100% SAF
- Highlighting and Exploring Open Questions

CAAFI R&D Team

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www.caafi.org
Outline

Qualification/certification

Jet Fuel 101

Why 100% SAF

SAF & SAF Blends

Drop-in vs non-Drop-in SAF

OEM Experience

Standardization

Considerations for 100% SAF
Fuel is an engine operating limitation...

Regulatory authorities certify A/Cs & engines to operate using specified fuels
If a synthetic fuel (e.g., SAF) is a “drop-in” fuel, no equipment certification is required as the final fuel is Jet A/Jet A-1
Drop-in fuel evaluations is to find the candidate fuel “equivalent” to Jet A/A-1
If a fuel is not “equivalent” to Jet A/A-1, it is another fuel; the equipment could be certified to it
Jet A/A-1
Mixture of hydrocarbons in kerosene range

C_{12.2}H_{23.4} (Jet A)
H/C=1.92 (mole)

H/C classes: normal-, iso-, cyclo-paraffins & aromatics, olefins & heteroatoms (S, N)

- ~20%
- ~30%
- ~30%
- ~20%
- <1%
Why 100% SAF?

Many in the aviation industry, from manufacturers to airlines, have announced “zero-emission” goals and plans. A reduced carbon (down to zero and even to negative) fuel is central to the discussion.

Current major needs regarding SAF:
• ramp-up SAF production (availability)
• establish SAF price parity with conventional jet (cost)
• level playing field with ground transportation for aviation (regulatory framework)

100% SAF is not an immediate need, however, this is the time to start the process to get ready for it
• technological & operational readiness
• standardization
SAF & SAF blend

**What many think:**

Synthetic Jet A/A-1 + Conventional Blend Component = SAF Blend

(Petroleum Jet A/A-1)  (Jet A/A-1)

**What really is the case:**

Synthetic Blend Component* + Conventional Blend Component = SAF Blend

(SAF*)  (Petroleum Jet A/A-1)  (Jet A/A-1)

Multiple ways to produce the synthetic blend component today;
some identical-to-jet, some like-jet, some nothing like jet…

* Not all synthetic blend components are sustainable. For the purposes of this presentation the term SAF will be used.

Synthetic blend component, by itself, is not necessarily a finished aviation fuel that could be used in aircraft.
SAF blends are all the same product...

FT-SPK synth. blend comp’t (sbc) + Jet A/A-1 conv. blend comp’t (cbc) – (50% blend limit)

<table>
<thead>
<tr>
<th>Blend</th>
<th>cbc</th>
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<th>cbc</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEFA-SPK sbc           + cbc</td>
<td>(50%)</td>
<td>HFS-SIP sbc + cbc</td>
<td>(10%)</td>
<td>FT-SKA sbc + cbc</td>
<td>(50%)</td>
<td>ATJ-SPK sbc + cbc</td>
<td>(50%)</td>
<td>CHJ sbc + cbc</td>
<td>(50%)</td>
<td>HC-HEFA-SPK sbc + cbc</td>
<td>(10%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Partially synthetic Jet A/A-1 (drop-in, fleet-wide & infrastructure compatible)

When blended they all result in the one and the same product: Jet A/A-1
Unblended SAF (neat, 100%)...is it❓

FT-SPK sbc
HEFA-SPK sbc
HFS-SIP sbc
FT-SKA sbc
ATJ-SPK sbc
CHJ sbc
HC-HEFA-SPK sbc

100%

Identical to Jet A/A-1 (fleetwide compatible, drop-in)
Like Jet A/A-1 (limited fleet compatible, non-drop-in)
Not-like Jet A/A-1 (not acceptable as a stand-alone jet fuel)

(appends on the producer)

Variation of composition among pathways and even among producers for a pathway
When unblended they do not all result in one and the same product
A specification is needed to define 100% SAF (in progress; early stages)

- aromatics: ~17% ~0%
- energy cont.: ~43.2MJ/kg + 0-3%
- density: ~800kg/m³ - 0-8%
- Cetane #: ~45 ± 20-30%
- Sulfur: ~0ppm (synth.) 500-800ppm (conv.) ~0ppm
Pathways coming

- **ATJ-SKA sbc**  
  - 100%  
  - Identical to Jet A/A-1 (fleetwide compatible, drop-in)

- **HEFA-SKA sbc**  
  - Like Jet A/A-1 (limited fleet compatible, non-drop-in)

- **HDO-SAK sbc**  
  - Not-like Jet A/A-1 (not acceptable as a stand-alone jet fuel)

- **CPK-0 sbc**  
  - Blending of approved blend components will open a door to get to drop-in 100% SAF by blending non-drop-in blend components
  - or (TBD)

- **HTL sbc**

- **SPK sbc + SAK sbc**

More pathways on the way…initially most, if not all, will be approved at 50% but could meet 100% drop-in SAF requirements when defined.

