SPARC
Southeast Partnership for Advanced Renewables from Carinata

10th Carinata Biomaterials Summit

Next Steps for SAF
Sustainable Aviation Fuel

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.

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Steve Csonka
Executive Director, CAAFI

15Mar'23

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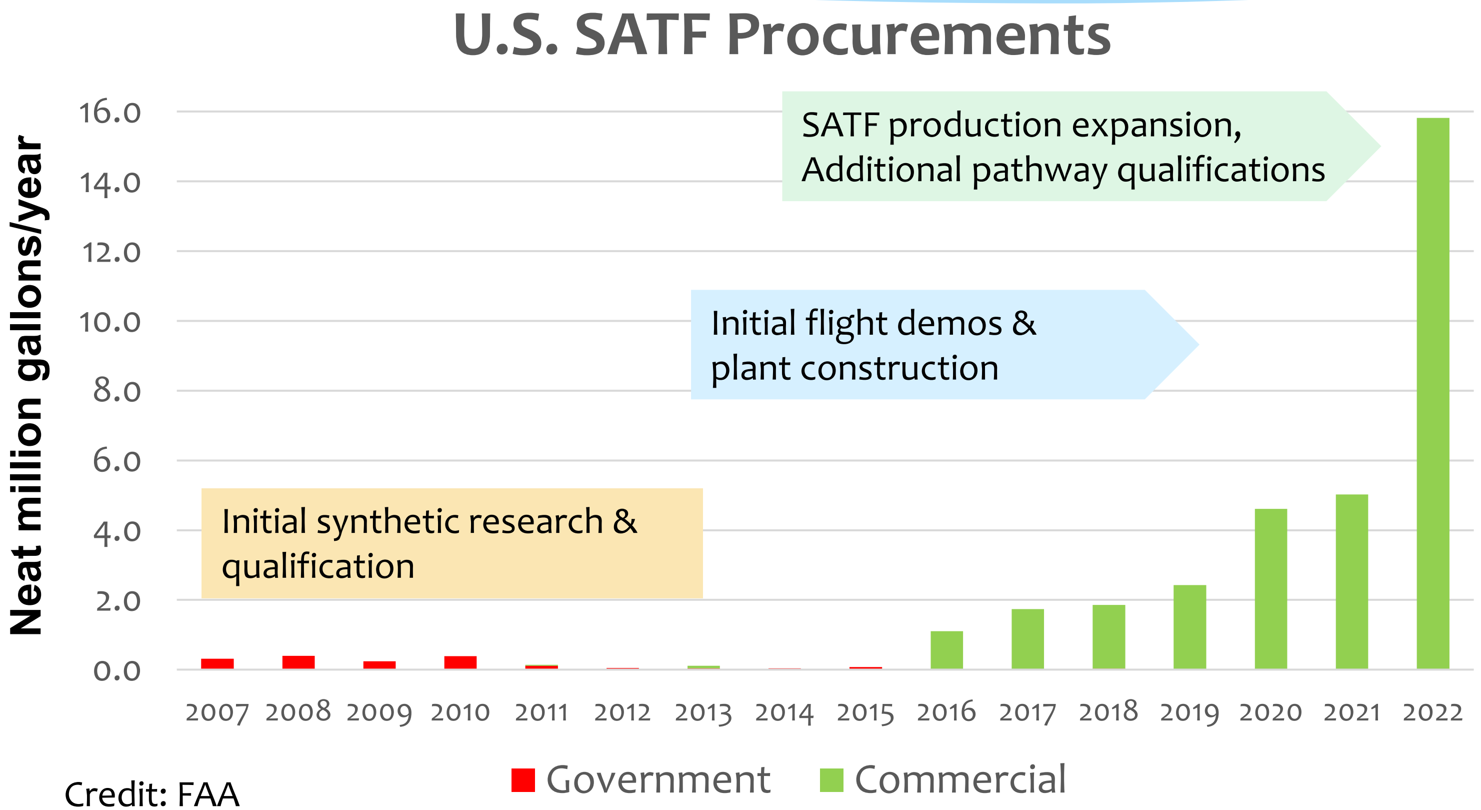
Where we stand on U.S. SAF consumption

