

Sustainable Alternative Jet Fuel - Scene Setting discussion

**DOE / EERE / BETO SAJF Workshop:
Macon Marriott City Center
Macon, GA
14-15Sep'16**

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14Sep'16

SAJF Sustainable Alternative Jet Fuel

a.k.a. aviation biofuel, biojet, alternative aviation fuel

Alternative: Creating synthetic jet fuel by starting with a different set of hydrocarbons than petroleum ... a synthetic comprised of molecules essentially identical to petroleum-based jet (in whole or in part) – **enables drop-in approach – no changes to infrastructure or equipment**

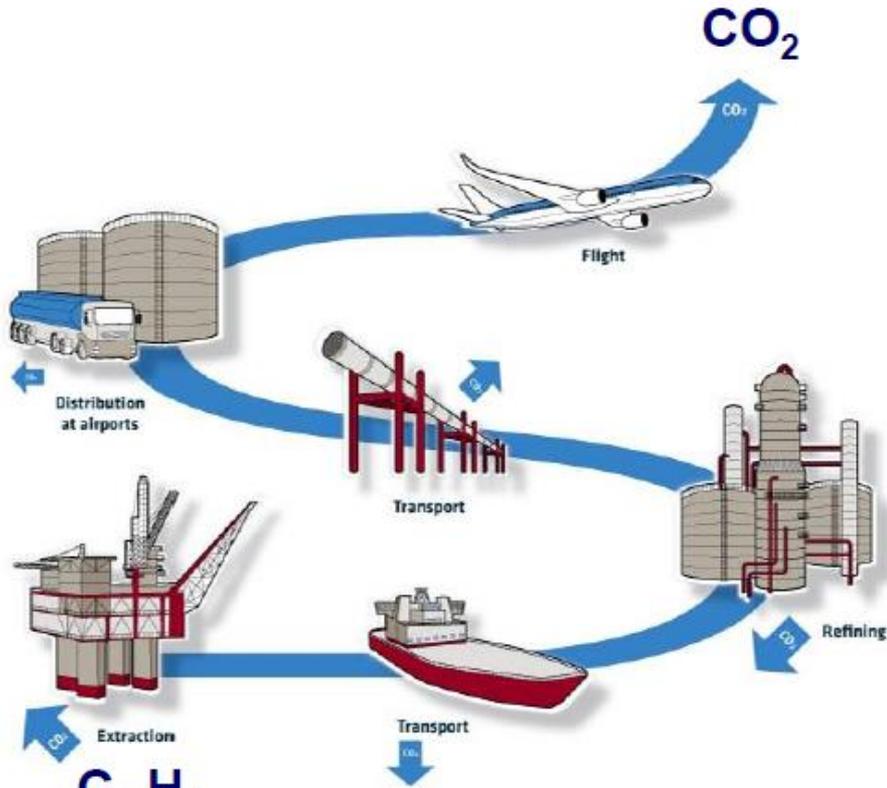
Sustainable: Doing so while taking Social, Economic, and Environmental progress into account

Jet Fuel: Delivering the properties of ASTM D1655

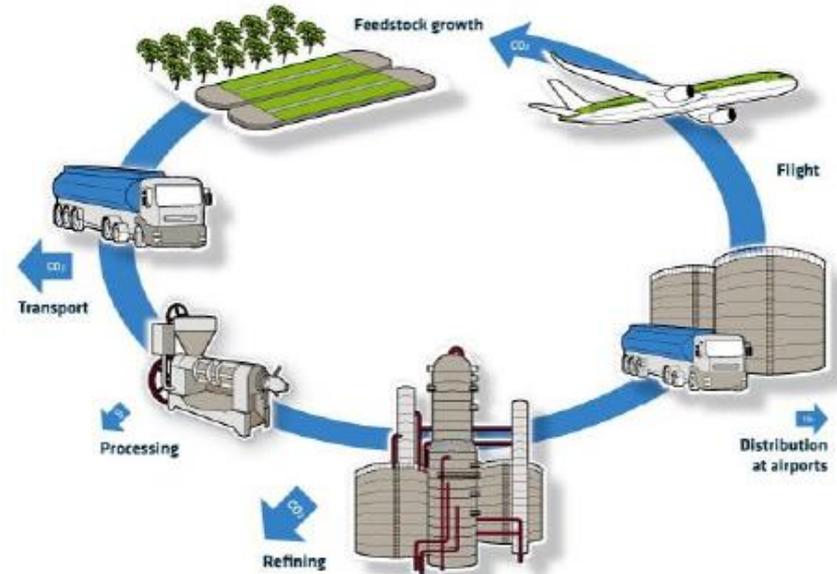
Net LCA GHG reduction: Benefit comes from leaving carbon molecules in the ground; Instead, utilizing the carbon already in the biosphere via recycling or dual use

