Current Status of Alternative Aviation Fuels

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Overview

• Alternative Jet Fuels (AJFs)
  — Fuel Demand, Driver and Benefits

• Status and Latest Activities in the AJFs Sector

• AJFs: Outstanding Challenges
## Fuels for Distillate and Jet Market

### US Liquid Fuels and Products Market Size (billion gallons/year)

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2050</th>
<th>Growth Rate 2015 – 2050 (%/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>141</td>
<td>114</td>
<td>-0.7%</td>
</tr>
<tr>
<td>Diesel</td>
<td>61</td>
<td>64</td>
<td>0.3%</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas&lt;sup&gt;[1]&lt;/sup&gt;</td>
<td>39</td>
<td>54</td>
<td>1.0%</td>
</tr>
<tr>
<td>Other&lt;sup&gt;[2]&lt;/sup&gt;</td>
<td>31</td>
<td>38</td>
<td>0.7%</td>
</tr>
<tr>
<td><strong>Jet Fuel</strong></td>
<td><strong>24</strong></td>
<td><strong>39</strong></td>
<td><strong>1.4%</strong></td>
</tr>
<tr>
<td>Residual fuel oil</td>
<td>4</td>
<td>6</td>
<td>0.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>300</strong></td>
<td><strong>315</strong></td>
<td></td>
</tr>
</tbody>
</table>

1. Includes ethane, natural gasoline, and refinery olefins.
2. Includes kerosene, petrochemical feedstocks, lubricants, waxes, asphalt, and other commodities.

Biofuels are key to aviation GHG roadmap
Well-to-Wake GHG emissions of alternative jet fuels

- LCA functional unit gCO2e/MJ of fuel consumption (from GREET2016)
- LUC-related emissions are not included
- Other key factors: Technology readiness level (TRL), production costs, resource availability and fuel types

Source: simulation results with GREET2016 by ANL
Alternative Jet Fuels: Drivers and Benefits

- Environmental
  - Climate Change, Air Quality and Public Health
- Bio Economy
  - Jobs, employment and social welfare
  - Limit spending on foreign oil and reinvestment in domestic economy
- Energy Security
- Energy Diversity in fuel supplies
- Price Volatility
- Lower fuel cost in the long run
## ASTM Approved Pathways- Alternative Jet Fuels

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Company</th>
<th>Max % Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification &amp; F-T (FT-SPK)</td>
<td>Fulcrum, Red Rock</td>
<td>50%</td>
</tr>
<tr>
<td>Hydroprocessing F.O.G. (HEFA-SPK)</td>
<td>AltAir, Paramount, California</td>
<td>50%</td>
</tr>
<tr>
<td>Hydroprocessing of fermented sugars (HFS-SIP)</td>
<td>Amyris, farnasene, Brazil</td>
<td>10%</td>
</tr>
<tr>
<td>F-T with Aromatics (FT-SPK/A)</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Thermochemical Conversion of Isobutanol to Jet (ATJ SPK)</td>
<td>Gevo, Luverne, MN</td>
<td>30%</td>
</tr>
</tbody>
</table>
DPA Initiative Accomplishments

- Fuels are approved for use as jet fuel by ASTM at up to 50/50 blends.
- Fuels successfully demonstrated during Rim of the Pacific (RIMPAC) demonstration in 2012 for ships and planes.
- Fuels can be utilized in Navy’s warfighting platforms with no degradation to performance or mission.

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Feedstock</th>
<th>Conversion Pathway</th>
<th>Off-Take Agreements</th>
<th>Capacity (MMgpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emerald Biofuels</strong></td>
<td>Gulf Coast</td>
<td>Fats, Oils, and Greases</td>
<td>Hydroprocessed Esters and Fatty Acids (HEFA)</td>
<td>TBD</td>
<td>82.0</td>
</tr>
<tr>
<td><strong>Fulcrum Bioenergy</strong></td>
<td>McCarran, NV</td>
<td>Municipal Solid Waste</td>
<td>Gasification – Fischer Tröpsch (FT)</td>
<td>United, Cathay Pacific</td>
<td>10.0</td>
</tr>
<tr>
<td><strong>Red Rock Biofuels</strong></td>
<td>Lakeview, OR</td>
<td>Woody Biomass</td>
<td>Gasification – Fischer Tröpsch (FT)</td>
<td>FedEx, Southwest Airlines</td>
<td>12.0</td>
</tr>
</tbody>
</table>
Status of ASTM Certification of Alternative Jet Fuel

