GE Aviation

Managing the Cost of Fuel

Supply, Demand, and Policy.

Tom Maxwell
Mike Epstein
GE Aviation Portfolio... $19.2 B

Military engines & services

'08 Revenue $4.2

Commercial engines

$5.2

Commercial engine services

$6.8

Business & General Aviation

$0.4

Systems

'08 Revenue $2.2

Unison Engine Components

$0.4

A leading aviation technology business

(a- Includes GE’s 50% of CFMI & EA
CFMI is a 50/50 JV between GE and Snecma
EA is a 50/50 JV GE and Pratt & Whitney
Military and Commercial Cost of Fuel

Military

USAF Cost & Consumption

<table>
<thead>
<tr>
<th>Year</th>
<th>MBTUs</th>
<th>Billions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>380</td>
<td>$10</td>
</tr>
<tr>
<td>2004</td>
<td>360</td>
<td>$8</td>
</tr>
<tr>
<td>2005</td>
<td>340</td>
<td>$6</td>
</tr>
<tr>
<td>2006</td>
<td>320</td>
<td>$4</td>
</tr>
<tr>
<td>2007</td>
<td>320</td>
<td>$4</td>
</tr>
<tr>
<td>2008</td>
<td>320</td>
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Cost of fuel to the battlefield estimated at 10-100X purchase price

Commercial

2003

- FUEL: 14%
- OTHER: 86%

Loss: $-7B

2008

- FUEL: 31%
- OTHER: 69%

CO2 Tax: $30/ton worldwide

Loss: $-17B

Total Cost:

- Military: $187B
- Commercial: $44B

$165B

$187B

$-39B

$-17B
Managing The Cost of Fuel...

**COST OF FUEL**


**POLICY**

Energy – Eco - Stimulus
US, EU
DOD: USAF, Navy, DARPA
US states

**DEMAND**

Efficiency
New Product Intro
Materials, Aerodynamics
Advanced cycles

**SUPPLY**

Alt Fuels
Feedstock Diversity
Qualification Path
CO2 mitigation
Managing The Cost of Fuel…

COST OF FUEL


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Why Aviation Cares About Biofuels…

Industry Growth Projections

CO2 Growth Projections

Emissions continue to grow…
+35% CO2 over last 15 yrs

100-115 grams CO2 / PAX / km…
Cincinnati to Tel Aviv - 10,000 km. Yields about 1 ton per PAX.
EU ETS for aviation commencing 2012

Chief airline concern: money leaves aviation

EU CO2 Emissions (Million Tonnes)

- Cap level: 97% of baseline, 95% after 1 yr
- Baseline ('04-'06 avg)
- EU CO2 growth (notional)
- Required reduction
- Freely allocated
- Purchased allocation (15%)
- Additional airline / customer cost burden

CO2 exceedance:
- More efficient technology
- 3rd party offsets
  - Clean energy development
  - GHG sequestration
  - Forestation

GE analysis based on IATA, AEA, ERA, OAG data
ISSUES AT PLAY…

- Climate change legislation, Waxman-Markey.
- USCAP – GE charter member.

WHY POLICY MATTERS

Policy trajectory & lessons learned apply to biofuels
USAF Energy Strategy

Reduce Demand
10% reduction by 2015

Increase Supply
25% US based by 2016

Change the Culture
Train all personnel by 2010

Upgrades, Kits
SLEP, TF34 BRU

Coal, Gas, Bio to liquid
Fischer Tropsch

Leadership

Base Efficiency
3% reduction / year

Renewable Jet Fuel
Initiating mil qual…supporting commercial qual end ’10.

Training
Add to Academy training

ADVENT, HEETE
35% Efficiency gain

Co-processing.
Advanced Cellulosic.

KPP in every activity

Clear goals, objectives, plans and metrics
AFPM 10-1.1. June 16th, 2009
Managing The Cost of Fuel...

### COST OF FUEL

Environmental – direct & indirect costs.

