



Path to Alternative Jet Fuel Readiness

December 15, 2011

Welcome Statement

Welcome to the community. You have undertaken the significant task of making jet fuel with a final goal of having your fuel ASTM-approved and accepted for use by the aviation community at large. This guide, developed by the Commercial Aviation Alternative Fuels Initiative (CAAFI)[®], will help you navigate getting your fuel from concept to readiness for validation and use in flight. Below are some suggested steps to facilitate the process of reaching approval and deployment of your fuel. Not all of these steps are required, and we have attempted to differentiate among required steps and optional ones. However, even the optional steps outlined here are intended to facilitate the required steps by building interest in your fuel process.

Initial screening

Before approaching the aviation community with your fuel, there are a number of key initial considerations of which you should be aware.

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 elastomer compatibility (to ensure o-ring seal swell within the fuel system of the airplane), 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 vehicles) and the expense and slow replacement of the aircraft fleet.

Thus, the aviation community is focused on “drop-in” or fungible alternative fuels – these are fuels that have been shown to be functionally identical to petroleum-derived jet fuel. They are pure hydrocarbons (no oxygen, no ethanol, no water) and perform in an identical manner to petroleum-derived jet fuel. There are well-defined criteria for determining if the fuel is functionally identical to petroleum-derived jet fuel (see section below on ASTM specifications).

Other considerations you may want 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 you progress through the qualification process, fuel requirements will increase in increments of 500 mL, 10 gallons, 80 gallons, 4,000, 20,000 and culminating at 225,000 gallons if extensive engine testing is required.
- To sell fuel to airlines, you will need a greenhouse gas (GHG) Life Cycle Analysis (LCA) performed in accordance with recognized guidance that shows reduction in greenhouse gases over standard petroleum (with other aspects of sustainability also being beneficial).

Some useful background information

In this document, we will be referring to some external references you may wish to have on hand.

ASTM Specifications

The most crucial documents to help you understand qualification and production requirements for synthetic jet fuel are ASTM standards. The ASTM Standard Practice for qualification of drop-in aviation fuels is D4054-09, “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 D7566-11, “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 at www.caafi.org/resources/astm.html. As of this writing, Fischer-Tropsch (FT) Synthetic Paraffinic Kerosene (SPK) and hydroprocessed esters and fatty acids (HEFA) have been approved as synthetic blending components for use in jet fuel. New classes of synthetic fuel blending components can be added to the specification by annexation. If you have a new synthetic blending component, getting through ASTM approval will be a critical step on the path to your fuel’s acceptance. This is because aviation regulatory authority approval is automatically granted once a fuel is incorporated into D7566, allowing use in all existing commercial aircraft.

CAAFI Fuel Readiness Level and Feedstock Readiness Level

CAAFI has developed a communication tool called the Fuel Readiness Level, or 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 at www.caafi.org/information/fuelreadinesslevel.html. To assist in linking the FRL to the ASTM process, CAAFI has also developed a set of “exit criteria,” which is essentially a checklist of specific actions to determine the FRL level of your 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 at <http://www.caaafi.org/information/fuelreadinesslevel.html>.

In response to CAAFI members' concerns regarding feedstock availability and viability, CAAFI has also worked closely with the US 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. If you encounter concerns about your ability to produce significant quantities of fuel due to feedstock availability, or if you are a feedstock producer who wishes to clarify the status of development of your feedstock, you can use the FSRL as a self-check guide and as a communication tool to identify accomplishment and remaining barriers to full scale production. The FSRL is available at <http://www.caaafi.org/information/fuelreadinesslevel.html>.

Steps:

1. Getting to know the aviation community

As part of establishing your company as provider of alternative jet fuel, it is beneficial (although not strictly required) to develop relationships and engage the aviation community by letting them know what you are working on and its potential to meet aviation needs. In doing so, you will facilitate 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 your 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 are interested in your fuel, the faster you can enter the market.

One way to become familiar with and to the aviation community is to become involved in a coalition effort such as CAAFI. CAAFI includes stakeholders from all facets of the aviation community. The fastest route to becoming a member of CAAFI is by contacting:

- Richard Altman (Executive Director) - altrich@cox.net
- Nathan Brown (FAA, Head Strategy and Implementation Advisor) - nathan.brown@faa.gov
- Kristin Lewis (RITA, Head Research and Technical Advisor) - kristin.lewis@dot.gov

We will assist you in determining the best fit among the teams of CAAFI for your organization. The teams are: R&D, Certification/Qualification, Business/Deployment, and Environment. Many organizations have representatives on more than one team. If you have not already determined whether your process has been approved as jet fuel by ASTM, we can also assist you with that.

