Sustainable Aviation Fuel (SAF) Update

IRFA

2022 Iowa Renewable Fuels Summit

Emerging Markets Roundtable

First flight from continuous commercial production of SAF:
UAL 0708, 10 March 2016, LAX-SFO

Fuel from World Energy - Paramount
(HEFA-SPK 30/70 Blend)

Steve Csonka
Executive Director, CAAFI

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25Jan'22

Overall industry summary on SAF:

SAF are key for meeting industry's commitments on carbon reductions

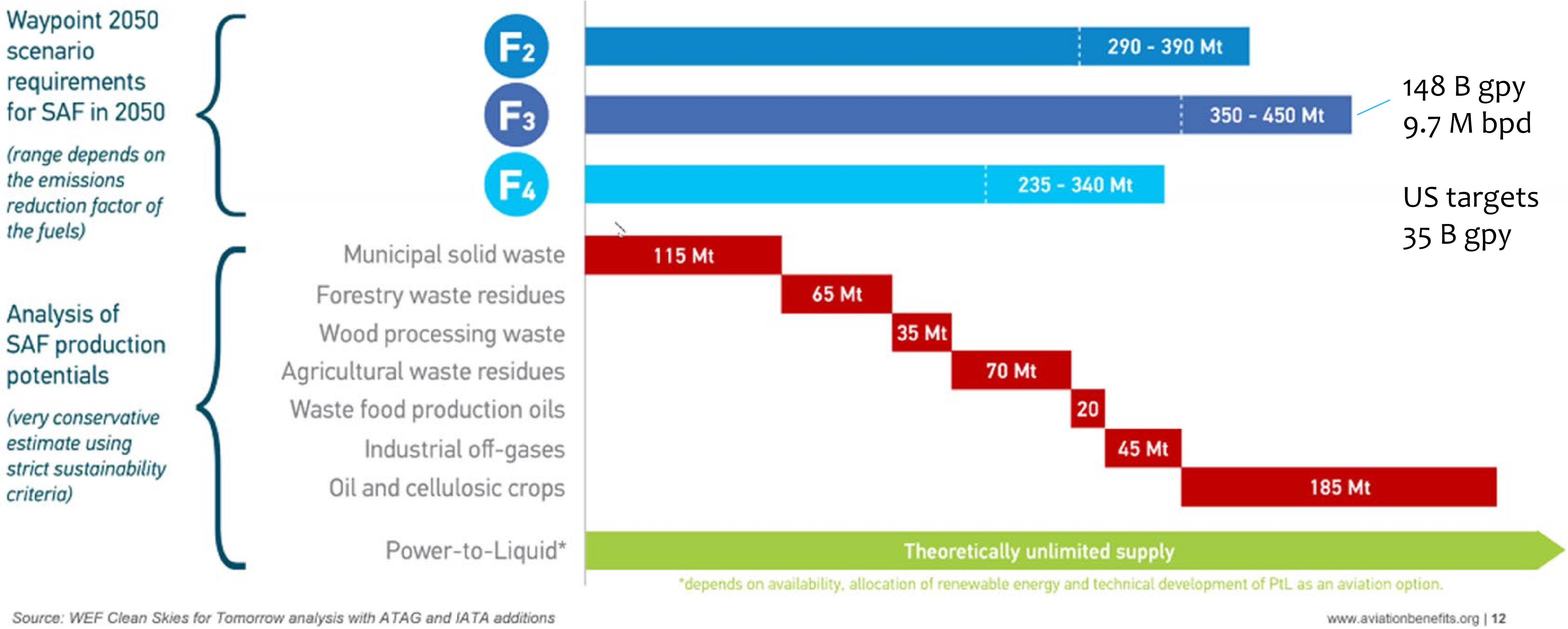
- Aviation enterprise aligned, representing a 26B gpy US & 97B gpy worldwide opt'y today
- Jet fuel demand expected to increase for foreseeable future … 3 - 5% per year (following COVID rebound)
- SAF delivers net GHG reductions of 65-100+%, other enviro services
- Segment knows how to make it; Activities from FRL 1 to 9, with many in "pipeline"
- Industry and Governments are working to foster, catalyze, enable, facilitate, …
  - Removing barriers: Pathways identified for fully synthetic SAF (50% max blend today), enhancing SAF value proposition by enabling deeper net-carbon reductions
- First 6 facilities on-line worldwide (5 from lipids), increasing run-rates, multiple offtakers
- Commercial agreements being pursued, fostered by policy and other unique approaches
- Additional work needed on "appropriate conversion process for targeted feedstocks" enabling affordability with sustainability
- SAF - an enabler for expanded production from agricultural, silviculture, aquaculture, …