### POLICY

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### DEMAND

**Efficiency**
New Product Intro
Advanced cycles
Materials, Aerodynamics

### SUPPLY

**Alt Fuels**
Feedstock Diversity
Qualification Path
CO2 mitigation
Modern aircraft fuel consumption is between 3 and 5 liters /100 km/PAX.

Commercial engine efficiencies driven by higher bypass ratios, higher core pressure & temperature ratios.

70% efficiency gain means 70% carbon emissions reduction.
Enormous SFC potential for next-gen aircraft
condition: Mach 0.84 / 35K feet / ISA
GEnx...Power for the 787 and the 747-8
Advanced Ceramic Material Technology

Material System Overview

- Silicon Melt Infiltrated Process for Ceramic Matrix Composite (CMC) Material
- Suppliers:
  - GE Aviation
  - Goodrich
- Manufacturing Process Scale-up In-Progress

Technology Development Status

- Material and Process Defined
- Achieved NPI TG5 on Lead Component
- Established Material Specifications
- Working Full Material Database
- Significant Engine Testing Planned In 2009-2011

Why Use Ceramic Matrix Composites (CMC’s) For Turbine Engine Applications?

- Significantly Higher Temperature Capability Than Metals
- Fracture/Crack Resistance Significantly Better Than Conventional Ceramics
- Lightweight

1/3 the weight of nickel based superalloys. Reduced parasitic cooling air for improved engine performance
F136 Engineering Status.

First production aircraft engine use of high temperature CMCs

First Engine To Test (625-004)
- Initiated one month ahead of schedule
  - 004 build 1 testing complete.
- Demonstrated successful engine operation and obtained critical validation data

Flight Test Clearance Process Started May 09
- Review began 18 months ahead of 1st flight
- Synchronized with LM flight test schedule
NAVY Task Force Energy (TFE) program

SFC Technology Demonstrator

- Program goal to demonstrate 3% SFC improvement vs F414-400.
  - EDE core plus technology to achieve –3% SFC at current thrust.
  - Based on F414 SFC Demonstrator configuration

- Complete testing and provide test data by September 2010
  - Generate plans for fleet qualification and technology insertion

F414 Biofuels Qualification

- Component testing initiated with Bio JP-5
- Ground tests planned early 2010.
Optimized fuel efficiency at ALL flight conditions. TRL 6 2012.

\[ \eta_{\text{overall}} = \eta_{\text{Propulsive}} \times \eta_{\text{Thermal}} \]

Variable Cycle GE ADVENT Concept

Maximizes Overall Efficiency by Optimizing Propulsive Efficiency & Thermal Efficiency.

\[ \eta_{\text{overall}} = \frac{\text{POWER DELIVERED TO THE VEHICLE}}{\text{POWER DELIVERED TO THE WORKING FLUID (AIR)}} \times \frac{\text{POWER DELIVERED TO THE WORKING FLUID (AIR)}}{\text{ENERGY CONTENT OF THE FUEL} \times \text{FUEL FLOW}} \]

\[ \eta_{\text{Propulsive}} = \frac{F_{\text{NET}} \cdot V_{\text{vehicle}}}{M_{\text{air}} \left( \frac{V_{\text{exhaust}}^2}{2} - \frac{V_{\text{vehicle}}^2}{2} \right)} = \frac{2}{1 + \frac{V_{\text{exhaust}}}{V_{\text{vehicle}}}} \]

\[ \eta_{\text{Thermal}} = \frac{M_{\text{air}} \left( \frac{V_{\text{exhaust}}^2}{2} - \frac{V_{\text{vehicle}}^2}{2} \right)}{M_{\text{fuel}} \times \Delta H_{\text{combustion}}} \]
ADVENT – ADaptive Versatile ENgine Technology

Optimized for efficiency at ALL flight conditions.

2012.

Propulsive Efficiency

Thermal Efficiency

Max Power

Max Power

ADVENT

Increased Bypass

Low Bypass

Baseline

Baseline

Compromised Speed
For Range and Persistence

Compromised Range and Persistence for Speed

FETT testing complete …170 hrs. Exceptional performance & SFC Margin

**SFC best in class**

- New Aero HPT
- 3D Aero PT
- 100% CFE738 Compressor Aero Improved erosion coating on blisks.
- FADEC with PHM.
Managing The Cost of Fuel...

