CAAFI®

Commercial Aviation Alternative Fuels Initiative®

Path to Alternative Jet Fuel Readiness

What is this guide and why is it needed?

This guide, developed by the Commercial Aviation Alternative Fuels Initiative (CAAFI®), is intended to help fuel producers progress from initial concept through the required ASTM International qualification process. The aviation community has recognized that navigating the synthetic aviation turbine fuel (SATF) qualification process can require significant resources, including funding, fuel, testing, and time and as such has taken a concerted effort to streamline the qualification process. This guide walks through the required steps for reaching qualification and outlines several optional opportunities intended to aid in meeting the required steps.

Who is responsible for qualifying new fuels?

In the U.S., the primary standard setting body for turbine fuels is ASTM International**.** The technical stakeholder community makes a technical determination through a consensus process that a candidate SATF is equivalent to Jet A/A-1. The process works by generating a research report containing the required test data and submitting it to the ASTM Sub-Committee D02.J06 for aviation fuels for review. Review determines if additional data are needed, and eventually, when all requests from the committee are satisfied, voting is conducted to finalize the qualification. Typically, the fuel producer(s) is primarily responsible for obtaining qualification for their SATF. To alleviate this burden, the fuel producer should take advantage of pre-screening (discussed later) and join with other producers with similar processes as well as take advantage of the Clearinghouse concept described below.

What are the ASTM specifications?

The ASTM standards detail the qualification and production requirements and guidance for SATF. The ASTM standard practice for qualification of "drop-in" aviation fuels is D4054, "Guideline for the Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives." The ASTM Standard Specification for petroleum-based Jet A/A-1 jet fuel is D1655, "Standard Specification for Aviation Turbine Fuels." and the standard specification for SATF is D7566, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons." D7566 specifies the performance properties and other criteria for individual synthetic blending components (SBC) in annexes that specify unique requirements for each SBC as well as the requirements for the final blend, the SATF. Links to these ASTM documents can be found on CAAFI's website, caafi.org, as can a list of fuel production processes that have been approved as blending components for use in jet fuel. New types of SBC can be added to the specification by annexation. Passing the ASTM qualification process is required because aviation regulatory authority qualification is automatically granted once a fuel is incorporated into

D7566, enabling it to be with/re-designated as a D1655 fuel, allowing its use in all existing commercial aircraft.

Why do aviation fuels require qualification?

Due to safety, the aviation industry has stringent requirements for aviation fuels. Along with the well-recognized requirements of the fuel having sufficient energy density and the ability to remain liquid at very cold temperatures, other requirements are aimed at materials compatibility and fungibility with standard jet fuel, known as "drop-in". Materials compatibility issues include compatibility with fuel-wetted metal and non-metal parts, engine and component wear, and compatibility with existing infrastructure. Fungibility is required due to the global nature of the aviation fueling infrastructure, the characteristics of airport fueling systems (which tend to have a single storage and distribution system for all aircraft) and the expense and slow rate of replacement of the aircraft fleet. So, to approach the perfect safety expected of aviation, aviation fuels must meet stringent requirements and be completely interchangeable with existing aviation fuels.

What is meant by Jet A/A-1, SAF, and synthetic fuels?

Jet A and Jet A-1 are the commercial aviation fuels as defined by a performance specification rather than a chemical composition. There are other jet fuels; for example, Jet B is used to enhance cold weather performance, and there are military fuels designated by number such as JP-5 and JP-8. However, nearly all fuel used commercially is Jet A or Jet A-1. Up until recently, Jet A/A-1 was produced solely from petrochemical sources. In order to achieve independence from petroleum sources and to reduce the impact on the environment, Sustainable Aviation Fuel (SAF) has been and is being developed. Note that the term Sustainable Aviation Fuel, or SAF, is often used synonymously with ASTM qualified synthetic aviation turbine fuels. Synthetic aviation turbine fuel (SATF) is what is defined by the ASTM standards and encompasses any non-petroleum-derived fuel, including those made from biomass and waste resources as well as fuels capturing and converting CO2. The term "synthetic" is used because they are made by chemical synthesis to duplicate the chemistry of petroleum-derived fuels. Sustainable Aviation Fuel (SAF) has an additional layer of requirements outside of the ASTM associated with greenhouse gas reduction and other sustainability considerations. This document focuses on synthetic aviation turbine fuels and their progression to commercial viability initially but also addresses the common sustainability considerations that are a critical part of the value proposition.

What is a "drop-in" fuel?

