New Sustainable Aviation Fuels (SAF) technology pathways under development

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Introduction

Since 2009, the aviation industry has qualified the use of seven pathways to produce synthesised (non-petroleum) jet fuel blending components. Details of these can be found in the body and annexes of specification ASTM[2] D7566, as well as in qualitative summaries by various industry practitioners (e.g. CAAFI). The industry has also qualified the co-processing of jet fuel in existing refineries via the use of two pathways defined in ASTM D1655, Annex A1. When these synthesised fuels are produced from wastes or renewable resources in accordance with sustainability criteria such as those required for CORSIA Eligible Fuels[3], they are considered SAF. Over the next several years, based on ongoing evaluation and testing, the industry is expected to consider qualification from many additional pathways. The industry currently envisions that these new pathways also will be added to the two specifications above, using the guidelines of ASTM D4054.

Although sufficient fuel was produced for all seven approved pathways to enable initial pathway approvals, at present, SAF for regular civil aviation use has only been produced via two of the seven specifications, and by fewer than 10 refineries/biorefineries worldwide. This mismatch between the pursuit of SAF pathway qualification and actual SAF production can be driven by changing priorities of the technology developer or producer since qualification, additional technical discovery or changing market conditions that lessen interest in the pathway, and/or a reflection of the difficulty (e.g., cost, effort, permitting, financing, acquiring offtake) of bringing such a production plant online to produce "economically viable" SAF.

Additional qualifications are typically being pursued to address these challenges through:

- Lowering the cost of production by introducing processes that have lower capital and operating expenses:
  - Utilising lower temperatures, lower pressures, lesser-cost materials;
  - Advancements in catalyst designs and separation technologies;
  - More selective conversion or retention of feedstock hydrocarbon structures.
- Utilising lower cost feedstocks, especially waste streams or those available on a continuous basis (24x7) to support continuous production, and avoid significant feedstock storage and handling:
  - Municipal solid waste, wet wastes, manures, food processing wastes, sanitary water treatment process waste, and similar feedstocks.
- Enabling the widest range of agricultural and silviculture feedstocks, targeting availability around the world.
- Addressing promising feedstocks that do not yet have effective conversion processes.
- Potentially producing a wider range of hydrocarbons that fully emulate petroleum-based jet fuel to lower or eliminate blending requirements (i.e. 100% SAF).

1 The Commercial Aviation Alternative Fuels Initiative, https://www.caafi.org/default.aspx
2 ASTM International – see Overview - https://www.astm.org/about/overview.html
3 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

- Improving throughput, easing handling constraints, reducing feedstock pre-processing.
- Enabling higher total carbon utilisation, as well as lowering total carbon intensity of the process.
- Being more resistant to feedstock contamination or more accommodating to feedstock non-homogeneity/ uniformity.
- Utilising refinery co-processing in order to leverage existing capital, as well as to enable blending and SAF delivery using existing infrastructure and at lower total cost.

Pathway development currently in-process

As of this writing (March 2022), several active ASTM Industry Task Forces are working toward the qualification (testing, evaluation, and industry approval) of new or derivative pathway specifications. These include:

- Five new active pathways targeted for ASTM D7566 (two additional pathway evaluations are currently on hiatus):
  - Virent SAK[4] – use of aqueous phase reforming of sugars and catalytic processing;
  - Shell IH2[5] – Integrated hydropyrolysis and hydroconversion of lignocellulosic materials;
  - Global Bioenergies[6] – Alcohol-to-Jet (ATJ) derivative utilising biochemical production of isobutene;
  - Swedish Biofuel[7] – ATJ derivative starting with the mixed alcohols;
  - Indian CSIR-IIP[8] – Catalytic processing of lipids for more fully formulated SAF; and,
- Three co-processing Task Forces targeted for ASTM D1655 Annex A1 expansion:
  - The potential relaxation (increase) of the current 5% volume restrictions for existing co-processing definitions.
  - The evaluation of coprocessing of pyrolysis oil from recycled used tires.
  - The evaluation of coprocessing of hydroprocessed biomass and out-of-spec jet fuel batches containing SAF.

