U.S. Air Force Alternative Fuel Efforts: Fischer-Tropsch and Beyond

Tim Edwards
Propulsion Directorate

88ABW-2009-1702, 88ABW-2009-4026
AFRL Major Thrusts

• High level goals:
  – 2011 – 50/50 F-T blend certification for all systems (Alternative Fuel Certification Office (AFCO))
  – 2016 – 50% of domestic consumption contains synthetics (F-T + ?) (~400M gal), “greener” than petroleum, cost-competitive

• AFRL major efforts (joint w/ AFPET) (coord w/ CAAFI)
  – F-T certification support (properties, mat’l compatibility, toxicology)
  – Aviation biofuel certification
  – Key parameters
    • Performance (“drop-in”)
    • Cost (“competitive”)
    • Production potential (“significant”)
    • Lifecycle greenhouse gas footprint (“less than petroleum”)
    • Sustainability (“?”)
### Timeline Summary

**Near-Term Strategy**

- **July**
  - Draft FT ASTM Research Rpt
- **Aug**
  - FT ASTM Research Rpt Issued
- **Sept**
  - FT ASTM Research Rpt OEM App’l
- **Oct**
  - FT Fuel Spec ASTM Ballot
- **Nov**
  - FT ASTM Research Rpt ASTM Ballot
- **Dec**
  - ASTM Approval of Spec and Research Rpt

**Longer-Term Strategy**

- **2008**
  - DARPA Fuel Samples at WPAFB
  - DXXXX Spec Wrkg Grp
  - HRJ Task Force
- **2009**
  - DXXXX Spec Ballot
- **2010**
  - HRJ ASTM Research Rpt Issued
- **2011**
  - HRJ xx% Blend ASTM App’l
- **2012**
  - HRJ ASTM App’l
- **2013**

ASTM Synthetic Fuels Task Force
December 8, 2008
Mark Rumizen, CAAFI
Certification “Pipeline”

- Fuels may travel along conveyor at different rates!
- AF energy security goals benefit by feedstock diversity

New! DESC Solicitation
SP0600-09-R-0704 600K gal
moving fast, “drafting” F-T SPK

New! ASTM D7566

Approved fuels (ASTM D7566, MIL-DTL-83133F)
Certification Processes – MIL-HDBK-510, ASTM D4054

which rigs?

which engines?
Fit-for Purpose Properties

FIT-FOR-PURPOSE PROPERTIES

CHEMISTRY
Hydrocarbon chemistry (carbon number, type, distribution)
Trace Materials/Metals

BULK PHYSICAL AND PERFORMANCE PROPERTIES
Boiling Pt Distribution
Vapor/Liquid Ratio
Thermal Stability Breakpoint
Lubricity
Response to Lube Improver
Viscosity vs Temp
Specific Heat vs Temp
Density vs Temp
Surface Tension vs Temp
Bulk Modulus vs Temp
Thermal Conductivity vs Temp
Water Solubility vs Temp
Solubility of Air (oxygen/nitrogen)

FIT-FOR-PURPOSE PROPERTIES

ELECTRICAL PROPERTIES
Dielectric Constant vs Density
Electrical Conductivity and Response to Static Dissipator

GROUND HANDLING/SAFETY
Effect on Clay Filtration
Filtration (Coalescers & monitors)
Storage Stability
Peroxides
Potential Gum
Toxicity
Flammability Limits
Autoignition Temperature
Hot Surface Ignition Temp

COMPATIBILITY
Other Additives/Fuels
Engine/Airframe Seals, Coatings, Metallics
Research Reports

• Used to support commercial specifications (data also used for military certification)
• Addresses whether “drop-in” fuels fall within experience base
Experience Base

- World Fuel Survey
- PQIS database
- Newly developed data
ASTM D7566 Fuel Specification

Key Provisions

- Body of Spec Applies to Finished Semi-Synthetic Fuel
- Annex for Each Class of Synthetic Blending Component
- Allow Re-Certification to D1655 No need for separate tracking
- Annex 1
  - Hydroprocessed SPK
    - Includes 50% FT Fuel
- Issued in August 2009
- Hydroprocessed Renewable Jet (HRJ) Added to Annex 1 in Next Revision
Baseline Fischer-Tropsch Fuels

• Form basis of Research Report to support specification

- Sasol IPK: ~4% n-paraffins
- Shell GTL: ~26% n-paraffins
- Syntroleum S-8: ~22% n-paraffins
- Sasol Oryx (GTL-1): ~72% n-paraffins
- Sasol Oryx isomerized (GTL-2): ~20% n-paraffins

Cetane = 31
Cetane = 60

HYDROCARBON NUMBER

C-5, C-130
C-17, B-1, F-15
F-22, KC-135R
B-52, T-38

10
50/50 Blend

• No serious concerns with any materials tested to date

• Still analyzing/testing any “Gaps” identified by various platforms and AFCO

100% SPK

• 100% SPK (0% aromatics) fuel may not be feasible due to material compatibility issues

• Working with AFRL/RZ to investigate/identify the minimum aromatic content needed in the fuel
  – Is 8% the right number?
Self-Sealing Bladder Testing

- Evaluating self-sealing bladders as function of fuel aromatic level
- May be more constraining on aromatic level than o-rings
Emissions Collaboration

- Emissions study conducted with multiple partners on modified NASA DC-8 (CFM-56) – Jan ’09
  - Multiple F-T fuel blends (Sasol, Shell, 50/50, & 100%)
- Particulate emission reductions proportional with F-T blend %
Beyond F-T – Biofuels!