"Drop-in" is a critical term to understand when discussing SATF and SAF. The aviation community wanted to ensure that possible fuels were not only fungible, i.e., interchangeable commercially, but completely safe to use in the wide variety of aircraft that use jet fuel. The term "drop-in" therefore requires that the fuel can be used, mixed, stored and transported in any circumstance that Jet A/A-1 may be used in an aircraft with no detriment to performance or safety. Once a potential fuel is qualified as "drop-in", and produced and blended as per the specifications, then it is transparent to the operators whether their aircraft is using sustainable (or synthetic) aviation fuel or a petroleum-derived fuel. Note that there are currently efforts to define and specify a "non-drop-in" fuel type that does not contain a class of chemical compounds known as "aromatics" that are essential for seal swelling and sealing in older engines and

aircraft. Once the ASTM standard for such a fuel is defined, and if such fuels are qualified for use, they must be kept separate from the commercial supply chain of "drop-in" and petroleum-derived jet fuels. Furthermore, a "non-drop-in" fuel can only be used by aircraft and engines that have been either certified or granted exceptions to operate on the "non-drop-in" fuel.

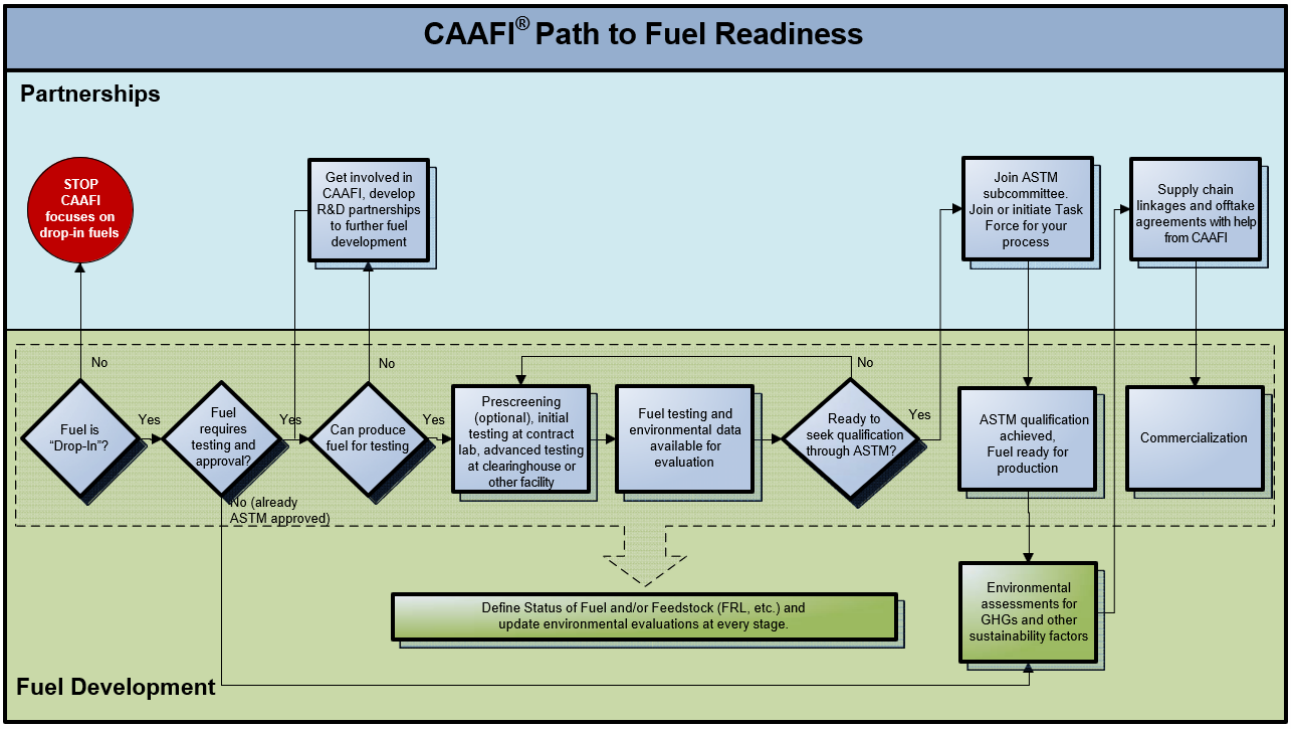
What should be considered before starting this path?