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**SUPPLY**

Alt Fuels
- Feedstock Diversity
- Qualification Path
- CO2 mitigation
FUEL…The Workhorse Fluid

Fuels in an aviation application:

• Provides an energy source, which is converted to mechanical energy and thrust.

But there’s more…

• Cools airframe avionics, hydraulic fluids and system electronics.
• Provides proper stress in aircraft wings.
• Fuel-draulics….actuators, valves, variable geometry, etc.
• Provide an energy source to an on-board APU

Aviation Fuel Used For Multiple Purposes…Drives Complex Requirements and Exacting Specifications
Explosion of activity in the last 6 – 9 months...


**CFMI**…Continental Airlines.  Biodiesel in Jet-A.

**USAF**…F-T Approval. Initiating Biofuels Qual.

**GE90**…Multiple Customer Requests

**CF6**…KLM Flight Test – November 23rd.  1st PAX flt.

**CF34**… Embraer, Amyris & Petrobras.

**GE Research**…DARPA Programs for HRJ, Cellulosic

Industry wide participation.  Issues & Goals Vary.
ASTM Spec…Certification Process

Table 1 Properties
Flash Point, Freeze Point, Energy Density, Thermal Stability

Fit For Purpose Properties

Component Test
Combustor ignition & LBO, Altitude restart, Fuel Control, Fuel Nozzle Spray & Coking

Engine Test

Engine Lean Blowout
No distinguishable difference between conventional Jet-A and 50-50 blends
• Incredible number and variety of new ideas surfacing – no clear winner
• Concepts, technologies…renewable, non renewable, and in-between
• Durable policy, oil price movement, unique IP may drive opportunity
Renewable & Non Renewable Processes to Produce Jet Fuel

Petroleum
- Conventional oil

Coal
- Lignite
- Sub-bituminous
- Bituminous
- Anthracite

Existing Refinery
- Petroleum

F-T Plant
- Syn gas CO + H2

Jet Fuel Blends.
- Refinery co-products
  (Diesel, Naptha, Light gases, etc)
Renewable & Non Renewable Processes to Produce Jet Fuels

- Explosion of new ideas for aviation sector fuel.
- No clear renewable winner.
- Co-products drive viability & complexity.
- Numerous policy challenges...

Petroleum
- Conventional oil
- Oil sands
- Heavy crude

Natural Gas
- Conventional
- Coal bed methane
- Natural gas from shale deposits
- LNG

Coal
- Lignite
- Sub-bituminous
- Bituminous
- Anthracite

Bio-oil crops
- 1st gen food crops
- Algae
- Camelina
- Seed crops
- Halophytes
- Jatropha
- etc

Biomass
- Wood waste
- Ag waste
- MSW
- Low grade cellulosic
- other

Existing Refinery
- Petroleum

F-T Plant
- Syn gas CO + H2

Modified Refinery
- Plant oils

Fermentation
- sugar

Jet Fuel Blends
- Refinery co-products (Diesel, Naptha, Light gases, etc)
- Ag co-products (meal, etc)
- Food for human consumption.
- Power / cogen.
Lessons Learned

- DARPA broke multiple paradigms.
  - It’s NOT just about F-T.
  - Alt fuel CAPX doesn’t need to be $Billions
  - Jet fuel can be produced from MANY sources

- Process H₂ significant cost factor.
  - “Buy” versus “produce” can help mitigate.

- Logistics significant cost factor.
  - Feedstock & product transportation.
  - Vertical integration is essential.

- Local feedstocks imply local solutions.
  leveraging multiple pathways to Jet-A.

Next Steps

- Cellulose derived renewable fuel (HRJ)
  - Current DARPA funded program

- Scale up current process to show feasibility.
Products that meet today’s needs and tomorrow’s challenges…

Aviation industry must address **DEMAND** (efficiency) and **SUPPLY** (alternatives).

Energy diversity is essential. Consistent, long term policies can be enabling.

GE is developing products and services to address these needs.

GE is committed to creating **environmentally softer products**.