. However, the growth in enplanements and jet fuel use has constrained fuel infrastructure at some airports, and in some instances demand exceeds pipeline capacity. This is compensated for by truck deliveries or fuel tankering—where an aircraft flies with more fuel than required for its flight. Truck deliveries supplement pipeline deliveries but are not as

[16] Based on deadweight in metric tons converted to million gallons based on a jet fuel density assumption of 6.7 pounds/gallon.

efficient, as deliveries are handled by the airside service contractor along with security procedures for both the fuel truck driver and entry into the secure area of the tank farm.

The purpose of airline fuel consortiums, common at U.S. airports, is to pool resources and ensure quality and timely delivery of jet fuel to all airlines through shared infrastructure. The airline consortium model allows airlines to source fuel from multiple fuel producers. Airline fuel consortiums do not buy or sell fuel but act as the operator of the fuel infrastructure. Airlines are responsible for purchasing fuel and ensuring quality. The consortium may directly operate the infrastructure system or contract out operations to a third party.

3.2 SAF and Jet A Blending

SAF from a stand-alone facility must be blended with Jet A prior to use in an aircraft. Several possible locations for blending include existing terminals, airports, petroleum refineries, and new/dedicated blending sites. While all the locations evaluated are technically capable of blending fuel, there are practical considerations that make some locations less optimal. It is preferable to certify the SAF/Jet A blend as ASTM D1655 and mitigate any potential fuel quality issues upstream of an airport. All locations with require capital investment to add infrastructure.

- **Terminals:** Terminals are the optimal location for blending because they have existing tanks, associated equipment, blending software, trained staff, insurance, and permits that cover these activities. Nearly all terminals lease tanks and associated equipment to third parties for storage and blending activities. Terminals have long provided blending as a service for their on-highway transportation fuel customers. SAF storage and blending could occur in existing tanks if available but may require new tanks in infrastructure constrained areas.
- **Airports:** Blending at airports is not recommended. This would be the first instance of certifying the SAF blend as ASTM D1655. An airport's tank farm would require significant capital investment to add tanks for SAF storage, blending, additional off-spec tanks, associated equipment, software, and additional staff. There would be an increase in truck traffic delivering SAF, which would impact larger airports accustomed to receiving fuel by pipeline. Additional laboratory testing and paperwork are necessary for blended fuel. Different insurance would be necessary to cover blending activities. EI 1533 states that blending should only occur upstream of airports (EIA 2022). Def Stan 91-091 (fuel quality standard used outside of the United States) prohibits blending at airport depots (Energy Institute 2022).[17]
- **Refineries:** Each refinery has a unique design. Refinery fuel storage is generally sized for its capacity, with limited or no excess storage. A limited number of refineries could receive third-party fuel into their fuel storage area, and off-loading equipment would be needed. The refinery could receive the third-party SAF, blend with their Jet A, recertify, and transport fuel in a business-as-usual scenario by pipeline and truck to airports.
- **Greenfield/brownfield sites:** It is feasible to establish a new site or repurpose an industrial site to store and blend SAF. This would be a capital-intensive effort. Permitting both the facility and any associated pipelines would take years. This option would likely

[17] There is an exception for small volumes for development projects.

only be considered in geographic areas with severe capacity constraints for existing infrastructure (terminals, pipelines, and rail).

Blending at terminals upstream of airports results in business as usual at airports; using the same pipeline, trucks, tank farms, and hydraulic systems are used to deliver the SAF/Jet A blend to aircraft. Blending can take place at a terminal directly connected to an airport by pipeline or thousands of miles away and delivered by pipeline to terminals serving the airport(s) of interest. The source of SAF, purchaser, end user, logistics, infrastructure availability, and cost are all factors that could impact preferred terminal locations for blending. As an example, imported SAF from Neste was blended in Texas and delivered to New Jersey via the Colonial Pipeline and onward on the Buckeye Pipeline to LaGuardia International Airport to Delta Air Lines as a demonstration (Delta 2022). The investment in infrastructure would occur at terminals, not airports.

How to blend the fuel is another consideration with cost and infrastructure availability implications. Leasing more tanks increases costs; however, Option 1 (described below) is the current and preferred method of blending SAF and Jet A at terminals. Inline (or ratio) blending—in which both fuels are delivered to a tank at the same time—is preferred to sequential (or splash) blending, in which fuels are delivered to a tank one at a time. A best practice is to add mixing equipment to tanks to ensure a homogenous blend (Energy Institute 2022).

