Aviation's Market Pull for SAF (Sustainable Aviation Fuel) and the indispensable linkage to the work of EERE and BETO

EESI
Environmental and Energy Study Institute

EESI Briefings Series:
Investments in Clean Energy and Transportation Innovations in the Federal and Private Sectors

Steve Csonka
Executive Director, CAAFI

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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).

Only U.S. facility offering continuous production of SAF at present.
Other batch production & tolling occurring due to extreme customer interest.

13Apr'23

CAAFI - Public/Private Partnership

www.caafi.org

An aviation industry coalition established in 2006 to facilitate and promote the development and commercialization of sustainable aviation fuel (SAF), coincident with the industry's sustainability commitments

Goal is development of non-petroleum, drop-in, jet fuel production with:

- *Equivalent safety & performance*
- *Comparable cost*
- *Environmental improvement*
- *Security of energy supply for aviation*

SAF - Synthetic kerosene, primarily from renewable or circular economy H-C sources

Enables its diverse stakeholders to build relationships, share and collect data, identify resources, and direct research, development and deployment of alternative jet fuels

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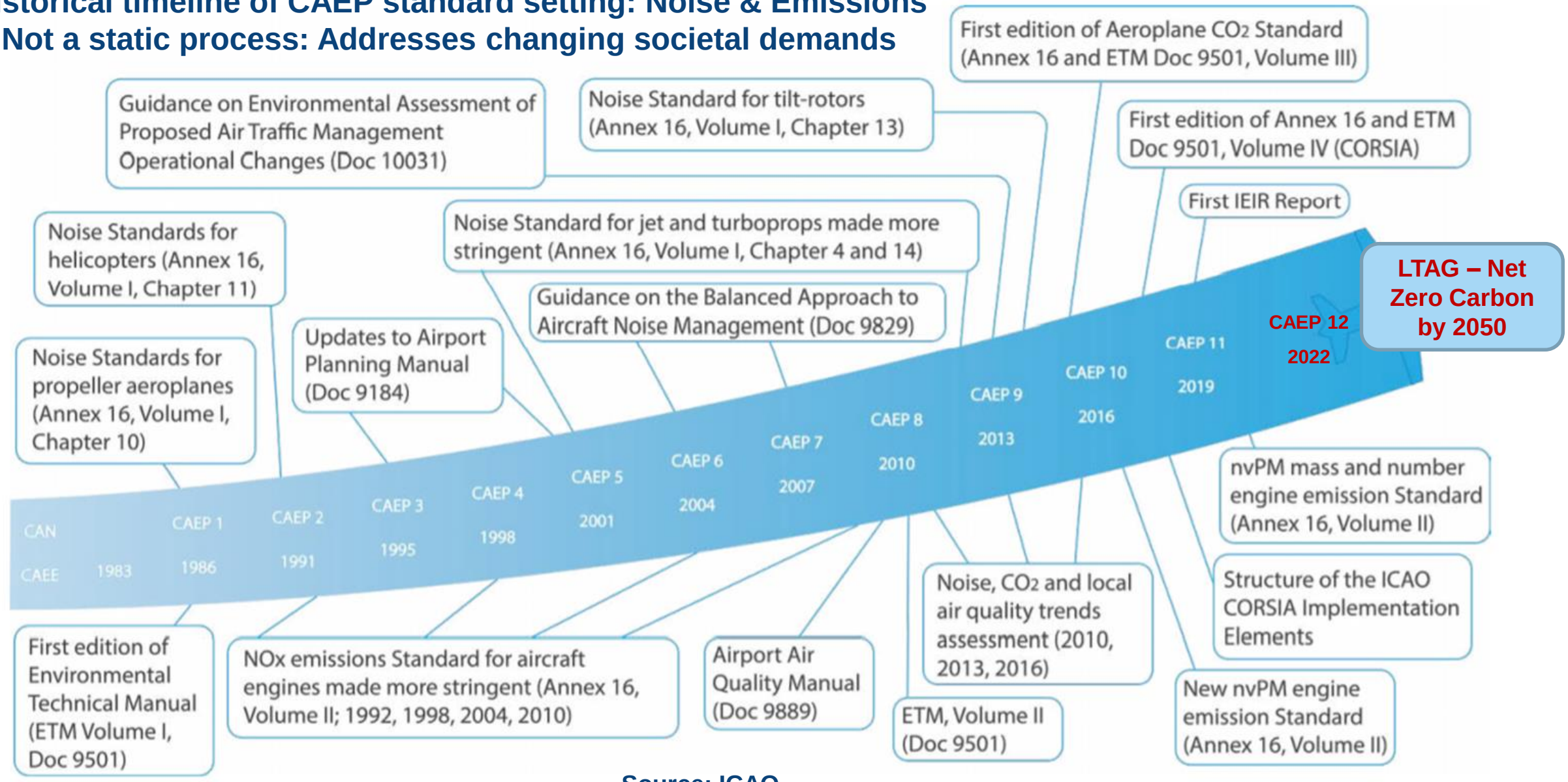
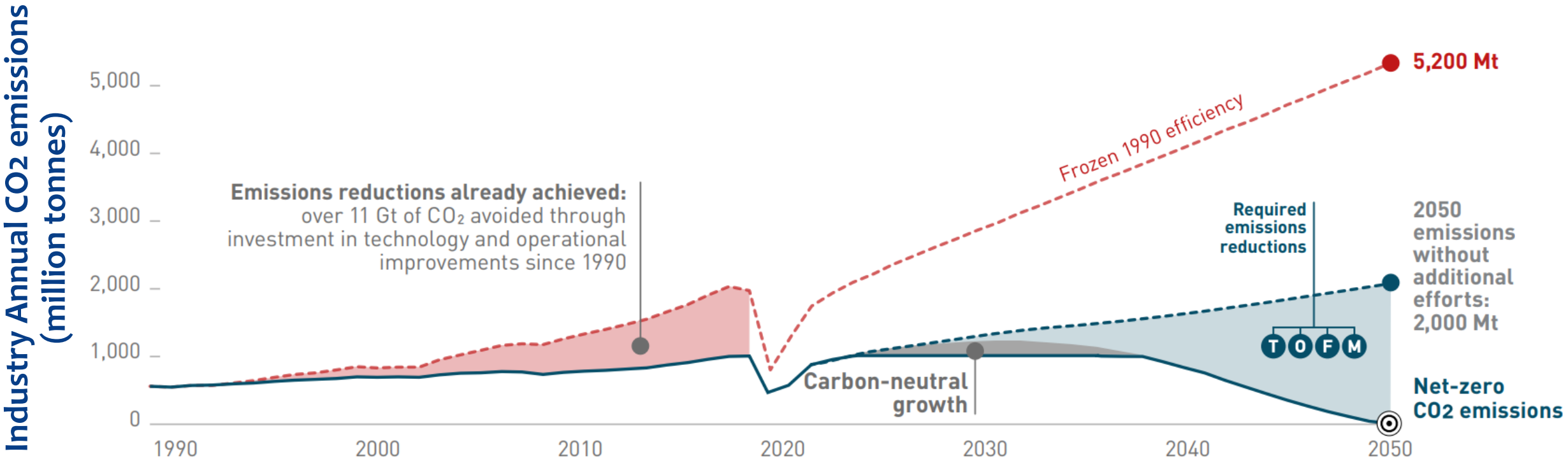
Aviation takes its environmental responsibility seriously

