Sustainable Aviation Fuel (SAF) Update

Team Call update, 11Jan’22

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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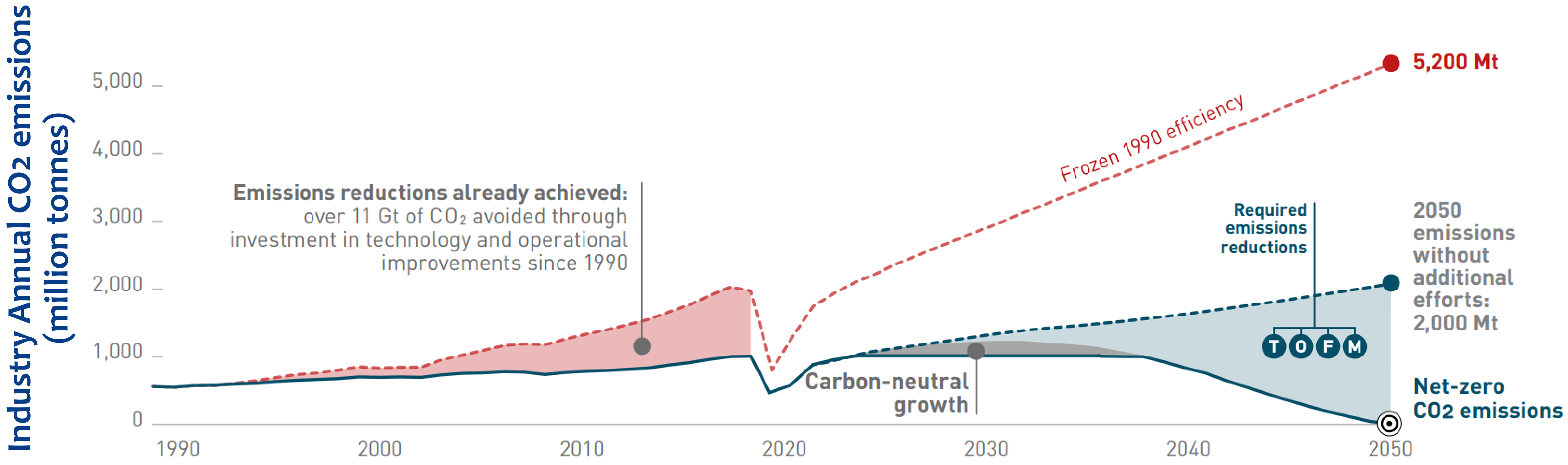
Civil Aviation commitments on CO_2 reductions



T Technology, including radical new
O Operations and Infrastructure
F Sustainable Aviation Fuels
M Market-based measures

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Courtesy of ATAG: https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

Aviation is committed to the use of SAF

- 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

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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?

- Industry growing faster than new efficiency-technology can be incorporated, and radical new technology likely cannot start impacting fleet prior to 2040
  - Operations and infrastructure have limited, modest inefficiencies
- SAF delivers significant net lifecycle carbon reductions as a drop-in fuel
- SAF is available starting yesterday
- SAF usage can grow quickly when appropriately enabled/required by policy
- Progress being made on remaining technical barriers
- SAF commercial development can take place worldwide, commensurate with the available resources

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.

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Aviation industry path to SAF evaluation and qualification – foundation of enabling specifications

* **ASTM D1655 - Standard Specification for Aviation Turbine Fuels**
  * **A1.1.2 …** Aviation turbine fuels with synthetic components produced in accordance with Specification D7566 meet the requirements of Specification D1655.
* **ASTM D4054 - Standard Practice for Qualification and Approval of New Aviation Turbine Fuels**
  * **1.1** This practice covers and provides a framework for the qualification and approval of new fuels and new fuel additives for use in commercial and military aviation gas turbine engines…
* **ASTM D7566 - Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons**
  * **1.2 …** Aviation turbine fuel manufactured, certified and released to all the requirements of this specification, meets the requirements of Specification D1655 and shall be regarded as Specification D1655 turbine fuel.

