

**Pratt & Whitney**

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A United Technologies Company

P&W  
FAA CLEEN Update

November 2013

# AGENDA

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Alternative Fuel Evaluation

FAA CLEEN Program Status

# **ALTERNATIVE FUEL EVALUATION**

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# P&W'S ROLE IN ALTERNATIVE FUELS & REDUCING CARBON FOOTPRINT IN AVIATION



## P&W position in Congressional hearing, press releases, and interviews

### **Design fuel-efficient engines**

P&W's PurePower® engine family reduces fuel burn by more than 12% and dramatically cuts emissions

### **Validate alternative fuels**

Support customer initiatives  
Evaluate impact on the engine  
Provide a timely and cost-effective path for approval and field use



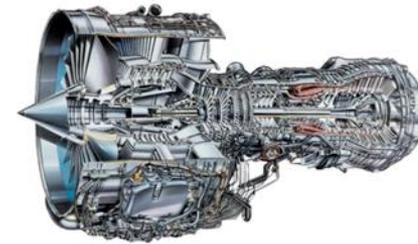
# ENGINE MANUFACTURERS' REQUIREMENTS



High energy content

Drop-in technology invisible to the engine

Requires no redesign, component development program, or re-certification



ASTM Requirement: Do No Harm

# FAA CLEEN – ALTERNATIVE FUEL EVALUATION



## Alternative fuel blends for demonstration tests

Baseline fuel and fuels to be tested from three different processes

Baseline Jet A (or Jet A-1) conforming to ASTM D1655

30/70 Kior HDCJ/Jet A  
50/50 Kior HDCJ/HEFA  
50/50 ARA CH/Jet A  
100% ARA CH

} Completed

20% Amyris Farnesane

Kior Hydroprocessed Depolymerized Cellulosic Jet (HDCJ)  
Containing 50% by volume synthetic aromatics



Applied Research Associates (ARA) Catalytic Hydrothermolysis (CH)  
Containing 16 to 24% by volume synthetic aromatics



Amyris Farnesane  
C-15 molecules



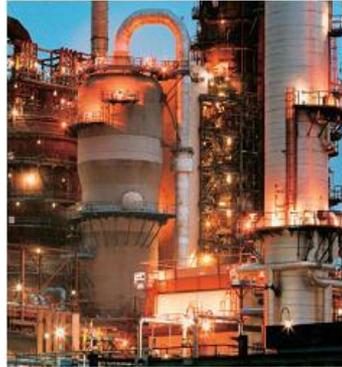
# HYDROPROCESSED DEPOLYMERIZED CELLULOSIC JET (HDCJ) **KiOR**



**Renewable Biomass Feedstock**



**Thermo Catalytic Conversion**



**Bio-crude Hydrotreating**



**Blendstock Fractionation**



- ✓ Abundant supply
- ✓ Non-food residue
- ✓ Lignocellulose

**Hydroprocessed Depolymerized Cellulosic Jet**  
 Approx 47% aromatics  
 Blend at 30% into jet or 50/50 with zero aromatic FT, HEFA, or ATJ

... hydrocarbons  
 ... Jet, Distillate  
 ... rich (30-45%)



