Alternative Fuels Strategy and Results

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“Energy is the single most important challenge facing humanity today” Richard Smalley 2004

Top Ten Problems Facing Humanity Over the Next 50 Years

- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism and War
- Disease
- Education
- Democracy
- Population
Aim for Balanced Solutions

National Energy Strategy

Need to Consider Inter-related Issues of Energy Strategies

Economic Sustainability

Energy Supply Security

Climate Change

Aim for Balanced Solutions

Tim Skone DOE/NETL 2008
Every Energy Source Has an Impact

Global Energy Strategy

Need to Consider Inter-related Consequences of Energy Strategies

Food

Every Energy Source Has an Impact

Energy

Water
Energy Security = Reliable supply at a reasonable cost and produced in an environmentally sustainable manner
Formally established the AF Energy Program:
Strategy, Goals, Objectives and Metrics

Integrity - Service - Excellence
Vision:
Make Energy A Consideration In All We Do™

Strategy:
Reduce Demand
Increase Supply
Change the Culture
Over $9 billion spent for energy in 2008

Aviation
- Fuel Used: 2.4B gallons
- Fuel Cost: $7.7B

Facilities
- Energy Used: 66.8M MBTU
- Energy Costs: $1.1B

Ground Equipment and Vehicles
- Fuel Used: 89.8M gallons
- Fuel Costs: $284.2M

DoD Aviation ~10% of domestic jet fuel market

SOURCE: AF Total Cost of Operations Data Base
CAAFI’s Sponsors / Stakeholders

Stakeholders

- FAA
- ATA
- AIA
- ACI
- Aircraft OEMs
- Aircraft Engine OEMs
- Aircraft Equip Cos
- Aerospace Industries Association
- Federal Aviation Administration
- Air Transport Association

Sponsors

- US Army
- DARPA
- USAF
- DESC
- NRC
- Canada
- ANP Brazil
- Bauhaus
- UK MoD
- NIST
- NASA
- DESC
- USAF
- US Army
- DARPA
- USN
- USDA DOE
- DOC
- Air Cargo Airlines
- ALPA
- Airport Operators
- ASTM CRC
- Oil Companies
- Bio-Fuels Companies
- Energy Companies
- Universities
- Think Tanks
- IATA
- NetJets
- Air Transport Council International
- Airlines
- Airport Operators
- NetJets
- Consultants

Over 300 Sponsors/ Stakeholders from All Continents
Alternatives to Oil: US Energy Resources

Domestic Resources

- 1.4 trillion barrels (shale)
- 900 billion barrels of FT (coal)
- 0.15 billion barrels (pet coke)
- 22.7 billion barrels oil reserves
- 240 billion barrels of oil (EOR)
- Billion+ tons of biomass

Total 2.3+ trillion barrels equivalent
Mature Process:
Fischer Tropsch is a proven process with benefits including:
- Maturity: South African aviation use 1999
  - CTL – South Africa, China
  - GTL – Malaysia, Middle East
  - BTL -- Germany
- Chemical similarities to conventional fuels
- Manufactured fuel
  - No sulfur
  - Reduced particulates
  - High/Low temperature stability
FT Fuels Reduce Emissions

- Less Pollutant Emissions
  - ~3.5% less CO$_2$ (100% FT)
  - 50% to 90% less particulate matter (PM)
  - 100% reduction in SOx
  - ~1% less fuel burn (increased gravimetric energy density)

Hydrocarbon types in Syntroleum S-5

- Zero aromatics
- Zero sulfur
- No heteroatoms

Highly Paraffinic Fuel – normal and isoparaffins
Petroleum derived fuels are rich in aromatics, cycloparaffins, and heteroatoms
B-52 Certified for 50/50 Blend!
8 Aug 2007
The Certification Challenge

New Engines

Existing Fuel

1950’s

1970’s

1990’s

2000’s

New Fuel

Drop-In Replacement
50/50 Blend

Mark Rumizen FAA 2008
Synthetic Blend Components in Certification Phase

AF Certification complete in 2010 Fuel Class Listed in Int’l Fuel Specifications (Expected Sept ’09)

Fischer-Tropsch (FT)

