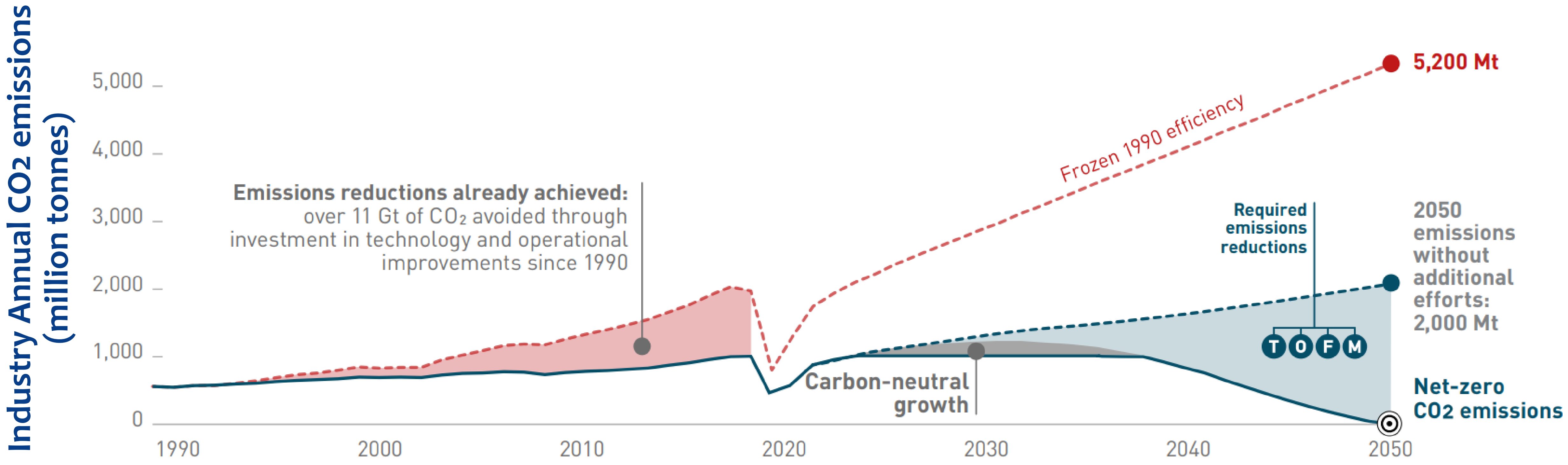
Thursday, 29Sep, Module 4, Session 2A
Roundtable Discussion

Advanced Biofuels (Sustainable Aviation Fuel - SAF) and the Potential for Palm Oil

Steve Csonka
Executive Director, CAAFI
Commercial Aviation Alternative Fuels Initiative

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 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

  3 B gpy by 2030
  35 B gpy by 2050
- Business Aviation similar commitments at Oct'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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A4A airlines' individual carbon / SAF commitments

Beyond NZC by 2050, and building to 2B gpy SAF by 2030 (commitments of Mar'21)

Alaska Airlines	NZC by 2040; Deal with Microsoft for SAF from SkyNRG/World Energy; SAF supply at SFO from Neste; SAF R&D investments with WSU-PNNL; Work with Carbon Direct
American Airlines	Allocation with Kuehne+Nagel and Deloitte ; 9 M usg SAF supply at SFO from Neste; Science based target by 2035 with SBTi; 10 M offtake from Prometheus
Atlas Air Worldwide	SAF demo work with Exolum/Avikor on Spain – Mexico flight;
Delta	Commits to be first global carbon-neutral airline; Collaboration with corporate customers (Deloitte, Takeda); targeting 10% SAF by 2030; SAF test purchase from Chevron (El Segundo)
FedEx Express	Achieve NZC by 2040; $2B investment target; $100M on Yale Center for Natural Carbon Capture
Hawaiian Airlines	
jetBlue	NZC by 2040; 10% SAF penetration by 2030; World Energy SAF supply; offtakes with SGPreston
Southwest	Collaboration with NREL on new pathways; MOUs with Marathon & P66 – focus on CA refinery retrofits
United	UA First U.S. Airline to Pledge to Reduce Own Emissions by 50% (vs. 2005) by 2050; 13Sep'18. $40M SAF Investment Fund; 27Oct'19; SAF usage at LAX since 2016
UPS	30% SAF usage by global air fleet by 2035
Air Canada	Midterm goal, -20% from 2019 air ops by 2030. $40M investments in SAF and carbon reductions and removals. [14Mar'21, Leaveless (aircanada.com)]

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U.S. SAF production forecast

Announced intentions, neat*

Est. Year-end Production (M gpy)

By YE '22 — ~20 M
- gevo Luverne/Silsbee
- Fulcrum BioEnergy Sierra 7
- world energy Paramount+ 7
- NESTE HDRD Frac 8+?