Initiation underway, still early

- **Seven years of sustained commercial production and use**
- **Commercial & General 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.
2022 data as of September 2022

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U.S. SAF production forecast

Announced intentions, neat*

Est. Year-end Production (M gpy)

~15 M

By YE '23 (~55 M)
- LanzaJet Freedom Pines 10
- Montana Renewables Great Falls 30

2024 (~450 M)
- gevo Net Zero-1 SD 55
- Phillips 66 Rodeo 290
- AEMETIS Carbon Zero #1 Riverbank 22
- Montana Renewables Great Falls' +30

2025 (~992 M)
- Diamond Green Diesel Port Arthur 235
- world energy Paramount B 250
- USA BioEnergy (Renewable Energy Solutions) Bon Wier, TX 26
- Fulcrum BioEnergy Centerpoint 31

2026 (~1,415 M)
- AEMETIS Carbon Zero Riverbank+ 22
- LanzaJet Hennepin 120
- world energy Houston 250
- Fulcrum BioEnergy Trinity 31

2027 (~1,445 M)
- SkyNRG Americas NW #1 30

2028 (~1,470 M)
- Velocys Bayou Natchez, MS 25
- Tallgrass Tbd, Midwest 135

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

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

SAF: from a diverse set of world-wide feedstocks

Wastes, residues, purpose grown, circular-economy byproducts

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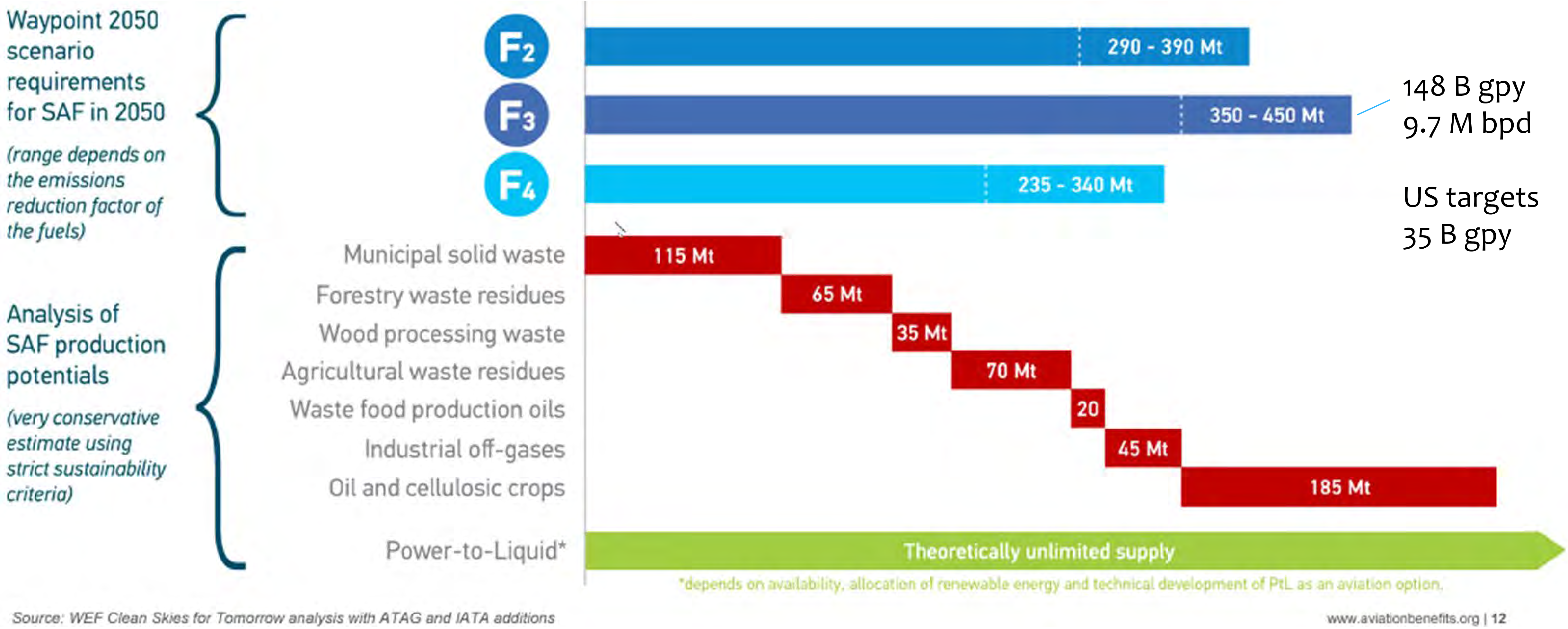
SAF-production-potential outlook: 2050

