Commercial Aviation Alternative Fuels Initiative®

Path to Alternative Jet Fuel Readiness

Updated March 2018

Introduction

This guide, developed by the Commercial Aviation Alternative Fuels Initiative (CAAFI®), is intended to guide fuel producers from concept through the required ASTM qualification process to commercial uptake. The aviation community has recognized that navigating the fuel 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. The D4054 Clearinghouse Concept that is intended to consolidate the testing and data review of candidate fuels is one such improvement. However, most of the responsibility for obtaining approval rests with the fuel producer(s) of the candidate fuel. This guide walks through the required steps for reaching approval and outlines several optional opportunities intended to aid in meeting the required steps by building interest in candidate fuel processes.

Initial Screening

There are a number of key initial considerations to be aware of before approaching the aviation community with a candidate fuel.

First, and most importantly, due to safety, the aviation industry has stringent requirements for aviation fuels that go beyond the properties listed in the specifications. 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. 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.

Thus, the aviation community is focused on “drop-in” or fungible alternative fuels. These alternative fuels are pure hydrocarbons (i.e., formed of carbon and hydrogen only) and perform in an identical manner to petroleum-derived jet fuel, as determined by well-defined criteria in specifications from accepted standard setting bodies. In the U.S., the primary standard setting body for turbine fuels is ASTM International (see section below on ASTM specifications).

Other considerations to assess at the outset:

- Jet fuel may not be more profitable than other products. However, the aviation fuel buyers are a concentrated, coordinated group of purchasers who may be willing to enter into long-term off-take agreements and offer a stable customer base to producers.
- 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 less than a liter to tens of gallons to thousands or tens of thousands of gallons if extensive engine testing is required.
- To sell fuel to airlines, the fuel producer will 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).
- In order 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 GHG LCA must be performed in accordance with the GHG LCA methodology of CORSIA as well as demonstrate compliance with other CORSIA requirements. Such requirements will be outlined in a Standards and Required Practices document prior to CORSIA implementation.

Background Information

The following external references will be useful for a fuel producer that is considering undertaking alternative fuel qualification and commercialization.

ASTM Specifications

The most crucial documents for understanding qualification and production requirements for synthetic jet fuel are the ASTM standards. 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 specification for petroleum-based Jet A/A-1 jet fuel is D1655, "Standard Specification for Aviation Turbine Fuels." and the specification for synthetic jet fuels is D7566, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons." D7566 specifies the performance properties and other criteria for individual alternative jet fuel synthetic blending components in annexes that specify unique properties for each blending component. 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 classes of synthetic fuel blending components can be added to the specification by annexation. Getting through the ASTM approval process is a critical step on the path to getting the aviation community to accept a new alternative fuel because aviation regulatory authority approval is automatically granted once a fuel is incorporated as an annex into D7566, enabling it to be cross-registered with D1655 and allowing its use in all existing commercial aircraft as jet fuel.

CAAFI Fuel Readiness Level and Feedstock Readiness Level

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's Sustainability Team 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.

Steps:

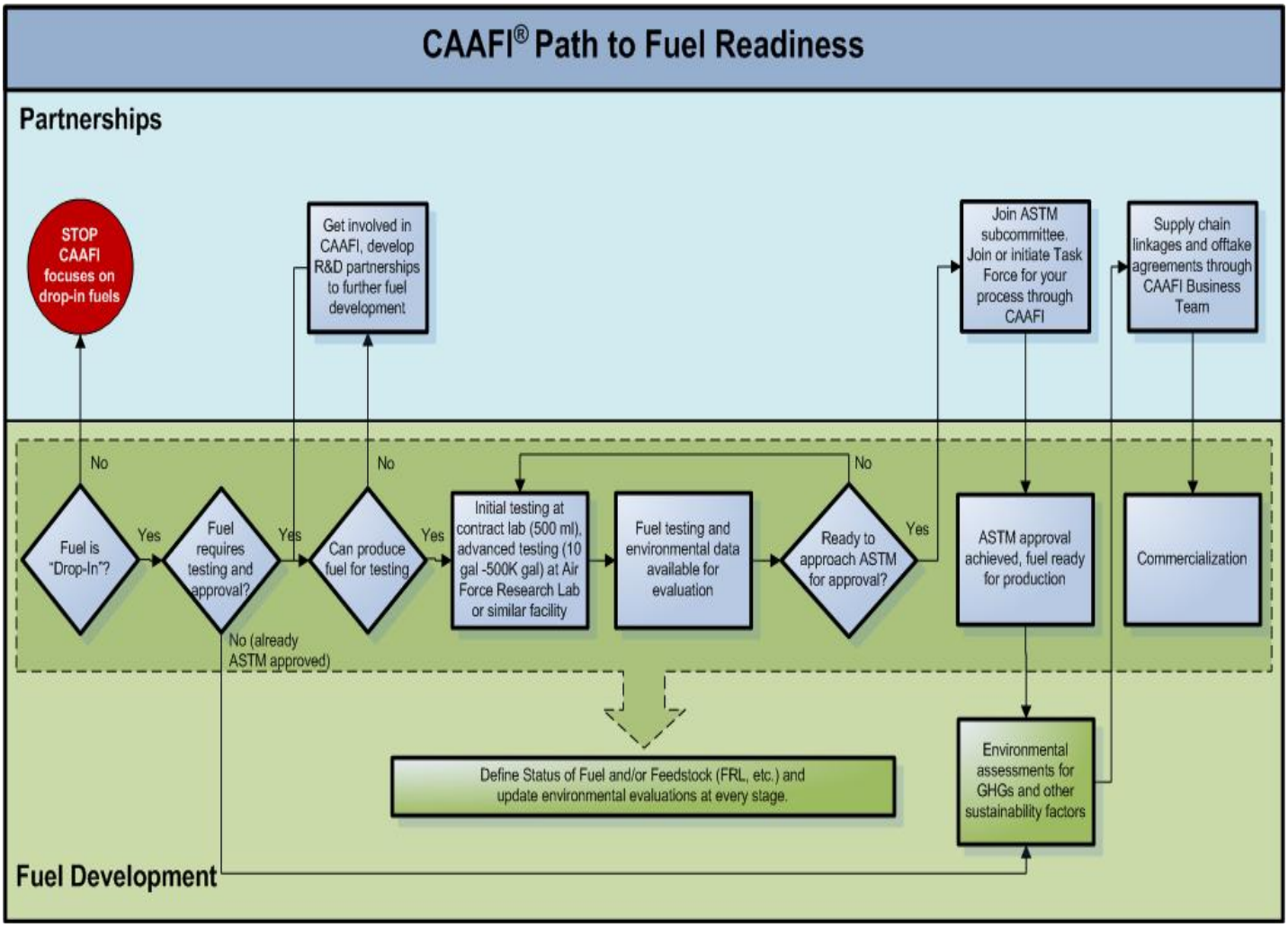
1. Get to know the aviation community

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, approved, and 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

There are several critical areas in which a new fuel producer must demonstrate 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 sold to airlines.

FAA's Aviation Sustainability Center (ASCENT), or Center of Excellence for Alternative Jet Fuels & Environment, funded the establishment of the D4054 Clearinghouse. The Clearinghouse is intended to provide a "one-stop-shop" for management of the testing and data review program for candidate fuels. The University of Dayton Research Institute (UDRI) is the project leader for

this activity. UDRI is initially funded under ASCENT to support Phase 1 (Tier 1 and 2) testing and Phase 1 research report review of candidate SAJFs. 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. For example, National Research Council Canada proposed to support some Tier 3 and 4 testing and the U.S. military is expected to conduct a portion of the testing. Contact info@caafi.org to connect with the D4054 Clearinghouse Team.

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 turbine fuels)
3. UK MoD DEF STAN 91

CAAFI Fuel Readiness Level Exit Criteria Checklist
Testing can be broken into the following general steps:

1. 500 mL (FRL3) - Initial tests – e.g., distillation curve, freeze / flash point, thermal stability
2. 10 gallons (FRL4) – Testing of both neat fuel and blended fuel (50/50 with standard jet)
    a. Reverification of initial tests
    b. Additional tests include chemical characterization (gas chromatography), corrosivity, hydrogen, sulfur and gum content, particulate matter, and others
3. 80 gallons (FRL 6.1) – fit-for-purpose properties including toxicity, materials compatibility
4. 2000-5000 gallons (FRL6.2) – hot section oxidation/erosion
5. 200-2000 gallons (FRL 6.3) – component, rig and emissions testing
6. 6000 – 100000 gallons (FRL 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)

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 bioenergy sustainability resources:

- 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. 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 approved for use

ASTM International Committee D.02, Petroleum and Lubricants, Subcommittee J, is responsible for the evaluation and approval of new aviation fuels. Prospective alternative fuel producers will need to participate in this committee and engage the other committee members in the evaluation and approval process. The approval 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 approved, 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 approval 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 synthetic process pathway to the ASTM Subcommittee. In doing so, they will increase the community's familiarity with the particular pathway, and will start building interest in certification.

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. CAAFI has assisted in the establishment of

various ASTM task groups that either obtained or are currently working toward approval. CAAFI welcomes new ideas for ASTM task groups and can help identify collaborative opportunities for the purposes of ASTM approval. These task groups typically do not require intellectual property (IP) sharing, as the ASTM approval is primarily focused on product characteristics rather than process details. Even companies that are very concerned about revealing IP have successfully worked with task groups.

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

4. Commercialization

Once a fuel has been approved, 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 has a specific Business team that focuses on facilitating signing of offtake agreements for commercial scale fuel production and can also provide linkages between supply chain participants.

Conclusion

This document is intended to serve as a guide through the process of getting an alternative aviation fuel from concept to commercialization through validating the properties and performance of a fuel, building relationships to help move the fuel through the testing and ASTM approval process and, finally, introducing a new and approved fuel to market. Thank you for your interest in the sustainable future of the aviation industry.

This document is constantly evolving. 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.

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