2023 — ~66 M
- Red Rock Biofuels Lakeview 6
- LanzaJet Freedom Pines 10
- Montana Renewables Great Falls 30

2024 — ~463 M
- gevo Net Zero-1 SD 55
- Phillips 66 Rodeo 290
- AEMETIS Carbon Zero #1 Riverbank 22
- Montana Renewables Great Falls' +30

2025 — ~770 M
- world energy Paramount B 250
- USA BioEnergy Renewable Energy Solutions Bon Wier, TX 26
- Fulcrum BioEnergy Centerpoint 31

2026 — ~1,193 M
- AEMETIS Carbon Zero Riverbank+ 22
- LanzaJet Hennepin 120
- world energy Houston 250
- Fulcrum BioEnergy Trinity 31

2027 — ~1,248 M
- VELOCYS Bayou Natchez, MS 25
- SkyNRG Americas NW #1 30

Unannounced or In-development efforts:
- 60+ additional new-entrants collaborating with CAAFI
- Outlined expansion goals of: LanzaJet, Gevo, Alder, Fulcrum, …
- Refinery co-processing / conversion
- Renewable Diesel switching pending BTC evaluation

Exact Timing & Production tbd

73% from lipids

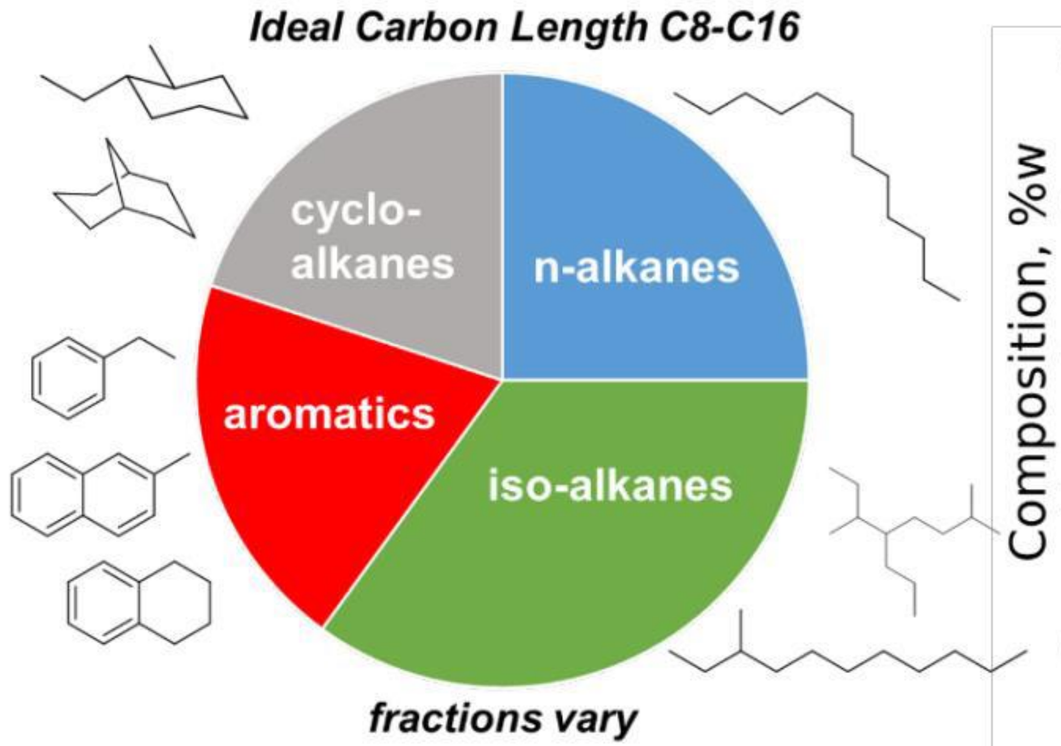
- Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified. Does not include various small batches produced for testing technology and markets.
- Does not include fractions of substantial Renewable Diesel capacity (existing and in-development)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