- **Option 1:** Off-load SAF to a terminal and store it in a dedicated SAF tank. Store Jet A in separate tanks. Both SAF and Jet A batches are tested to ensure compliance with ASTM D7566 and ASTM D1655, respectively. SAF and Jet A are blended at the desired ratio into a third tank. Sampling from the third tank would follow the steps outlined in Section 2.2: Certification of Quality to generate a COA demonstrating that the blended fuel meets ASTM D7655. If it does, the blended fuel is designated as ASTM D1655 and is ready for shipment via pipeline or truck to airports.[18]
- **Option 2:** This option is not in use and entails off-loading SAF into a Jet A storage tank at a terminal (Figure 11). Sampling from the tank would follow the steps outlined in Section 2.2: Certification of Quality to generate a COA demonstrating that the blended fuel meets ASTM D7655. If it does, the blended fuel is designated as ASTM D1655 and is ready for shipment via pipeline or truck to airports. For this option, it is a recommended best practice to deliver SAF via dedicated infrastructure (EI 2022).

[18] Blending that takes place at a terminal upstream of those connected to terminals would ship to downstream terminals in a business-as-usual scenario, where it is tested to ensure compliance with ASTM D1655 and a COA is generated.

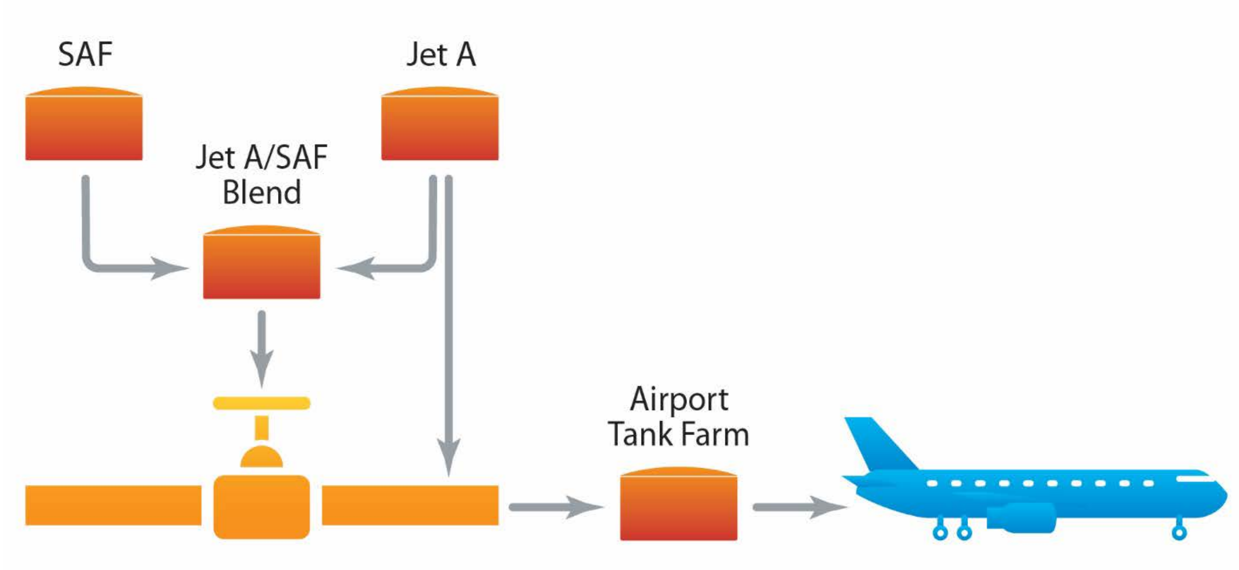

Figure 10. Current method of blending Jet A and SAF at a terminal

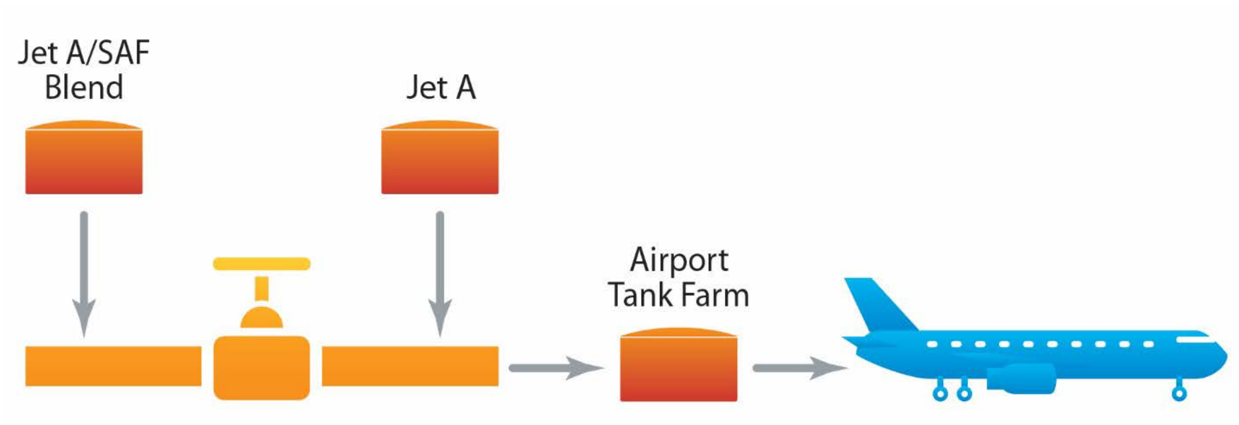

Figure 11. Alternative method of blending Jet A and SAF at a terminal

Neat SAF from two different annexes (pathways) cannot be commingled into a tank for blending with Jet A (ASTM 2024, Energy Institute 2022). As an example, fuel produced from the HEFA and ATJ pathways cannot be commingled in the same tank. SAF from two different annexes that have been segregated and blended with Jet A and certified as ASTM D1655 can be blended. It is important when blending such fuels that they do not exceed the allowable percent per ASTM limits. SAF produced by the same annex can be commingled in the same SAF tank and blended simultaneously with Jet A. For example, HEFA from two different producers can be commingled in a tank.

Existing SAF plants typically move their fuel to terminals for blending. Montana Renewables and Neste deliver neat SAF to California terminals for blending. LanzaJet is moving their neat SAF to Savanah, Georgia terminals for blending. World Energy was the first domestic petroleum refinery conversion and SAF plant and is located in close proximity to Los Angeles. Due to these factors, they bring in Jet A, blend and certify on-site, and the blended fuel is delivered by truck to area airports.