Potential producers should be aware of and consider the following:

- Qualification as a "drop-in" fuel may require a significant amount of fuel, engine and aircraft testing. The amount of fuel required for testing will depend on the specific characteristics of the fuel and the process and feedstocks utilized to produce the fuel. As candidate fuels progress through the qualification process, fuel requirements will increase in increments from a few gallons to thousands of gallons, and if engine endurance testing is required, up to tens of thousands of gallons or more could be needed.
- A "Fast Track" approach has been developed that enables the fuel producer to focus on Tier 1 testing and other limited tests as required, reducing the need for significant fuel production during qualification. However, there are criteria that need to be met to be qualified for a Fast Track process. Upon completing the Fast Track qualification, the resulting alternative jet fuel can only be blended up to a maximum of 10% of the final fuel product.
- Prescreening testing of small amounts of fuel, described in CAAFI's Prescreening Guidance, can provide an early assessment of potential combustion issues and can offer more confidence for future development and investment decisions.
- In addition to ASTM qualification the fuel producer would need a greenhouse gas (GHG) Life Cycle Analysis (LCA) performed in accordance with recognized guidance that shows reduction in greenhouse gas emissions over standard petroleum (with other aspects of sustainability also being beneficial) if there is a desire to sell the fuel as sustainable.
- For an alternative jet fuel to aid airlines in meeting their obligations under the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the fuel producer can use an existing default CLA value for their pathway or they can pursue an actual GHG LCA value, which must be calculated in accordance with the GHG LCA methodology of CORSIA. The fuel producer must also demonstrate compliance with other CORSIA sustainability requirements. Third party certification by an ICAO-approved Sustainability Certification Scheme is required to demonstrate compliance with the CORSIA requirements.

What are the steps to ASTM qualification?

The steps are illustrated in the following figure and explained below:



1. Get to know the aviation community

As part of establishing a company as a provider of alternative jet fuel, it is beneficial (although not required) to develop relationships and engage with the aviation community. Doing so, facilitates the development of momentum, collaboration with similar companies, and the aggregation of resources to accelerate fuel recognition, testing and approval. The time it takes to get a new fuel tested, qualified, and introduce into the aviation market will depend upon the resource investment and the size of the collaborating team working to certify and develop agreements for your fuel; the more aviation stakeholders that are interested in a new candidate fuel, the faster it can enter the market.

One way to become involved with the aviation community is through a coalition effort such as CAAFI. CAAFI includes stakeholders from all facets of the aviation community as well as the alternative jet fuel sector, including airlines, aircraft and engine manufacturers, energy producers, feedstock producers, researchers, international participants and U.S. government agencies. Visit the Join CAAFI page to learn more about the free opportunity to become a member of CAAFI.

CAAFI can facilitate discussions with the appropriate participants to help evaluate and test new fuels. To do so, it can be helpful to utilize the CAAFI communication tools (FRL and FSRL) that are designed to help understand the current status of a process or feedstock. In addition to using the CAAFI communication tools, it may be useful to estimate a timeframe for reaching the next few readiness levels.

2. Establish your product as a viable aviation fuel for technical and environmental performance

There are several critical areas in which a fuel producer with a new fuel must demonstrate to show the viability of their fuel for aviation, including fuel performance/fitness for purpose and environmental benefits. Progress in each of these areas can occur in parallel. However, significant failure to perform due diligence and achieve basic progress in either of these areas can entirely halt a fuel's acceptance by the aviation community.

2a. Conduct Technical/Performance Evaluation

Several ASTM standards clearly define the stringent specifications for technical performance of aviation fuels that every fuel must meet in order to be used.

FAA's Aviation Sustainability Center (ASCENT), or Center of Excellence for Alternative Jet Fuels & Environment, funded the establishment of the U.S. D4054 Clearinghouse. The U.S. Clearinghouse is intended to provide a "one-stop-shop" for management of the testing and data review program for candidate fuels. The U.S. Clearinghouse is managed by University of Dayton Research Institute (UDRI) (contact Zach West: zachary.west@udri.udayton.edu). Most of the ASTM D4054 Tier 1 and Tier 2 (Phase 1) testing under the U.S. Clearinghouse is carried out by laboratories such as UDRI and Southwest Research Institute (SWRI) and supported by funding from FAA. Support of Phase 2 (Tier 3 and 4) testing and final research report reviews will be contingent on the identification of other sources of funding or in-kind support.

Since then, two other Clearinghouses have been established, one in UK and the other in EU, to help the producers advance in their qualification process.

In order to conduct the Phase 1 and 2 testing, there must be suitable volumes of the candidate fuel. The requirements and guidelines for fuel characteristics can be found in the following specifications and documents:

1. ASTM D4054 (Qualification of new turbine fuels and additives)
2. ASTM D7566 (Synthetic aviation turbine fuels)
3. UK MoD DEF STAN 91-091
4. CAAFI Fuel Readiness Level Exit Criteria Checklist

There is a well-define pre-screening approach (see CAAFI's Prescreening Guidance) that can be used to test small amounts of fuel in advance of entering the formal ASTM D4054 process that can enhance certainty prior to undertaking the larger D4054 approach.