Achieving net LCA GHG reduction

Reduction in carbon being introduced to biosphere



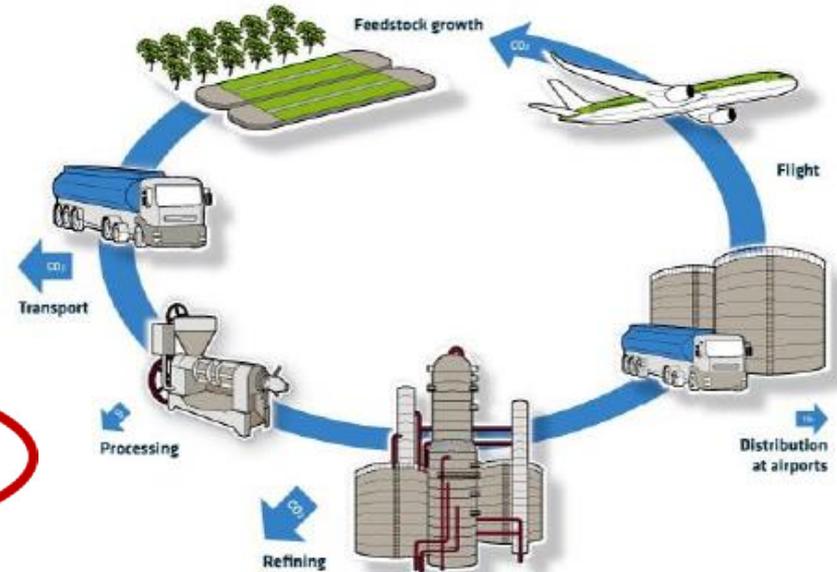
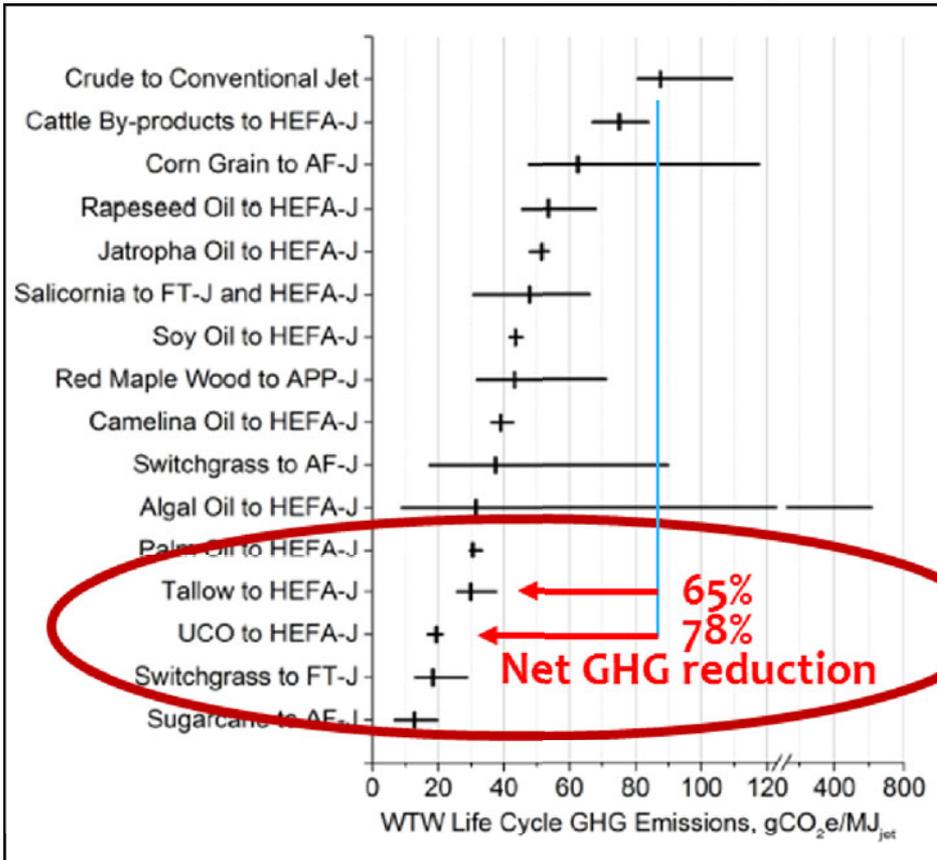
Petroleum based Jet