Once you have joined CAAFI and established contact with a team, we can facilitate discussions with the appropriate participants to help evaluate and test your fuel. To do so, it can be helpful to utilize the CAAFI communication tools (FRL, and FSRL), which are designed to help the various teams understand the status of your process or feedstock. In addition to using the CAAFI communication tools, you may wish to estimate a timeframe for reaching the next few levels. You may add your upcoming milestones to CAAFI Roadmap (current version can be

found at www.caafi.org/resources/roadmaps.html. An updated version of this tool is under construction), which will alert other stakeholders to your intended activities and timeframe and generate interest as you draw near to full scale production.

2. Establishing 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. These are fuel performance/fitness for purpose and environmental benefit. Progress in each of these areas can occur in parallel. However, significant failure to perform due diligence and achieve basic progress in any of these areas can entirely halt your fuel's acceptance.

2a. Technical/Performance Evaluation

Several ASTM standards clearly define the stringent requirements for technical performance of aviation fuels. In order to sell your fuel, you must prove your fulfillment of these specifications

If you cannot fund the testing and approval out of your own resources, your first task will be to establish potential funding sources for fuel testing and the approval process. Initial testing is usually performed by the Air Force Research Laboratory (and Southwest Research Institute) with their existing funding through roughly FRL 6.1 (see below). Beyond that point, further testing must be negotiated within the CAAFI community.

Second, you must begin producing fuel in suitable volumes for the current testing stage of your product. The requirements and guidelines for fuel characteristics can be found in the following specifications and documents:

1. ASTM D4054-09 (Qualification of new turbine fuels and additives)
2. ASTM D7566-11 (Synthetic turbine fuels)
3. UK AFC DEF STAN 91-91
4. CAAFI Fuel Readiness Level Exit Criteria Checklist (available at <http://www.caafi.org/information/fuelreadinesslevel.html>)

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 – 500000 gallons (FRL 6.4) – engine and flight tests

The next question is where you will have your fuel tested. The initial tests (item #1) can be done at any accredited analytical laboratory. For the more advanced tests, the Air Force

Research Lab (AFRL) is an excellent resource, with experience testing many alternative aviation fuels. If you would like to find out about getting your fuel tested at AFRL, you may contact Tim Edwards (james.edwards@wpafb.af.mil). The various engine manufacturers (e.g., Pratt & Whitney, GE, Rolls Royce) are able to perform hot section testing (item #4 above). For further information on these options, you can also contact industry representatives by inquiring through CAAFI.

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

2b. Environmental Evaluation

You should be continually looking for ways to improve the environmental performance of your fuel production process and feedstock. Aviation fuel purchasers will be looking for a greenhouse gas emissions (GHG) Life Cycle Analysis (LCA) indicating that your fuel produces lower life cycle GHG emissions than conventional fuel made from petroleum. Your GHG LCA should be performed according to an internationally accepted methodology. Third party, objective, peer-reviewed studies are generally 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) – available at www.caafi.org/information/reports.html
- Stratton et al. 2010. Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels – most recent version available at <http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf>
- GREET-for-Jet (Argonne National Lab model modified for aviation fuel –available at (<http://greet.es.anl.gov/>)

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 the RFS2 can be found at <http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm>. Information on petitioning to add a new fuel (and current petitions) can be found at: <http://www.epa.gov/otaq/fuels/renewablefuels/compliancehelp/rfs2-lca-pathways.htm>

Other sustainability metrics may also become important to the execution of fuel purchasing agreements and more information will be added to this briefing as the requirements evolve. You may wish to familiarize yourself with the following bioenergy sustainability resources:

- The Global BioEnergy Partnership (GBEP) Sustainability Indicators for Bioenergy (agreed to by many governments as guiding sustainability principles) – available at / <http://www.globalbioenergy.org/programmeofwork/sustainability/en/>
- RSB Sustainability Criteria - accepted as European Union Renewable Energy Directive (EU-RED) compliant. (<http://rsb.epfl.ch/>)
- A new ISO standard on Sustainability Criteria for Bioenergy (TC248) is anticipated to be issued in 2013.

- ISO14025 provides some information on self reporting of sustainability measures

Environmental due diligence (performance of appropriate analyses) will soon be able to be measured and communicated using the CAAFI Environmental Progression (in development).

3. Getting your 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 two alternative aviation fuel specification (D7566) annexes (Annex 1 for Fischer-Tropsch fuels, Annex 2 for HEFA fuels) were passed as the result of a collaborative effort among the ASTM members, largely organized by CAAFI, to acquire and evaluate the data and address subcommittee member concerns. The timeline and testing that occurred to achieve those two certifications are described in Appendix A of this document.