“second generation”
- Cellulose
- Lignin

“first generation”
- Triglycerides (fats, oils)
  - C16:1
  - C18:0

“BTL”
- CO + H₂
- alcohols
- “direct fermentation”

“HRJ”
- pyrolysis
- gasification (or co-gasification with coal)
- hydroprocessing

Sugars
- “direct fermentation”
- jet fuel components

“first generation” components
Alternative Fuels
On-Going Analysis

TRL 9 – current fuels JP-8, Jet A

TRL 8 – generic F-T 50/50

TRL 5 (?) – HRJ 50/50 (flight demonstrated)

TRL 2

More Challenging Biofuels

TRL 2-3
Combustion Evaluation

### Composition
- Aromatics, cycloparaffins, \(n\)- and \(i\)-paraffins
- Hydrocarbon chain length

### Properties
- Density vs T
- Viscosity vs T
- Flash point
- Heat of combustion
- Boiling range
- Vapor pressure
- Surface tension
- Cetane
- ...

### Combustion Performance
- Lean blow out
- Altitude relight
- Transient accel/decel
- Instability
- Emissions/efficiency
- Liner/nozzle heating
- Engine control response
- ...

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Composition and properties are interlinked, affecting combustion performance.
Prototype Combustion Evaluation Process

Fundamental expts

↓ fail

↓ pass

Flame tube rigs

↓

Sector rigs

↓

Full annular

↓

Engines

10.5 cSt

11.5 cSt

13 cSt

H: FA8650-09-D-2925-0005
P: FA8650-09-D-2923-0010
G: FA8650-09-D-2922-0007
W: FA8650-09-D-2924-0006
R: FA8650-09-D-2921-0007
Reference Fuel Repository

- Reference fuel repository being established for surrogate components
- Spreadsheet for components
- Issues: cost vs purity vs volume
- Plan:
  - Phase 1 – conventional components (n-alkanes, aromatics, etc.)
  - Phase 2: Isoparaffins

Existing 40 F storage at WPAFB

Sam Tanner – 176 drums in ‘09!
Catalogue Prices for 99% Purity

Cost / 55 gal drom

Carbon number

$100,000,000
$10,000,000
$1,000,000
$100,000
$10,000
$1,000

99% Purity
isoalkanes
n-propylbenzene
n-butylbenzene
“Biocarbon” Analysis

- ASTM D6866 assesses fraction of carbon that is “modern” using C14
- Initial assessment

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<th>Fuel</th>
<th>Feedstock</th>
<th>% modern C</th>
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<td>WPAFB JP-8</td>
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<tr>
<td>Sasol IPK</td>
<td>coal</td>
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<td>Shell SPK</td>
<td>nat. gas</td>
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<td>Syntroleum R-8</td>
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<td>R-8X</td>
<td>Salicornia</td>
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<td>JP-8/R-8 50/50</td>
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<tr>
<td>UOP DARPA “biojet”</td>
<td>bio + pet. aromatics</td>
<td>73</td>
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Summary

- Interest in alternative fuels remains high
  - 50/50 F-T blend is nearing transition

- Biomass-derived fuels are current S&T focus
  - “Drop-in” petroleum replacements/blendstocks are focus in near term – fully synthetic in mid term
  - Assessment criteria must be defined: performance, cost, manufacturing potential, GHG footprint, sustainability
  - Biofuels may not always be “greener” than petroleum or CBTL (w/CCS)
  - Scale-up/cost/land use issues
**Assured Aerospace Fuels Research Facility (AAFRF)**

- **Description:** Research facility to assess properties and performance of alternative jet fuels from domestic feedstocks (Coal/Biomass/Natural Gas)
  - **Use:** Generate research quantities (15-25 gal/day) of alternative jet fuel
    - Evaluate properties to optimize specifications for new types of fuels
    - Evaluate processing, catalysis and feedstock influence on fuel properties
    - Evaluate processes to enhance production of alternative jet fuels

- **Status**
  - Phase I installed at WPAFB
  - Phase II being assembled
  - Phase III undergoing conceptual design
  - Enclosure for housing AAFRF in detailed design
**Alternative Fuels R&D Roadmap**

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<th>Year</th>
<th>2008</th>
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<td>HRJ 50/50?</td>
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