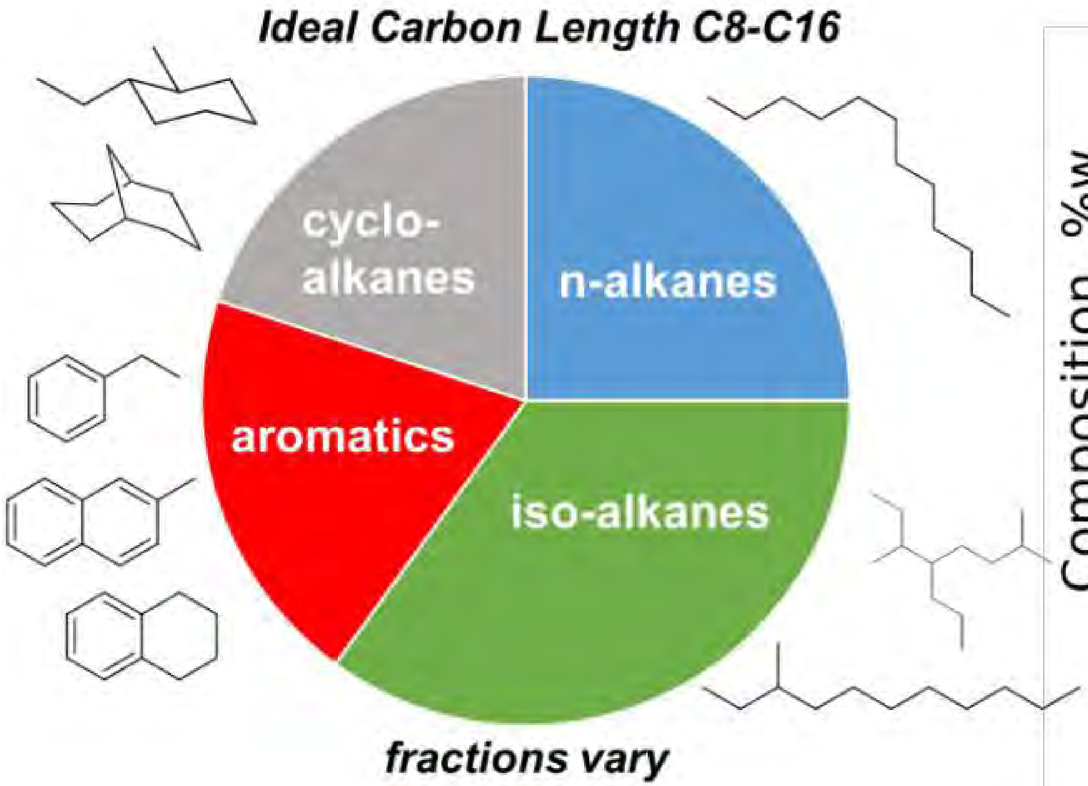
Targets of opportunity with low ILUC and affordability