Beyond currently active pathway development

The aviation community recognises that researchers and practitioners are continuously developing and refining ways to create SAF and to produce it at lower cost and from a continuously broadening set of technologies and feedstocks. This is especially true given the consolidated messaging coming from industry and governments indicating that they will be focused on development and use of SAF as the primary means of aviation decarbonisation for the next several decades. As such, early interactions suggest emerging work is likely in the following areas (not all of which will necessarily require new pathways, but in some cases perhaps expansion of current pathway definitions):

- Coprocessing with a widening range of biocrudes leveraging hub-and-spoke feedstock energy supply chains with distributed, early energy-densification processes.
- Technologies targeting use of currently recalcitrant waste streams and circular-economy byproducts.
- Concepts around hybrid (bio- and thermo-chemical processes) or multi-technology conversions.
- Production of hydrocarbon fuels using renewable sources of gaseous hydrogen and carbon (which may or may not require new pathway definitions).

CAAFI expects to see quite a few more approaches from companies currently pursing pyrolysis, hydrothermal liquefaction, and other hybrid biochemical and thermochemical concepts. Several additional exploratory approaches that are likely to result in near-term Task Force efforts include:

- REVO[9] – Hydroprocessed Esters and Fatty Acids (HEFA) derivative that produces cycloalkane content.

4 https://www.virent.com/products/jet-fuel/
5 https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/benefits-of-biofuels/ih2-technology.html
6 https://www.global-bioenergies.com/group/isobutene-vert/?lang=en
7 http://www.swedishbiofuels.se/
8 https://www.csir.res.in/readbook?bid=MTQ3ODcx&submit=view
9 https://www.e-revo.jp/english/

- OMV Re-Oil[10] – Pyrolysis of non-recyclable plastics.
- Green Lizard – Hybrid pyrolysis of mixed cellulosics.
- Forge LTH[11] – Pyrolysis of lipids.
- Enerkem[12] – Catalytic Hydroprocessing of lignocellulose fractionated to oligomers.
- Vertimass[13] – ATJ derivative using consolidated catalytic conversion of ethanol.
- Alder Fuels[14] – Upgrading of fractionation streams of fast pyrolysis of lignocellulose.

As inspection technologies continue to improve in capability, and we continue to learn more about the functionality and combustion of different hydrocarbon chemical species in aviation systems, we may see ourselves working in the direction of a compositional-based specification for jet fuel, providing much greater flexibility to the evaluation of future SAF pathways.

Background Definitions

Following are some definitions to help bridge the gap between the work being done in the technical community and terminology that is being used colloquially to discuss SAF and future pathway qualification efforts:

ASTM D1655: This is the conventional jet fuel specification that defines requirements for Jet A and Jet A-1 produced from petroleum. It has been used globally by the aviation industry since 1959 to ensure a safe and consistent jet fuel is available for all aircraft.

ASTM D4054: This ASTM standard practice defines the scope of fuel property, rig, and engine testing to be considered when evaluating a new synthetic jet fuel. It also describes the overall evaluation process and the prominent role of the engine and aircraft manufacturers to ensure the exemplary safety record of jet fuel is maintained with these new fuels.

ASTM D7566 Pathway: Per ASTM D4054, a pathway includes the definition of a synthetic jet fuel blending component as defined by: its allowable feedstock(s); the conversion process and its attributes; and the final characteristics of the neat component. These are all detailed in both the body of D7655 and its Annexes. The pathway will also specify blending requirements. The blending component is not truly a viable jet fuel until after it is blended with petroleum-based jet fuel, and final specification tests are completed. At that point, the blended mixture is reclassified as ASTM D1655 jet fuel and becomes fully fungible with all other D1655 jet fuel. If certain sustainability requirements are met (as defined by different policy mechanism, e.g., CORSIA), then the fuel can be referred to as SAF. It is important that buyers understand the sustainability attributes of both the blending component as well as the final blended product, because aspects such as the carbon intensity of the blending component and blend percentage matter. Some people refer to the neat blending component as SAF (or neat SAF) too, but until the blending and final specification testing are done, it cannot be used as jet fuel.

ASTM Task Force: A voluntary group of interested parties who agree to work together on the development and approval of an ASTM committee proposal. Task Forces are formed and operate at the discretion of the committees; new Task Forces are formed by committee motions and consensus voting. New Pathway Task Forces are typically led by the entity who has developed the synthetic conversion technology, and/or an entity who wants to commercialise such technology.

Synthetic jet fuel blending component: The portion of synthetic jet fuel produced from non-petroleum sources. D7566 also defines the neat blending component itself, allowing it to be sold/purchased separately if desired, but it must be blended and certified as meeting all applicable D7566 criteria prior to use as a jet fuel.