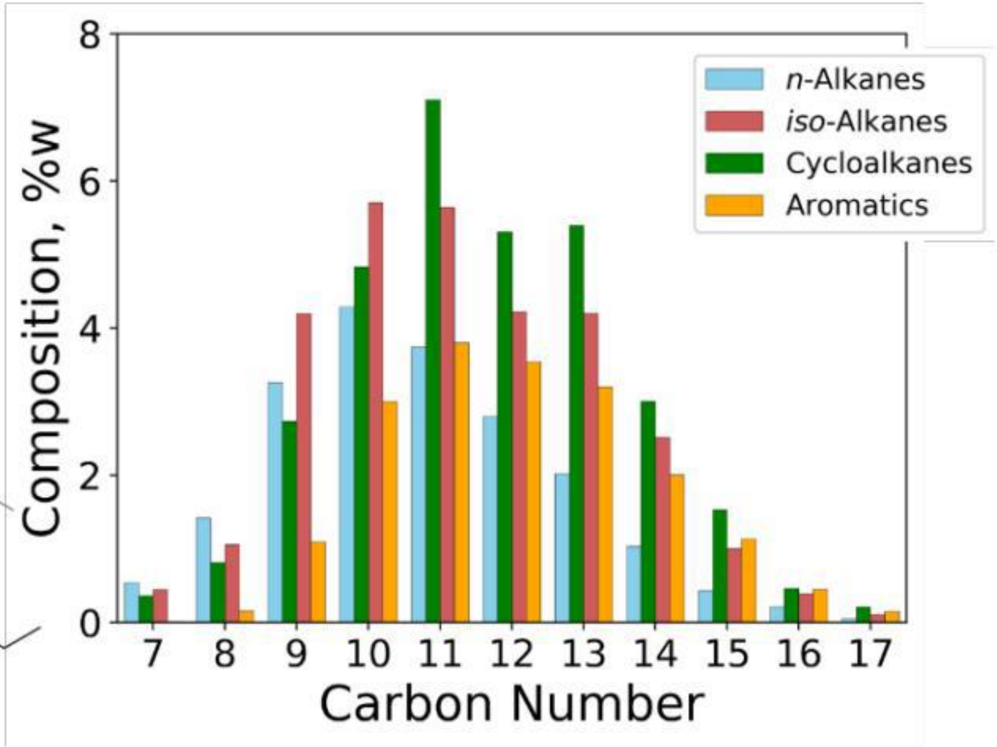
SAF Progress - technical

* 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

Typical jet fuel chemical composition





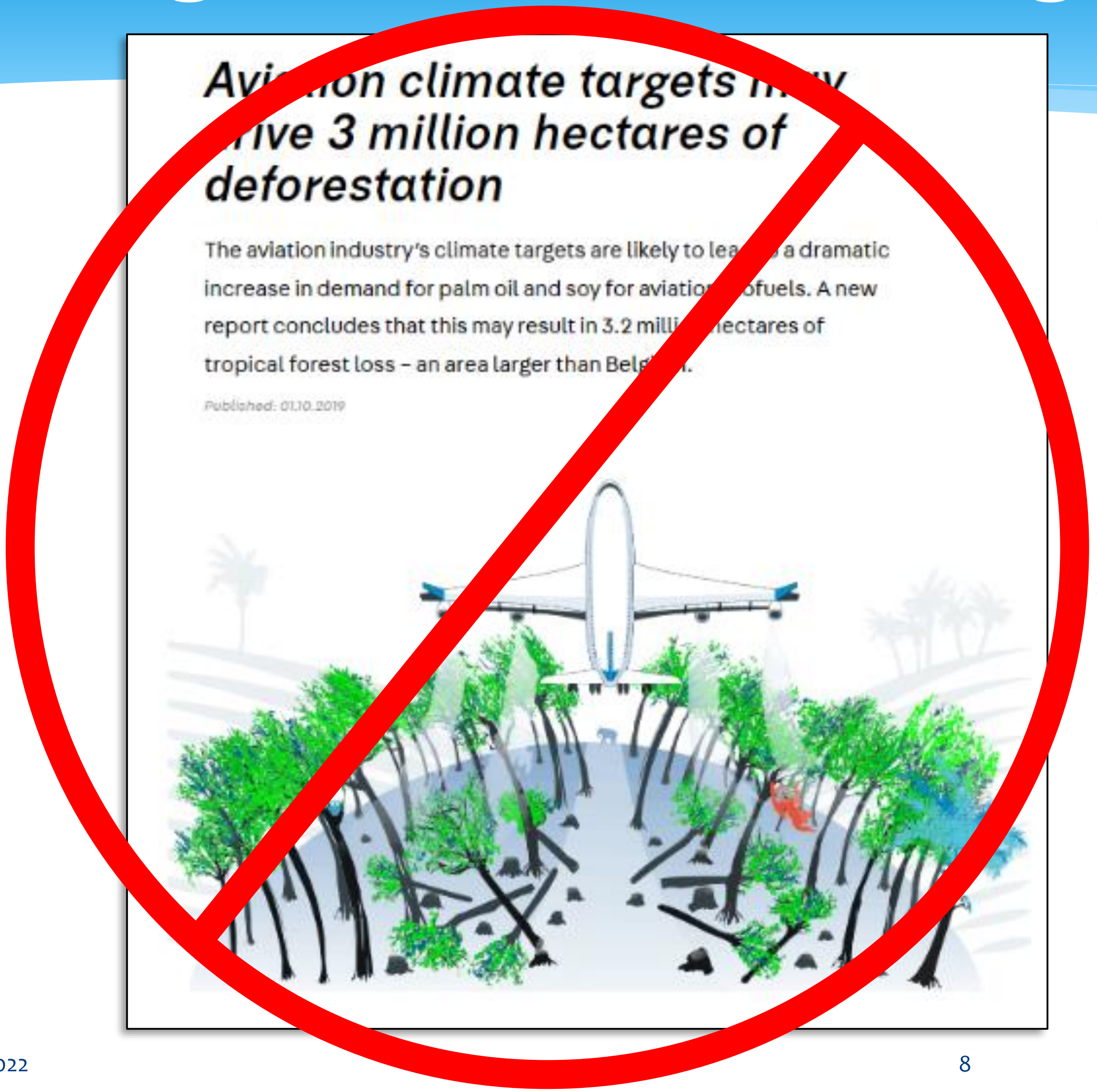
Aromatics are limited to 25%

Olefins and heteroatoms are limited (not allowed)

- Olefins (<1%) (gum formation)