Aviation is committed to the use of SAF
"with commensurate assistance from governments"

* Airline commitment at 28Sep IATA/ATAG Forum: NZC by 2050, with a focus on SAF
* Further commitments to 10% SAF usage by 2030
  * A4A & US Government Grand Challenge Announcement, 09Sep'21 — 3 B gpy by 2030, 35 B gpy by 2050
  * 60 companies in Clean Skies for Tomorrow program (IAG, oneworld, …), 22Sep'21
* Business Aviation similar commitments at 12Oct'21 NBACE
* Offtake committed for SAF production slates from first 7+ refineries, 5–15 years
* CORSIA incorporates SAF, developing new Long-Term Goal in current CAEP Cycle
* Countries now adopting additional targets and policy approaches for domestic SAF usage (RFS, LCFS, tax policy), including SAF blending mandates in the EU
* Aviation also interested in carbon abatement via adjacent tech: PtL, BECCS, DACCS
* OEMs and DOD continuing R&D, evaluating acquisition options

SAF-production-potential outlook

Targets of opportunity with low ILUC and affordability



148 B gpy
9.7 M bpd

US targets
35 B gpy

What is SAF (Sustainable Aviation Fuel)?
a.k.a. aviation biofuel, biojet, alternative aviation fuel

Aviation Fuel: Maintains the certification basis of today's aircraft and jet (gas turbine) engines by delivering the properties of ASTM D1655 – Aviation Turbine Fuel – enables drop-in approach – no changes to infrastructure or equipment, obviating incremental billions of dollars of investment

Sustainable: Doing so while taking Social, Economic, and Environmental progress into account, especially addressing GHG reduction

How: Creating synthetic jet fuel with biochemical and thermochemical processes by starting with a different set of carbon molecules than petroleum … a synthetic comprised of molecules essentially identical to petroleum-based jet (in whole or in part)

…Unabashedly - Lowest societal-impact way to decarbonize civil aviation!!

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Why SAF? Enables aviation decarbonization!

- Industry growing faster than new efficiency-technology can be incorporated, and radical new technology likely cannot start impacting fleet prior to 2040
- SAF delivers significant net lifecycle carbon reductions as a drop-in fuel
  - No required $T replacements of: fleet, distribution infrastructure, new airports
- SAF is available starting yesterday
- SAF usage can grow quickly when appropriately enabled/required by policy
- Progress being made on remaining technical barriers, and commercial approaches
- SAF commercial development can take place worldwide, commensurate with the available resources – of which there are many

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How SAF is made - Biorefinery example

1 Feedstocks (sourcing H & C)
- Lipids
- Lignocellulose
- Starches / Sugars
- Waste streams
- Circular economy byproducts

2 Conversion Processes
- Biochemical (microbes, e.g. fermentation)
- Thermochemical (heat, pressure, catalysts)

Biocrude

3 Refinery Processes
- Hydrotreament
- Hydrocracking
- Hydroisomerization
- Distillation

C7-C17 pure HC suitable for jet

4 SAF Blending Agents: ASTM D7566 Annex A1 - Ax

5 SAF Blending Agent ASTM D7566 Annex A1 - Ax + Conventional Jet Fuel ASTM D1655

BLENDING TANK*

6 ASTM BLEND CERTIFIED AS BEING ASTM D7566 & D1655 COMPLIANT (CoA); THEN RE-IDENTIFIED AS ASTM D1655

Fully fungible with all jet fuel infrastructure

*Blending can occur at multiple locations (e.g., at the SAF production facility, intermediate terminal, conventional petroleum refinery, other storage or blending infrastructure), but must be followed by batch compliance testing and certification as identified in D7566 and D1655.

