Aviation Biofuel Update

BRDB TAC 3Q'16 Meeting

Madison, WI

Wed, 17Aug'16

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COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

13Jul'16

Sustainable Alternative Jet Fuel - Progress & Challenges

DOE Bioenergy 2016, Breakout Session 1-D:

Launching Renewable Aviation Fuels

Walter E. Washington Convention Center
Washington DC
Wed, 13Jul'16

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COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

CAAFI – Public/Private Partnership
A reflection of the 23+B gpy US Jet "market pull"

An aviation industry coalition established to facilitate and promote the introduction of sustainable alternative jet fuel (SAJF)

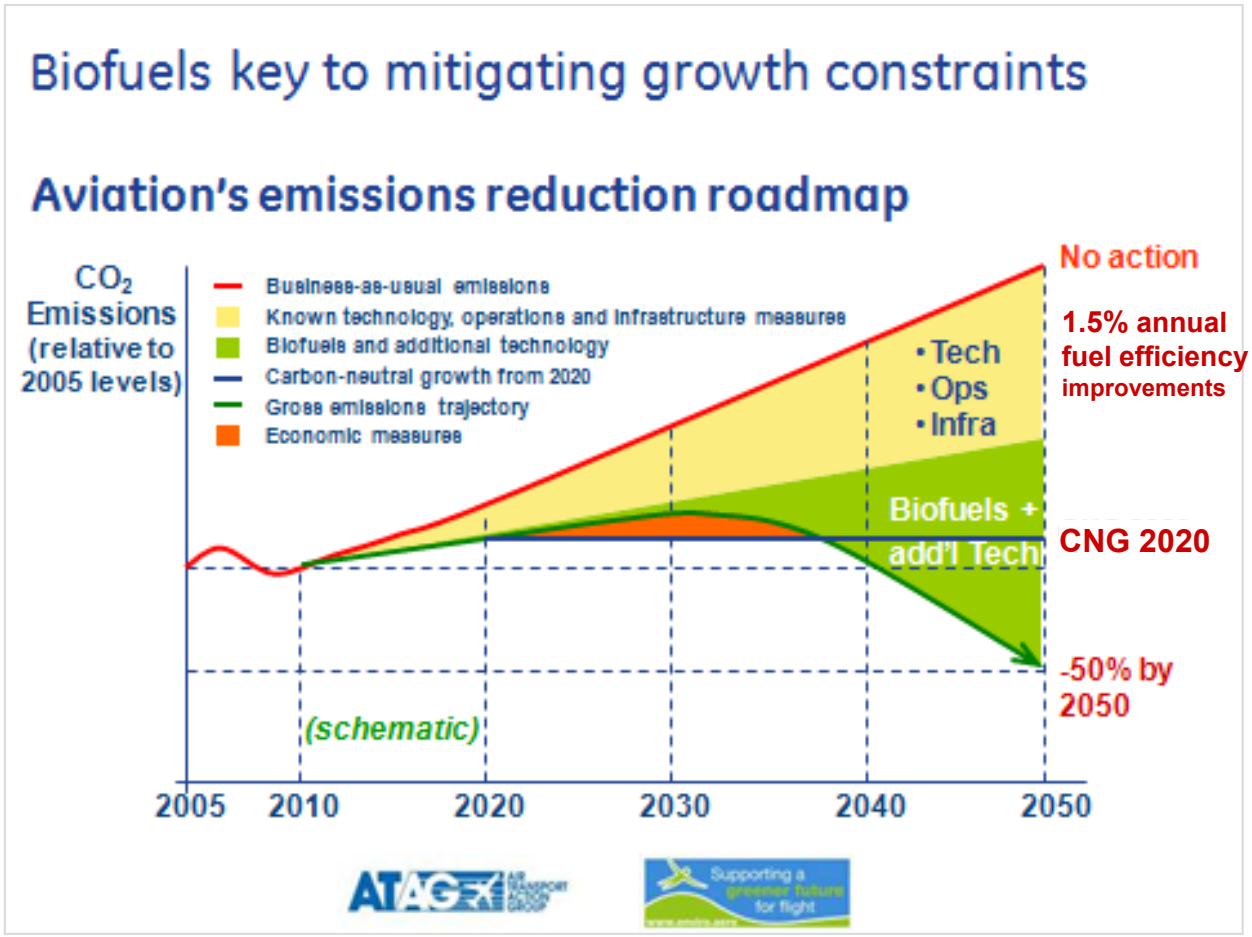
Goal is development of non-petroleum, drop-in, jet fuel production with:

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

Synthetic kerosene, primarily from renewable sources

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

Com'l Aviation's commitment
To decouple carbon growth from demand growth



This commitment is currently being converted into pending regulation through an ICAO/CAEP "basket of measures":

* **CO_2 Standards**
* **MBMs – will monetize carbon**

Similar commitment from BizAv & DOD

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Overall industry summary:

- Industry aligned on need! Com'l, BizAv, US DOD
- Other challenges we've met:
  - Technical viability proven & versatile solutions identified
  - Modest amounts of SAJF coming online
    - AltAir from Mar'16, followed by three DPA facilities in '18, …
- 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

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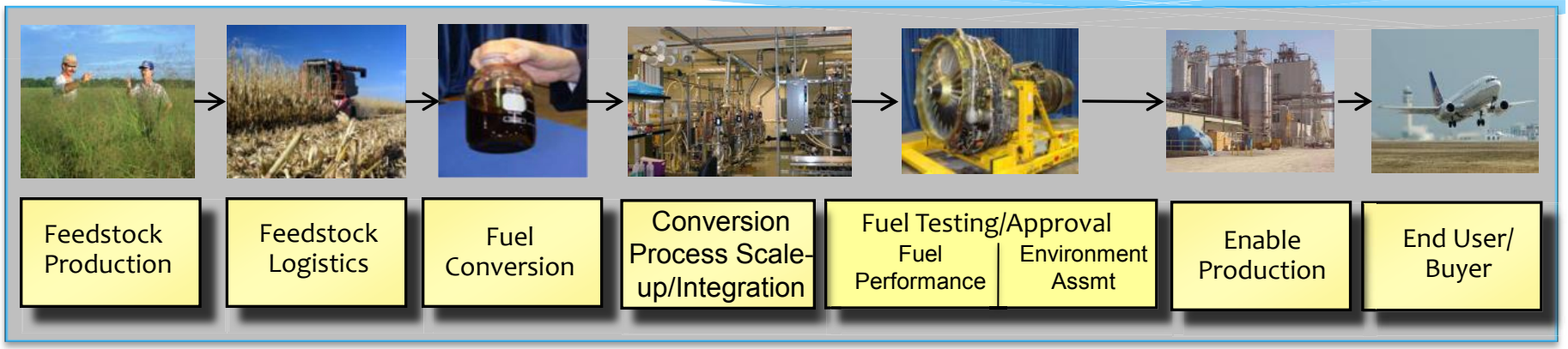
Where we're working
CAAFI facilitation – broad and deep

- Feedstock Development
- Pathway Development
- Sustainability
- Price Point
- Risk Reduction
- Institutional Alignment
- Analysis / Tools
- Regional Engagement
- Int'l Engagement

… via cooperative R&DDD efforts

Directly and through several PPPs



USDA: BCAP & CIP, Feedstock Development Center Grants, AFRI/NIFA Caps

DOE: FS&L, BRCs
ARPA-E: PETRO, TERRA, pheno-

DOE & DOD: R&D grants

USDA & DOE: R&D grants, IBR

FAA & DOD: C/Q Fuel testing

FAA, DOD, & NASA: Enviro Analysis

USDA, USN, & DOE: Defense Production Act and Biorefinery Program

EPA: Renewable Fuel Standard

DOD/DLA & Airlines: fuel purchase

FAA: Guidance for Airports

Airline offtake agreements

… plus OEMs, and more in process

United	+	AltAir Fuels	=	5 M gpy from 2016
United	+	Fulcrum BioEnergy	=	90-180 M gpy Over 10 yrs
Alaska Airlines	+	Hawai'i BioEnergy	=	Supply from 2018
Cathay Pacific	+	Fulcrum BioEnergy	=	375M usg
British Airways	+	~~Solena Group~~	=	180M usg over 11 years
Southwest	+	Red Rock Biofuels	=	3 M gpy
FedEx	+	Red Rock Biofuels	=	3 M gpy