Coal
Natural Gas
Biomass

Syn Gas (CO, H$_2$)
Gasify
FT Process

Conventional Refinery Processes

Syn-Crude
Bio-Crude
Hydroprocessing

Hydroprocessed Renewable Jet (HRJ) from Bio-Oils

Plant/Algae Oils
Oil Extraction

Hydroprocessing

SPK

Fit-For-Purpose Property Testing Underway

Mark Rumizen FAA 2009
Hydrotreated Renewable Jet
“HRJ” Fuels

Seed Crops

Animal Fats
(Tyson Syntroleum)

Halophytes

Jatropha

Algae

[Images of different crops and fuels]
Identifying and characterizing biomass jet fuel
- Foundation for next certification step

“Hydrotreated Renewable Jet” (HRJ)
- Rapid certification possible due to composition similarities to Fisher-Tropsch
- Reduce lifecycle greenhouse gases (joint FAA/DOE/EPA studies underway)
- Testing DARPA 100% biojet candidates
- Evaluating Syntroleum/Tyson “yellow grease” HRJ

Other biomass-derived fuels
- Non-food seed oils (near term)
- Halophytes, algae (far term)
- Cellulosic materials (far term)

Increase Supply: Biomass-Derived Fuel Blend Certification
Emissions and Environmental Impacts

Combustion Emissions

CO\(_2\): 71%
Water: 28%
CO, HC, NO\(_x\), SO\(_x\), Primary PM\(_{2.5}\): < 1%

Atmospheric Chemistry and Physics

Primary PM\(_{2.5}\)
Secondary PM\(_{2.5}\)
SO\(_x\)
NO\(_x\)
UHC
CO
Ozone
Global Climate Change

Population Exposure and Health Impacts

Emissions from Fuel Production

Cooling Effects
Warming Effects

Jim Hileman MIT 2009
Fischer-Tropsch Fuels
Significantly Reduced Particulate Emissions

<table>
<thead>
<tr>
<th>% Change in PM Mass EI</th>
<th>Engine 7</th>
<th>Engine 8</th>
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</thead>
<tbody>
<tr>
<td>Idle</td>
<td>-50%</td>
<td>-28%</td>
</tr>
<tr>
<td>1.3</td>
<td>-36%</td>
<td>-28%</td>
</tr>
<tr>
<td>1.5</td>
<td>-39%</td>
<td>-31%</td>
</tr>
<tr>
<td>Max</td>
<td>-38%</td>
<td>-38%</td>
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-30-50% reduction in Particulate Mass EI with 50/50 FT/JP-8

<table>
<thead>
<tr>
<th>% Volume of FT Fuel in JP-8</th>
<th>12.5</th>
<th>25</th>
<th>37.5</th>
<th>50</th>
<th>62.5</th>
<th>75</th>
<th>87.5</th>
<th>100</th>
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<tr>
<td>% Change in Particle Number Density</td>
<td>Idle</td>
<td>Cruise</td>
<td></td>
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<tr>
<td>Idle</td>
<td>-12%</td>
<td>-13%</td>
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<tr>
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<td>-25%</td>
<td>-30%</td>
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<td>1.5</td>
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<tr>
<td>Max</td>
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<td>-61%</td>
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75-95% reduction in Particle Number with 100% FT

TF33 Engine/B-52 Aircraft

T63 Engine

Engine Power or EPR

75-95% reduction in Particle Number with 100% FT
• Voluntary carbon dioxide (CO₂) inventory used to:
  — Evaluate policy and operational impacts
  — Support sustainability
  — Identify risk areas
  — Understand investment and mitigation areas

<table>
<thead>
<tr>
<th></th>
<th>2007 CO₂ Emissions (million metric tons)</th>
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<tr>
<td>Aviation Operations</td>
<td>23.98</td>
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<tr>
<td>Facility Electricity and Steam</td>
<td>6.93</td>
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<td>Stationary Fuel Combustion</td>
<td>2.37</td>
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<tr>
<td>Ground Transportation and Equipment</td>
<td>1.12</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>34.40</strong></td>
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CO₂ inventory paves way for change
Section 526