**Jet Fuel Products**

**Target 30% HDCJ in Jet A**



**Renewable Hydrocarbon Blendstocks**

**HDCJ Blendstock**

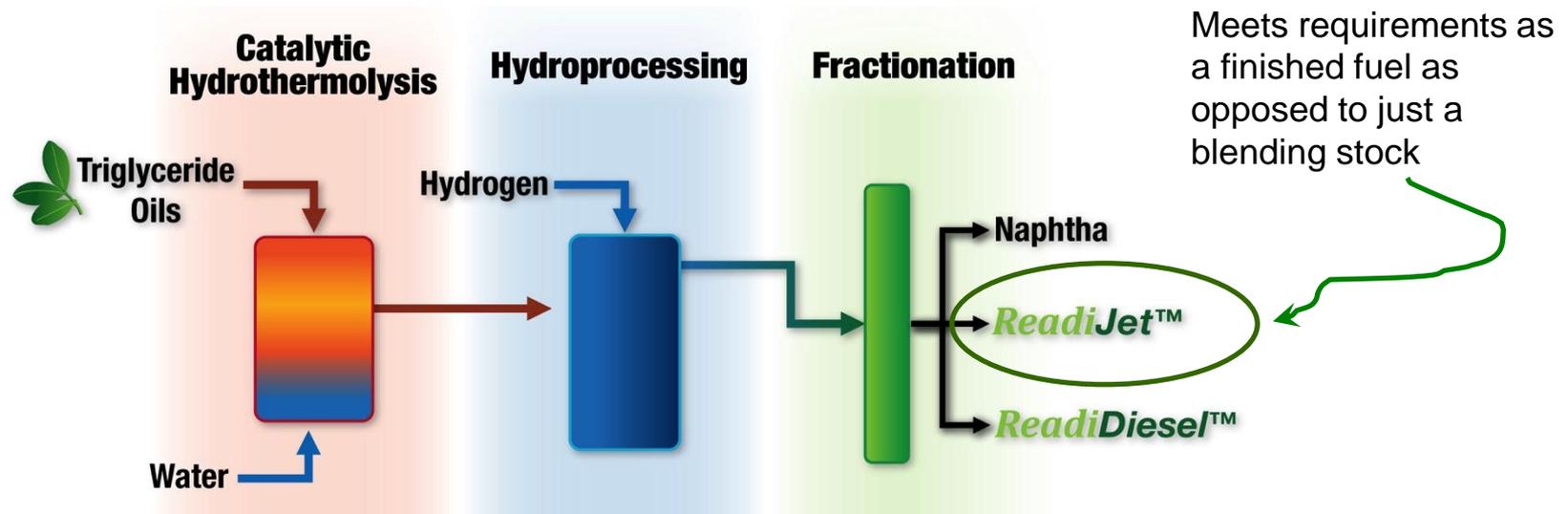
**Gasoline + Diesel**

# CATALYTIC HYDROTHERMAL PROCESS (CH)



Hydrothermally cracks triglyceride oils into hydrocarbons

*Same hydrocarbon types as petroleum - normal distribution*



## Catalytic Hydrothermal Process

Applied Research Associates / Chevron

16 to 24% aromatics

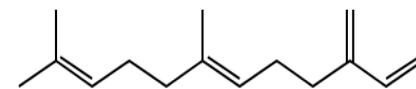
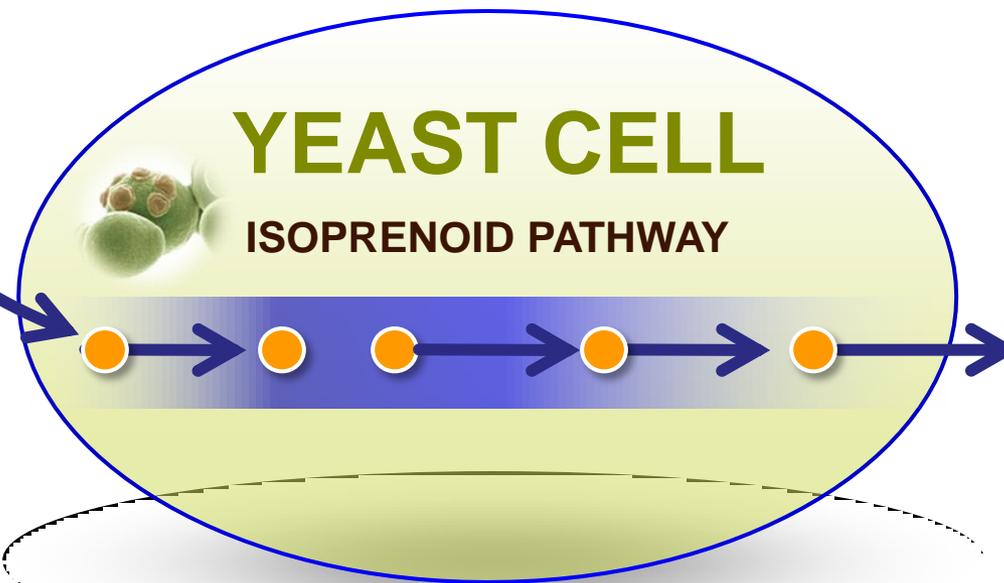
ARA Readijet meets all ASTM requirements except is not made from petroleum



# DIRECT SUGAR TO HYDROCARBONS (DSHC)



SUGAR SOURCE



C12 HYDROCARBONS



**Direct Sugar to Hydrocarbons**  
Amyris /Total (Total is largest refinery in Europe  
Produces C-15 hydrocarbons (Farnesane)  
Blended into fuel at 10%