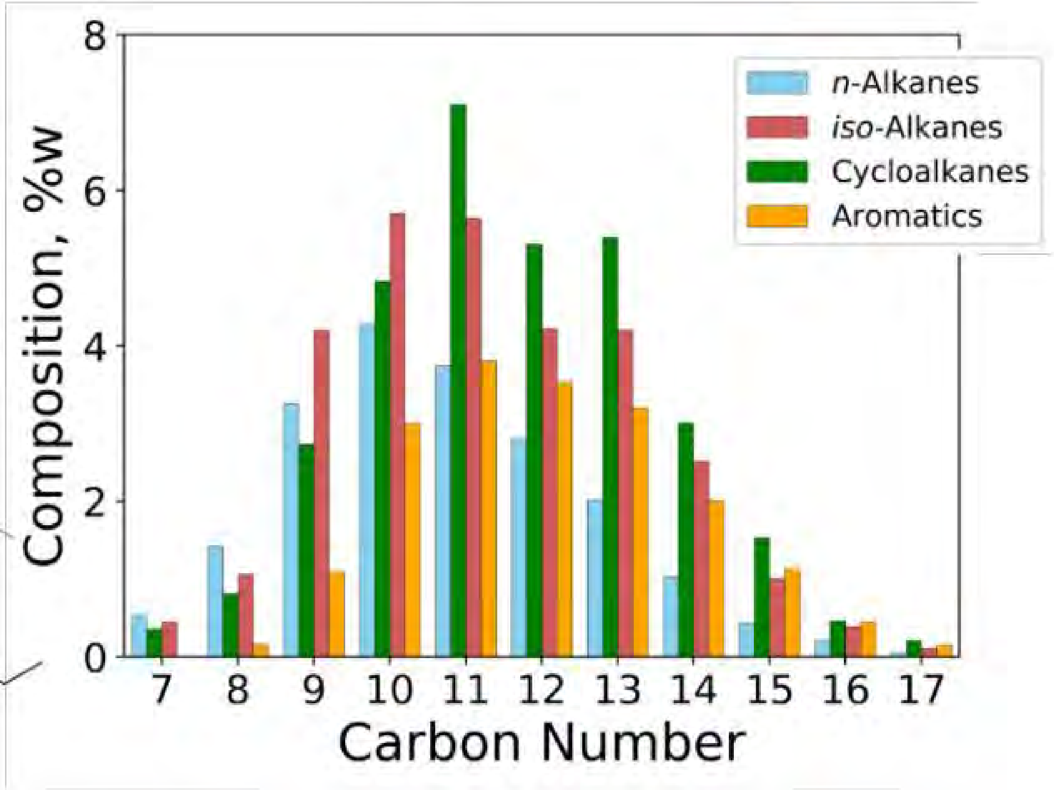


148 B gpy
9.7 M bpd

US targets
35 B gpy

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

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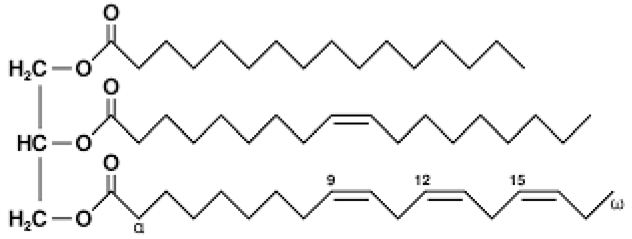
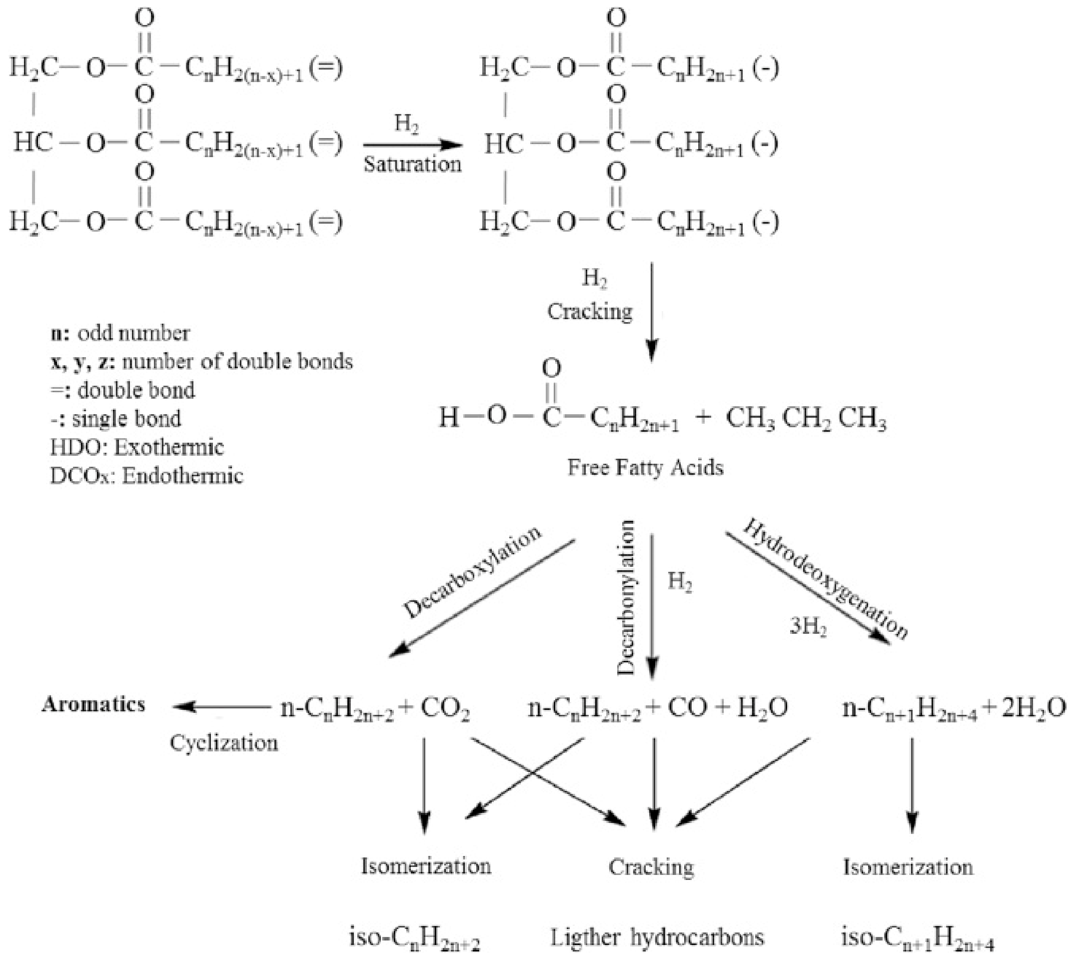
Lipid conversion solutions & R&D remaining

- **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

Lipid multi-generational development plan (MGDP)
Action Area, Workstream, Activities: FI.1, FI.2, and FI.3

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)

