Air Force Future Fuel Utilization

Tim Edwards
Air Force Research Laboratory
Propulsion Directorate

MACCCCR Fuels Research Review,
September 9, 2008

88ABW-2008-0011
AF Alternative Fuel Program

- Near-term goal: 50/50 F-T (SPK)/JP-8 blend certified in all AF vehicles by 2011 (POC: ASC Alternative Fuel Certification Office (AFCO))
  - Coordinating w/ Commercial Aviation Alt. Fuel Initiative (CAAFI)
  - Revisions to Jet A (ASTM D1655) and JP-8 (MIL-DTL 83133F)
  - Goal: “drop-in” replacement for current fuels

- SPK characteristics

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<thead>
<tr>
<th></th>
<th>Jet (avg)</th>
<th>SPK</th>
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<tbody>
<tr>
<td>Density</td>
<td>0.81</td>
<td>0.75</td>
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<td>Aromatics, %</td>
<td>17</td>
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<tr>
<td>Cetane (IQT)</td>
<td>45</td>
<td>60</td>
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<tr>
<td>Sulfur, ppm</td>
<td>~500</td>
<td>~0</td>
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<tr>
<td>ΔHc, BTU/lb</td>
<td>18600</td>
<td>18900</td>
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</table>
ASTM Turbine Engine Fuel Approval Process

Fuel Evaluation (ASTM Guidance)
- Specification Properties Pass
- Fit For Purpose Properties (FFP) Pass
- Comp/Rig Testing Pass
- Engine Testing Pass
- Further Evaluation? Yes
  - Add’l Data As Required
  - FAA Review
  - Approved
  - OEM Spec/SB
  - Report
  - ASTM Specification
- Report
- Fuel Specification Approval (ASTM Process)
  - FAA Review
  - Accept
  - Reject
  - Add’l Data As Required
  - Re-Eval As Required
  - ASTM Review & Ballot
  - Pass
  - Fail

Equipment Evaluation/Approval
- OEM Internal Review
  - Report
  - Fail
  - Pass

Start
- ASTM Turbine Engine Fuel Approval Process

Fuel Specification Approval (ASTM Process)
- FAA Review
- Accept
- Reject
- Add’l Data As Required
- Re-Eval As Required
- ASTM Specification

ATA/IATA Meeting
Aug 19, 2008
Mark Rumizen, ANE-110

Federal Aviation Administration
Property “Experience Base”

- Shell 100% FT (0.737)
- Syntroleum 100% FT (0.775)
- Syntroleum 50/50 Blend (0.777)
- Shell 50/50 Blend (0.786)

JP-8 Spec Limits (0.775-0.839)
Composition?

C_7
C_{11}
C_{16}

5309 Jet A
5308 Jet A
5305 Jet A
5304 Jet A
5303 Jet A
Composition?

C

C_{11}

C_{16}

5327 Jet A

5322 Jet A

5321 Jet A

5317 Jet A

5314 Jet A
Jet fuel: 20% n-paraffins, 40% iso-paraffins, 20% naphthenes (cycloparaffins), 20% aromatics

AIAA 2006-7972
Alternative Fuel Composition

Cetane ~ 35?

Sasol IPK
~4% n-paraffins

Cetane ~ 60

Shell GTL
~26% n-paraffins

Cetane ~ 60

Syntroleum S-8
~22% n-paraffins

Sasol Oryx (GTL-1)
~72% n-paraffins

Sasol Oryx isomerized (GTL-2)
~20% n-paraffins

HYDROCARBON NUMBER

MASS %
Combustion Results (1)

- AE3007 full annular combustor
- JP-8 and 100% F-T (S-8)
- No significant performance differences

R-R LibertyWorks, Jan 2008
Combustion Results (2)

- CFM 56 engine combustor
- Jet A-1 and 100% F-T (S-8), blend
- No significant performance differences
50/50 Blend Results

• No difference (except soot) seen in B-52, C-17, B-1, F-15, F-22, ...

• So, further combustion research unnecessary, right? ....

• Well, ....NO. Specifying 50/50 SPK and moving beyond has identified a number of deficiencies in understanding:
  – Maximum flash point (vs density, viscosity)
  – Cetane requirement
  – Minimum aromatics

• On to biokerosene! (?)
All Alternative Fuels the Same?

Fuel W (-55 C f.p.)

Fuel Z (74 C flash, -78 C f.p.)

Fuel Y (-44 C f.p.)

JP-8

Fuel X (-55 C f.p.)