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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.

ASTM D4054 progression history

Time and fuel volume requirements for industry approval continue to drop due investments made by FAA and others

ASTM D7566 Annex	Fuel Type	ASTM data review	Final phase II research report	Addition to ASTM Specification (D7566)	Estimated gallons of fuel produced for testing	Estimated time from first review to approval	Composition	Commercial Entity
A1	**FT-SPK**	09/2007 est.	09/2008	09/2009	710,000[1]	3 years	Mostly normal/ iso-paraffins	Sasol
A2	**HEFA-SPK**	06/2008 est.	05/2010	07/2011	626,000[2]	3 years		various
A3	**HFS-SIP***	06/2011	04/2013	06/2014	16,000	3 years		Amyris
A5	**ATJ-SPK (isobutanol)**	12/2010	04/2015	06/2016	93,100[3]	5 1/2 years		Gevo
A5	**ATJ-SPK (ethanol)**	09/2016	07/2017	04/2018	50[4]	1 1/3 years		LanzaTech
A4	**FT-SPK/A**			11/2015			A1 with addition of aromatics	Sasol
A6	**CHJ**	06/2012	10/2018	01/2020	79,000	7 years	Wider range of molecules	ARA/CLG
A7	**HHC-SPK HC-HEFA****	02/2019	06/2019	03/2020	50	~1 year	~40% cycloparaffin	IHI

[1]USAF fuel purchases in 2007-08 for fleetwide qualification
[2]USAF & Navy fuel purchases in 2009-11 for fleetwide qualification
[3]USAF, Navy and CLEEN fuel purchases in 2012-2014
[4]Only Tier 1-2 testing due to existing knowledge base and similarity to approved fuels

**Approved at 10% volume*
***First Fast Track approval – approved at 10% volume blend limit*
ARA/CLG – Applied Research Associates / Chevron Lummus Global
Find additional details in either ASTM D7566 or keep up to date at:
http://www.caafi.org/focus_areas/fuel_qualification.html

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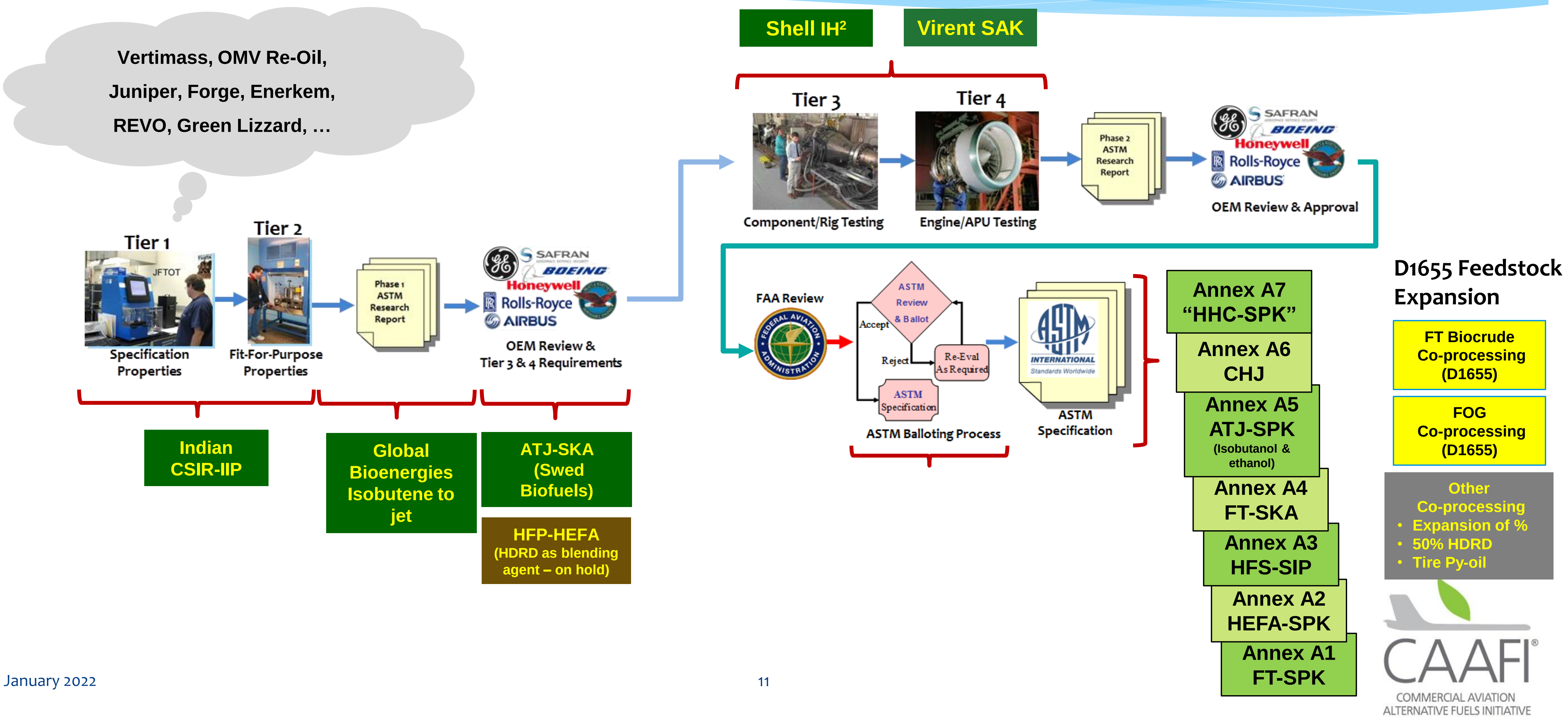
SAF Progress - technical