“No Federal Agency shall enter into a contract for procurement of an alternative or synthetic fuel, including fuel produced from nonconventional petroleum sources, for any mobility-related use, other than research and testing, unless the contract specifies that the lifecycle greenhouse gas emissions associated with the production and combustion of the fuel supplied under the contract must, on an ongoing basis, be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources.”
GHG Life Cycle Analysis

The Aviation Fuel Life Cycle Assessment Working Group
Prepared for
U.S. Air Force
April, 2009

• Guidance for GHG LCA
  – Draft Issued April 23
  – Includes Land-Use Impacts

• USAF Led Working Group
  – CAAFI, DOE, Universities, FAA, Boeing

• Peer Review Complete – revision in progress
• To achieve commercial growth rates, algae must be “fed” carbon dioxide from another source (beyond ambient).
• Have electricity, aviation, and biomass co-product output.
Land use change and process uncertainties contribute to potential problems using some alternative fuels

Jim Hileman MIT 2009
Carbon Neutral U.S. Aviation Growth

- Assessed potential for carbon neutral growth from 2006 to 2025.
- Analysis used biofuel life-cycle GHG emissions and yield per hectare.
- Circles show land area requirements for three existing and two hypothetical feedstocks.
- Soybean and palm requirements both exceed current production levels.
- Analysis looked at single feedstock solutions – practical approach is to consider multiple feedstock solutions.
  - **Need feedstocks with high yield and low life-cycle emissions that do not require arable land.**

Notes:
1. Assumed no land use change emissions with all of the feedstocks.
2. Land areas are given relative to continental U.S. for illustrative purposes (e.g., palm trees do not grow in Colorado).

Legend:
- Soy oil (oil yield ~550L/ha)
- Herbaceous biomass (using F-T process with ~11,000 kg biomass/ha)
- Palm oil (oil yield ~5600 L/ha)
- Feedstock B (oil yield ~10,000L/ha)
- Feedstock D (oil yield ~50,000L/ha)

Jim Hileman MIT
Contributions of Aviation to Global Climate Change

- CO₂ Emissions ~50% of the impact
  - Engine efficiency and alt fuels
  - Combustor design could address ~27%
    - Examine realistic lower limits for NOx and soot relative to CO₂
- Alternative fuels may impact ~74%
  - CO₂ recycling with properly chosen biofuels
    - Reductions in soot
    - Relationships between soot and sulfur and contrails exploration
Cellulosic Fuels R&D
(Next Generation Biofuel)

Advanced Fermentation
- Genetically Engineered Microbes
- Fermentation

Alcohol Oligimerization
- Fermentation
- Dehydroxylate
- Olefins

Pyrolysis
- Bio-Crude

Conventional Refinery Processes
- Polymerization
- Olefins

Sugar
- sugarcane
- switchgrass
- corn stover

Lignocellulose
- forest waste

Mark Rumizen FAA 2009
Sustainability

• Need to develop an aviation consensus view
  – Environmental sustainability
    • Water usage
    • Water pollution
    • Local air quality
    • Global air quality
    • Land use changes
  – Business sustainability
    • Aviation sector performance is closely linked to fuel costs
Energy Return On Investment

Notional Concept:

\[
\text{Price Of Oil} \sim \frac{(\text{Energy in the Fuel}) - (\text{Energy to Produce Fuel})}{(\text{Economic Cost of Producing bio-oil}) + (\text{Cost to Produce Fuel})}
\]
AF Alternative Fuel Score Card

- Business Readiness
- Technical Readiness
- Economic Readiness
- Sustainability
- Environmental Readiness
- Energy Return on Investment
- Manufacturing Readiness Level
- Greenhouse Gas Readiness
- Greenhouse Gases Life Cycle Analysis
- Technology Readiness Level

- ~88gCO2eq/MJ
Summary

- Air Force energy policy – Reduce Demand, Increase Supply and Change the Culture
- Air Force has led the way forward to evaluate and certify alternative fuels
- Alternative fuels offer potential to reduce greenhouse gas and particulate emissions
- Air Force will certify its entire fleet by 2011 to use a 50/50 blend of FT fuels
- Air Force starting certification of HRJ biofuels
- Cellulosic derived fuel offer potential for low carbon footprint but require R&D