Aviation Biofuel Update

BRDB TAC 3Q’16 Meeting
Madison, WI
Wed, 17Aug’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
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

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”:

* CO2 Standards
* MBMs – will monetize carbon

Similar commitment from BizAv & DOD
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
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

Research & Development
Certification & Qualification

Environmental
Business

17 August 2016
...via cooperative R&DDD 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: FS&L, BRCs
NSF
NASA
USAF
FAA
DOE
CIP
AFRI/NIFA Caps

EPA: Renewable Fuel Standard

17 August 2016
Airline offtake agreements
... plus OEMs, and more in process

<table>
<thead>
<tr>
<th>Company</th>
<th>Agreement Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITED</td>
<td>5 M gpy from 2016</td>
</tr>
<tr>
<td>Alaska Airlines</td>
<td>90-180 M gpy Over 10 yrs</td>
</tr>
<tr>
<td>Cathay Pacific</td>
<td>Supply from 2018</td>
</tr>
<tr>
<td>British Airways</td>
<td>375M usg</td>
</tr>
<tr>
<td>Southwest</td>
<td>180M usg over 11 years</td>
</tr>
<tr>
<td>FedEx</td>
<td>3 M gpy</td>
</tr>
<tr>
<td></td>
<td>3 M gpy</td>
</tr>
</tbody>
</table>

17 August 2016
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

Fossil HC
Lipids
Cellulose
Sugars & Starch
Wastes & Syngas

Gasify  Pyrolize  Torefy  Saccharify  Deconstruct  Digest

Separate  Ferment  Dehydrate  Catalyze  Process

FT  CH  CC  APR  HL  Oligomerize

Distill  Hydrotreat  Hydroprocess  Hydro-Isomerize

FT-SPK, HEFA-SPK, HFS-SIP, FT-SPK/A, ATJ-SPK, ...
### SAJF approved production pathways

<table>
<thead>
<tr>
<th>Process</th>
<th>Maximum Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syngas FT (FT-SPK)</td>
<td>50% max blend</td>
</tr>
<tr>
<td>Hydroprocessed lipids (HEFA-SPK)</td>
<td>50% max blend</td>
</tr>
<tr>
<td>Biochem sugars (HFS-SIP)</td>
<td>10% max blend</td>
</tr>
<tr>
<td>Syngas FT w/ aromatic alkylation (FT-SPK/A)</td>
<td>50% max blend</td>
</tr>
<tr>
<td>Isobutanol conversion (ATJ-SPK)</td>
<td>30% max blend</td>
</tr>
</tbody>
</table>

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

GranBio, UOP, LT, SwB
### ASTM D7566 “pipeline” examples

<table>
<thead>
<tr>
<th>Approach</th>
<th>Feedstock</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) CHyP (syngas, non-FT)</td>
<td>Cellulose</td>
<td>Proton Power</td>
</tr>
<tr>
<td>2) Microbial conversion</td>
<td>Sugars - isobutene</td>
<td>Global Bioenergies</td>
</tr>
<tr>
<td>3) HTL</td>
<td>Cellulose</td>
<td>Algenol, Genifuel, Sapphire</td>
</tr>
<tr>
<td>4) Catalytic HTL</td>
<td>Cellulose</td>
<td>Licella, Muradel, QUT</td>
</tr>
<tr>
<td>5) SBI CGC PICFTR</td>
<td>Lipids - biodiesel</td>
<td>SBI Bioenergy</td>
</tr>
<tr>
<td>6) CCL</td>
<td>Lipids</td>
<td>Tyton</td>
</tr>
<tr>
<td>7) Hydrogenotrophic Conv.</td>
<td>CO2 / Producer Gas</td>
<td>Kiverdi</td>
</tr>
<tr>
<td>8) Cyanobacterial Prod.</td>
<td>CO2</td>
<td>Joule</td>
</tr>
<tr>
<td>9) STG+ GTL</td>
<td>c1-c4 Gas / Syngas</td>
<td>Primus</td>
</tr>
<tr>
<td>10) Acid Deconstruction</td>
<td>Cellulose</td>
<td>Mercurius</td>
</tr>
<tr>
<td>11) Thermal Catalytic Conv.</td>
<td>Cellulose</td>
<td>Shell/CRI/IH2</td>
</tr>
<tr>
<td>12) Thermal Deoxyg.</td>
<td>Lipids</td>
<td>Forge Hydrocarbons</td>
</tr>
<tr>
<td>13) Ionic Liquid Decon.</td>
<td>Cellulose</td>
<td>JBEI, tbd</td>
</tr>
<tr>
<td>14) Metal Catalytic Conversion</td>
<td>Cellulose</td>
<td>Purdue research</td>
</tr>
<tr>
<td>15) Enzymatic Conversion</td>
<td>Lignin</td>
<td>GLBRC &amp; JBEI</td>
</tr>
</tbody>
</table>

17 August 2016
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

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

**SAJF Pathways**

- FT-SPK, FT-SPK/A
- HEFA-SPK
- HFS-SIP
- ATJ-SPK
- Hydrotherm oils (CH)
- Renewable Diesel
- Refinery Co-processing
- SBI
- Forge, Tyton, ...

**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)

- HW UOP: Ecofining / GreenJet
- Neste NEXBTL:
Ex: Lipid pathway applicability
Conversion of fats, oils & greases

SAJF Pathways

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

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

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)

ARA - unique value prop. => 100% drop-in
Unlock existing 1 B+ gpy HDRD production
Front-end: Blend with crude
Mid: FCC, HC, Coker ?
Back-end: Hydroprocessing
Unlock existing biodiesel production
Toward improved affordability

17 August 2016
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

17 August 2016
**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
Steve Csonka
Executive Director, CAAFI
+1-513-800-7980
Csonka.CAAFI.ED@gmail.com
Steve.Csonka@caafi.org
www.caafi.org