# GE Aviation

# Managing the Cost of Fuel

## Supply, Demand, and Policy.

Tom Maxwell
Mike Epstein

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# GE Aviation Portfolio… $19.2 B

## Military engines & services

'08 Revenue $4.2

## Commercial engines

$5.2 –a)

## Business & General Aviation

$0.4

## Systems

'08 Revenue $2.2

## Unison Engine Components

$0.4

## Commercial engine services

$6.8

($ in billions)

**A leading aviation technology business**

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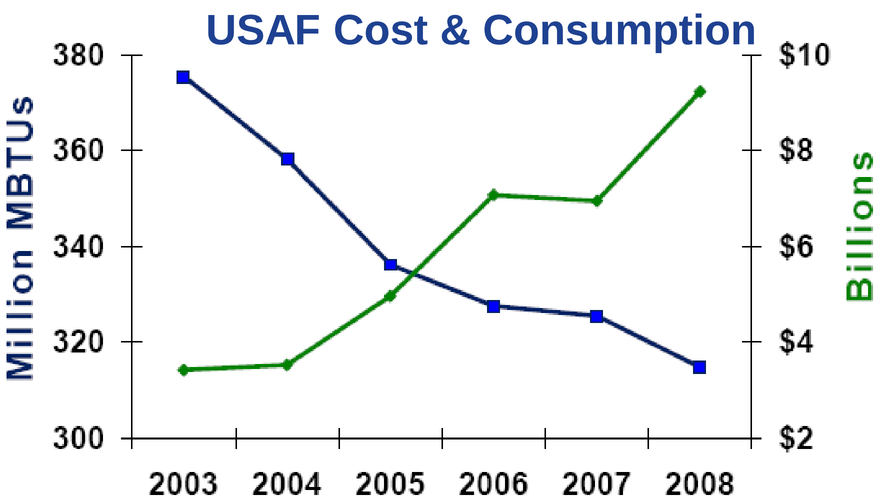
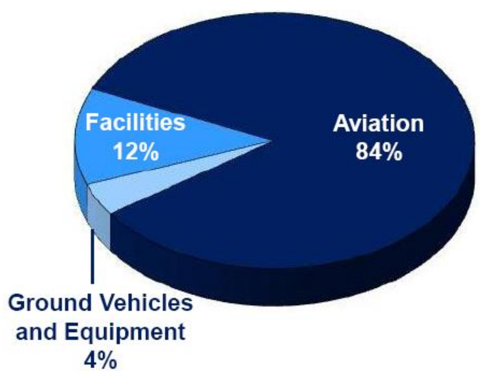
*(a- Includes GE's 50% of CFMI & EA*
*CFMI is a 50/50 JV between GE and Snecma*
*EA is a 50/50 JV GE and Pratt & Whitney*

# Military and Commercial Cost of Fuel

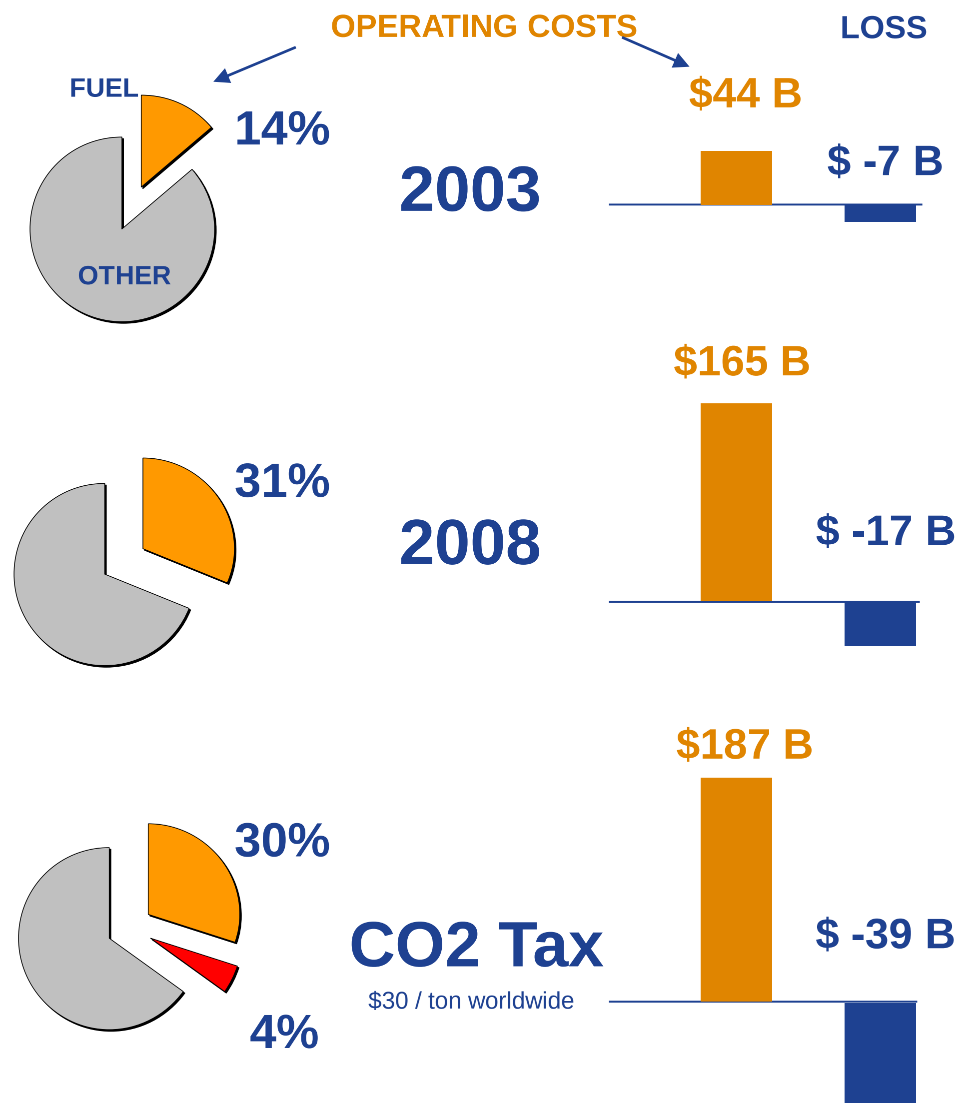
## Military




**Cost of fuel to the battlefield estimated at 10-100X purchase price**

## Commercial



# Managing The Cost of Fuel…

## COST OF FUEL

Direct Costs. Price, Volatility, (Un) availability. Total cost of delivered fuel.
Environmental – direct & indirect costs.