Historical timeline of CAEP standard setting: Noise & Emissions
Not a static process: Addresses changing societal demands



Source: ICAO

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

Majority of CO_2 emissions come from medium- and long-range flights, and larger aircraft

Global CO_2 emissions from aviation – 2018, in % of total CO_2 emitted

	Flight Range Category (km)							Total Share CO_2 Emissions	Global Fleet
Aircraft Type [UAV, UAM, GA, Feeder]	0-500	501-1000	1001-2000	2001-3000	3001-4500	>4500			
Commuter <19	<1%							<1%	4%
Regional 20-80	1.2%	1.2%	0.8%	0.1%					
Short Range 81-165	1.6%	5.8%	10.1%	4.0%	2.0%				
Med. Range 166-250	1.1%	4.9%	13.1%	8.4%	6.9%	8.5%		43%	18%
Long Range >250	0.1%	0.5%	1.6%	1.6%	1.9%	24.2%		30%	12%
Total	~4.5%	~12.4%	~25.6%	~14.1%	~10.7%	~32.7%			

Hybridization, electrification, fuel switching, … to start in this space

Technology needed for large aircraft electrification or H2 not viable for decades, without major paradigm changes!

Source: World Economic Forum – Mission Possible Platform, DiioMi

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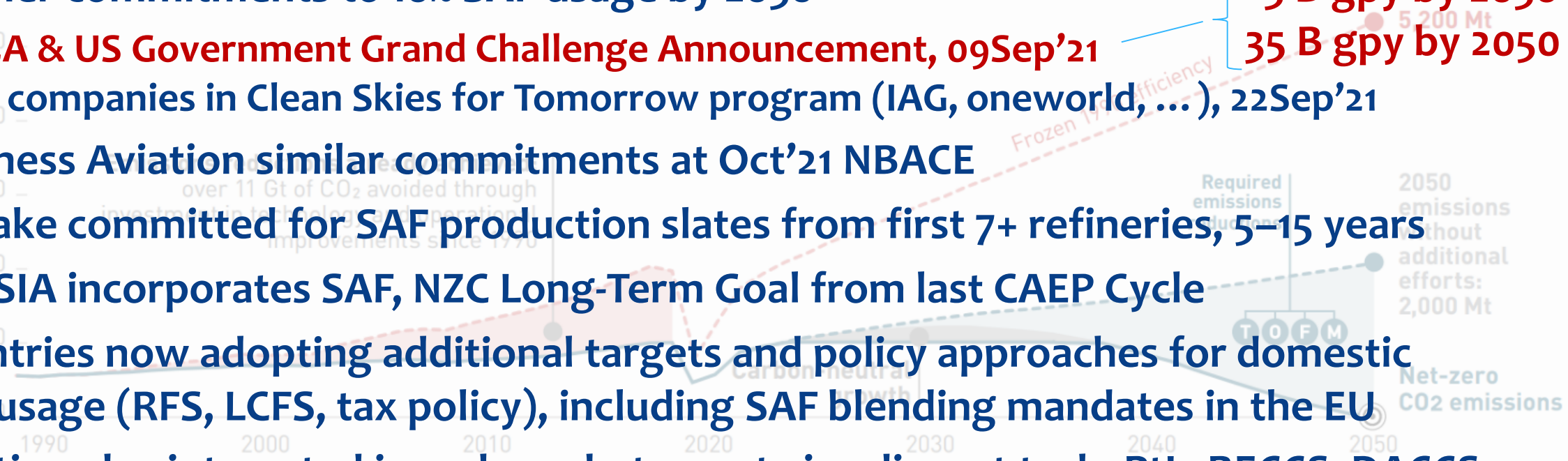
Aviation is committed to the use of SAF

- Airline commitment at Sep'21 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
  - 60 companies in Clean Skies for Tomorrow program (IAG, oneworld, …), 22Sep'21
- Business Aviation similar commitments at Oct'21 NBACE
- Offtake committed for SAF production slates from first 7+ refineries, 5–15 years
- CORSIA incorporates SAF, NZC Long-Term Goal from last 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

3 B gpy by 2030
35 B gpy by 2050



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A4A airlines' individual carbon / SAF commitments

Beyond the joint A4A commitment for NZC 2050

*Commitments as of 06Apr'23)

Alaska Airlines	NZC by 2040; Offtakes with World Energy, Neste, Gevo, Aemetis
American Airlines	50M gallon absolute reduction of fuel by 2025; 10% SAF use by 2030; reduce GHG emissions intensity by 45% by 2035; Offtakes with Neste, Gevo, Aemetis, Prometheus; Yield10 feedstock MOU
Atlas Air Worldwide	Reduce absolute Scope 1 emissions by 20% by 2035; SAF demonstration flights
Delta	Pledge to be first carbon-neutral airline; 10% SAF use by 2030; Offtakes with Aemetis, Gevo, DG Fuels, Northwest Advanced Biofuels
FedEx Express	NZC by 2040; $2B investment target; $100M for Natural Carbon Capture Center
Hawaiian Airlines	Offtake with Gevo for 50M usg over 5 years; Par Pacific MOU for domestic production
jetBlue	NZC by 2040; 10% SAF use by 2030; Offtakes with Neste, SGPreston, Fidelis New Energy; Aemetis
Southwest	NZC by 2050; 10% SAF use by 2030; reduce carbon emission per available seat by 20% by 2030 as compared to 2019; Offtakes with Marathon, Phillips 66, Velocys, Neste
United	Reduce GHG emissions by 100% (vs 2005) by 2050; $100M SAF Investment Fund; Offtakes with World Energy, Fulcrum, Blue Blade Energy, Neste, Alder Fuels
UPS	30% SAF usage by global air fleet by 2035
Air Canada	20% reduction from 2019 air ops by 2030. $40M investments in SAF and carbon reductions and removals; Net-zero GHG emissions by 2050 throughout global operations