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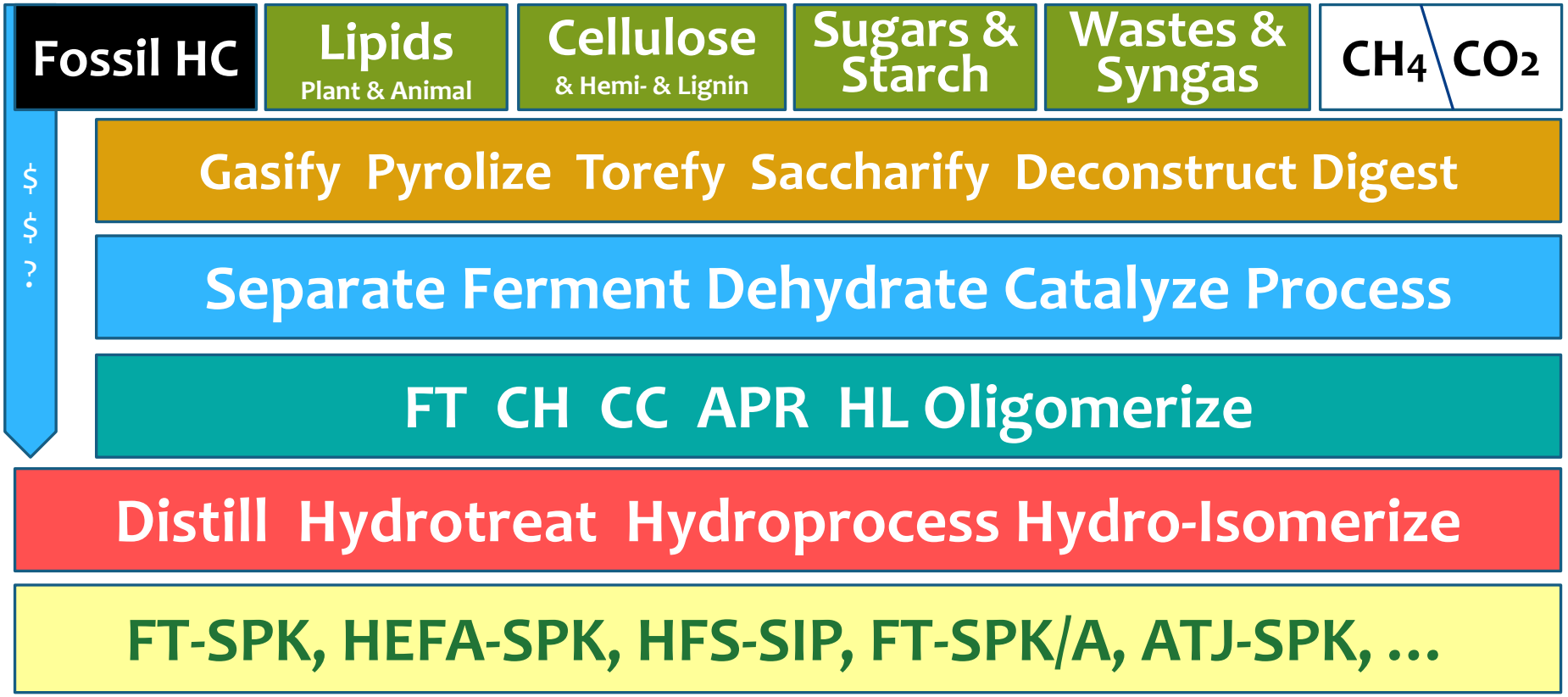
Other commercial activity

* Several entities are engaged in commercial development of existing and soon-to-be 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
* Other commercial-scale technology demos to occur in next 12 months that should prove to be enabling

