100% SAF

- Background, status, considerations

Gurhan Andac, Ph.D., GE Aviation
Stephen Kramer, Ph.D., P&W

CAAFI®

Biennial General Meeting 2022

June 3, 2022

www.caafi.org

Terminology disclaimer

Not all synthetic fuels (SATF) are sustainable (or SAF)

Industry fuel standard ASTM D7566 and some other relevant documents are for synthetic fuels, sustainable or not

For the purposes of this presentation, we will use the term “SAF”

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

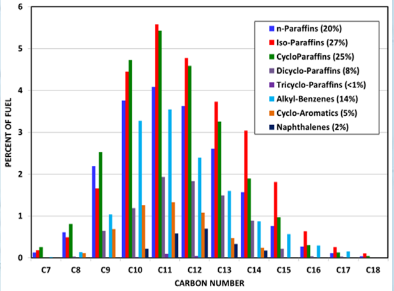
- technological & operational readiness
- standardization

Good, although not immediately pressing, reasons to proceed with the work on 100% SAF now!

CAAFI®

What is SAF & SAF blend?

Jet A/A-1: ~80-85% paraffins
+ 15-20% aromatics



Hydrocarbon distribution
(Gas Chromatography)

What many seem to think:

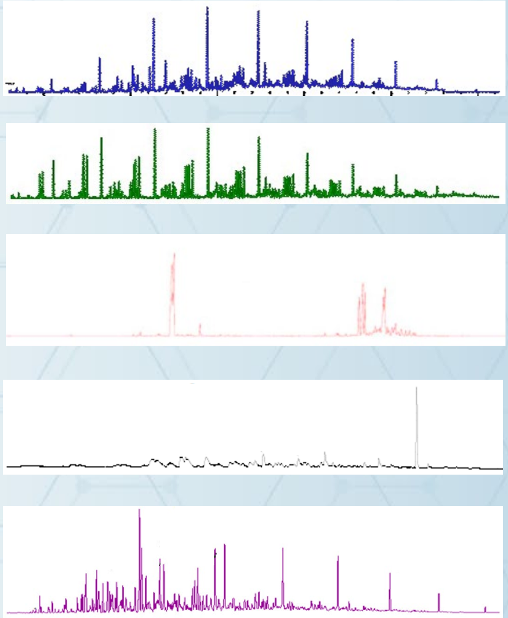
~~Synthetic Jet A/A-1~~ + Conventional Blend Component = SAF Blend

(SAF*) (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)



1st one is petro-jet fuel, all others are SAF!!!

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

* There is confusion on SAF terminology in industry – is SAF the synthetic blend component or the final finished fuel (the blend)???

Synthetic blend component, *by itself*, is not necessarily a finished aviation fuel that could be used in aircraft

CAAFI®

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)

HEFA-SPK sbc	+ cbc	(50%)
HFS-SIP sbc	+ cbc	(10%)
FT-SKA sbc	+ cbc	(50%)
ATJ-SPK sbc	+ cbc	(50%)
CHJ sbc	+ cbc	(50%)
HC-HEFA-SPK sbc	+ cbc	(10%)

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

When blended they all result in the one and the same product: Jet A/A-1

CAAFI®

Unblended SAF (neat, 100%)…is it 🍎?

	100%
FT-SPK sbc	→ 🍏
HEFA-SPK sbc	→ 🍏
HFS-SIP sbc	→ 🍌
FT-SKA sbc	→ 🍎
ATJ-SPK sbc	→ 🍏 🍌 (depends on the producer)
CHJ sbc	→ 🍎
HC-HEFA-SPK sbc	→ 🍏

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

	🍎	🍏
aromatics	~17%	~0%
energy cont.	~43.2MJ/kg	+ 0-2%
density	~800kg/m³	- 0-8%
Cetane #	~45	± 20-30%
Sulfur	~0ppm (synth.) 500-800ppm (conv.)	~0ppm