• ASTM Certifications in process
  – Catalytic hydro-thermolysis of lipids to jet fuel – ARA
  – Alcohol to jet – synthetic paraffinic kerosene (bio/thermochemical butanol or ethanol – Lanzatech, Byogy
  – Synthetic kerosene/synthetic aromatic kerosene – catalytic conversion of sugars and aqueous phase reforming to jet fuel – Shell/Virent
  – Hydro-treated esters and fatty acids+ (HEFA)+ - wider cut HEFA with renewable diesel – Boeing
  – Pyrolysis from lignocellulosic feedstocks – UOP, Kior
  – Fischer-Tröpsch synthetic kerosene with aromatics – Sasol, Rentech
  – Co-processing – multiple approaches – Chevron, BP, Phillips 66

• Pathways in future that could enter pipeline
  – Vertimass – catalytic conversion of alcohols
  – Global Bioenergies – biochemical production of isobutene
  – Algenol – hydrothermal liquefaction of algae
Latest Activities in Industry

- **AltAir** – United Airlines has begun using commercial scale alternative jet fuel volumes for regularly scheduled flights from LAX. Purchase 15 mgy from AltAir Paramount over 3 years.

- **Gevo** – Lufthansa agreement for alcohol-to-jet from Luverne, MN facility. 8 mgy from Gevo or up to 40 mgy over 5 years.

- **Fulcrum** – Strategic partnership between United, Cathay Pacific, BP Ventures, Air BP businesses to invest $30 million. 10 year off-take for 50 mgy from plants in North America. *(DOE funded)*

- **Red Rock** – 3 million gallons/year of renewable jet fuel for 3 years for FedEx Express. Southwest purchase agreement from Lakeview, Oregon facility to convert 140,000 dry tons/year of woody biomass into 15 million gallons/year of renewable jet, diesel, and naphtha. *(DOE funded)*

- **Byogy** – AVAPCO biomass-to-ethanol with Byogy alcohol-to-jet process to produce jet fuel from woody biomass. DOE award of $3.7 million to develop demonstration scale biorefinery. *(DOE funded)*

- **UOP** – Petrixo Oil and Gas to produce renewable jet and diesel at new refinery in Fujairah, UAE to convert 500,000 metric tonnes of renewable feedstocks into 1 million tons/year of biofuels.

- **KLM and SkyNRG** for 3 year agreement enabling LAX flights.

- **Neste, KLM, SAS, Lufthansa, SkyNRG Nordic, and Oslo Airport.**
Where we are: Transitioning to AJF, Fuel Purchase Agreements (1 of 2)

- AltAir Fuels + United = 5 M gpy from 2016
- World Fuel Services + Gulfstream = 3 yr agreement 30/70 blend
- Sky NRG + KLM = 3 yr agreement Enabling LAX flts
- Fulcrum + Cathay Pacific = 375M usg
- United + Southwest = 90-180 M gpy Over 10 yrs
- Red Rock Biofuels + FedEx = 3 M gpy
- United + FedEx = 3 M gpy
Where we are: Transitioning to AJF, Fuel Purchase Agreements (2 of 2)

- Total + Amyris + Cathay Pacific = 48 A350 deliveries 10% blend
- HAWAII BioEnergy + Alaska Airlines = Supply from 2018
- SG Preston + JetBlue = 10M gpy, 10 yrs
- Gevo + Lufthansa = Up to 40M gal Over 5 yrs (MOU)
- Neste + SkyNRG + Lufthansa Group = Bioport on demand
Alternative Aviation Fuel Challenges

- AJFs properties
- Co-product handling method in aviation fuel LCA
- Scale and Maturity of the technology
- Finances
- ASTM Approval process
- Off-take Agreements
- Competitiveness versus fossil jet
- Regulations
  - EPA
  - LCFS
  - ICAO
Criteria for Alternative Fuels in Aviation

• Engine re-light at altitude, polar climate, in winter - transport properties of alternative fuels and/or blends have to be within acceptable limits (viscosity, freeze point, fluid flow at low temperatures).