Sustainable Alternative Jet Fuel

Achieving net LCA GHG reduction

Reduction in carbon being introduced to biosphere

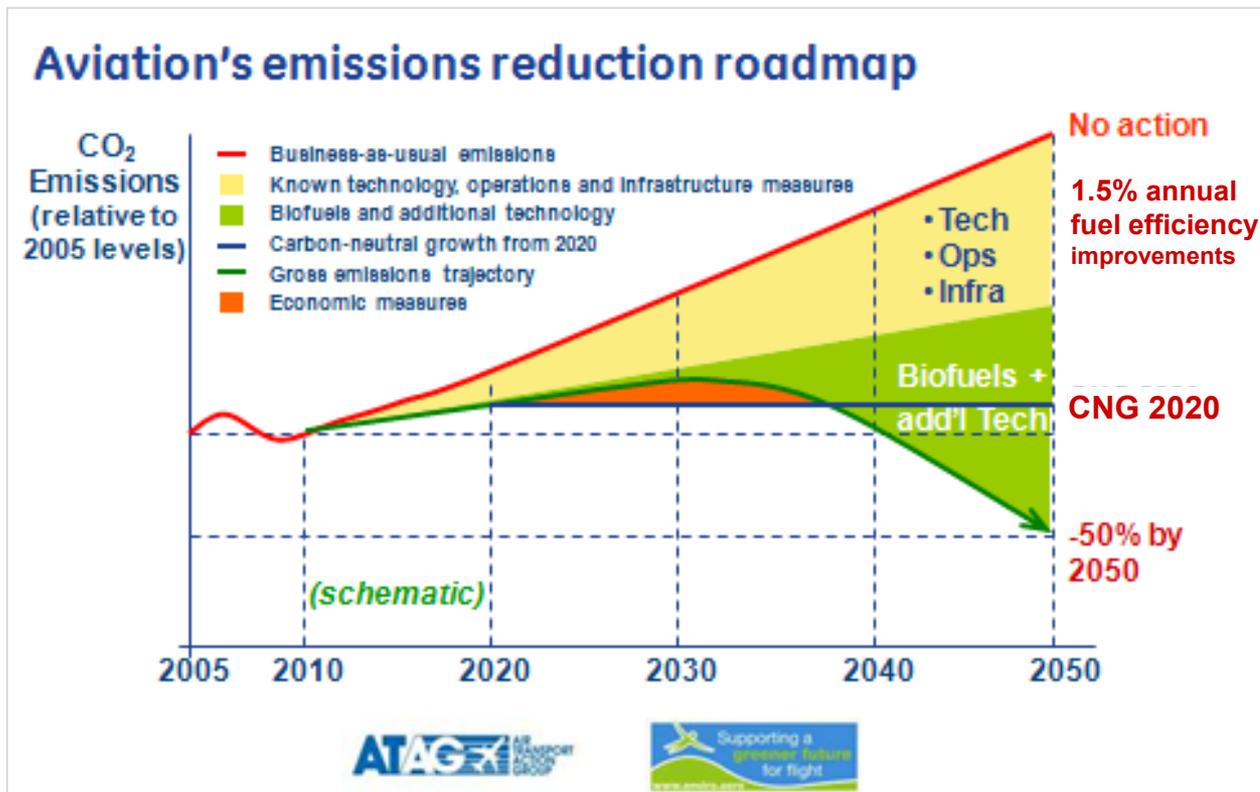


Sustainable Alternative Jet Fuel

Com'l Aviation's CO₂ commitments

To decouple carbon growth from demand growth

SAJF a key component of GHG containment strategy



This industry commitment is currently being converted into regulation through an ICAO/CAEP “basket of measures”:

- * CO₂ Standards
 - * MBMs – will monetize carbon
- Similar commitment from BizAv & DOD

Overall industry summary:

- * **Industry aligned on need! Com'l, BizAv, US DOD = 23B gpy in US**
 - * Demand / interest is not the limiting factor
- * **Other challenges we've met:**
 - * Technical viability proven & versatile solutions identified
 - * Feedstock sources / volumes validated
- * **Modest amounts of SAJF coming online**
 - * AltAir from Mar'16, followed by three DPA facilities in '18, ...
 - * Several others in development
- * **Challenges remaining? Sure:**
 - * Risk, **affordability**, financing, execution, more feedstocks and processes
 - * Working a full range of Public-Private-Partnership activities to break down barriers, lower risk, facilitate supply

SAJF offtake agreements

Beyond numerous demonstration programs neat quantities



SAJF offtake agreements

Beyond numerous demonstration programs neat quantities



48 A350 deliveries
10% blend



Supply
from 2018

Tba



Tba (wk of 19Sep)



10M gpy, 10 yrs



Up to 40M gal
Over 5 yrs (MOU)

NESTE



(Bioport on demand)



BRITISH AIRWAYS



180M usg
over 11 years

First refinery online!

AltAir Fuels in Paramount, CA

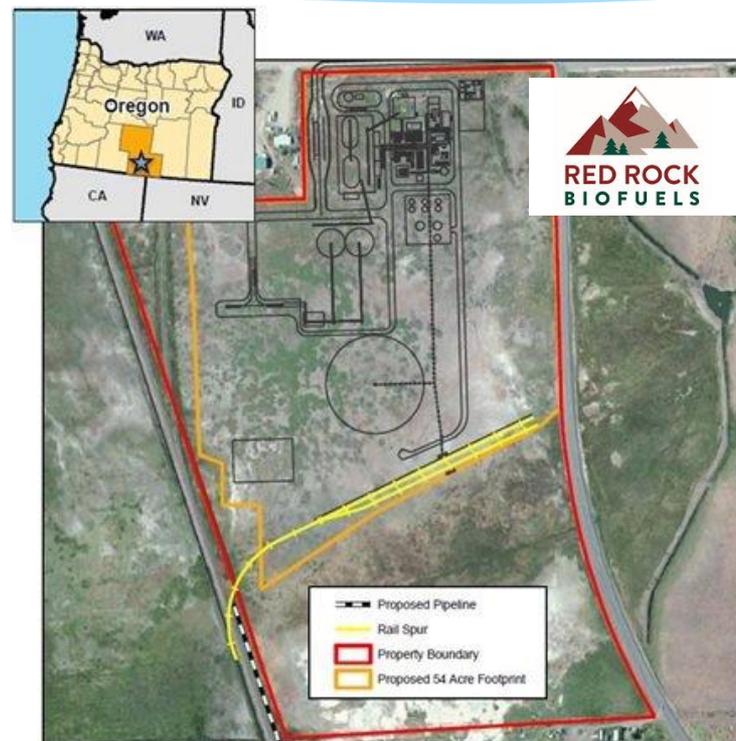


- First dedicated US production facility for HEFA-SPK and HDRD fuels with ongoing production
- Repurposing of Alon refinery
- Tallow feedstock initially

- * 40M gpy nameplate capacity in “Phase 1”
- * SAJF being delivered to airlines and suppliers
 - * United (LAX), WFS (Gulfstream), SkyNRG (KLM)
- * HDRD (F76) being delivered to Navy under DLA FY’16 contract
- * Ownership evaluating 5-7X expansion in next 2-3 years

DPA Recipient: Red Rock Biofuels

- * 16 M gpy of renewable, liquid transportation fuels
 - * From 175,000 tpy of woody biomass
 - * 3M gpy SAJF offtake agreement from each of Southwest Airlines and FedEx
 - * \$70 million DPA Title III award for ~\$200 million refinery
- * Replicable approach targeting 10 additional sites
 - * E.g. - working with CAAFI in southeast F2F2 State Initiative



TCG Global gasifier
Velocys FT reactors
Haldor Topsoe (or Valero) upgrading

DPA Recipient: Fulcrum Bioenergy

- * 10-11 M gpy syncrude production plus power – FT process
 - * From 200,000 tons of post-recycled waste
- * Subsequent plants at 3-6X size; targeting 8 plants by 2022 delivering 300 M gpy middle distillates



TRI Gasifier, EFT FT unit
Waste agreements
comprising ~4% of US
total landfill volume



WASTE CONNECTIONS INC
Connect with the Future®

- * Replication approach →



Courtesy Fulcrum-Bioenergy
<http://www.fulcrum-bioenergy.com/index.html>

19 September 2016



DPA Recipient: Emerald Biofuels

- * **Emerald One: 88 M gpy HDRD capacity from conversion of lipids**
- * **Development program to achieve >500M gpy portfolio**



Non-edible oil feedstocks
Honeywell UOP Green
Diesel/Jet Technology
Port Arthur, TX ?