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
Standardization is needed to define 100% SAF (in progress)

CAAFI®

Pathways in the pipeline

100%

- ATJ-SKA sbc →
- HEFA-SKA sbc →
- HDO-SAK sbc →
- CPK-0 sbc → or (TBD)
- HTL sbc →
- HFP-HEFA-SPK →
- SPK sbc + SAK sbc →

Identical to Jet A/A-1 (fleetwide compatible, drop-in)

Close to Jet A/A-1 (limited fleet compatible, non-drop-in)

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

Blending of approved blend components will open a door to get to drop-in 100% SAF by blending non-drop-in blend components

More pathways are in the horizon that has 100% drop-in SAF potential
Blending of approved blending components is an important path to 100% SAF

CAAFI®

Summary for reference

Process Pathway	Qualified Today	Blend Limit (%)	Future 100% Drop-In
FT-SPK, Fischer-Tropsch Synthetic Paraffinic Kerosene	√	50 🍎	NO 🍏
HEFA-SPK, Hydrogrocessed (Fatty) Esters and Fatty Acids Synthetic Paraffinic Kerosene	√	50 🍎	NO 🍏
HFS-SIP, Hydroprocessed Fermented Sugars Synthesized iso-Paraffins	√	10 🍎	NO 🍌
FT-SKA, Fisher-Tropsch Synthetic Kerosene with Aromatics	√	50 🍎	YES 🍎
ATJ-SPK, Alcohol-to-Jet Synthetic Paraffinic Kerosene	√	50 🍎	NO 🍏 and 🍌
CHJ, Catalytic Hydrothermolysis Jet	√	50 🍎	YES 🍎
HHC-SPK, Hydroprocessed Hydrocarbon Synthetic Paraffinic Kerosene	√	10 🍎	NO 🍏
ATJ-SKA, Alcohol-to-Jet Synthetic Kerosene with Aromatics	X	50 🍎	YES 🍎
HEFA-SKA, Hydroprocessed (Fatty) Esters and Fatty Acids Synthetic Kerosene with Aromatics	X	50 🍎	YES 🍎
HDO-SAK, Hydrodeoxygenated Aromatic Kerosene	X	25 🍎	NO 🍌
CPK-0, Cycloparaffinic Kerosene	X	50 🍎	TBD 🍎 or 🍏
HTL, Hydrothermal Liquefaction	X	50 🍎	YES 🍎
HFP-HEFA-SPK, High Freeze Point Hydroprocessed (Fatty) Esters and Fatty Acids Synthetic Paraffinic Kerosene	X	15-30 (TBD) 🍎	NO 🍌

Current pathways can yield product at 100% which is:

🍎 Identical to Jet A/A-1 – fleet-wide & infrastructure-wide compatible

🍏 Close to Jet A/A-1 but not identical – not fleet-wide & infrastructure-wide compatible

🍌 Nothing like Jet A/A-1 – not viable jet fuel

Another path to 100% drop-in SAF:

Blending of blend components (🍏 + 🍌 = 🍎)

CAAFI®

🍎 Drop-in 100% SAF: will need specification ASTM D7566 updated - short/medium term

🍏 Non-Drop-in 100% SAF: will need new specification, and separate infrastructure - medium/long term (if pursued)

vs - ASTM Task Forces

Drop-in: not just compatible with particular engine and/or aircraft, but fleet-wide and infrastructure-wide compatible

	100% or A + B	
Composition:	Fully formulated Jet A/A-1	**Subset** of Jet A/A-1
Applicability:	Fleet Wide drop-in	**Designated** aircraft/engines only
Example pathways:	CHJ (D7566 Annex A6), FT-SKA (D7566 Annex A4), future: ATJ-SKA, HEFA-SKA, blending of blend components	FT-SPK (D7566 Annex A1) HEFA-SPK (D7566 Annex A2) ATJ-SPK (D7566 Annex A5) *certain types*
Specification:	ASTM D7566	**New standard** needed
Substantiation/Certification:	Not required	**Required** for each intended aircraft/engine model
Infrastructure:	No impact	**Separate** supply chain/handling/storage required