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SAF (Sustainable Aviation Fuel)
a.k.a. aviation biofuel, biojet, alternative aviation fuel, SATF

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 – The lowest societal-impact way to decarbonize civil aviation!!

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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 earlier development)
  * Utilizing thermo-chemical, bio-chemical, and refinery coprocessing conversion processes to produce pure hydrocarbons, followed by standard refinery processes
  * Enabling use of all major sustainable feedstocks
    (lipids, sugars, lignocellulose, hydrogen & carbon sources, circular-economy byproduct streams)
  * Following blending with petro-jet, SAF is drop-in, indistinguishable from petro-jet
  * Some future pathways expected to produce SAF blending components that will need less, or zero, blending
  * Expanding exploration of renewable crude co-processing with refineries
  * Continuing streamlining of qualification – time, $, methods

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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.

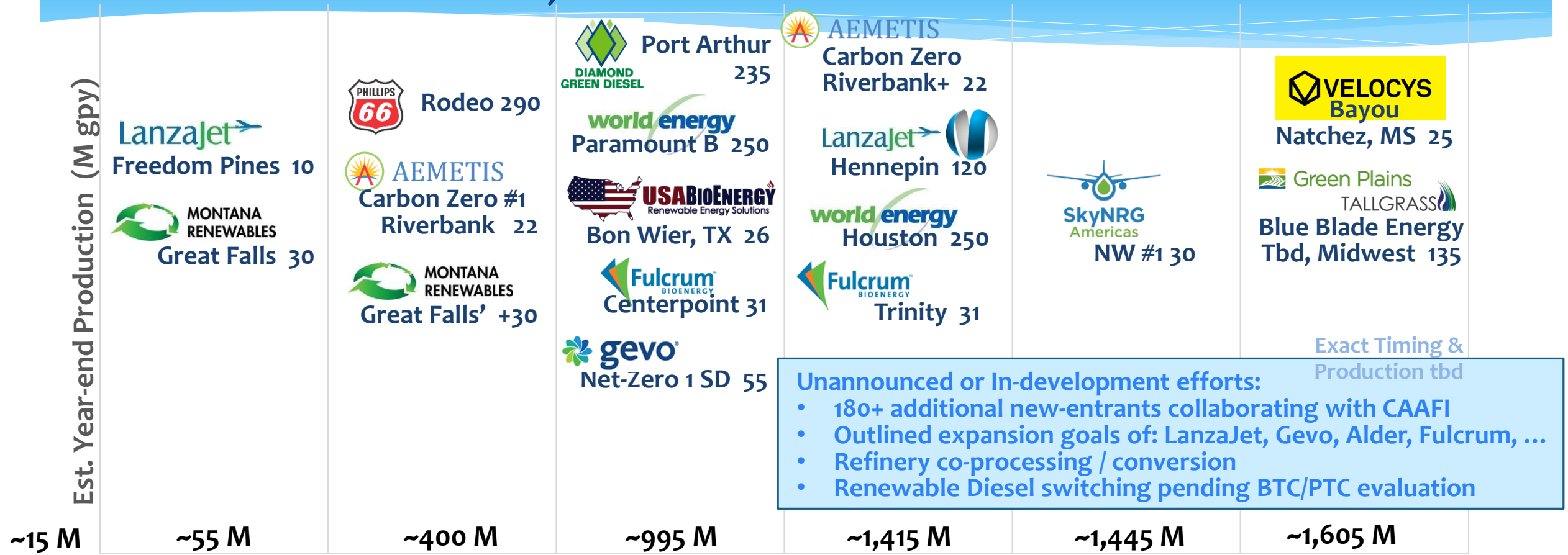
ASTM D7566 Annex	Technology Type	Process Feedstock	Process Feedstock Sources	Blend Requirement	Certification Date	Technology Developer*/ Licensor	Commercialization Entities
A1	Fischer-Tropsch Synthetic Paraffinic Kerosene (**FT-SPK**)	Syngas (CO and H_2 at approximately a 1:2 ratio)	Gasified sources 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, Shell, 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, UrbanX, 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.