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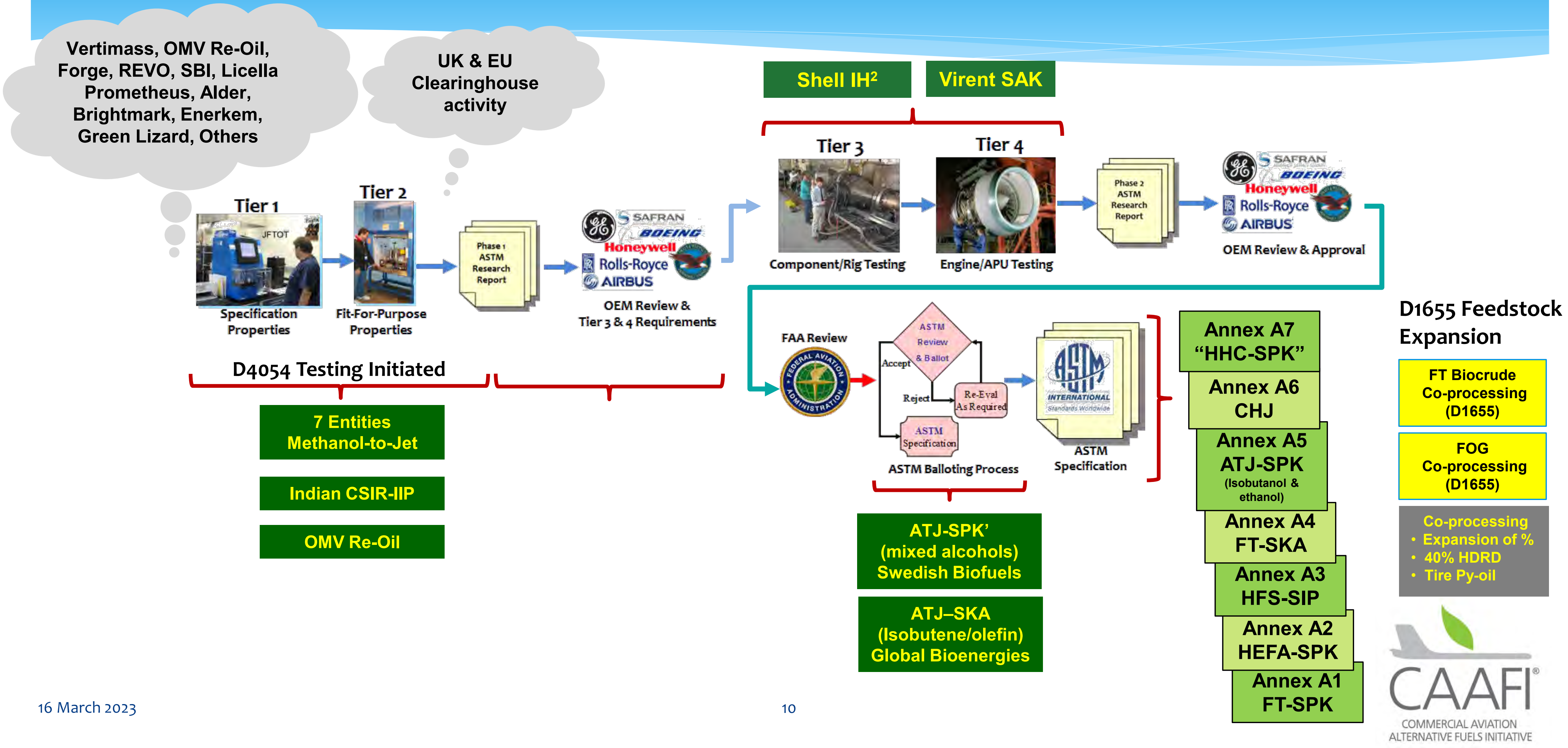
Pathway qualification progress



Co-processing:

Blending bio-crude liquids with petroleum streams at various points in an existing refinery to produce fuels with lower carbon intensities

* Viewed as way to achieve significant scale more quickly …
  * Without CapEx burden of stand-alone biorefineries
  * Leveraging existing distribution infrastructure; foregoing need for SAF blending
* Caution: renewable carbon in finished fuel products not uniformly distributed
* Definitions added to ASTM D1655, *Annex A1. FUELS FROM NON-CONVENTIONAL SOURCES*
  * Two existing Co-processing pathways
    * 5% v/v F.O.G. (to enable HDRD production (e.g. BP Cherry Point))
    * 5% v/v FT biocrude (plan for Fulcrum at Marathon Anacortes)
  * Three new Task Forces
    * Use of pyrolysis oil from tire deconstruction – P66
    * Increasing v/v limits (perhaps to 30%) – BP
    * Use of HVO (perhaps at 40%) & re-refining of slop/transmix/off-spec – Exxon Mobil

Promising emerging technologies / feedstocks

* Those that lower cost or increase value of total production slate
  * Catalytic processes
  * Higher carbon utilization from feedstocks
  * Lower CapEx and/or Lower OpEx – enabling use of low-cost, plentiful, 24x7 supply
  * Integrated 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
* In some other cases, difficult to envision near-term tangible progress

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