- S, N, O containing (limited allowance)

Pie chart adapted from Tim Edwards
Composition/Carbon number from Josh Heyne

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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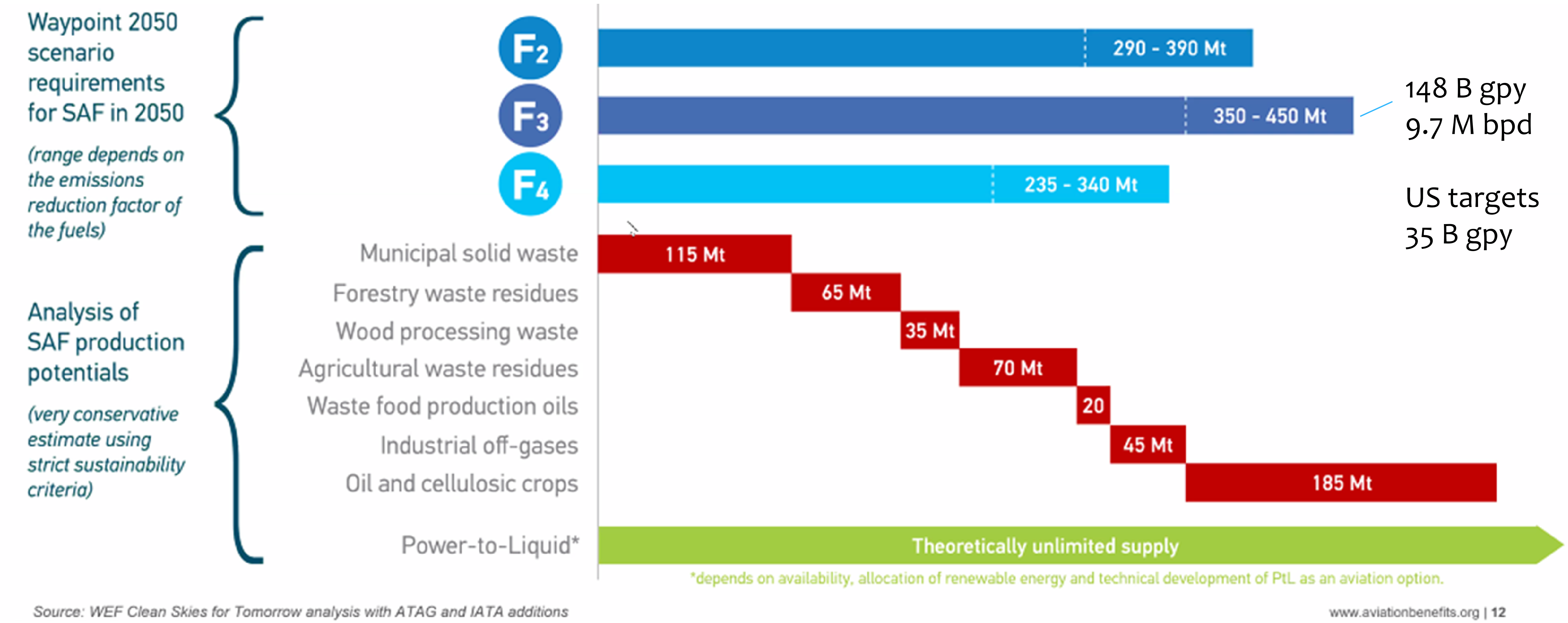
SAF-production-potential outlook