U.S. SAF production forecast

Announced intentions, neat*



Unannounced or In-development efforts:

- 180+ additional new-entrants collaborating with CAAFI
- Outlined expansion goals of: LanzaJet, Gevo, Alder, Fulcrum, …
- Refinery co-processing / conversion
- Renewable Diesel switching pending BTC/PTC evaluation

- 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 in-development) that can be shunted to SAF based on policy support

12 April 2023

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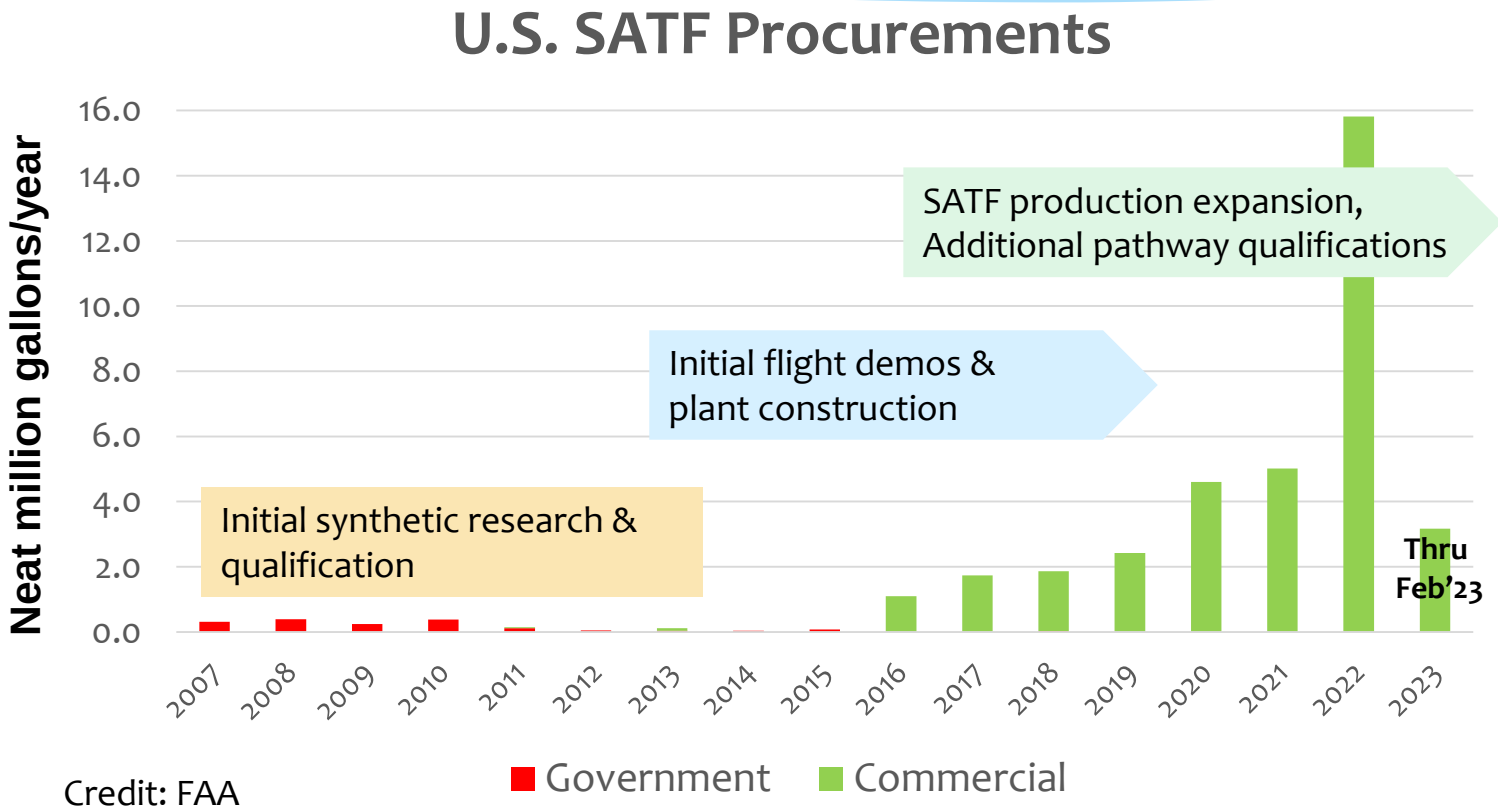
Where we stand on U.S. SAF consumption
Initiation underway, still early