Reported blend ratios have been about 30% SAF and 70% Jet A (Schwanz 2023, Signature Aviation 2024). A terminal blending SAF in Crockett, California, takes additional steps to ensure fuel quality. This terminal has a third-party testing company check incoming trucks to ensure they do not contain any jet fuel. The inspection process also includes a check of the SAF filtration system, SAF content, and water and ensures compliance with all regulations. After the truck is loaded with the SAF blend and a 10-minute settling period, fuel is tested from each truck compartment to ensure compliance with ASTM D1655 (Schwanz 2023). After demonstrating compliance, the truck leaves the terminal to deliver the fuel to airport(s).

3.2.1 Terminal Information

Terminals receive, store, blend, and off-load fuels for their customers. There are approximately 1,200 terminals storing refined petroleum products in the United States, though not all of them store jet fuel (EIA 2024f). Terminals receive a fee for leasing tanks and associated equipment, storing and blending fuels for their customers. Lease terms vary but are generally at least 1 year (and longer if capital improvements are necessary to accommodate a fuel and blending). Terminals have several ownership types, including refinery owners (33%), midstream companies with pipelines (36%), and midstream companies that may own one or more terminals (31%).[19]

Oil and refinery companies own the fuel, though they also lease tanks and associated equipment to third parties.

- **Oil/refinery:** Vertically integrated companies that explore and drill for oil and refine it and companies that purchase crude and refine it. These companies may also own pipelines. While these are purpose-built to store their fuels, they also lease space for third-party fuel storage. The refinery companies with the most terminals (not necessarily capacity) include MPLX (Marathon Petroleum Corporation), Philips66, and Shell (inclusive of their investment in Equilon Enterprises and Motiva) (EIA 2024f).
- **Pipeline:** Midstream companies that own pipelines and lease storage space to customers at their terminals. Buckeye Partners, Sunoco, Kinder Morgan, and Magellan account for more than 70% of terminals in this category (EIA 2024f).
- **Terminal:** Midstream companies that own one or more terminals but do not own pipelines or refineries. There is limited consolidation of ownership in this category.