Targets of opportunity with low ILUC and affordability



148 B gpy
9.7 M bpd

US targets
35 B gpy

Current focus on lipid solutions

Positive attributes

* Straightforward – nature gives us something very nearly a paraffinic fuel
* Low cost conversion to distillate fuels (SAF, HDRD)
* Significant domain knowledge and infrastructure around grains and oils
  * Handling, storage, processing, transport
  * Rapid energy densification via crush
  * Subsequent fungibility, and ease of working with fluid feedstock
* Main byproduct of protein/meal production – addresses other key concern – feeding a world of 10B
  * Other co-product markets in chemicals and materials
* Less farmer apprehension with annuals versus perennial lignocellulosics
* Promise of winter cover oilseeds with minimal LUC/ILUC
* Potential for use of brown greases – relatively untapped market
* Eventual promise of ubiquitous algae production? Microbial lipids?
* Advanced work on oil production from non-traditional plants, or sequestration in lignocellulose

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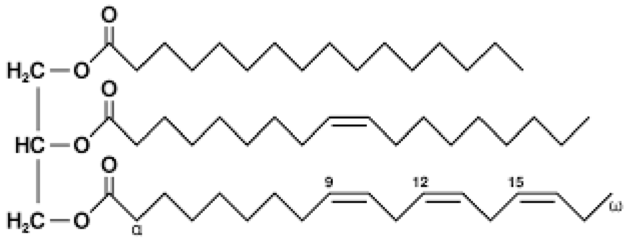
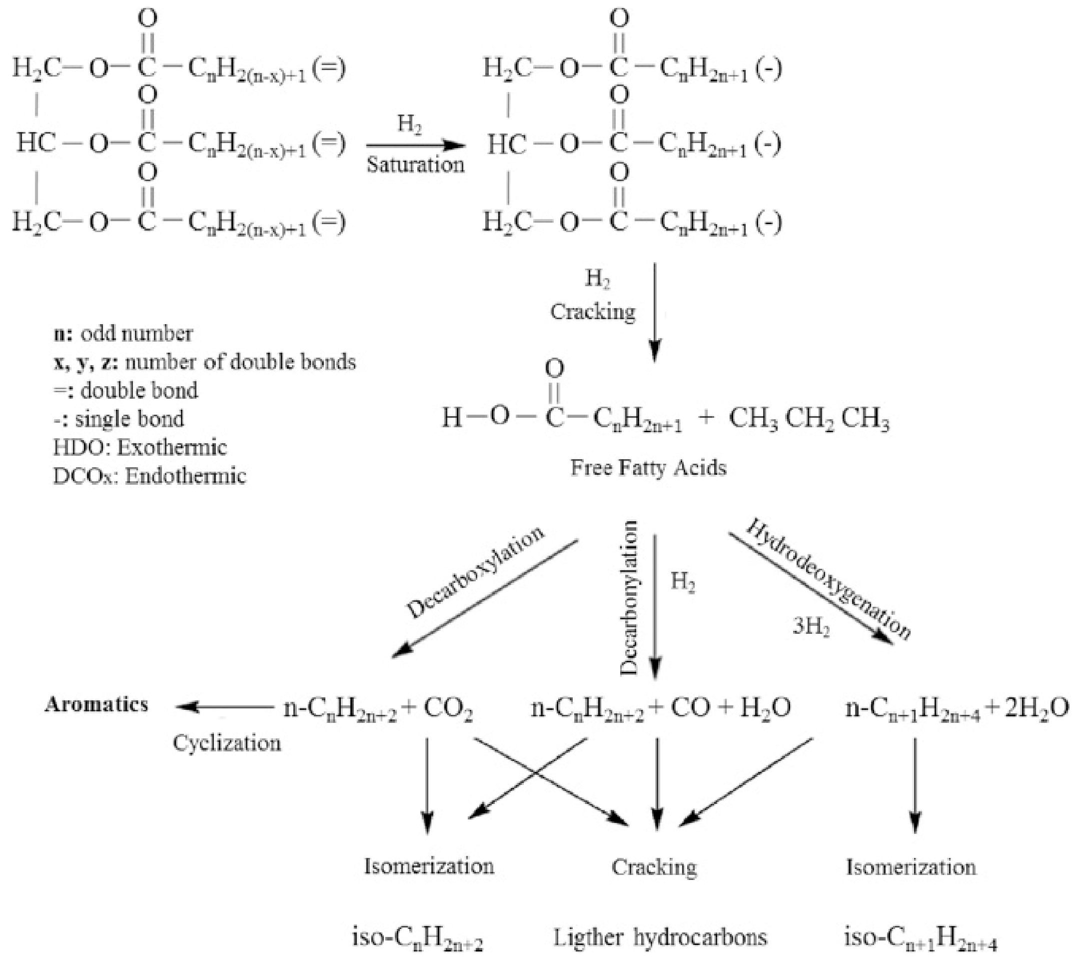
Lipid conversion solutions & R&D remaining