Courtesy Beaumont Enterprise, photo by Jake Daniels
<https://emeraldonellc-public.sharepoint.com/>

Other commercial activity

- * Several entities are engaged in com'l development of existing and pending qualified pathways
- * CAAFI working with several producers in feasibility studies and business development efforts (Farm-to-Fly 2.0 State Initiatives)
- * Numerous high quality applications to DOE IBR and USDA CAP and Foundational programs expected
- * Other commercial-scale technology demos to occur in next 12 months that should prove to be enabling

SAJF approved production pathways

Approved

→ Syngas FT (FT-SPK)	50% max blend
→ Hydroprocessed lipids (HEFA-SPK)	50% max blend
→ Biochem sugars (HFS-SIP)	10% max blend
→ Syngas FT w/ aromatic alkylation (FT-SPK/A)	50% max blend
→ Isobutanol conversion (ATJ-SPK)	30% max blend

- * These approval represent significant bodies of effort
 - * 3-5 years, \$10-15 M investment
 - * **Process begs for improvements**
- * Entities may not achieve commercialization for several years following approval

ASTM D7566 qualification activity

Approach	Feedstock	Notes
SK/SAK (CCS-APR) CH	Sugars Lipids	Virent: Steps 5/1 ARA: Step 3 r.r. in devel.
HEFA Expansion	Lipids – renewable diesel	LanzaTech, UOP
HDCJ (pyrolysis)	Cellulose – biocrude	Chevron, BP, Phillips66
Co-processing	Biocrude	Byogy, LT, SwB
CATJ-SKA	Sugars – alcohols	Vertimass, Poet ?
ATJ-SPK expansion	Sugars – ethanol / xOH	GranBio, UOP, LT, SwB