| POLICY | DEMAND | SUPPLY |
|---|---|---|
| **Energy – Eco - Stimulus**<br>US, EU<br>DOD: USAF, Navy, DARPA<br>US states | **Efficiency**<br>New Product Intro<br>Materials, Aerodynamics<br>Advanced cycles | **Alt Fuels**<br>Feedstock Diversity<br>Qualification Path<br>$CO_2$ mitigation |

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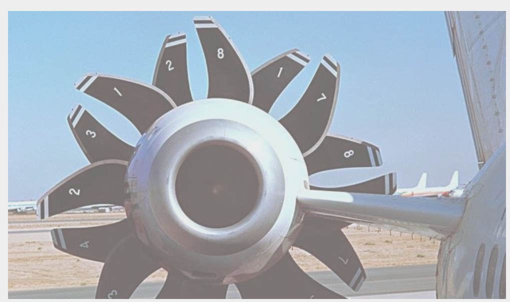

### SUPPLY

**Alt Fuels**

Feedstock Diversity
Qualification Path
$CO_2$ mitigation

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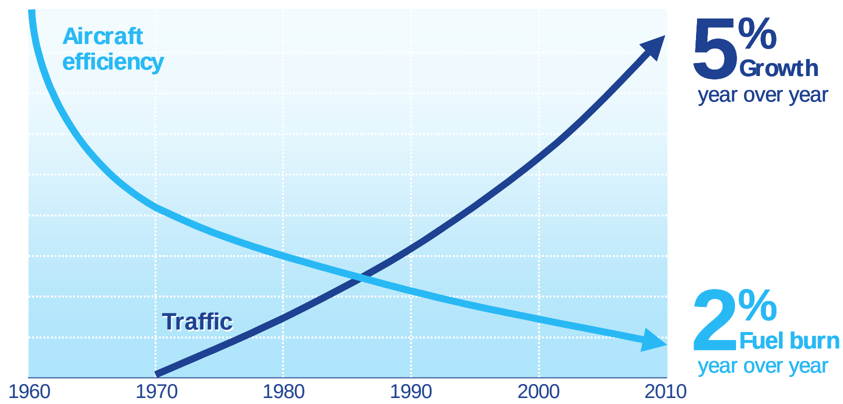
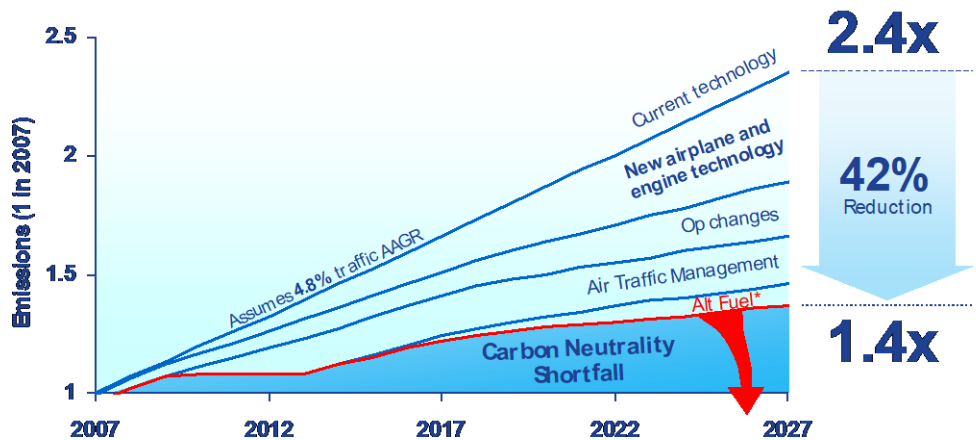
# Why Aviation Cares About Biofuels…