The availability of tanks for lease changes over time as leases expire. Both the timeline and cost to add SAF storage and blending activities at a terminal will vary. The lowest-cost and shortest-timeline scenario is using existing tanks at terminals that currently store jet fuel. Terminals that do not currently store jet fuel are also an option, and an inquiry should be made to determine if available tanks could be converted for SAF and blending activities. Adding SAF to a terminal not currently storing Jet A would have a longer lead time, and there would be a capital investment to add dedicated associated equipment such as pipes, pumps, and off-loading equipment. Another consideration is how SAF would be delivered to a terminal. If the SAF would be primarily delivered by rail, terminals with rail infrastructure and secondarily terminals near rail transmodal facilities will need to be identified.

[19] This is a subset of data from EIA (2024g). The percent represent the number of terminals, not capacity. Terminals that solely store crude oil, marine fuels, heating oil, and asphalt were removed.

In areas with geographical constraints, it is recommended to evaluate terminals upstream by pipeline to find available tank and blending infrastructure. For situations where it is essential to blend in a desired geographic area where tank infrastructure is constrained, there is the potential to build new tanks. If terminals have space, they are generally open to adding new infrastructure to support a customer, and the lease fees could accommodate the capital expenditure of the terminal owner (or, less commonly, the fuel owner leasing the space pays the capital expense upfront). EI 1533 has a section on SAF and SAF/Jet A blend design and handling equipment (Energy Institute 2022).

While terminals can change fuels stored after a thorough cleaning, not all tanks would be available to store jet fuel due to their configurations. For example, some diesel tanks have external floating roofs that would not be used. Ideally, a customer storing SAF could lease two existing tanks—one for neat SAF and one for blending with Jet A, with the assumption that Jet A is already available and stored at the terminal. There would be costs for associated dedicated equipment such as dedicated pipes, pumps, and other equipment.

Both the timeline and cost to add SAF storage and blending activities at a terminal will vary. The quickest and lowest-cost option is expected to be at a terminal that currently stores jet fuel and has available tanks for lease. It is anticipated that more time would be needed to add these activities to a terminal that does not currently store jet fuel but has tanks available for lease. The longest lead time and highest costs will occur where new tanks and associated equipment need to be built to accommodate SAF and blending.

The implications, permits, and processes to add a new tank will vary widely based on location and are reliant on local and state authorities. Existing terminals will be aware of the steps they need to take to add new equipment and activities at their location. Air quality in an area determines thresholds for permitting. Adding a new source of emissions from a tank could lead to a New Source Review, a Clean Air Act program (EPA 2024b). The addition of SAF and blending activities and any impacts on emissions, as well as location, will inform permit needs. Changing fuels stored in existing tanks is less likely to trigger public notice requirements than new tanks, but again depends on local jurisdictions having authority.

There are federal environmental laws that regulate activities and infrastructure at terminals. The following is a summary of significant federal regulations that apply to terminals. This is not intended to be a complete list. In many instances, states, territories, Tribal nations, and municipalities manage federal environmental permits on EPA's behalf (EPA 2024a).

- An EPA operating permit is required to ensure compliance with air emissions regulations (40 CFR 1C, Parts 70 and 71).
- The purpose of the Spill Prevention, Control, and Countermeasure regulation is to prevent discharges of petroleum into navigable waters and applies to facilities with aboveground store tank capacity exceeding 1,320 gallons or underground storage capacity exceeding 42,000 gallons (40 CFR 112; Defense Logistics Agency 2019). It requires secondary containment for the largest storage tank and "sufficient freeboard to contain precipitation" (40 CFR 112).
- The National Pollutant Discharge Elimination System ensures that stormwater does not contain fuel. This requires monthly tank inspections to check for leaks (40 CFR 122).

- The International Code Council's International Fire Code, generally adopted by state fire marshals, contains design and operational standards for types of facilities, processes, and materials for use at fuel terminals.

Terminals are also subject to state and local regulations. Local authorities having jurisdiction refers to regulating organizations, offices, or individuals responsible for overseeing codes and standards. Examples of authorities having jurisdiction include local fire marshals, state energy and environment offices, air and water boards, and similar organizations or offices.