Testing can be broken into the following general steps:

Testing Step	Volume	FRL	Description	Prescreening – Tier alpha and beta	Fast Track	Full D4054 Testing and Qualification for D7566
Alpha	>0.5 ml		GCxGC with property predictions	✓		
beta	30 – 60 ml		Alpha and key physical properties	✓		
1	600 ml	3	Initial tests – e.g., beta	✓	✓	✓

			and thermal stability			
2	10 gallons	4	Testing of both neat fuel and blended fuel (50/50 with standard jet) 1. Reverification of initial tests 2. Additional tests include chemical characterization (gas chromatography), corrosivity, hydrogen, sulfur and gum content, particulate matter, and others		✓	✓
3	10-100 gallons	6.1	Fit-for-purpose properties including toxicity, materials compatibility		✓	✓
4	2,000-5,000 gallons	6.2	Hot section oxidation/erosion			✓
5	250-10,000 gallons	6.3	Component, rig and emissions testing			✓
6	6,000-100,000 gallons	6.4	Engine and flight tests			✓

If a fuel producer has already partnered with a large petrochemical company or a university with extensive fuels testing capability, they may also be able to perform some or most of this testing through those organizations.

2b. Conduct Environmental Evaluation

Continually finding ways to improve the environmental performance of a fuel production process and feedstock is highly beneficial for gaining interest in qualifying a candidate fuel. Aviation fuel purchasers are looking for a LCA indicating that a fuel produces lower lifecycle GHG emissions than conventional fuel sourced only from petroleum. The GHG LCA should be performed according to an internationally accepted methodology. Third party, objective, peer-reviewed studies are the most credible.

Previous aviation fuel specific work on GHG LCA include:

- The US Air Force Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels (AFRL-RZ-WP-TR-2009-2206)

- Stratton et al. 2010. Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels
- GREET-for-Jet (Argonne National Lab model modified for aviation fuel)
- ICAO-GREET (Argonne National Lab model specifically developed for ICAO CORSIA).
- ICAO Document 06: CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels.
- ICAO CORSIA Document 07: CORSIA Methodology for Calculating Actual Life Cycle Emissions Values.
- ICAO CORSIA Supporting Document "CORSIA Eligible Fuels - Life Cycle Assessment Methodology"

Although aviation fuel is not mandated in the EPA's Renewable Fuel Standards program (RFS2), it can qualify for Renewable Identification Numbers (RINs) if the EPA deems the feedstock/process combination meets certain GHG reduction goals. Information on petitioning to add a new fuel (and current petitions) can be found here.

Other sustainability metrics are also important to the execution of fuel purchasing agreements. Here are a few SAF and bioenergy sustainability resources:

- ICAO Document 05: CORSIA Sustainability Criteria for CORSIA Eligible Fuels.
- ICAO CORSIA Guidance to Sustainability Certification Schemes (SCS) for application of CORSIA Sustainability Criteria, Themes 4 to 8, for CORSIA Sustainable Aviation Fuel produced on or after 1 January 2024.
- ISO standard 13065:2015 on Sustainability Criteria for Bioenergy specifies principles, criteria and indicators for assessing environmental, social and economic sustainability of bioenergy supply chains.
- The Global BioEnergy Partnership (GBEP) Sustainability Indicators for Bioenergy (agreed to by many governments as guiding sustainability principles)
- Voluntary sustainability certification schemes such as the Roundtable on Sustainable Biomaterials (RSB), the International Sustainability and Carbon Certification (ISCC) and others. Several sustainability certification schemes have been approved to execute SAF certifications for ICAO CORSIA. A set of voluntary sustainability certification schemes, including some feedstock specific programs and some full supply chain sustainability certification schemes, are already approved for use under the European Union's Renewable Energy Directive.
- ISO14025 provides some information on self-reporting of sustainability measures

Environmental due diligence (performance of appropriate analyses) can be measured and communicated using the CAAFI Environmental Progression tool.

See CAAFI's webpage on Sustainability for more information.

3. Get fuel qualified for use

ASTM International Committee D02, Petroleum and Lubricants, Subcommittee J, in particular the J06 section, is responsible for the evaluation and qualification of synthetic aviation turbine fuels. Prospective alternative fuel producers will need to participate in this committee and engage

the other committee members in the evaluation and qualification process. The qualification process is outlined on CAAFI's website here.