In-Process

ASTM D7566 “pipeline” examples

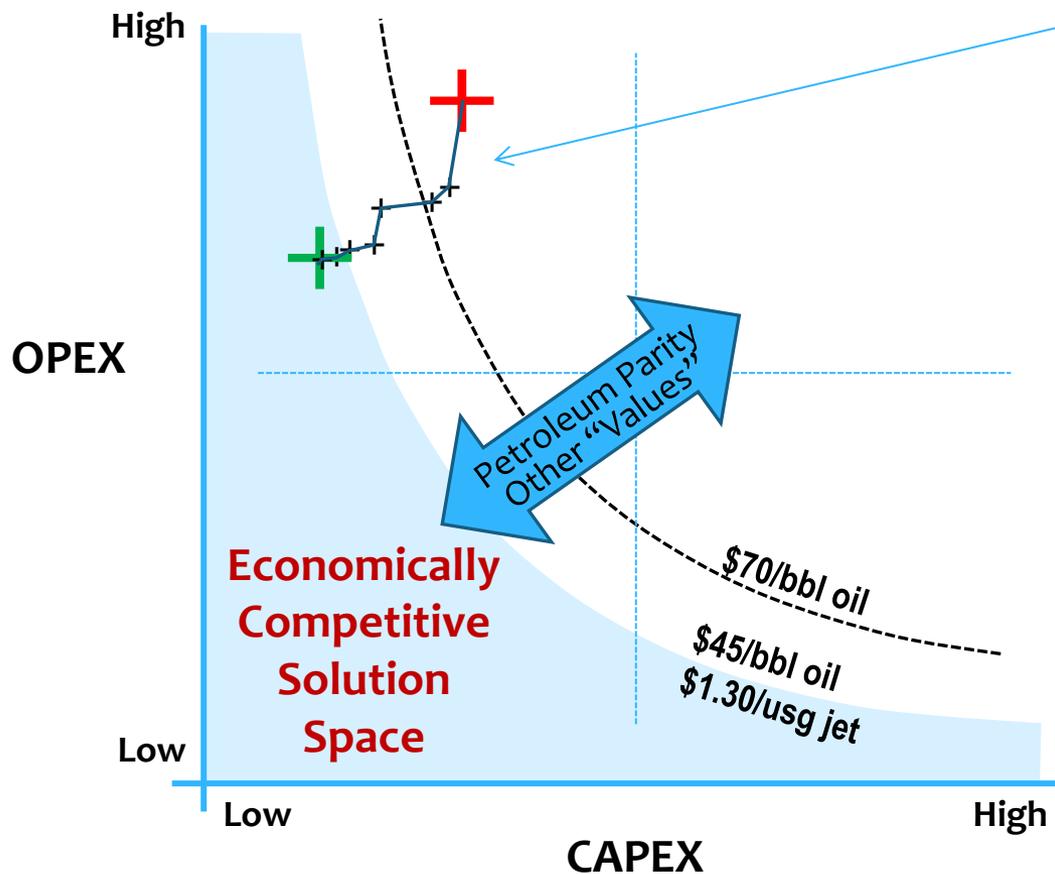
Approach	Feedstock	Notes
1) CHyP (syngas, non-FT)	Cellulose	Proton Power
2) Microbial conversion	Sugars - isobutene	Global Bioenergies
3) HTL	Cellulose	Algenol, Genifuel, Sapphire
4) Catalytic HTL	Cellulose	Licella, Muradel, QUT
5) SBI CGC PICFTR	Lipids - biodiesel	SBI Bioenergy
6) CCL	Lipids	Tyton
7) Hydrogenotrophic Conv.	CO ₂ / Producer Gas	Kiverdi
8) Cyanobacterial Prod.	CO ₂	Joule
9) STG+ GTL	c1-c4 Gas / Syngas	Primus
10) Acid Deconstruction	Cellulose	Mercurius
11) Thermal Catalytic Conv.	Cellulose	Shell/CRI/IH ₂
12) Thermal Deoxyg.	Lipids	Forge Hydrocarbons
13) Ionic Liquid Decon.	Cellulose	JBEI, tbd
14) Metal Catalytic Conversion	Cellulose	Purdue research
15) Enzymatic Conversion	Lignin	GLBRC & JBEI
...	...	Renmatix, Cool Planet, Infinite Fuels, Anellotech, ...

Pre-Pipeline

Why we care about the pipeline

- * **We need SAJF affordability**
 - * Processes applicable to low-cost, available feedstocks
 - * Lowering CapEx, OpEx, Enabling margin; using byproducts
 - * Leverage existing biofuel infrastructure or adjacent production
- * **We need SAJF availability**
 - * Available for processing regionally, world-wide, with available, applicable feedstocks
 - * No single feedstock is of sufficient volume
 - * Feedstock development cannot realistically progress to scale without the potential for offtake from multiple producers
- * **We need continuous / sustained commercialization activity**

Achieving cost competitiveness



Enabled by:

- * R&D
- * D&D Support
- * Policy
- * Commercialization learning-curve progression
- * Build-out – Scale
- * Competitive uses
- * Valued co-products
- * ...

Enabling approaches informed by analytics

Ex: Lipid pathway applicability

Conversion of fats, oils & greases

SAJF Pathways

- * FT-SPK, FT-SPK/A
- * HEFA-SPK
- * HFS-SIP
- * ATJ-SPK

- HW UOP: Ecofining / GreenJet
- Neste: NEXBTL
- UPM:

SAJF Intentions (first facilities)

AltAir Fuels	40 M gpy (30% jet)
Emerald Biofuels	88 M gpy
SG Preston	120 M gpy (77% jet)