S-8

controlled by flash  controlled by freeze
### CAAFI Aviation Alternate Fuels Roadmap

**Level 2 / Scenario 1 - Long Term**

<table>
<thead>
<tr>
<th>Category</th>
<th>2005</th>
<th>2007</th>
<th>2010</th>
<th>2015</th>
<th>2030</th>
<th>2050</th>
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<tr>
<td><strong>Alternative Fuel Products</strong></td>
<td>SASOL Jet Fuel FT Test</td>
<td>Nigeria GTL C17 Fuel Test</td>
<td>Qatar Production US CTL Biomass Co-fired</td>
<td>Bio-butanol for ground use</td>
<td>Either Industrial Solar or Resurgence in Nuclear Power</td>
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<td>Shell Bintulu GTL</td>
<td>Boeing/ Air New Zealand</td>
<td>US CTL Ductio approved</td>
<td>Cellulose ethanol for use</td>
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<td></td>
<td>Syntroleum Jet fuel in B-52</td>
<td>Boeing/ Virgin Biojet Demo</td>
<td>Bio-jet fuel approved</td>
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<td><strong>Economics &amp; Business</strong></td>
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<td>70% USAF Domestic CTL Sourcing (2025)</td>
<td>Future Aircraft for Advanced Fuel</td>
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<td>Spec for 100% SASOL</td>
<td>Spec for 50/50 Generic FT Blend Listed in ASTM</td>
<td>ASTM Lists 100% FT Generic</td>
<td>ASTM Bio Fuel Spec</td>
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<td><strong>Certification</strong></td>
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<td>50% USAF Syn fuel use</td>
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<td>Spec for 50% SASOL Blend</td>
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<td><strong>Environmental</strong></td>
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<td>70% USAF Domestic CTL Sourcing (2025)</td>
<td>Future Aircraft for Advanced Fuel</td>
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<td>Scoping study</td>
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<td>50% USAF Syn fuel use</td>
<td>Future Aircraft for Advanced Fuel</td>
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<tr>
<td></td>
<td>GE/cruise ships burn biofuel in turbine</td>
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<td>Future Aircraft for Advanced Fuel</td>
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<td>B-52 emissions</td>
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<td>50% USAF Syn fuel use</td>
<td>Future Aircraft for Advanced Fuel</td>
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<td>Boeing/ Virgin 747 Test</td>
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<td>50% USAF Syn fuel use</td>
<td>Future Aircraft for Advanced Fuel</td>
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<td>Biofuel Tested, CFM</td>
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<td>50% USAF Syn fuel use</td>
<td>Future Aircraft for Advanced Fuel</td>
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<td>F/T swell lubricity issues solved</td>
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<td>B-52 syn-fuel flight test</td>
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<td>50% USAF Syn fuel use</td>
<td>Future Aircraft for Advanced Fuel</td>
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**Status as of April, 2008**
# Aviation Alternate Fuels Roadmap