## Fermented Sugar to HCs



Fermentation

Genetically Engineered Microbes



C-12 Hydrocarbons



Plant/Animal Oils

## Catalytic Hydrothermolysis (CH)



Oil Extraction



Catalytic Hydrothermolysis



Bio-Crude

## Conventional Refinery Processes



Hydroprocessing & Fractionation



Jet Fuel



Renewable Biomass

## Hydroprocessed Deploymerized Cellulosic Jet (HDCJ)



Pretreatment



Pyrolysis



Bio-Crude

# ENGINE DEMONSTRATION TESTS

## **P&WC Turbofan Engine Model PW615F**

Cessna Citation Mustang

1460lbs thrust, 2-spool turbofan engine

Reverse flow combustor, dual-channel FADEC



## **Engine Test Plan**

Following tests to be completed for each test fuel

Engine exhaust emissions (gaseous species)

Engine exhaust particulates matters (LII & smoke number)

Engine performance characterization (SFC, Thrust)

5 Test points: Ground Idle to Takeoff

Basic engine operability handling

- Accel and decel time check

- Negative fuel spike (Lean blow-out margin)



## **Post Test Inspection**



# COMBUSTOR RIG TESTS

## Single nozzle can combustor rig

P&WC combustor rig located at Laval University, Canada

Representative fuel nozzle (JT15D) and ignitor (PW600)

Maximum air flow rate

Cold start capability: fuel and air (75°C test range)

Altitude relight (sea level up to representative altitude)



## Combustor test plan

Following tests to be completed for each test fuel

Cold start mapping at sea level constant pressure

Altitude relight mapping at constant speed

# KIOR AND ARA ENGINE AND COMBUSTOR TESTS SUCCESSFULLY COMPLETED



No significant difference on engine performance (fuel flow at take-off)

Similar engine starts, accel, decel, surge and flameout margins characteristics

No significant difference on gaseous emissions (CO, HC, NOx)

No significant difference in smoke & Particulate Matters (PM) emissions



**Amyris scheduled to start end of November 2013**

Photo Credit: Pratt & Whitney Canada

# **FAA CLEEN PROGRAM STATUS**

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# FAA CLEEN PROGRAM STATUS

## Certification of GTF validates UHB potential

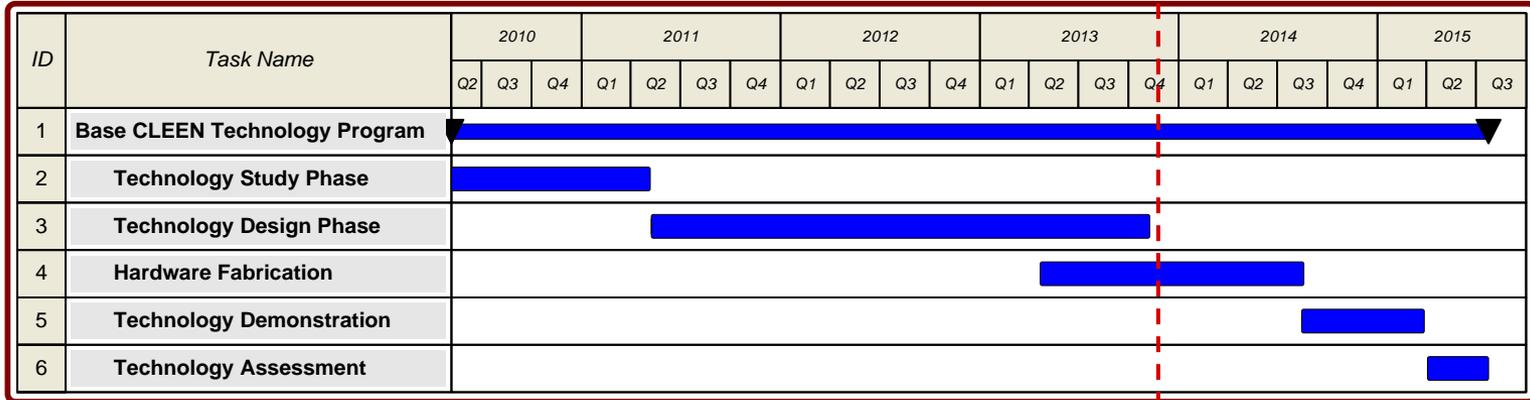


Photo Credit: Pratt & Whitney



# FAA CLEEN PROGRAM STATUS

## Program on track for successful completion



Nov 2013

Company	Technology	Goal Impact	Projected Performance
P&W	Ultra-high bypass ratio Geared Turbofan w/ advanced fan system with reduced weight and drag	Fuel-burn	> 20% reduction
		Emissions	60% reduction in NOx (re: CAEP 6)
		Noise	25 EPNdB reduction (re: Stage 4)