SAJF conversion mechanisms

Challenge … doing it at the price of petroleum refining



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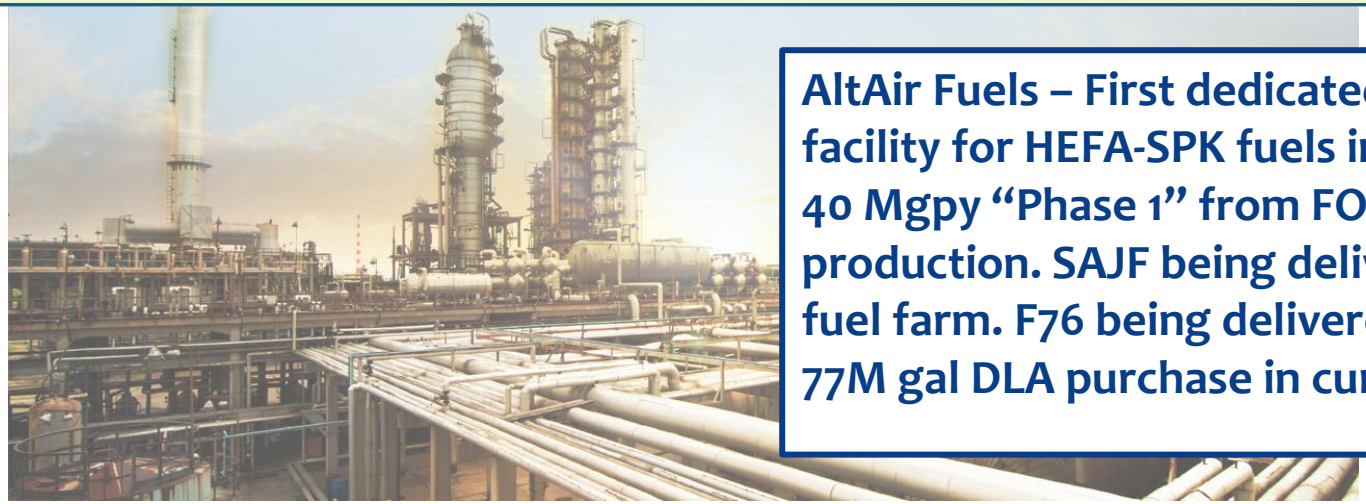
SAJF approved production pathways

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



AltAir Fuels – First dedicated US production facility for HEFA-SPK fuels in Paramount, CA, 40 Mgpy "Phase 1" from FOG. Currently in production. SAJF being delivered to the LAX fuel farm. F76 being delivered to Navy via 77M gal DLA purchase in current fiscal year.

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ASTM D7566 qualification activity

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

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ASTM D7566 "pipeline" examples

Pre-Pipeline

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/IH2
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

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Why we care about the pipeline

* We need SAJF affordability
  * Processes applicable to low-cost, available feedstocks
  * Lowering CapEx, OpEx; Enabling margin via byproducts
* We need SAJF availability
  * Available for processing regionally, world-wide, with available, applicable feedstocks
  * Feedstock development cannot realistically progress to scale without the potential for offtake from a bioproduct producer
* We need commercialization activity / fuels soon
  * Leverage existing biofuel infrastructure or adjacent production

Ex: Lipid pathway applicability
Conversion of fats, oils & greases

SAJF Pathways

Approved

- 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	5 x 120 M gpy (77% jet)

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In- Process & Pipeline

- Hydrotherm oils (CH)
- Renewable Diesel
- Refinery Co-processing
- SBI
- Forge, Tyton, …