- Approaching 8 years of sustained commercial production and use
- Commercial & Business Aviation engaged
- Two facilities in operation, several others in physical construction
- Cost delta still a challenge, with practicalities favoring renewable diesel
- Worldwide: Growing number of entities produced ~80M usg SAF in 2022 – Finland's Neste the market leader



Credit: FAA

*Reflects voluntarily reported data on use by U.S. airlines, U.S. government, manufacturers, other fuel users, and foreign carriers uplifting at U.S. airports.
^2017-2021 calculation includes reported EPA RFS2 RINs for jet fuel.
2023 data as of Feb. 2023 summary

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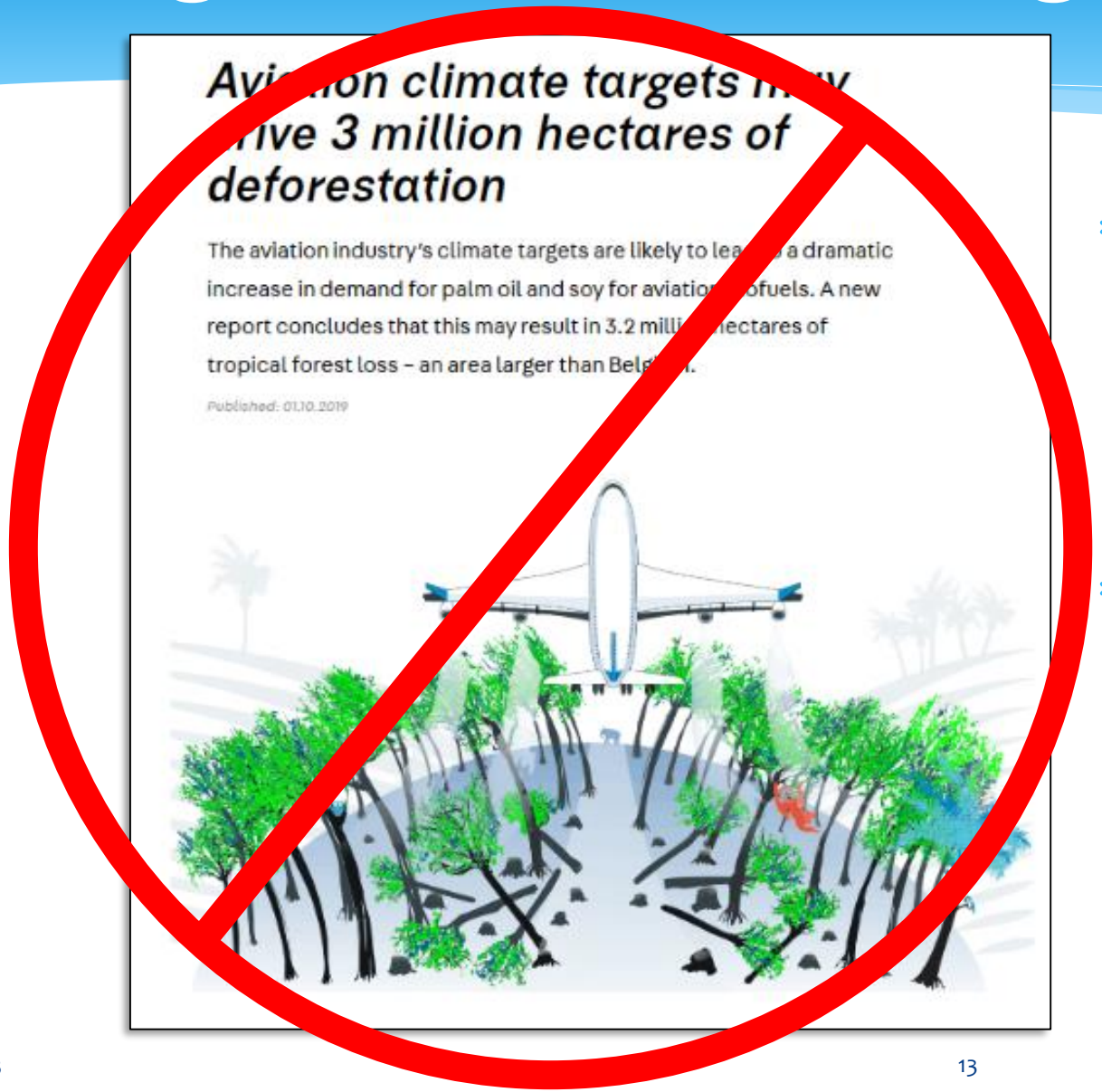
No single feedstock is targeted, nor sufficient