## Industry Growth Projections




## CO2 Growth Projections

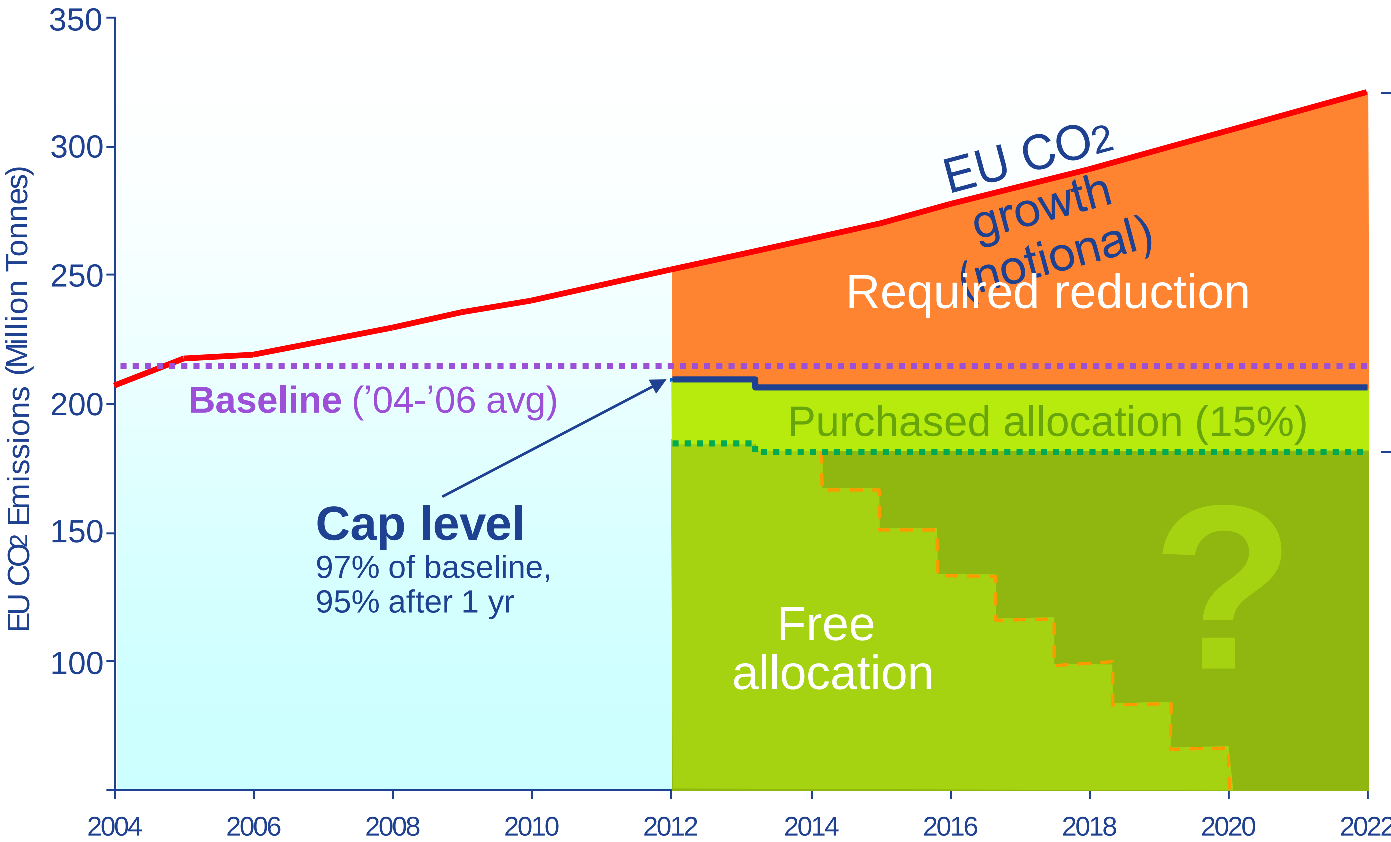



Emissions continue to grow…

+35% $CO_2$ over last 15 yrs

# EU ETS for aviation commencing 2012

## Chief airline concern: money leaves aviation




$

Additional airline / customer cost burden

**$CO_2$ exceedance**

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

GE analysis based on IATA, AEA, ERA, OAG data

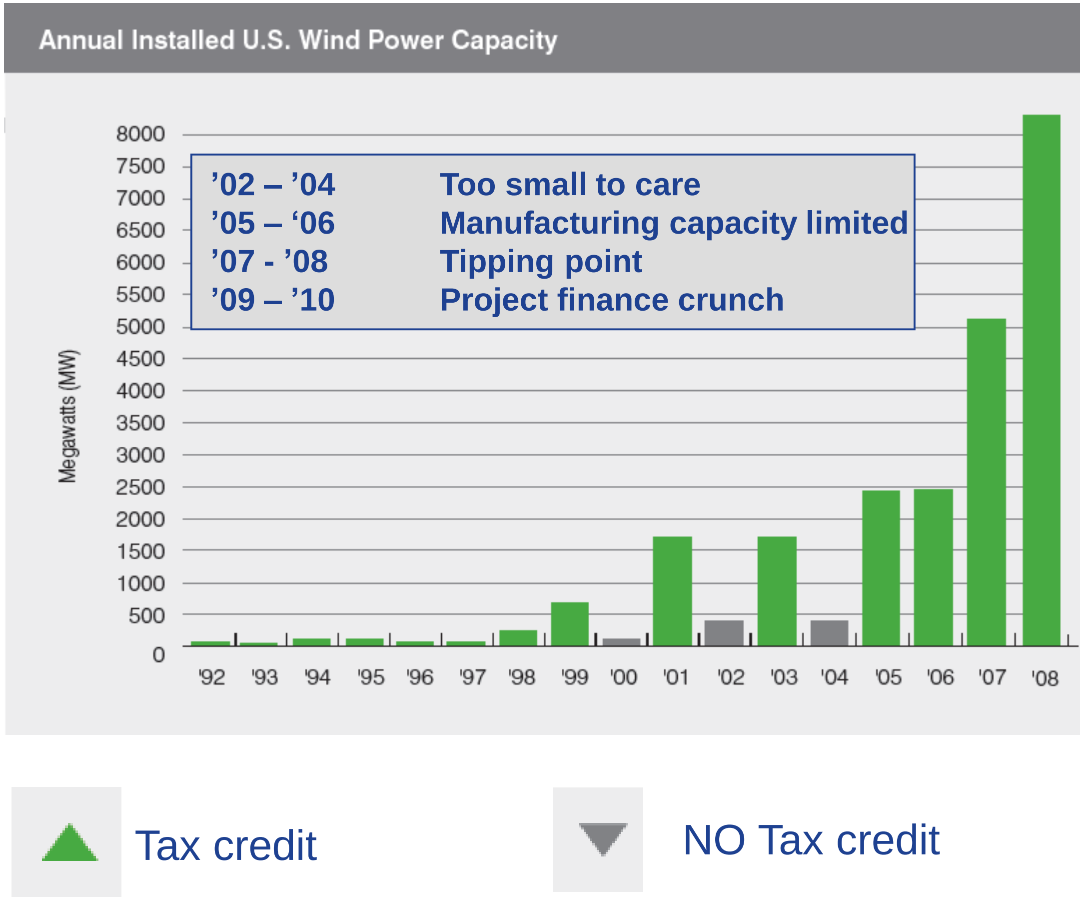
# US Policy…

## ISSUES AT PLAY…

- Climate change legislation, Waxman-Markey.
- ARRA. American Recovery and Re-investment Act.
- Energy Bills – EPACT05 and EISA 2007.
- USCAP – GE charter member.

