Sustainable Alternative Fuel Use in the Military and Commercial Aviation

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Sustainable Alternative Fuel Use Agenda

• Definitions
• Great Green Fleet 2012 and 2016
• From the Great Green Fleet to the New Normal
• Commercial Aviation Industry
• Cost Competitiveness
• International Interoperability
• Future of Sustainable Alternative Fuels
• Roles for You and Notre Dame
• EYA
Sustainable Alternative Jet Fuel (SAJF)
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
USS Princeton (CG 59) refuels from oiler USNS Henry J. Kaiser (T-AO 187) in the Pacific Ocean.

Royal Australian Navy S-70B Sea Hawk helicopter.

SECNAV and CNO aboard USS Chafee.

USS Princeton (CG 59), USS Nimitz (CVN 68).

2012 GGF DEMONSTRATION
Great Green Fleet Launches

January 2016
U.S. Navy oiler delivering alternative fuel to a Japanese ship

February 2016
Italian oiler delivers alternative fuel to the U.S. Navy

June 2016
11+ million gallons to 9 countries

July 2016
August 2016 – Great Green Fleet arrives in Sydney Harbor
Energy Conservation Measures and Operational Procedures

• Energy Conservation Measures installed to extend the range of the Fleet and keep ships on station longer in between refuelings at sea
  – Stern Flaps
  – Bow Bulbs
  – Propeller Coatings
  – LED Lights
  – Others

• Operational Procedures are conscious energy behaviors to increase our mission capability. Some examples:
  – Steady State Transit
  – Trail Shaft
  – Auto Pilot
  – Low Power Radar Operations
  – Drift Operations
From the Great Green Fleet to the New Normal

• 2016 Energy Efficiency Efforts had measurable results

• Real mission capability was demonstrated through the Fleet-wide employment of energy conservation measures and synthetic fuels.
  – 18,000 Operating Hours’ worth of fuel saved
  – Fuel for 5 ships for a year

• Sustainable alternative fuels are essential to maintain international interoperability

• Strategic flexibility and fuel security result from diversity of global energy supplies
August 2017 -- U.S. Navy awards another contract for 60 M gallons of a 30% blend of F-76 alternative fuel. Fuel delivery started on 1 October 2017.
First flight from continuous commercial production of SAJF, 10 Mar 2016
Fuel from AltAir Fuels, Paramount, CA (HEFA-SPK 30/70 Blend)
Now being delivered to LAX fuel farm for everyone’s upload
Commercial Aviation’s CO₂ Commitments
Decouple carbon growth from demand growth

Biofuels a key component of GHG containment strategy
**Overall Industry Summary:**

Sustainable Alternative Jet Fuel (SAJF) Activity

- SAJF are key for meeting industry’s commitments
  - Aviation enterprise aligned; SAJF delivers net GHG reductions
  - Segment knows how to make it; Activities from FRL 1 to 9
  - Commercial agreements being pursued
  - Pathway identified for fully synthetic (50% max blend today)

- CAAFI originally put in place to work a full range of Public-Private Partnership activities to break down barriers and lower risk: foster, catalyze, enable, facilitate, participate

- Making progress, but still significant challenges – only modest production – focus on enabling commercial viability

- Potential for acceleration a function of engagement & success replication
CAAFI - Public/Private Partnership
A reflection of the 22+B usg U.S. Jet “market pull”

An aviation industry coalition established to facilitate and promote the introduction of alternative aviation fuel

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

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

www.caafi.org
Where CAAFI is working
Facilitation – broad and deep

Feedstock Development
Pathway Development
Sustainability
Price Point
Risk Reduction
Institutional Alignment
Analysis / Tools
Regional Engagement
International Engagement

Research & Development
Certification & Qualification

Environmental
Business

DOE
DOD
USDA
EPA
FAA
NASA
Airlines
Producers
Investors
States
Academia
Industry
Tech.
Commerce
You
Farmers
USDA
...via cooperative R&D efforts
Directly and through several PPPs

Feedstock Production
Feedstock Logistics
Fuel Conversion
Conversion Process Scale-up/Integration
Fuel Testing/Approval
Fuel Performance
Environment Assmt
Enable Production
End User/Buyer

USDA: BCAP & CIP, Feedstock Development Center Grants, AFRI/NIFA Caps
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
DOD/DLA & Airlines: fuel purchase
FAA: Guidance for Airports

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

USDA
DOE
NSF
NASA
FAA
DOD
EPA

CAAFI
SAJF offtake agreements
Beyond numerous demonstration programs

AltAir Fuels + UNITED = 5 M gpy from 2016
World Fuel Services + Gulfstream = 3 M gpy each
Sky NRG + KLM = 3 M gpy each
Fulcrum Bioenergy + CATHAY PACIFIC = 375M usg