• Flame stability – compounds in alternative fuels should not adversely impact flame stability.

• Energy content – should be as high as fossil derived jet fuel or higher.

• Emissions
  – Aromatics – too much can cause soot, too little can cause seal swell problems which becomes a maintenance issue.
  – Greenhouse gas emissions should be lower than fossil derived jet fuel on a life cycle basis – requirements by DOD, DOE, and ICAO.
Co-products in the bio-aviation fuel pathways

- Oil Crops
  - Algae
  - Waste Oil
    - Oil Extraction
      - Meal
      - Bio-Oil
        - Hydroprocessing
          - Other fuels
            - Hydroprocessed Renewable Jet
          - Alcohol
            - ATJ
            - Alcohol-To-Jet
              - Other fuels
                - Electricity
                  - Hydroprocessed Renewable Jet
            - Sugar
              - STJ
              - Sugar-To-Jet
                - Other fuels
                  - Electricity
                    - Alcohol-To-Jet
            - Syngas
              - Fischer-Tröpsch Synthesis
                - Other fuels
                  - Other fuels
                    - Fischer-Tröpsch Jet
              - Pyro-Oil
                - Pyrolysis
                  - Biochar
                    - Other fuels
                      - Electricity
                        - Sugar-To-Jet
            - Gasification
              - Syngas
                - Other fuels
                  - Electricity
                    - Pyro-Oil
                      - Pyrolysis
                        - Other fuels
                          - Electricity
                            - Syngas
                              - Fischer-Tröpsch Synthesis
                                - Other fuels
                                  - Other fuels
                                    - Fischer-Tröpsch Jet
                                - Pyro-Oil
                                  - Pyrolysis
                                    - Biochar
                                      - Other fuels
### The Issue of Scale

<table>
<thead>
<tr>
<th></th>
<th>LAX</th>
<th>IAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel burn in gallons/hour for wide-body aircraft</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>Biofuel/fossil ratio: 20/80</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Average flight time from airport to Europe about</td>
<td>12.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Additional hours of fuel requirement for reserve and alternate destination requirements</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total flight hours</td>
<td>14.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Non-stop flights/day to Europe</td>
<td>36</td>
<td>7</td>
</tr>
<tr>
<td>Gallons/year for non-stop flights</td>
<td>114,318,000</td>
<td>19,162,500</td>
</tr>
<tr>
<td><strong>Number of facilities of size ~19 Million/gallons/year</strong></td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
Gas-to-Liquids Micro-Channel Technology

• First distributed scale Fischer-Tröpsch product commercially produced at Envia landfill gas and waste biomass GTL plant in East Oak landfill, Oklahoma City, Oklahoma
  – Team: Waste Management, NRG, Velocys, Ventech, Envia - to convert gas to paraffin wax, diesel, and naphtha at distributed scale
  – Scale: 1,000 barrel/day (15 million gallons/year) compared to conventional Fischer-Tröpsch scale of 30,000 barrels/day (460 million gallons/year) or more
  – Price: with natural gas at $3.89/million Btu, Velocys can produce diesel at $1.57/gallon (no RIN or LCFS credits)
  – Conversion efficiency: 57 – 76 gallons/ton waste biomass
  – 15.3 million gallons/year from 200,000 tons of biomass
ASTM D4054 Process

**Tier 1**
- 0.5 gal
- Specification Properties

**Tier 2**
- <100 gal
- Fit-For-Purpose Properties

**Tier 3**
- ~500 gal, $500K
- Component/Rig/APU Testing

**Tier 4**
- >10,000 gal, $5,000K
- Engine/APU Testing

**Total approval process:** $8-10M, 3-4 years

**ASTM Specification**
- ASTM Review & Ballot
  - Accept
  - Reject
  - Re-Eval As Required

**ASTM Balloting Process**

**OEM Review & Approval**

**ASTM Research Report**
ICAO sets standards and recommended practices for international aviation.

It has set a goal for international aviation to achieve carbon neutral growth from 2020.