USCAP
United States Climate Action Partnership

## WHY POLICY MATTERS




**Policy trajectory & lessons learned apply to biofuels**

# USAF Energy Strategy

| Reduce Demand | Increase Supply | Change the Culture |
|---|---|---|
| 10% reduction by 2015 | 25% US based by 2016 | Train all personnel by 2010 |

SHORT TERM

**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**

LONG TERM

**Clear goals, objectives, plans and metrics**

AFPM 10-1.1. June 16th, 2009

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Feedstock Diversity
Qualification Path
$CO_2$ mitigation

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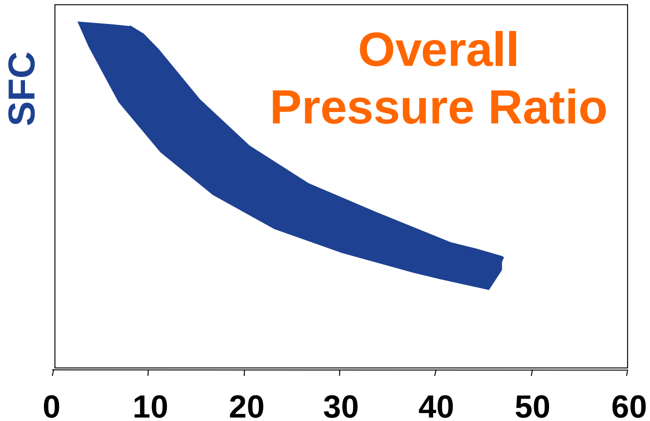
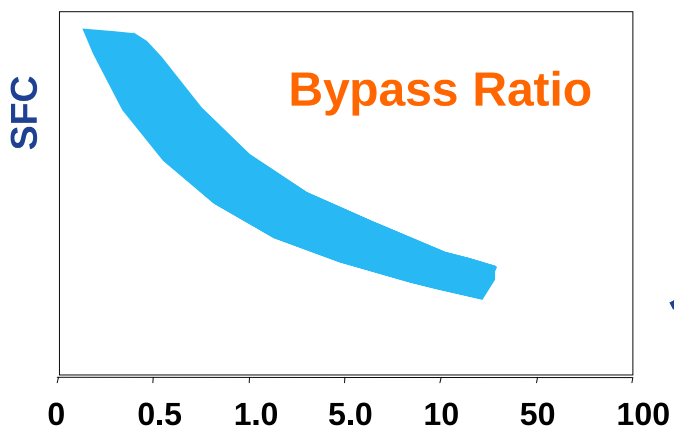
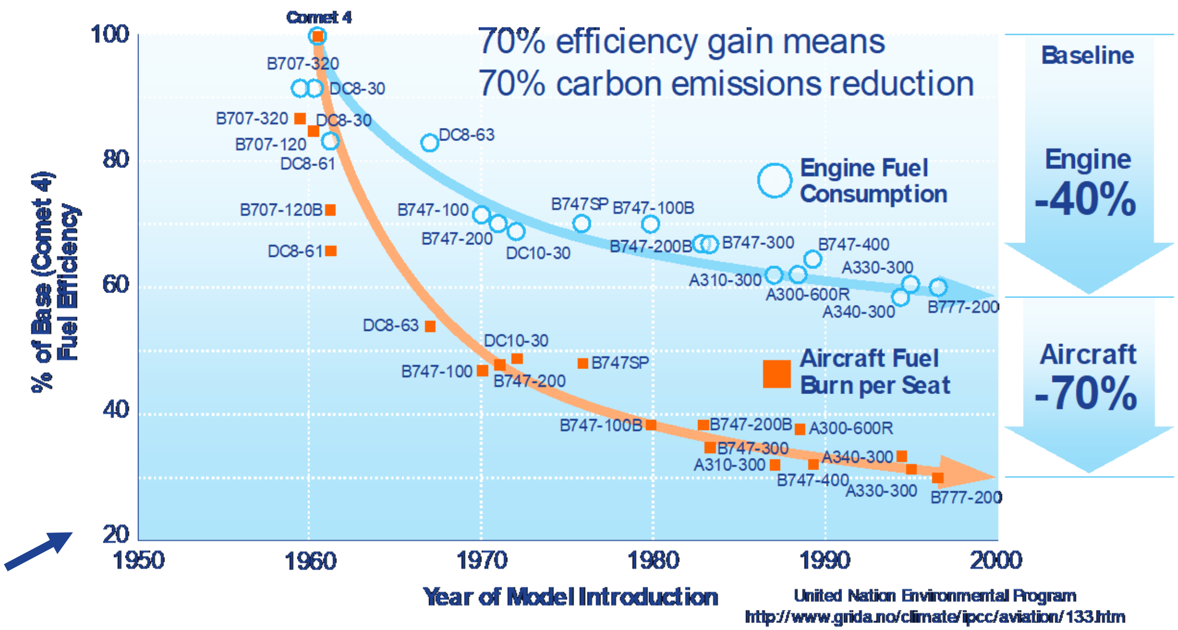
# Engine Fuel Consumption…