United Airlines + Cathay Pacific = 90-180 M gpy
United Airlines + air bp = Over 10 yrs
United Airlines + Southwest = Over 10 yrs

RED ROCK BIOFUELS + FedEx = 3 M gpy each going into Bay Area, CA
SAJF offtake agreements
Beyond numerous demonstration programs

- Total
- Amyris
- Cathay Pacific
- jetBlue
- SG Preston
- Lufthansa
- gevo
- Lufthansa Group
- Neste
- SkyNRG Nordic
- OSL
- KLM
- SAS
- British Airways
- Alaska Airlines

48 A350 deliveries
10% blend
10M gpy, 10 yrs
Up to 40M gal
Over 5 yrs (MOU)
(Bioport on demand)
Focus on new engagement
Focus on new engagement
### SAJF approved production pathways

Annexes to ASTM D7566: D1655 fuel following blending

<table>
<thead>
<tr>
<th>Approved</th>
<th>50% max blend</th>
<th>10% max blend</th>
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<tbody>
<tr>
<td>Syngas FT (FT-SPK)</td>
<td>50% max blend</td>
<td></td>
</tr>
<tr>
<td>Hydroprocessed lipids (HEFA-SPK)</td>
<td>50% max blend</td>
<td></td>
</tr>
<tr>
<td>Biochem sugars (HFS-SIP)</td>
<td>10% max blend</td>
<td></td>
</tr>
<tr>
<td>Syngas FT w/ aromatic alkylation (FT-SPK/A)</td>
<td>50% max blend</td>
<td></td>
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<tr>
<td>Isobutanol conversion (ATJ-SPK)</td>
<td>30% max blend</td>
<td></td>
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</tbody>
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* Commercialization for each in development, in some cases by multiple parties who would use licensing
* Entities may not achieve commercialization for several years following approval
Navy Synthetic Fuel Specification Status

2017
FT & HEFA Added to JP-5 Spec (50%)

2017
SIP Added to F-76 Spec (20%)

2016
SIP Added to JP-5 Spec (10%)

2014
FT & HEFA Added to F-76 Spec (50%)

2013
FT & HEFA Added to JP-5 Spec (50%)

2018
CHCJ Added to JP-5 Spec (100%)

2018
CHCD Added to F-76 Spec (100%)

FT: Fischer-Tropsch
HEFA: Hydrotreated Esters and Fatty Acids
SIP: Synthetic Iso-Paraffins
ATJ: Alcohol to Jet
CHCD: Catalytic Hydrothermolysis Conversion Diesel
CHCJ: Catalytic Hydrothermolysis Conversion Jet

FT: Fischer-Tropsch
HEFA: Hydrotreated Esters and Fatty Acids
SIP: Synthetic Iso-Paraffins
ATJ: Alcohol to Jet
CHCD: Catalytic Hydrothermolysis Conversion Diesel
CHCJ: Catalytic Hydrothermolysis Conversion Jet
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

CAPEX

OPEX

Economically Competitive Solution Space

Petroleum Parity

Other “Values”

- $70/bbl oil
- $45/bbl oil
- $1.30/usg jet

Low

High

Low

High
Qantas Flight – LAX to MEL 28 Jan 2018
Maintain Interoperability
Sustainable Alternative Fuels in Aviation
2010: 50%
Sustainable Alternative Fuels in Aviation

2016: 100%
Sustainable Alternative Energy in Ships

1775: 100%
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Back Up Slides

CAAIFI

Fueling solutions for secure & sustainable aviation
Achieving net LCA GHG reduction
Reduction in carbon being introduced to biosphere

Petroleum based Jet
Achieving net LCA GHG reduction
Reduction in carbon being introduced to biosphere

CO₂

Petroleum based Jet

CₘHₙ

Sustainable Alternative Jet Fuel

Feedstock growth

Distribution at airports

Transport

Refining
Achieving net LCA GHG reduction
Reduction in carbon being introduced to biosphere

Sustainable Alternative Jet Fuel

Net GHG reduction 65%, 78%
Why Aviation cares about SAJF
Sustainable Alternative Jet Fuel, a.k.a. biofuel, biojet

Aviation commitments
* Decouple carbon growth
* No other viable options!

Industry alignment on SAJF value proposition
* Net carbon relief!
* Supply surety, Price stability
* Energy security
* Lower “criteria pollutants”
* Improved energy mass density
* Minimal infrastructure impact
* Economic development

SAJF works! Challenges, yes … but abundant options!
* Multiple feedstocks, conversion technologies, entrepreneurs