- **Straightforward – nature gives us something very nearly a paraffinic fuel**



- **Additional conversion R&D:**
  - **Catalytic conversions**
  - **Pyrolysis**
  - **Combined with HTL feedstocks**
- **Other research:**
  - **Use of raw crush oils or full algal cells**
  - **Conversion processes that result in the addition of cycloparaffins and naphthenic compounds**



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Lipid questions?

Quantity of lipids available, and when?

- Lots of opinions – answer will depend on policy and market signals
  - ABFA sponsored study suggests no issues with producing:
    - 9B gpy by 2030 (32 Mt), 21B gpy by 2040

What's the best lipid?

- Answer depends on conversion process to a degree. Some generalities:
  - All bonds will need to be saturated – hydrogen drives cost
  - Where does fractionation of longer chains take place – short chains impact yield
  - Some studies have shown clear improvements in yield/cost (e.g. erucic acid content)
- What other by-products are produced
- Neste, Honeywell-UOP, Haldor-Topsoe, ARA and others have done a lot of work on this question

The BIG issue: achieving sustainability

ICAO document - CORSIA Default Life Cycle Emissions Values For CORSIA Eligible Fuels

USA	Switchgrass (herbaceous energy crops)		10.4	-3.8	6.6
Global	Switchgrass (herbaceous energy crops)		10.4	5.3	15.7

Table 2. CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels produced with the Hydroprocessed Esters and Fatty Acids (HEFA) Fuel Conversion Process

Region	Fuel Feedstock	Pathway Specifications	Core LCA Value	ILUC LCA Value	LS_f (gCO_2e/MJ)
Global	Tallow		22.5		22.5
Global	Used cooking oil		13.9		13.9
Global	Palm fatty acid distillate		20.7	0.0	20.7
Global	Corn oil	Oil from dry mill ethanol plant	17.2		17.2
USA	Soybean oil		40.4	24.5	64.9
Brazil	Soybean oil		40.4	27.0	67.4
Global	Soybean oil		40.4	25.8	66.2
EU	Rapeseed oil		47.4	24.1	71.5
Global	Rapeseed oil		47.4	26.0	73.4
Malaysia & Indonesia	Palm oil	At the oil extraction step, at least 85% of the biogas released from the Palm Oil Mill Effluent (POME) treated in anaerobic ponds is captured and oxidized.	37.4	39.1	76.5
Malaysia & Indonesia	Palm oil	At the oil extraction step, less than 85% of the biogas released from the Palm Oil Mill Effluent (POME) treated in anaerobic ponds is captured and oxidized.	60.0	39.1	99.1
Brazil	Brassica carinata oil	Feedstock is grown as a secondary crop that avoids other crops displacement	34.4	-20.4	14.0
		Feedstock is grown as a			

With focus on net GHG LCA reductions

* Petro-jet baseline = 89 gCO_2e/MJ
* CORSIA requires >10% reduction (<80.1)
* Many airlines are committing to 50%+ reductions (<44.5)
* To achieve 2050 goals, reductions will need to approach 100%, with some achieving carbon negativity

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XX Conferencia Internacional sobre PALMA DE ACEITE

EL PODER TRANSFORMADOR DE LA PALMA DE ACEITE

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Gracias