## Modern aircraft fuel consumption is between 3 and 5 liters /100 km/PAX.

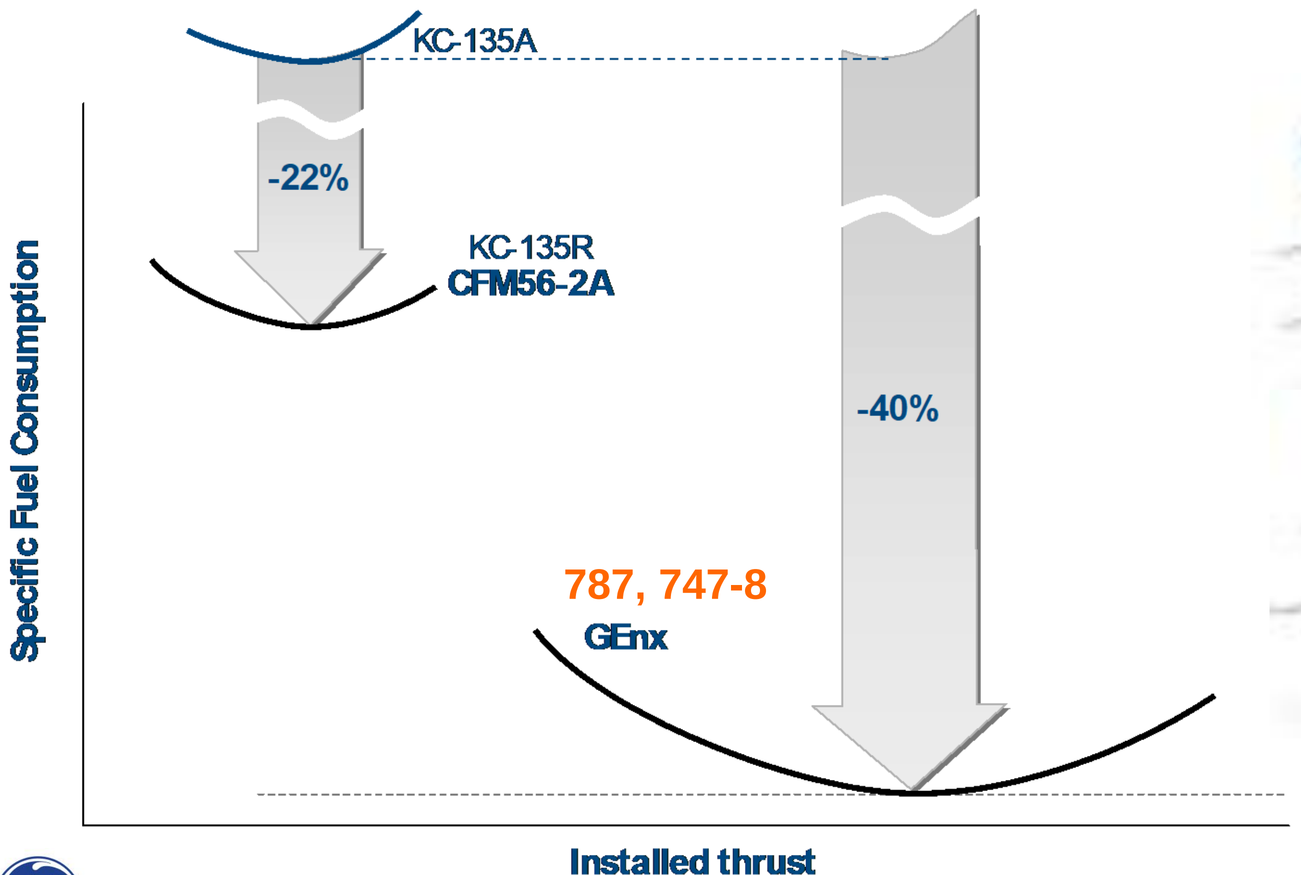



Commercial engine efficiencies driven by higher bypass ratios, higher core pressure & temperature ratios

# Passenger / Tanker / Cargo …

## Enormous SFC potential for next-gen aircraft

condition: Mach 0.84 / 35K feet / ISA

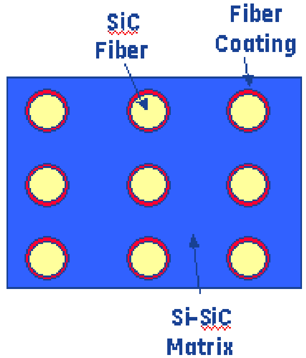



# GEnx…Power for the 787 and the 747-8

# 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

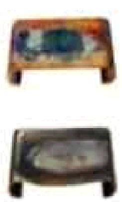
- Material and Process Defined
- Achieved NPI TG6 on Lead Component
- Established Material Specifications
- Working Full Material Database
- Significant Engine Testing Planned In 2009-2011

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

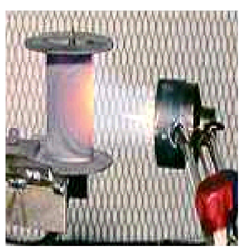
**Significantly Higher Temperature Capability Than Metals**

CMC (Not Melted)

Metal (Melted)



Simulated Engine Test Results



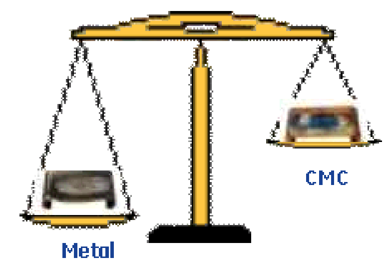
CMC Withstands Direct Flame Test

**Fracture/Crack Resistance Significantly Better Than Conventional Ceramics**

Advanced Ceramic Shatters

CMC Survives High Velocity Particle Impact Test

**Lightweight**




CMC Weight Only 1/3 Metal Weight

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

# F136 Engineering Status.

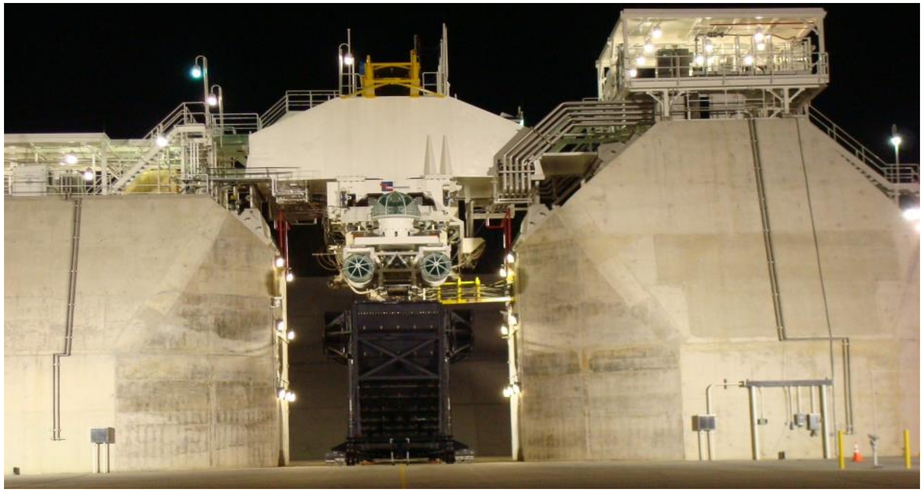
**First production aircraft engine use of high temperature CMCs**