* 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

In process SAF Pathways, via D4054 process

Additional technologies applicable to SAF



U.S. SAF production capacity forecast

Announced intentions, neat*

Year-end Production Capacity (M gpy)

By YE '21 (~25+ M)
- world energy — Paramount
- gevo — Silsbee

2022 (~200 M)
- Fulcrum BioEnergy — Sierra 7
- Red Rock Biofuels — Lakeview 6
- LanzaJet — Freedom Pines 10
- world energy — Paramount+ 150

2023 (~250+ M)
- AEMETIS — Carbon Zero #1 Riverbank 22
- EcoTechFuels, LLC — Wyoming 8
- SG Preston — NE #1 20+

2024
- gevo — Net Zero SD 22.5
- Phillips 66 — Rodeo 290
- Fulcrum BioEnergy — Gary, IN 21
- UX — Bakersfield 37
- Grays Harbor 60+

2025
- AEMETIS — Carbon Zero Riverbank+ 22
- LanzaJet — N. Am. #2 30
- ReadiFuels — Iowa 18
- Wellington Microtech — Utah 20
- USA BioEnergy, Renewable Energy Solutions — Beaumont 15

2026 (~900+ M)
- Velocys Bayou — Natchez, MS 33
- SkyNRG Americas — NW #1 10

40+ Entities Collaborating With CAAFI

Exact Timing & Production tbd

- Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified. Does not include various small batches produced for testing technology and markets.
- Does not include fractions of substantial Renewable Diesel capacity (existing and 10B gpy in-development) that can be pivoted to SAF based on policy support