Feedstock development - a lipids example

1

Feedstocks (sourcing H & C)
- Lipids
- Lignocellulose
- Starches / Sugars
- Waste streams
- Circular economy byproducts

Expansion

1) **Waste lipid aggregation**
   * Tallows, white grease, chicken fat, yellow grease, brown grease, …
2) **Industrial effluents and byproducts**
   * Tall oil, food processing oils (seafood processing), PFAD/POME, culled nut oils, …
3) **Existing oilseed / row crop expansion**
   * Rapeseed, canola, soy, sunflower, DCO, mustards, …
   * Introduction of multiple cropping concepts (inter-, relay-, dual-, …)
   * Palm (addressing oil palm sustainability issues of SE Asia)

R&DDD

4) **New oilseed / row crops** (with mitigated LUC/ILUC, e.g. winter cover cash crops, rotations/fallows, …)
   * Camelina, carinata, pennycress, …
5) **Tree / bush oils** (seed or leaf [e.g. eucalyptus] extraction)
   * Pongamia, coconut, hazelnut, jatropha, macauba (prevalent in tropics and subtropics; India reports 400 species, 10 of specific interest)
6) **Algae – micro, macro** (and more targeted conversion process refinement, e.g. HTL)
   * Bio-derived triglycerides and pure hydrocarbons (e.g. *Botryococcus braunii)*
7) **Advanced microbial conversion of lignocellulose/wastes to precursor molecules** (lipids, fatty acids)
   * Acetogens, oleaginous yeasts, cyanobacteria, fungal, methanogens…
8) **Engineered oil excrescence in biomass itself**
   * E.g. the work of ARPA-E PETRO, and DOE PETROSS and ROGUE (similar to crushing sugarcane or sugar beets to release a sugary juice, the crush of a modified tobacco or energy grass could produce a lipid stream)

SAF Progress - technical

* SAF are becoming increasingly technically viable
  * Aviation now knows we can utilize numerous production pathways

    (7 approved, 6 in-process, >15 in pipeline)
  * Exploring expanded use of all major sustainable feedstocks
    * Focus on 24x7, low-cost types to enable affordability and capitalization
  * Some future pathways will produce blending components that will need less, or zero, blending
  * Expanding exploration of renewable crude co-processing with refineries
  * Continuing streamlining of qualification – time, $, methods
* Challenge remaining is achieving reasonable cost and expanding production

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Sourced from CAAFI (Commercial Aviation Alternative Fuels Initiative - see www.caafi.org), 14Mar2021.
Information herein originates from the definitions in ASTM D7566 as well as industrial knowledge emanating from the work of CAAFI and industry practitioners.

ASTM D7566 Annex	Technology Type	Process Feedstock	Process Feedstock Sources	Blend Requirement	Certification Date	Technology Developer*/ Licensor	Commercialization Entities
A1	Fischer-Tropsch Synthetic Paraffinic Kerosene (**FT-SPK**)	Syngas (CO and H_2 at approximately a 1:2 ratio)	Gasified sources of carbon and hydrogen: Biomass such as municipal solid waste (MSW), agricultural and forestry residues, wood and energy crops; Industrial off-gases; Non-renewable feedstocks such as coal and natural gas.	Yes, 50% max	2009	****Sasol**, Shell, Velocys, Johson Mathey/BP, …	Sasol, Shell, Fulcrum, Red Rock, Velocys, Loring, Clean Planet Energy, …
A2	Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (**HEFA-SPK**)	Fatty Acids and Fatty Acid Esters	Various lipids that come from plant and animal fats, oils, and greases (FOGs): chicken fat, white grease, tallow, yellow grease, brown grease, purpose grown plant oils, algal oils, microbial oils.	Yes, 50% max	2011	**UOP/ENI,** Axens IFP, Neste, Haldor-Topsoe, UPM, REG …	World Energy, Neste, Total, SkyNRG, SGPreston, Preem, …, many entities using technology for renewable diesel too
A3	Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (**HFS-SIP**)	Sugars	Sugars from direct (cane, sweet sorghum, sugar beets, tubers, field corn) and indirect sources (C5 and C6 sugars hydrolyzed from cellulose);	Yes, 10% max	2014	**Amyris**	Amyris / Total
A4	Fischer-Tropsch Synthetic Paraffinic Kerosene with Aromatics (**FT-SPK/A**)	Syngas	Same as A1, with the addition of some aromatics derived from non-petroleum sources	Yes, 50% max	2015	**Sasol**	none yet announced
A5	Alcohol to Jet Synthetic Paraffinic Kerosene (**ATJ-SPK**)	C2-C5 alcohols (limited to ethanol and iso-butanol at present)	C2-C5 alcohols derived from direct and indirect sources of sugar (see A3), or those produced from microbial conversion of syngas	Yes, 50% max	2016	**Gevo, Lanzatech,** (others pending including Swedish Biofuels, Byogy, ...)	Gevo, Lanzatech
A6	Catalytic Hydrothermolysis Synthesized Kerosene (**CH-SK, or CHJ**)	Fats, Oils, Greases	Same as A2	Yes, 50% max	2020	**Applied Research Associates** (ARA) / CLG	ARA, Wellington, Sunshine, Euglena, ...
A7	Hydroprocessed Hydrocarbons, Esters and Fatty Acids Synthetic Paraffinic Kerosene (**HHC-SPK**, or **HC-HEFA**)	Algal Oils	Specifically, bio-derived hydrocarbons, fatty acid esters, and free fatty acids. Recognized sources at present only include the tri-terpenes produced by the Botryococcus braunii species of algae.	Yes, 10% max	2020	**IHI Corporation**	IHI