3.2.2 Airline, General Aviation, and Airport Roles

Many but not all airlines have entered into offtake agreements with existing and anticipated future SAF producers.[20] Airlines are responsible for ensuring fuel supply for their aircraft by working with airline consortiums at various airports and with fuel suppliers (both SAF and Jet A), terminals, and distributors. Airlines have been involved in evaluating the logistics to move SAF to their airport hubs. General and business aviation are other significant consumers of SAF as a solution to meet both their and their customers' corporate climate and environmental requirements and goals. General aviation also enters into offtake agreements and determines logistics for moving fuel to end users. Airlines share refueling infrastructure, and while one or more airlines may purchase SAF/Jet A blends, all airlines must agree to its use, as specific fuel is generally not directed toward a specific airline or flight.

Both airlines and general aviation are expected to participate in book-and-claim—an accounting practice that enables an entity to purchase and gain SAF benefits regardless of where the SAF/Jet A blend is used. Book-and-claim can help reduce costs by using the SAF/Jet A blend closest to where it is produced, and the SAF claim is captured by the entity (e.g., airline, business customer) who purchased it.

Airports do not purchase jet fuel, but they play an important role in preparing their location for SAF/Jet A blend use. Airports have brought together airlines, fuel producers, suppliers, terminals, and other entitles in the fuel supply chain to plan to enable SAF receipt and blending in their geographic location and scale for future greater volumes. San Francisco International Airport, Seattle-Tacoma International Airport, and Port Authority of New York and New Jersey airports, for example, have prepared studies to determine the infrastructure in their area to bring in and blend SAF for delivery to their airports.

3.2.3 European SAF Logistics and Blending

European aviation meets the same stringent quality standards as the United States. Europe does not have airline fuel consortiums. SAF plants currently supplying European markets are largely water-based, so neat SAF is more likely to travel by tanker or barge than truck or pipeline. It is expected in the future that SAF will be transported by train and/or truck. Blending occurs at either terminals or refineries. There are at least two petroleum refineries coprocessing SAF, and in these instances the blending and certification occur at the refinery, and it is business as usual throughout the supply chain (Eni 2023; TotalEnergies 2023).

[20] ICAO maintains a list of publicly announced offtake agreements: www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx.

Neat SAF loaded onto ships is certified with a certificate of quality at the loading port, upon receipt is checked for compliance with ASTM D7566 annex tables, and the Aviation Fuel Quality Requirements for Jointly Operated Systems checklist is completed. Before off-loading from a tanker, the previous documents are checked, a recertification test is conducted onboard, and then a COA is done after the fuel is delivered to a dedicated SAF tank at the terminal. A control check is performed on the dedicated SAF tank, and then it is pumped to a dedicated SAF blending tank where Jet A is also pumped. After blending, testing is done to ensure compliance with ASTM D7566 Table 1 Parts 1 and 2, and an Aviation Fuel Quality Requirements for Jointly Operated Systems checklist is performed. If it passes, a certificate of quality is generated, and the fuel can be delivered to the airport.

SAF/Jet A blend ratios range between 15% and 45%. At terminals, SAF generally requires more dedicated tanks and segregation for blending, and there are constrains within the existing European terminal infrastructure to lease and build new equipment. It requires significant capital investment to retrofit existing facilities to accommodate new fuels. SAF/Jet A blends are largely delivered by pipeline to airports—fewer European airports are serviced by truck. There are no airline fuel consortiums in Europe—airport tank farms are either owned by airports or joint ventures among fuel suppliers.

4 Conclusions

Both domestic and imported SAF volumes are increasing, and logistics and blending must be considered. It is preferable to certify the SAF/Jet A blend as ASTM D1655 and mitigate any potential fuel quality issues upstream of an airport. Therefore, existing terminals are the preferred location for blending fuel due to existing infrastructure and blending equipment, insurance, and experience for on-highway transportation fuels. Blending at terminals results in business as usual at airports; the same pipelines, trucks, tank farms, and hydraulic systems are used to deliver the SAF/Jet A blend to aircraft. Blending can take place at a terminal directly connected to an airport by pipeline or thousands of miles away and delivered by pipeline to terminals serving the airport(s) of interest. The source of SAF, purchaser, end user, logistics, infrastructure availability, and cost are all factors that could impact preferred terminal locations for blending. The lowest-cost and quickest-timeline scenario would be to use existing tanks at a terminal. Costs increase if new tanks are added to an existing terminal, and the capital investment would be significant and the timeline long to build a new terminal. It is business as usual at airports using the same pipelines and trucks to deliver SAF/Jet A blends as to deliver petroleum blends today. The capital investment in any infrastructure would be made upstream of an airport.

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