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In- Process & Pipeline

- 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

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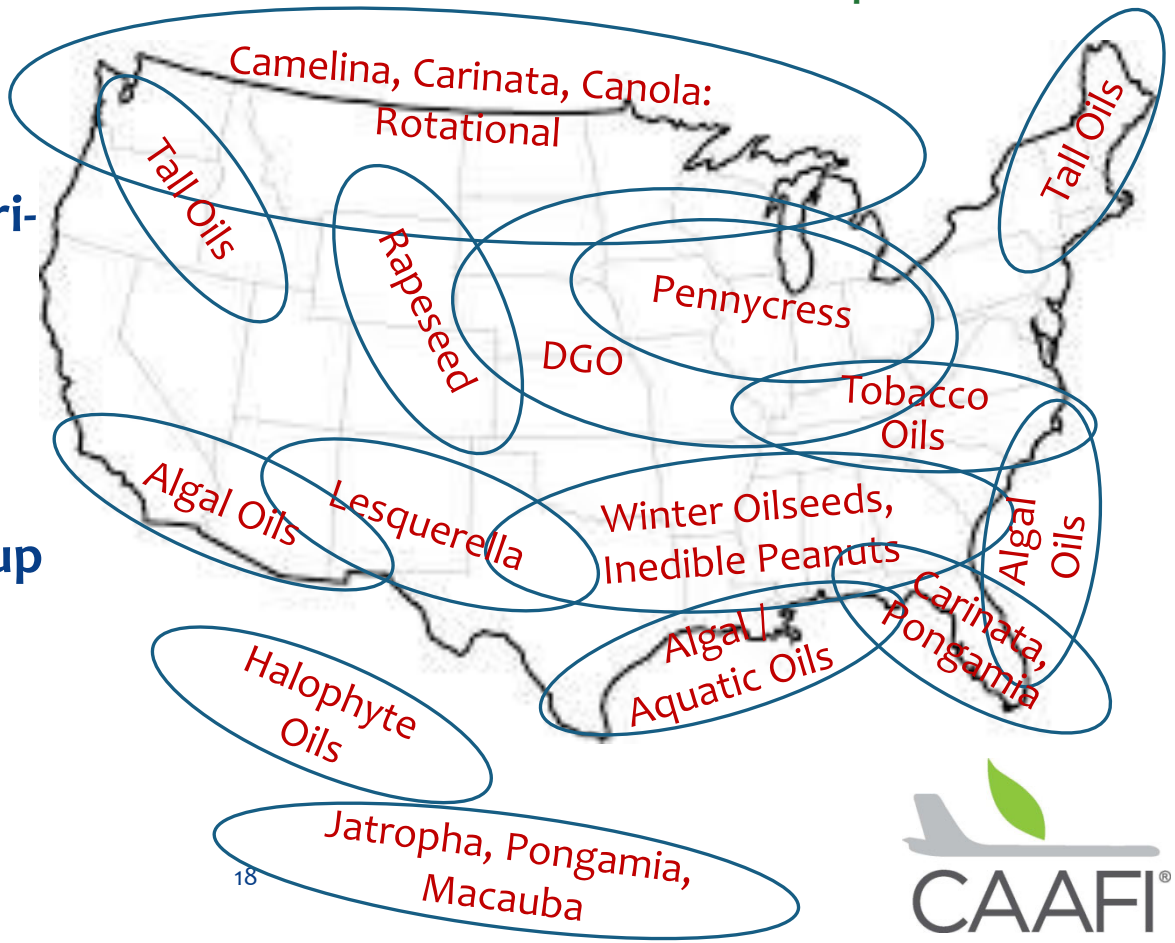
Lipid feedstocks
Potentially enabling of significant production …

- 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.



Recent focus on "waste" evaluations
And similar concepts with enviro-services, co-benefits

- Overcomes challenges associated with "classical" feedstocks – primarily price
- Avoids some challenging issues with "biofuels"
- Solves other landfill / conversion related issues
- Enables technical proving for later conversion to biomasses
- Matches interests of other constituencies

Examples:

- MSW
- Sanitary waste treat.
- Animal waste
- Animal processing
- Industrial wastes
- Forestry residuals

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Signs of progress

* Additional offtake agreements, operational demo's, and new commercial announcements
* Continued State Initiative engagement
* Announcement of Federal AJF R&D Strategy – mirroring findings from NAS/ASEB Low Carbon Aviation Committee
* Progression of ASCENT engagement in Supply Chain development, and NJFCP efforts
* Progress with ASTM "Quick Entry" qualification approach
* ICAO Assembly Agreement in Sep'16 – framework for MBM
* CAAFI Biennial General Meeting, 25-27Oct'16

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