ASTM Task Force est. Apr ’21
G. Andac (GE), Vice-Chair: M. Rumizen (FAA)
Approval of use of conforming 100% synthetic fuel as Jet A/A-1

ASTM Task Force recently formed
Establishing specification of 100% SPK
NOT approval of use as Jet A/A-1 or as a new fuel; only to be used for substantiation and certification

CAAFI®

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.

Rolls-Royce Trent 1000 engine flight – 100% HEFA-SPK.

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

Boeing 737 MAX ground & flight tests with Leap-1B engine – 100% HEFA-SPK.

Pratt & Whitney PW1100G Advantage engine test – 100% HEFA-SPK.

Boeing 737 MAX flights with Leap-1A engine – 100% HEFA-SPK/HDO-SAK blend.

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

CAAFI®

Drop-in/non-drop-in 100% SAF activities; more in progress…

Implications of 100% non-drop-in SPK ( ) SAF

Pros:

- Benefits from particulates and contrails perspective (devoid of aromatics)
- Benefits from fuel burn perspective (higher heat content)
- Availability (it could change)

Cons:

- Not Jet A/A-1
- Not compatible with a portion of the fleet
- Segregated infrastructure will be 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

At some point this question needs to be asked and answered:
Are the incremental benefits realized by going from *improved drop-in* (next slide) to non-drop-in merited given the cons (i.e., do pros outweigh cons)?

CAAFI®

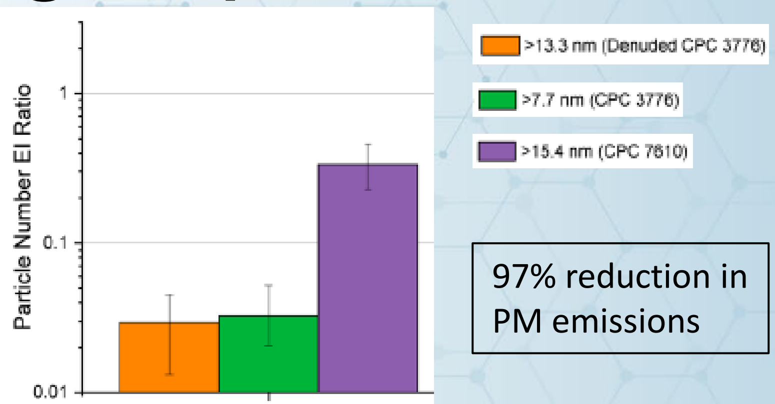
Other options that could be/are being explored

– Remain "drop-in" but with improved qualities compared to nominal drop-in jet fuel
  - ~8% aromatics (current spec minimum for synthetic fuels) vs ~17% of nominal conventional jet fuel; maybe even lower % if real limit is determined
  - Eliminate/limit certain type aromatics (e.g., no/little naphthalenes)

– Promote novel options which is non-aromatic but still could potentially be drop-in at 100% (one already under evaluation)

– Promote catalyst improvements that would lead to paraffins and aromatics in already approved pathways such as HEFA, FT, ATJ (ATJ-SKA, HEFA-SKA is already on the way…)

– …



92% SPK+8% naphthalene-free aromatics

97% reduction in PM emissions

Credits: NRC, LanzaJet, PNNL, Univ. of Alberta

>80% reduction in contrails

***Substantial* environmental/fuel burn benefits could still be achieved w/o compromising safety, w/o needing new infrastructure & standard**

Energy Fuels 2020, 34, 7218–7222: "Comparison of Particle Number Emissions from In-Flight Aircraft Fueled with Jet A-1, JP-5 and an Alcohol-to-Jet Fuel Blend"

CAAFI®

Thank You!

CAAFI®