- The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
- The CORSIA is implemented in phases, with the pilot phase (2021–2023) and first phase (2023–2026) expecting voluntary members and the second phase (2027–2035) requiring participation from all countries that have an individual share in the international aviation activities.
- While this strategy is likely to achieve emissions reductions via offsets, it is expected that additional policies will be required to stimulate biofuels development.
Regulations – U.S. EPA

• The U.S. EPA has authority over emissions from aircraft under Clean Air Act.

• EPA began to regulate jet emissions in 1974 and last revised its engine standards in 2012.

• EPA administers the Renewable Fuel Standards (RFS) which requires certain quantities of renewable fuels to be blended into motor gasoline and diesel fuel.

• Compliance with RFS is demonstrated through the use of Renewable Identification Numbers (RINs).

• The volume of jet fuel marketed does not contribute to fuel marketer’s renewable volume obligation, but production of biojet can generate RINs, which are then separated upon blending biojet into jet fuel.
Backup
DOE BETO Alternative Aviation Fuels Workshop

Public workshop organized September 14-15, 2016 in Macon, GA

• Workshop’s goals:
  – To advance the understanding of the current technical barriers for increasing the competitiveness of aviation biofuels.
  – The workshop focused on three technical areas that were organized as parallel breakout sessions:
    • Enhancing the techno-economic competitiveness of aviation biofuels.
    • Environmental and sustainability considerations and opportunities to improve the life-cycle benefits of aviation biofuels.
    • Ensuring robust feedstock and product supply chains to support aviation biofuels.
  – A report was prepared to summarize key findings from the workshop
Integrated Biorefinery Optimization FOA (funding opportunity announcement)

- Joint FOA with USDA up to $22.7 million in support of the optimization of IBRs
  - DOE share of up to $19.8 million
  - USDA-NIFA share of up to $2.9 million
  - Projects will focus on lowering technical and financial risk, addressing challenges encountered with the successful scale-up, and reliable, continuous operation of IBRs.

- Four topic areas:
  - **Topic Area 1:** Robust, continuous handling of solid materials and feeding systems to reactors under various operating conditions.
  - **Topic Area 2:** High value products from waste and/or other under-valued streams in an IBR.
  - **Topic Area 3:** Industrial separations within an IBR.
  - **Topic Area 4:** Analytical modeling of solid materials (dry and wet feedstocks, and/or residual solids remaining in the process) and reactor feeding systems.

To view the full FOA, visit EERE Exchange. Submission deadline for full applications is **April 3, 2017**. To apply for this FOA, applicants must register with EERE Exchange.
DOE BETO Biorefinery Optimization Workshop

• Tiger Team Effort

• Biorefinery Optimization Workshop
  – Public workshop organized Oct. 5-6, 2016, Chicago, IL
  – Advance the understanding of the current capabilities, barriers, and opportunities for integrated biorefineries working to produce biofuels, biochemicals, and bioproducts. Breakout sessions discussed the following:
    • Key technical and economic challenges facing feedstocks and solids handling processes.
    • Efforts in process intensification, scale-up, and CapEx/OpEx reduction.
    • Product and waste stream monetization.

• Biorefinery Optimization Workshop Summary Report Published on 2/27/2017
On December 28th, 2016, DOE announced up to $12.9 million for six projects related to the manufacturing of advanced or cellulosic biofuels, bioproducts, refinery-compatible intermediates, and/or biopower in a domestic pilot- or demonstration-scale integrated biorefinery.

<table>
<thead>
<tr>
<th>Project</th>
<th>Company</th>
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<tbody>
<tr>
<td>Demonstration-Scale Integrated Biorefineries</td>
<td>AVAPCO, LLC</td>
</tr>
<tr>
<td></td>
<td>LanzaTech, Inc.</td>
</tr>
<tr>
<td>Pilot-Scale Integrated Biorefineries</td>
<td>Global Algae Innovations</td>
</tr>
<tr>
<td></td>
<td>ThermoChem Recovery International, Inc.</td>
</tr>
<tr>
<td>Pilot-Scale Waste-to-Energy Projects</td>
<td>Rialto Bioenergy, LLC</td>
</tr>
<tr>
<td></td>
<td>Water Environment &amp; Reuse Foundation</td>
</tr>
</tbody>
</table>