* Extrapolation of uniformed positions, sacrosanct beliefs and pet-peeves can lead to extraordinary theories and positions
* Aviation has embraced verifiable sustainability and standards, and has shunned some more controversial solutions

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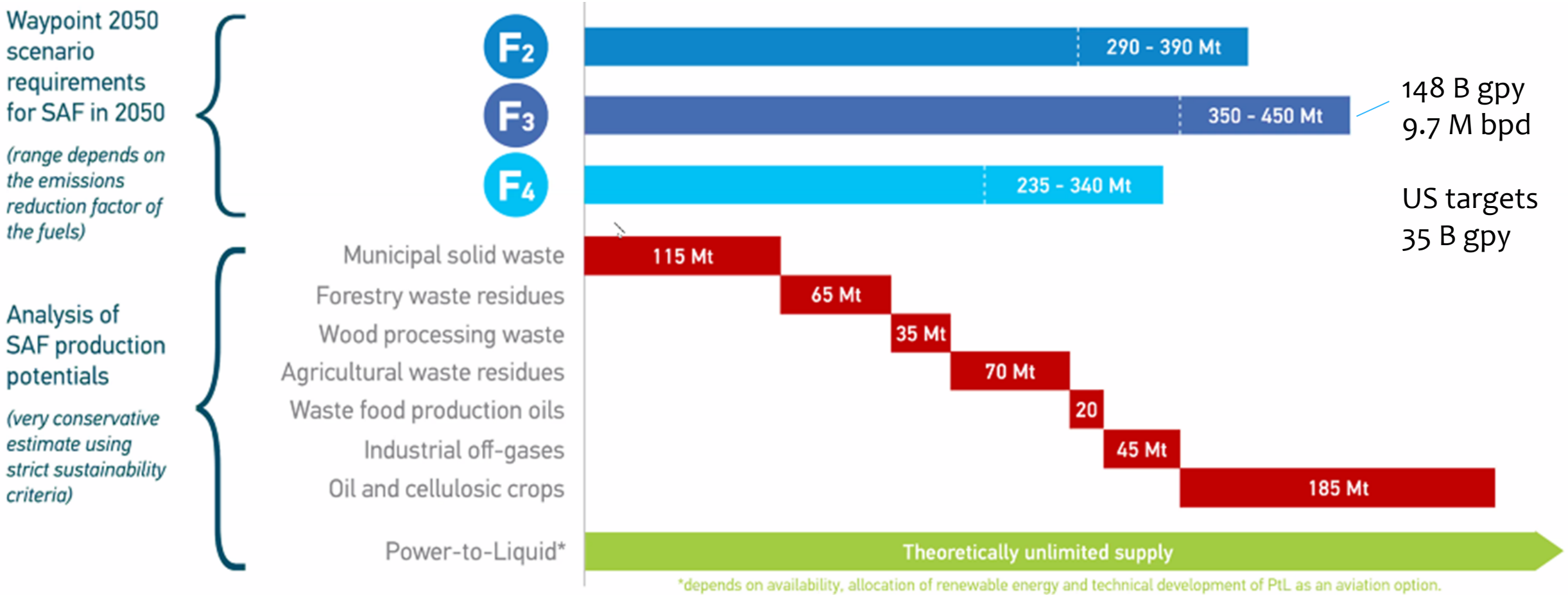
SAF production potential outlook: 2050