Blending of approved blending components is an important path.
## Drop-in vs non-drop-in SAF

<table>
<thead>
<tr>
<th>Composition:</th>
<th>Fully formulated Jet A/A-1</th>
<th>Subset of Jet A/A-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability:</td>
<td>Fleet Wide drop-in</td>
<td>Designated aircraft/engines only</td>
</tr>
<tr>
<td>Specification:</td>
<td>ASTM D7566</td>
<td>New standard needed</td>
</tr>
<tr>
<td>Regulatory Certification:</td>
<td>Not required</td>
<td>Required for each intended aircraft/engine model</td>
</tr>
<tr>
<td>Infrastructure:</td>
<td>No impact</td>
<td>Separate supply chain/handling/storage required</td>
</tr>
</tbody>
</table>

*or* +  

100% A + B

[Image: CAAFI logo]
Examples of OEM experience with 100% SAF

Swedish MoD Gripen flight with GKN RM12 engine (GE F404 derivative) – 100% CHJ.

Boeing 777 EcoDemonstrator flight with GE90 engines. On-wing engine tests – 100% HEFA-SPK.

Multiple engine tests with Rolls-Royce Trent & Pearl engines – 100% HEFA-SPK.

NRC Canada Falcon 20 flights with GE CF700 engines – 100% CHJ & HEFA-SPK/HDO-SAK blend.

Multiple ground/on-wing GE F414 engine tests – 100% CHJ.

Bell Ranger helicopters frequent flights with Pratt & Whitney engines – 100% FT-SPK.

Boeing EA-18G Growler flight (Secretary of NAVY) with GE F414 engines – 100% CHJ.

Airbus A350 Flightlab flights with Rolls-Royce Trent engines – 100% HEFA-SPK.

Combustor rig tests by OEMs – 100% HEFA-SPK, ATJ-SPK, ATJ-SKA, others…

Additional flights/tests among OEMs/airlines in work – 100% drop-in & non-drop-in SAF
ASTM Standardization
Specify 100% synthetic* fuel standardization

ASTM Task Force formed in Q1 ’21, Chair: G. Andac (GE), Vice-Chair: M. Rumizen (FAA)

“Standardization of Jet Fuel Fully Comprised of Synthesized Hydrocarbons”:

• Modify ASTM D7566 drop-in standard to allow 100% SAF
  − Establish a new set of requirements for 100% SAF (e.g., modify Table 1)
  − 1st step: approval of fully formulated SAF (likely CHJ)
  − Blending of approved synthetic blend components
  − Effort is approval of 100% SAF as Jet A/A-1

A separate ASTM Task Force is expected to be formed for SPK standardization

• ASTM Dxxxx for 100% non-drop-in SAF (likely SPK)
  − Effort is for establishing a standard defining SPK
  − Not approval of 100% SPK, but development a standard that could be used by OEMs to certify their equipment with

Multi-year efforts

*Standard is for synthetic fuels, sustainable or not. In this slide the term SAF is used synonymously with synthetic fuel
Can you expand Jet A/A-1 definition to accommodate (🍎) fuel?

Highly unlikely! The regulatory agencies allowed the concept of “drop-in” fuel on the premise that the synthetic fuel has properties identical to Jet A/A-1.

Any meaningful change to the definition of Jet A/A-1 has implications for the certification of entire fleet (past, present, future).

Of course, a non-drop-in fuel (e.g., SPK) could be separately defined in a new non-drop-in standard as “another” fuel, and equipment could be certified to it if desired.

Changing the definition of Jet A/A-1 has certification implication for all fleet (and infrastructure)
Implications of 100% SPK (🍎) type SAF

Pros:
- Maximally beneficial from particulates and contrails perspective (devoid of aromatics)
- Maximally beneficial from fuel burn perspective (highest heat content)

Cons:
- Not compatible with good portion of the fleet
- Segregated infrastructure needed
- New standard needed
- Wrong fuel could go to wrong aircraft – Safety concern?

Example considerations for new fuels:
- Cold Viscosity system performance and solidification
- Vapor pressure characteristics and impact on the performance of various pumps
- Bearing and gear cavitation potential
- Low lubricity performance
- Seal compatibility
- Thermal stability and tendency to varnish
- Effects on heat transfer performance
- De-congealing performance
- Buildups and deposits
- Dynamic shaft seals performance
- Icing characteristics
- Entrained air and bulk modulus
- Entrained water
- Biocide compatibility
- Filter life and pressure drop
- Matched valve compatibility
- Dynamics and stability
- Resistance to ignition, flammability

While environmental benefit of SPK is considered, the impact to safety should also be considered as well!
Regardless, getting ready for such possibility
Some other options that are being explored

- Remain “drop-in” with reduce aromatics compared to nominal
- 8% aromatics (current spec minimum for synthetic fuels) vs 16-18% of nominal conventional jet fuel; maybe even lower % if real limit is determined
- Limit/eliminate certain type aromatics (e.g., no/little naphthalenes)
- Promote novel options which is non-aromatic but still could be drop-in at 100% (there already is an example in evaluation)
- Promote catalyst improvements that would lead to paraffins and aromatics in already approved pathways such as HEFA and FT (HEFA-SKA is already on the way…)
- …

Substantial environmental/fuel burn benefits could still be achieved without compromising safety, needing new infrastructure & standard
Next...

Recap questions

Frontier paper reminder

Discussion
Thank You!