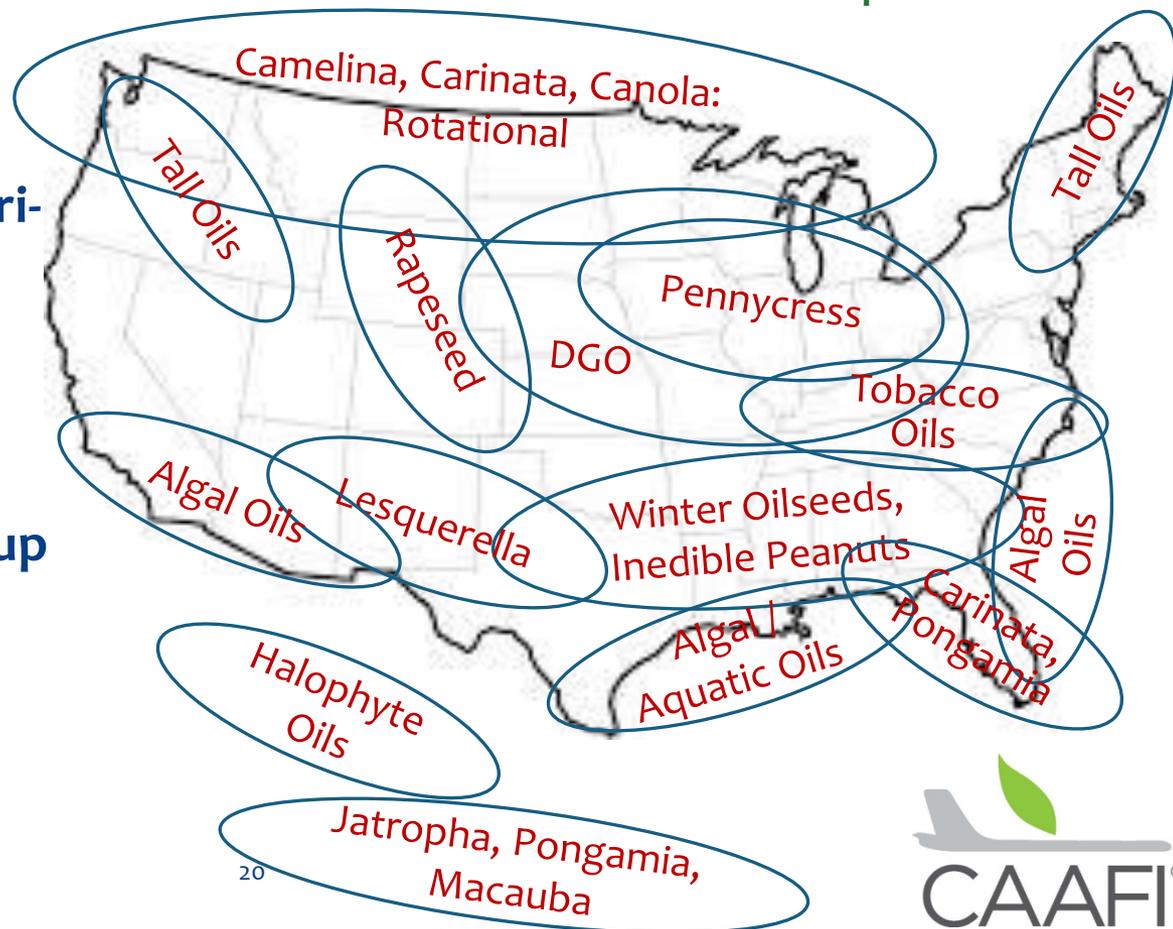
- * Hydrotherm oils (CH) → ARA - unique value prop. => 100% drop-in
- * Renewable Diesel → Unlock existing 1 B+ gpy HDRD production
- * Refinery Co-processing → Front-end: Blend with crude
Mid: FCC, HC, Coker ?
Back-end: Hydroprocessing ✓
- * SBI → Unlock existing biodiesel production
- * Forge, Tyton, ... → Toward improved affordability

Lipid feedstocks

Potentially enabling of significant production ...

- * Multiple conversion processes
- * Multiple feedstock developers
- * Multiple producers
- * Multiple low LUC/ILUC agri-based feedstocks, **plus:**
 - * White Grease, Chicken Fat, Tallow
 - * UCO / Yellow Grease
 - * Brown Grease, Biosolids
- * Easier supply chain scale-up leveraging biodiesel and RD production capacity
- * Lowered H2 cost & availability helps

Targeting most sustainable solutions:
Low, or Zero, impact LUC/ILUC & F-v-F solutions;
Environmental Services a plus.



Summary of needs

Reference the Federal Alternative Jet Fuel R&D Strategy

- * **Four categories of need identified:**

1. **Feedstock Development, Production and Logistics**
2. **Fuel Conversion and Scale-up**
3. **Fuel Testing and Evaluation**
4. **Integrated Challenges**

- * **Modelling, TEA, LCA form a basis for informing the strategic approaches to be taken with the remainder**

- * **Need your insight on key needs, missing elements, and prioritization**

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