The process for getting a fuel approved includes the following steps:

- a. The ASTM Subcommittee establishes a Task Force. This Task Force should be led by a group of companies with similar pathways who want to pursue certification for new synthetic blend components to oversee and guide the qualification process.
- b. Data and research are acquired through fuel, engine, component, and rig testing; these are to be submitted as supporting documentation for the qualification process (see previous section). The process is detailed in ASTM D4054-09 Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives. This result of the research and testing effort is referred to as the “Research Report.” Copies of previous Research Reports for FT SPK and HEFA are available through CAAFI, and are useful for understanding the scope of data needed to support adding a fuel to ASTM D7566.
- c. Initial balloting occurs at the subcommittee level when the Research Report and proposed specification are ready.
- d. ASTM allows a period for comments and review.
- e. Comments are addressed to assuage concerns expressed (additional data generation/research if required). These may be discussed and voted on at the semiannual ASTM meeting.
- f. Final balloting at the committee level occurs when all subcommittee level comments are addressed.
- g. Ballots are considered passed with a unanimous affirmative vote, or when negative votes are withdrawn or overruled by the committee or subcommittee members. Upon passage of the ballot, ASTM adds the new fuel to the D7566 standard as a new annex.

If your fuel has not yet been approved, it is to your benefit to get to know the ASTM process and players. As a first step, we suggest you attend an ASTM meeting and arrange side meetings with active parties and Subcommittee J leadership. Subcommittee J members are generally available to mentor new entrants into the fuel approval process. If you already have data on your fuel, you can request to present properties and fuel data to the ASTM Subcommittee. In doing so, you will increase the community’s familiarity with your technology and fuel production, and will start building interest in certification. But be prepared to attend ASTM Subcommittee J meetings and make a case for the committee to pursue this technology pathway.

To encourage the formation of an ASTM Task Force for your fuel process, it is helpful to find other companies similar to yours with whom you can work to increase visibility and interest for your fuel process. CAAFI has assisted in the establishment of two different ASTM task groups that are currently working toward approval – a group focused on synthesized kerosenes containing aromatics (SKA) and a group focused on alcohol-to-jet pathways (ATJ). Other proposed efforts include pyrolysis and synthetic biology (genetically-engineered organisms converting sugars or photosynthate into hydrocarbons). CAAFI welcomes new ideas for ASTM task groups and can help you identify other companies with whom you may be able to join forces for the purposes of ASTM approval. These task groups typically do not require intellectual property (IP) sharing, as the ASTM approval is 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 while it is possible to pursue fuel approval on your own, the duration of the approval process will be inversely proportional to the resources invested and the size of the collaborating team.

4. Commercialization

Once your fuel has been tested and approved and you are nearly ready to start commercial production, you will want to link up with appropriate players in other parts of the supply chain (for example, feedstock producers, etc.) and, of course, with purchasers (e.g., airlines). A multifaceted stakeholder organization, such as CAAFI, can provide networking venues. CAAFI also has a specific Business and Deployment team that focuses on facilitating signing of offtake agreements for commercial scale fuel production and can also provide linkages between supply chain participants

Conclusion

Congratulations! You have moved one step closer to getting your alternative aviation fuel ready for commercial use by understanding the process to get you there. We hope that this document will help guide you through the process of validating the properties and performance of your fuel, building the relationships to help move your fuel through the testing and ASTM approval process and, finally, introducing your fuel to market. We welcome your contribution to the sustainable future of the aviation industry.

This document is constantly evolving. We welcome your feedback and suggestions, as well as any questions with which we may be able to help you. Please feel free to contact the CAAFI R&D Team Trichairs at info@caafi.org.

The trichairs are:
Mike Epstein, GE
Michael Lakeman, Boeing
Stephen Kramer, Pratt & Whitney



Commercial Aviation Alternative Fuels Initiative®

APPENDIX A

Summary of FT and HEFA Development/Certification Processes

FT Fuels

July 2008 – task force at ASTM formed to develop new synthetic jet fuel specification with FT synthetic blending components included in initial version

2008-2009 – two ballot rounds of draft specifications conducted, input solicited from experts throughout aviation fuel community

Research report containing evaluation data for candidate FT fuels balloted and reviewed

June 2009 – specification balloted and passed through subcommittee

September 2009 – committee level approval obtained

HEFA –

Mid-2008 began testing of HEFA at AFRL (coordination of UOP, USAF, Boeing, FAA)

December 2009 – data from fuel fit-for-purpose, engine and flight testing compiled into ASTM research report by Boeing.

March 2010 – after review and input from OEMS and others, ready for initial ballot May 2010.

May 2010 – Initial balloting brought up comments, some of which were significant enough to require additional data

July 2010 – January 2011 – continued testing of HRJ fuel to resolve comments and associated issues.

May 2011 – specification approved by ASTM subcommittee

July 2011 - committee level approval obtained