Specification: Once a pathway is qualified by the industry, it is adopted as a specification (e.g. HEFA-SPK as defined by ASTM D7566 Annex A2). Any entity can subsequently produce synthetic jet fuel under the definitions in the

10 https://www.omv.com/en/blog/reoil-getting-crude-oil-back-out-of-plastic
11 http://www.forgehc.com/home.html
12 https://enerkem.com/company/
13 https://www.vertimass.com/vertimass-technologies/
14 https://www.alderfuels.com/

pathway, and subsequently certify that such fuel meets the specification, to allow commerce to take place between the producer and the buyer.

Certification: The process by which a producer or downstream handler of the fuel validates that the fuel being transacted meets the requirements of the specification under which the fuel is being purchased. Neither the industry nor the FAA "certifies" new pathways.

Qualification: The process by which the industry and government members of ASTM evaluate and issue a specification definition, i.e., an ASTM D7566 annex, for a new conversion pathway. This is what happens in the ASTM deliberation processes, summarised as follows.

It is important to note that ASTM International, as an entity, does not own or drive the process of developing or qualifying new SAF technologies, rather they create the framework, process, and repository under which individual industries create test methods, specifications, classifications, guides, and practices for their own needs. In the case of synthetic jet fuels, the work is accomplished by Committee D02 (Petroleum Products, Liquid Fuels, and Lubricants), and Subcommittees J0 (Aviation Fuels) and J0.06 (Synthetic Aviation Turbine Fuels). These groups are comprised of hundreds of volunteer aviation and petroleum experts, as well as many related industry practitioners (e.g., laboratories, testing devices, academia). Their role is to ensure that appropriate testing and evaluation has occurred to ensure that fuel components produced and blended to the specification detail are sufficiently controlled to perform in a consistently acceptable manner as drop-in fuels. Such work gets accomplished via the use of Task Forces, but the results of such work are reported and balloted for approval by the full subcommittee and committee. Any negative ballots are adjudicated before the specification change is adopted, resulting in more work being done to address technically persuasive concerns, or to dismiss technically non-persuasive objections.

Not all fuel qualification efforts are performed solely by ASTM committee or Task Force activities but are also augmented by related work that occurs within the petroleum and aviation industries, or related working groups (e.g., CRC Aviation Committee[15], UK MOD Aviation Fuels Committee). In the U.S., the Federal Aviation Administration has funded multiple programs where supporting work is performed (e.g., CLEEN, ASCENT, and CAAFI).[16]

These committees and ASTM welcome and encourage participation of interested and informed parties from around the world. The aviation industry itself then encourages the adoption and harmonisation of ASTM specification changes with other specification bodies (e.g., DEF-STAN/MIL-DTL, and various countries with their own specification systems) in order to have a unified, world-wide approach.

Engagement with the evaluation of additional pathways

Entities interested in the evaluation or potential development of additional SAF pathways can contact the following for more information, or consider directly joining the overall efforts on SAF as a member of ASTM D02.J0:

- CAAFI and CAAFI Pre-screening activities
- Mark Rumizen (mark.rumizen@faa.gov)– Chair of ASTM D02.J0.06
- Steve Zabarnick (Steven.Zabarnick@udri.udayton.edu) – Manager of the FAA Clearinghouse efforts at UDRI
- Anna Oldani (Anna.L.Oldani@faa.gov) – FAA office of Energy and Environment, providing oversight of Clearinghouse efforts
- ASTM Committee D02, Petroleum Products, Liquid Fuels and Lubricants[17]

In closing, note that several additional governments are focusing on support for enabling higher throughput of efforts leading to more qualifications, through elements like R&D and new Clearinghouse efforts (EU and UK), and all such efforts are welcome.

15 https://crcao.org/events/
16 CLEEN – Continuous Lower Energy, Emissions, and Noise, https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen#:~:text=The%20Continuous%20Lower%20Energy%2C%20Emissions%20and%20Noise%20%28CLEEN%29,the%20FAA%20is%20a%20cost-sharing%20partner%20with%20industry; ASCENT – the Aviation Sustainability Center, one of FAA's Centers of Excellence, https://ascent.aero/ ; CAAFI – the Commercial Aviation Alternative Fuels Initiative
17 https://www.astm.org/get-involved/membership.html