The existing alternative aviation fuel specification (D7566) annexes were passed as the result of a collaborative effort among the ASTM members to acquire and evaluate the data and address subcommittee member concerns.

If a fuel of interest has not yet been qualified, it is beneficial to get to know the ASTM process and involved parties. CAAFI suggests attending an ASTM meeting and arranging side meetings with Subcommittee J leadership. Subcommittee J members are generally available to mentor new entrants into the fuel qualification process. If a fuel producer already has data on a fuel, they can request to present properties and fuel data and make the case for pursuing the candidate SATF to the ASTM Subcommittee. In doing so, they will increase the community's familiarity with the particular pathway and will start building interest in qualification. For more information about approaching ASTM and getting involved in Subcommittee J06, reach out to the J06 chair, Gurhan Andac (gurhan.andac@geaerospace.com) or to CAAFI at info@caafi.org for guidance.

To encourage the formation of an ASTM Task Force for a fuel process, it is helpful to find other companies producing fuel with similar feedstocks and technology to increase visibility and interest for the particular fuel process pathway. These task groups typically do not require intellectual property (IP) sharing. Even companies that are very concerned about revealing IP have successfully worked through Task Forces.

Please remember that the duration of the qualification process will be inversely proportional to the resources invested and the size of the collaborating team.

4. Commercialization

Once a fuel has been qualified, a fuel producer should link up with appropriate parties in other parts of the supply chain (for example, feedstock producers, logistics, etc.) and, of course, with purchasers (e.g., airlines) as they near commercial production. CAAFI can facilitate linkages between supply chain participants and potential end users interested in offtake agreements.

What additional information may be useful?

CAAFI has developed the Fuel Readiness Level (FRL) that describes the steps involved in development, scale up, testing, approval, and commercialization of a novel alternative aviation fuel. The volumes of fuel production necessary to meet fuel testing and certification requirements, for example, are delineated in FRL steps 3-5. While use of the FRL is not *required* to develop a new fuel, it can clarify the technical development stages and the associated testing and activities. Information on the FRL can be found here. To assist in linking the FRL to the ASTM qualification process, CAAFI has also developed a set of "Exit Criteria," which is a checklist of specific actions to determine the FRL level of a specific process and the remaining requirements to be fulfilled. These CAAFI FRL Exit Criteria include the components of ASTM testing as well as other aspects of fuel development and are available here.

In response to CAAFI members' concerns regarding feedstock availability and viability, CAAFI has also worked closely with the U.S. Department of Agriculture (USDA) to develop a

Feedstock Readiness Level (FSRL) tool. The FSRL describes the steps involved in introducing or expanding production of a novel, dedicated energy crop. The FSRL can be used as a self-check by fuel producers if they encounter concerns about their ability to produce significant quantities of fuel due to feedstock availability, or by feedstock producer who wish to clarify the status of development of their feedstock, to identify remaining barriers to full scale production

FSRL evaluations are stored and available on USDA's National Agricultural Library Ag Data Commons. This catalog and archive of bioenergy feedstock development assessments is intended to enable stakeholders to identify gaps in research, development or investment that need to close to facilitate the readiness of a particular feedstock and it allows those developing alternative fuel facilities to see what feedstocks may be available in the near-term in a particular region.

To facilitate FRL and FSRL evaluations, CAAFI developed the Environmental Progression document with input from a variety of stakeholders to provide guidance on which environmental analyses might be best performed during the development of a new fuel production process. For example, aspects of environmental sustainability that are potentially difficult to mitigate or are irreversible (e.g., land use conversion and biodiversity impacts or invasive species introduction) need to be evaluated prior to facility establishment or feedstock introduction. Some of these (e.g., invasive species risks and/or impacts) also need to be evaluated both during scale up and during operations. Critical sustainability indicators such as GHG emissions may also be preliminarily evaluated prior to scale up (screening level GHG LCA). Other evaluations may be done during scale up (e.g., study level GHG LCA). Other measures may not be possible until a commercial facility is in development (e.g., acquisition of permits) or established (e.g., compliance with permits, comprehensive GHG LCA). In many cases these evaluations should also be repeated over the course of development and/or process refinement, as the evaluation results may change substantially due to changes (including possible improvements) over time. This tool parallels the FRL and FSRL tools and can be used in conjunction with them to better understand the developmental status of a fuel and/or feedstock.

Please contact us with questions

Please feel free to contact CAAFI at info@caafi.org. We welcome your feedback and suggestions, as well as any questions with which we may be able to help you.