**(Level 3 / Scenario 1, R&D Near Term Only)**

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<th>Category</th>
<th>2006</th>
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<td><strong>DoD</strong></td>
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<td>B-52 demo</td>
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<td>All engines</td>
<td>F/T blend</td>
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<td>Bio-jet tests</td>
<td>T63 Engine</td>
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<td>N Dakota Biojet studies</td>
<td>Research Combustor</td>
<td>FT seal/ FT operability and RFID t</td>
<td>Expand material compatibility</td>
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<td>Fuel tank foam tests</td>
<td>DARPA biofuels 1/07 - 6/08 Engineering-OEM protocol</td>
<td>DARPA biocet samples to ARL</td>
<td>FT toxicology assessment</td>
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<td>Oil</td>
<td>FT evaluation in diesel engine</td>
<td>FT evaluation with AC fire protection</td>
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<td><strong>Engine Companies</strong></td>
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<td>B-52 demo 2-engines F/T blend</td>
<td>100% F-T SASOL Fuel approved</td>
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<td>Lab Test Of TecBio Biofuel</td>
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<td>Atmosmiser cold flow on biojet</td>
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<td>Tests to support F-T approval process</td>
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<td>Bio-fuel Sustainability Report</td>
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<td>Supply bio-fuel blends to NASA &amp; SwRI</td>
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<td>Test for lubricity seal swell for Biojet / synthetic blend</td>
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<td>APU cold start on biofuel</td>
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<tr>
<td>Bio-thermal stability test defined</td>
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<td>Materials compatibility test matrix between airframers</td>
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<td>Embraer Biojet demo</td>
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<tr>
<td>Embraer Biojet demo</td>
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<td><strong>Other Airframers</strong></td>
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<td>Sxfuel+JP8 blends</td>
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<td>TVC or other Combust.Sector, Perform+Env (NASA/AFRL/WPAFB)</td>
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<td>CFDF FT-JP8 blends, TVC Combustor</td>
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<td>Bio Fuel &amp; FT combustion kinetics</td>
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<td>FT fuel Engine test (NASA/USA/F/PW)</td>
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<td>HI PR test data (incl. emiss.)</td>
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<td>Comustor test of blends (NASA)</td>
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<td>Alt.Fuel Ground test performance + Emissions (NASA)</td>
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<td><strong>FAA/NASA</strong></td>
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<td>Cruise Range impact of F-T fuel, Air Canada</td>
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<td>1st generation Bio-fuel blend matrix performance tests (SwRI)</td>
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<td>CTL feasibility study, Indiana</td>
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<td>Biofuel therm stability in H</td>
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<td>UHBypass engine test E Fuels (NASA/PW)</td>
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<td>Biofuel+JP8 blends, TVC or other Combust.Sector, Perform+Env (NASA/AFRL/WPAFB)</td>
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<td>Comustor test of Syn&amp;Bio fuel blends (HPR Emissions (NASA)</td>
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<td>Quantify deposits on ellipseometer</td>
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<td>Swift develop. Syn+ renewable Jetfuel as</td>
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<td>Indiana compl. Agreement with CTL company</td>
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<td>Swift compl. D1655 Labtesting</td>
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<td>PSU, coal derived JP900 check status</td>
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</table>

Status as of November 08, 2007
Production of “Bio” Jet Fuel

“second generation”

Cellulose

Lignin

gasification (or co-gasification with coal)

CO + H₂

“BTL”

“first generation”

CH₃(CH₂)₇CH=CH(CH₂)₇C(O)O-CH₂

CH₃(CH₂)₇CH=CH(CH₂)₇C(O)-CH

CH₃(CH₂)₁₄C(O)O-CH₂

Triglycerides (fats, oils)

“direct fermentation”

“BTL”

“HXO”

“HFO”

“HAL”

Typical jet fuel molecule

Typical jet fuel molecule

“direct fermentation”

“BTL”

“HXO”

“HFO”

“HAL”

Typical jet fuel molecule
Jet Fuel vs Biodiesel

Key jet fuel requirement: -47 C freeze point
Ongoing “Biojet” Programs

- DARPA – 3 contract awards in 2007
  - General Electric (GE)
  - Universal Oil Products
  - University of North Dakota’s EERC
- Syntroleum/Tyson/Conoco - “waste animal fat”
- Boeing/Virgin fuels flight demo in 2008
- AFRL analyzing other submitted samples
- Key issues are production potential (“gallons/acre”), cost, and environmental impact

The Payoff

…the emission factor for [jet] fuel produced from biomass will be zero.

EU working document on aviation emissions trading*

*COMMISSION STAFF WORKING DOCUMENT, Accompanying document to the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community

ASTM Standard Practice – New Fuel and New Fuel Additive Approval Protocol. This is a guideline. Not every test is required.
Timeline Summary

Near-Term Strategy

- Draft FT ASTM Research Rpt
- FT ASTM Research Rpt Issued
- FT Fuel Spec ASTM Ballot
- ASTM Approval of Spec and Research Rpt

Longer-Term Strategy

- DARPA Fuel Samples at WPAFB
- DXXXX Spec Wrkg Grp
- HRJ Task Force
- DXXXX Spec Ballot
- HRJ ASTM Research Rpt Issued
- HRJ xx% Blend ASTM App’l
- HRJ ASTM App’l
Evolving Combustion Program

• Biofuel/synfuel combustion program similar to early 80s program “Fuel Effects on Combustion”
• Referee fuels developed for team use
• Data developed from basic research to full-scale combustor/engine data
• Product: “Rules and Tools” for fuel properties/composition effects on combustion
Summary

• Air Force alternative fuel program has high-level backing and momentum
  – Near-term goal – certification of all AF systems on 50/50 JP-8/F-T blend by “early 2011”.
  – Examining biofuels as possible next target

• Key issues
  • Consistency of jet fuels between manufacturers, processes and feedstocks
    – How to ensure consistent product in specification?
    – What are the limits of the fuel composition – property trade space?
  • Environmental Performance
  • Economic Viability