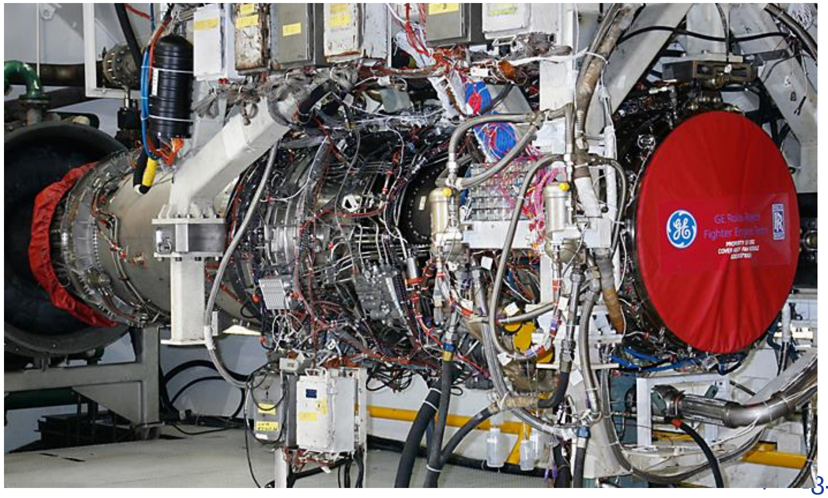
## First Engine To Test (625-004)

- 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





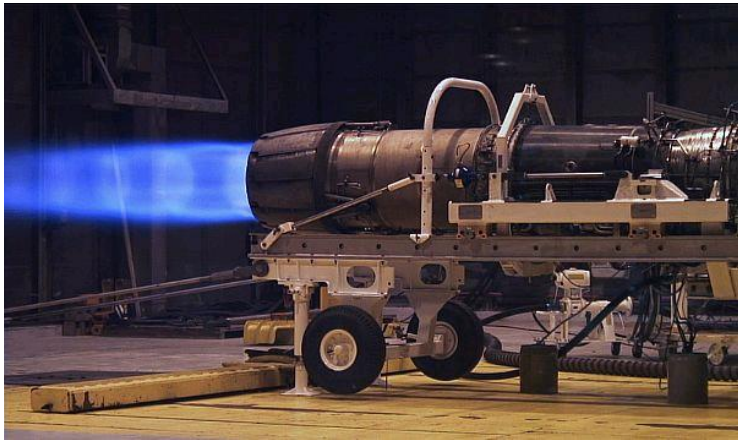
# NAVY Task Force Energy (TFE) program

## 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.
- Flight tests early 2nd qtr, 2010.

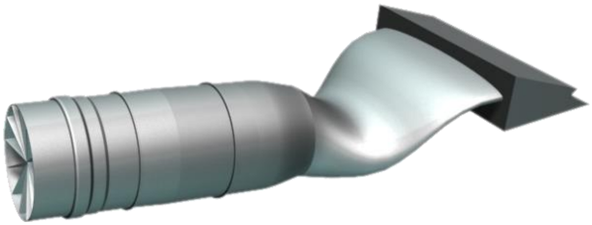


F404 engine from an F/A-18 runs on biofuel in a Naval Air Systems Command test at the Aircraft Test and Evaluation Facility, Patuxent River, Md.

Photos courtesy US Navy

# ADVENT – ADaptive Versatile ENgine Technology

## Optimized fuel efficiency at ALL flight conditions.  TRL 6  2012.



$$\eta_{overall} = \eta_{Propulsive}\,\eta_{Thermal}$$

Variable Cycle GE ADVENT Concept

**Maximizes Overall Efficiency by Optimizing Propulsive Efficiency & Thermal Efficiency.**

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

$\eta_{Propulsive}$

$$\frac{F_{NET} \bullet V_{vehicle}}{M_{air}\left[\frac{V^2_{exhaust}}{2} - \frac{V^2_{vehicle}}{2}\right]} = \frac{2}{\left[1 + \frac{V_{exhaust}}{V_{vehicle}}\right]}$$

$\eta_{Thermal}$

$$\frac{M_{air}\left[\frac{V^2_{exhaust}}{2} - \frac{V^2_{vehicle}}{2}\right]}{M_{fuel} \times \Delta H_{combustion}}$$

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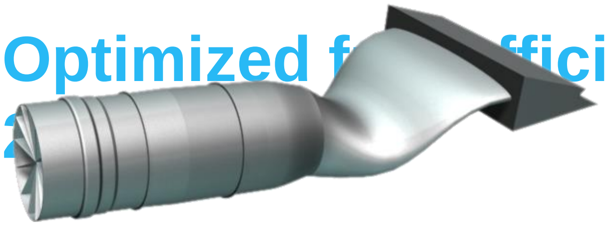
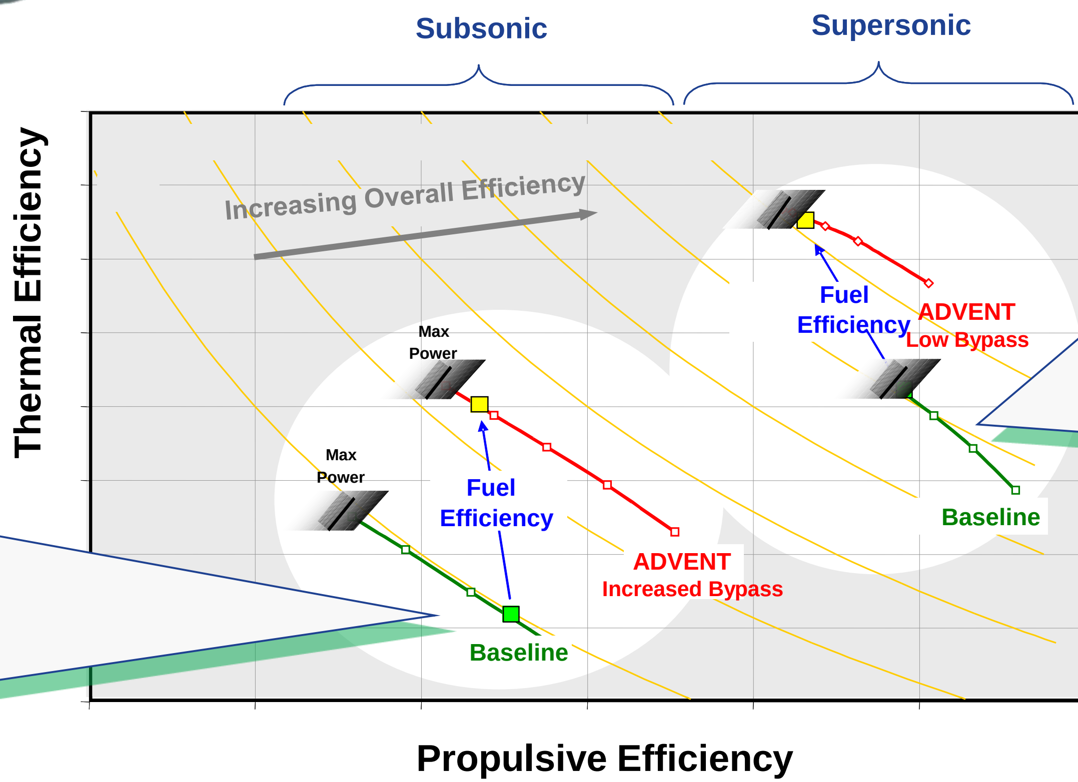
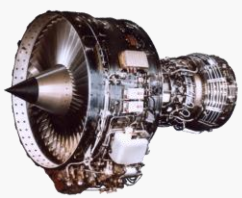
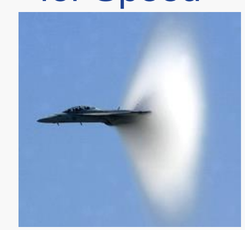