Targets of opportunity with low ILUC and affordability



Source: WEF Clean Skies for Tomorrow analysis with ATAG and IATA additions

Promising emerging technologies / feedstocks

- Those that lower cost or increase value of total production slate
  - Higher carbon utilization from feedstocks
  - Lower CapEx and/or Lower OpEx – enabling use of low-cost, plentiful, 24x7 feedstocks and integrated industrial systems
  - Finding higher value for production slip streams or byproducts
  - Capturing value from other environmental services
  - Driving to ultra low CI scores to increase value from rewarding policy
- Steady stream of low TRL examples for the above
- All of the above are the remit of EERI / BETO and other DOE offices

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SAF Grand Challenge (SGC) & Roadmap

* Basically a plan for Government Engagement to build a foundation for success
* Roadmap: Progress plan via multiple Action Areas - matrixed workstreams, via 6 key foci:
  * Feedstock Innovation – USDA focus
  * Conversion Technology & Processes – EERE/BETO focus: assisting in scaling to commercialization
  * Building Regional Supply Chains – Joint agency focus
  * Policy and Valuation Analysis – think tanks, academia, industry proposals; agency analysis of impact
  * Enabling End Use – FAA focus
  * Communicating Progress & Building Support – CAAFI focus
* The expanded approach outlined by the SGC is not fully funded at present. The IRA addresses some opportunities. So, efforts will likely be needed in subsequent budgets (various DOE Offices, FAA AEE, USDA Farm Bill, …), necessitating stakeholder advocacy.
* Industry working a set reciprocal commitments from all supply chain members (producers to buyers).

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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 – available starting today, allow decarbonization to commence while other technologies mature at appropriate paces
- Segment knows how to make it; Activities from FRL 1 to 9, with many in "pipeline"
- First facilities on-line (biorefineries and co-processing), increasing run-rates, multiple offtakers
- Numerous commercial agreements being pursued, fostered by policy and other unique approaches
- 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 – can policy close the gap in the meantime?
- **The work of DOE (via EERE/BETO, office of Science, LPO, BRCs, National Labs, and others) is key to creating the enabling foundation of success.**

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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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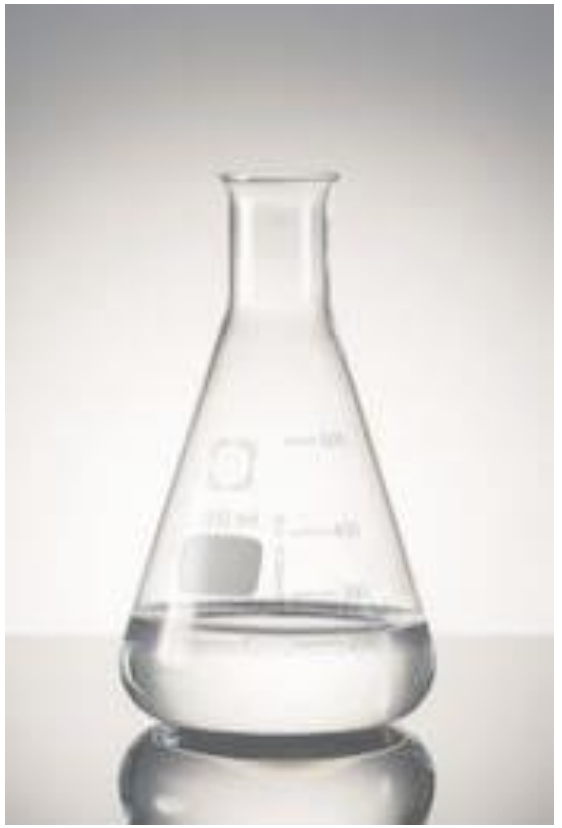

International efforts expanding
Various public-private partnerships advancing SAF

- **Canadian C-SAF (GARDN closed)**
  - Canadian Council for Sustainable Aviation Fuels is launched - C-SAF
- **Australia – New Zealand SAFAANZ – Jet Council**
  - SAF-report.pdf (asianaviation.com)
- **UK Jet Zero Council**
  - Jet Zero Council - GOV.UK (www.gov.uk)
- **WEF Clean Skies for Tomorrow**
  - Home > Clean Skies for Tomorrow Coalition | World Economic Forum (weforum.org)
- **aireg – Aviation Initiative for Renewable Energy in Germany**
  - Home (EN) - Aviation Initiative for Renewable Energy in Germany e.V. (aireg.de)

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