* The entity who was primarily responsible for pushing the technology through aviation's D4054 qualification is shown in bold.

** There are 3 major systems associated with FT conversion: Gasification, Gas Clean-up, and Fischer-Tropsch Reactor. This column focuses on the FT reactor only. There are over a hundred gasification entities in the world, and several of the major oil companies own and utilize gas clean-up technology. Further, up to the current time, FT reactors were only produced at very large scale. The unique technology brought to the market by Velocys *et al.* is a scaled-down, micro-channel reactor appropriately sized for processing of modest quantities of syngas as might be associated with a biorefinery.

SAF Grand Challenge (SGC)
CAAFI observations from the periphery

* SGC Execution Team (FAA, DOE, USDA) working with SAF IAWG on the Roadmap
  * Targeting 6-month completion commitment made at launch
  * Building off update of previous FAJFR&DS
  * Goals for 2030, 2040, 2050 – Workstreams starting immediately
* Vetting sessions held with academia and National Labs, will next turn to select industry sessions, and then more broadly
  * First session in planning for Feb., other listening sessions likely, possibly by topic
* Upon Agency agreement (March) – will announce and solicit further input via RFI
* Execution via multiple mechanisms, likely matrixed workstreams, via 3-4 key foci
  * Expanding Supply & Technologies for production
  * Expanding Regional Resources
  * Tools and Analysis
  * Barrier identification and mitigation opportunities
* Initiation will be focus of CAAFI Biennial General Meeting on 01-03Jun in D.C.

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Steve Csonka
Executive Director, CAAFI
+1-513-800-7980
Csonka.CAAFI.ED@gmail.com
Steve.Csonka@caafi.org
www.caafi.org
info@caafi.org

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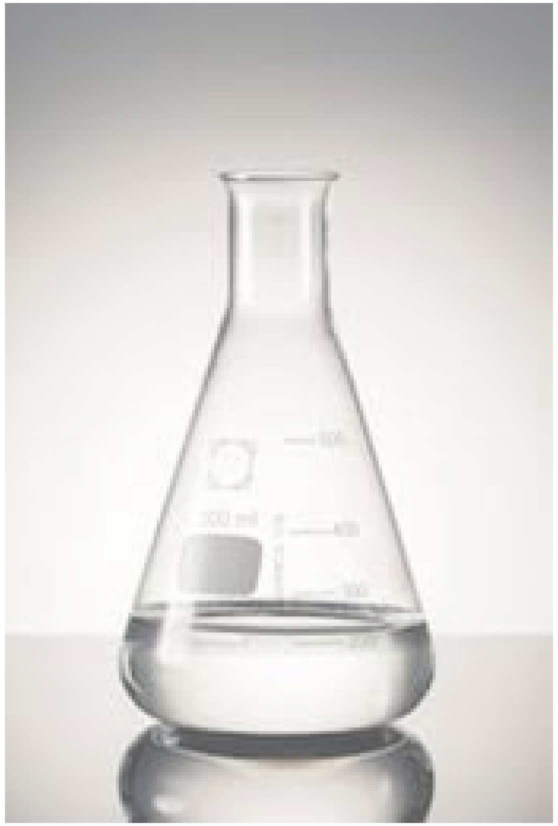

Next CAAFI Biennial General Meeting
01-03Jun’22, Washington, D.C.