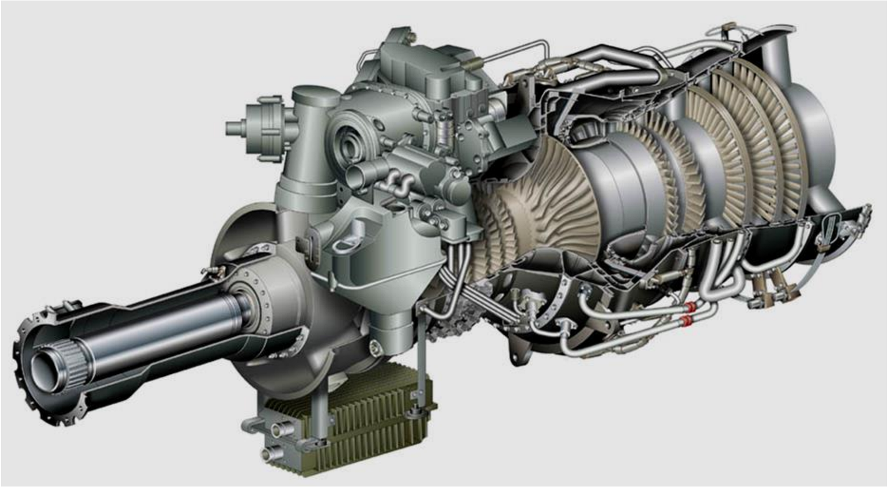
**Compromised Speed**
For Range and Persistence

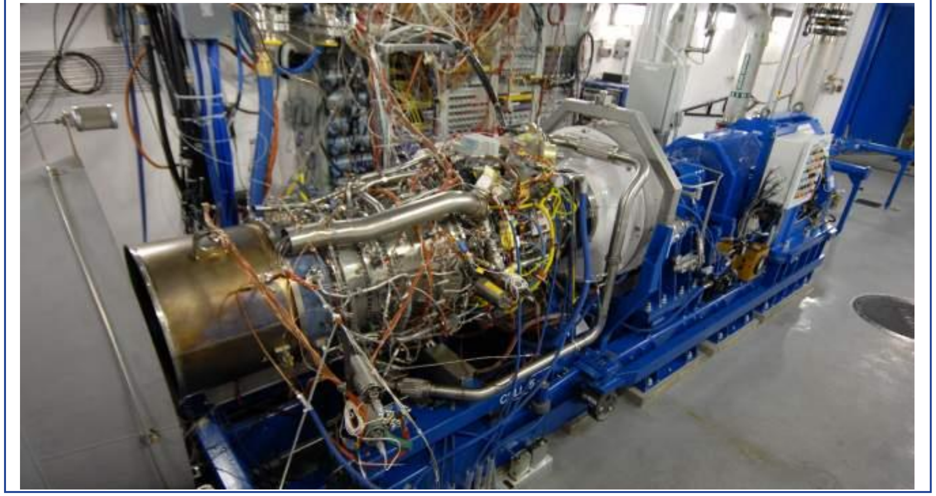
**Compromised Range and Persistence**
for Speed



# GE38 – Heavy Lift Power for the Sikorsky CH-53K (US Marine Corps) Airframe.

**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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### POLICY

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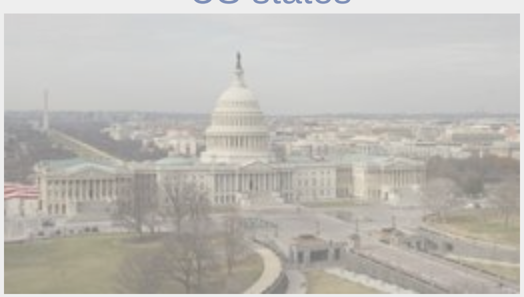

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Materials, Aerodynamics
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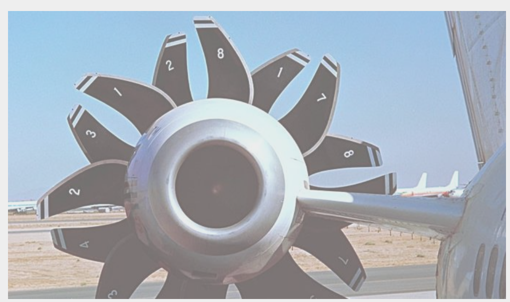



### SUPPLY

**Alt Fuels**

Feedstock Diversity
Qualification Path
CO2 mitigation

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# 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…