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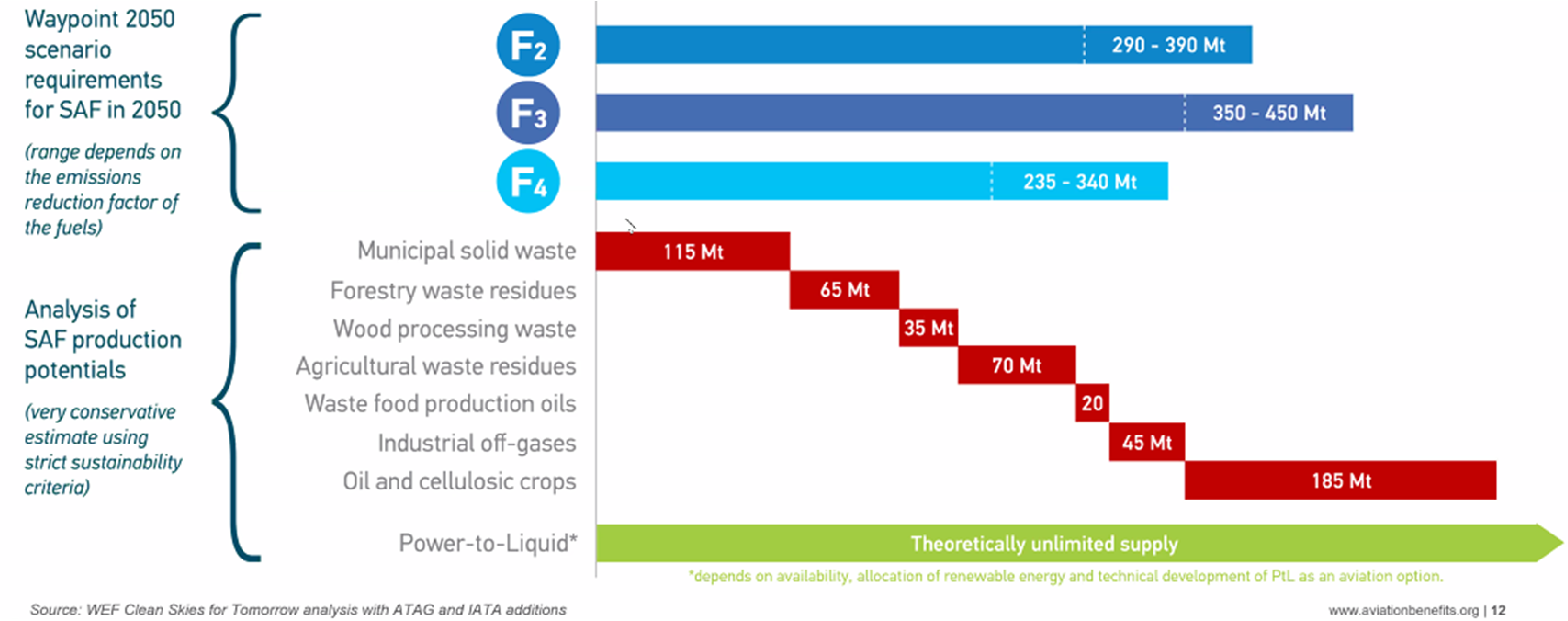
How we achieve SAF commitments / goals

* Affordability
  * Conversion technologies, system integration
  * Lower cost feedstocks, higher carbon utilization
  * Learning curve advancements and supply chain optimization
* Worldwide production expansion
  * All areas, local feedstock types
  * Additional grass roots efforts (like CAAFI, AIREG, …)
* Policy assistance to help bridge gaps of affordability and production
  * Valorization of additional environmental / societal services

SAF production potential

Targets of opportunity that do not compete for food or land use change



SAF Challenges … or Opportunities

SAF Challenges	… or Opportunities
* A new industrial sector	But from mature sectorial components
* SAF affordability –vs- petroleum	Fully burdened cost of petroleum & carbon;
	Have not even initiated learning curves
* Equitable treatment with road fuels	Synergistic production; Fed. Gov't support
* Impact to petroleum industry	SAF synergistic with petroleum infra.;
	Robust aviation sector; 483,000 SAF jobs; every state contributes
* Double production every year	$21B investment – but only 6% of petroleum's
* Significant investment	Capital available for sound business cases;
	Can be enablesd by policy support
* Food –vs- Fuel	Food and fuel, and fiber, and feed

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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
- 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"
- CAAFI and others are working to foster, catalyze, enable, facilitate, ... every region should consider
- 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
- Industry removing barriers: Pathways identified for fully synthetic SAF (50% max blend today), enhancing SAF value proposition by enabling deeper net-carbon reductions
- Additional work needed on "appropriate conversion process for targeted feedstocks" enabling affordability with sustainability

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.