**US Navy**…F414 Biofuels.   Gripen.

**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.**

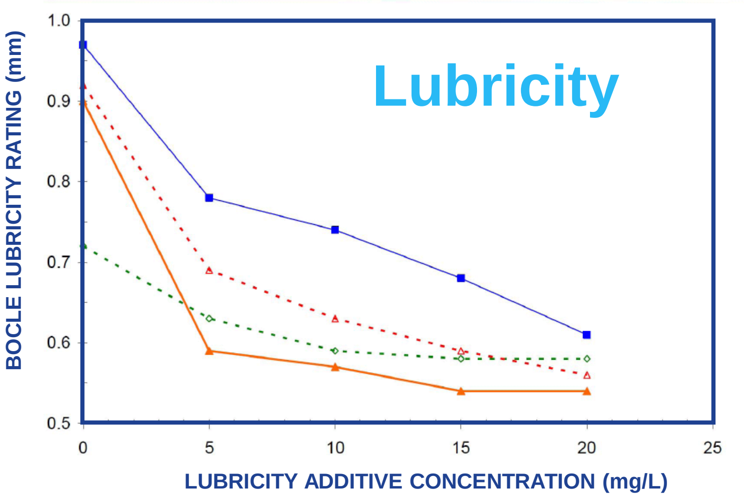
# ASTM Spec…Certification Process

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

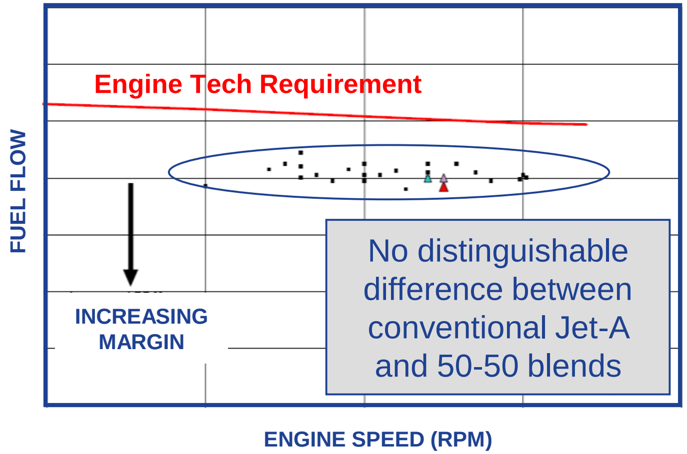
## Fit For Purpose Properties
Bulk Physical Properties, Electrical Properties, Storability, Auto-ignition.

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

## Engine Test
Performance, Operability & emissions. Limited endurance. Flight Test if airframers require.


## Engine Lean Blowout

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# Gen II BioFuels & Beyond…

Today → Tomorrow

**Feedstock**

| | Soy | Gen-2 Cellulosic | Halophytes | Algae | Enzyme/Bio | |
|---|---|---|---|---|---|---|
| **Yield** | **40** | **60-150** | **100-200** | **1,000-4,000+** | | **USG/ acre** |





**Processes**

- Fisher Tropsch<br>Hydro-treating
- Co-refining<br>Lignocellulosic<br>Pyrolysis
- Enzymatics<br>Adv. thermo-chem<br>Int eco-systems

- **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

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# Renewable & Non Renewable Processes to Produce Jet Fu

**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 Fu

- 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
Jatropa
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)

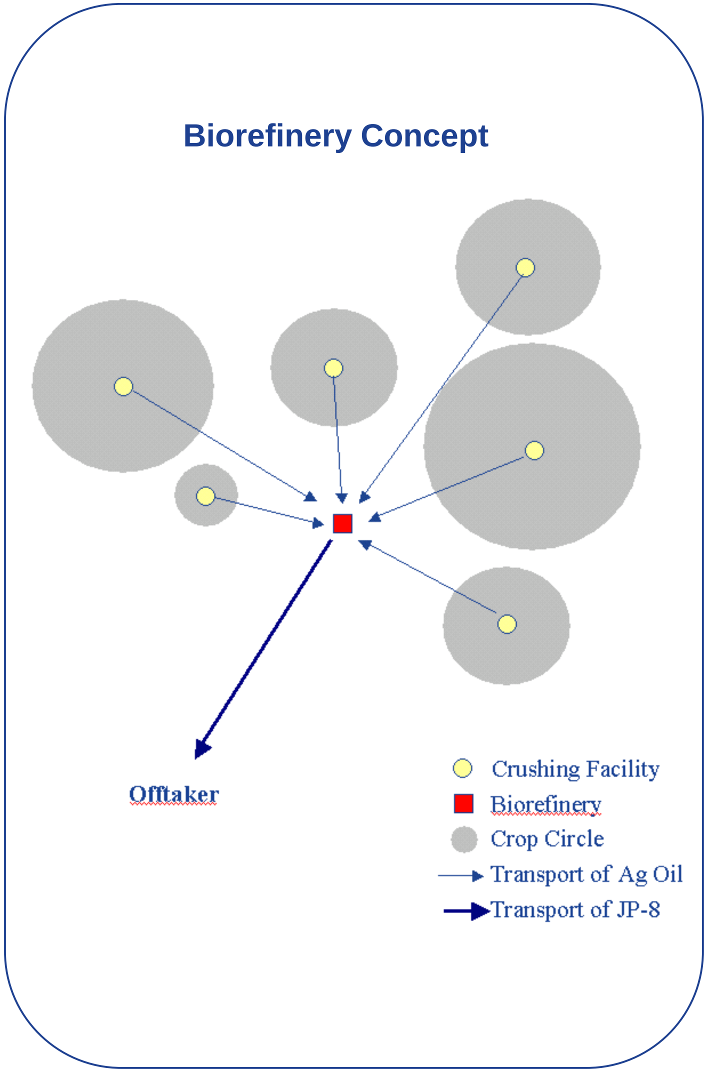
Food for human consumption.

Power / cogen.

# DARPA Bio Oil to Jet (BOTJ) Program

## 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 $H_2$ 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.

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# SUMMARY

# Products that meet today's needs and tomorrow's challenges…

**Petroleum**

**Bio**

**Natural Gas**

**Coal**

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**.

**F110**

**F136**

**GE38**

**T700 / CT7**

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