# TEST ASSET TRANSFERRED OVER TO CLEAN PROGRAM



## PW1500G Platforms



PW1519G  
19,000lbs



PW1521G  
21,000lbs



PW1524G  
23,300lbs



Engine X806

BOM Shortage Report In Place  
Pedigree Review Scheduled

# UHB FAN RIG TEST SUCCESS

## Demonstrated unsurpassed performance and efficiency

Key accomplishments (275+ hours of test)

- ✓ Validated rig upgrades
- ✓ Validated UHB model design
- ✓ Blade aero-mechanical performance consistent with advanced CFD predictions over range of angle of attack/crosswind conditions

World class fan efficiency

Stability and structural behavior meet design requirements

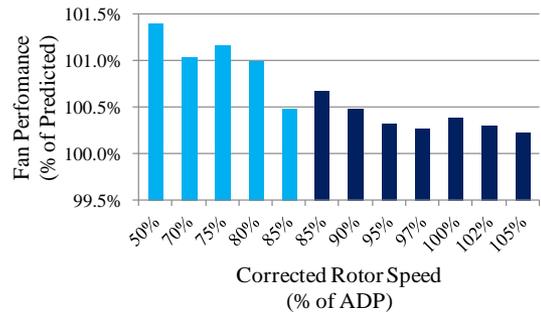
- ✓ Improved efficiency inlet aero performance consistent with advanced CFD predictions over range of AoA /Xwind conditions

Demonstrated margin to design requirements

- ✓ Demonstrate acoustic performance



UHB 22 inch Scaled Fan Rig Installed

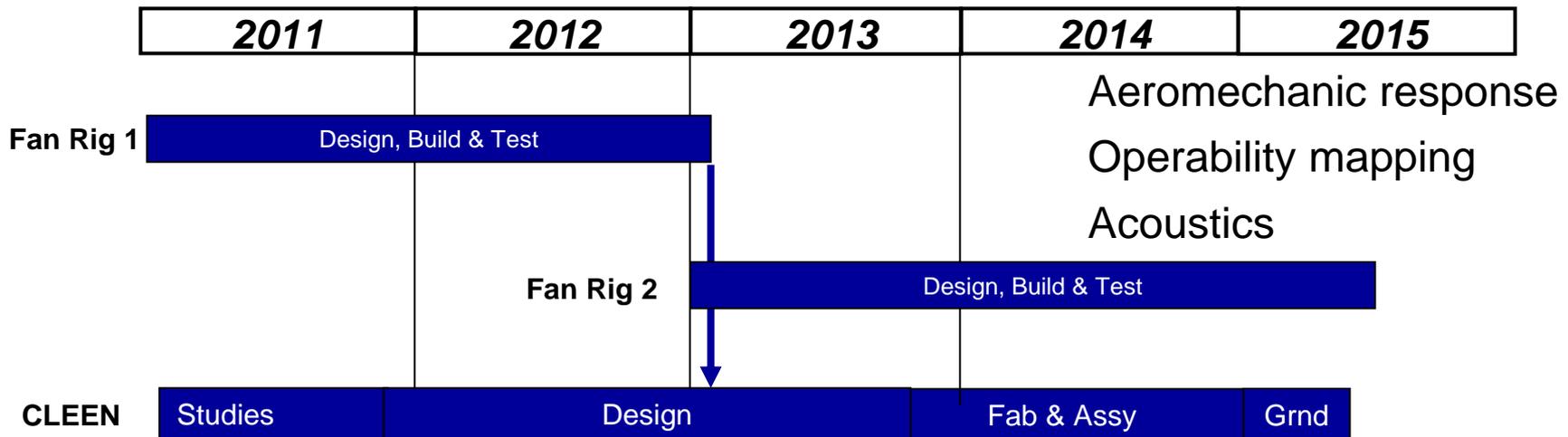


Measured Performance (Light Blue – Sea Level, Dark – Altitude) Agrees Well with Pre test Prediction Over Broad Range of Conditions

# FAN RIG 2

Fan Rig 2 will provide further validation for CLEEN technologies

Scaled CLEEN Hardware  
 Engine / Rig Comparison  
 Incorporate Learning into  
 Future Product Designs



# DETAIL DESIGN COMPLETED

Fan structural and aero assessments completed

Nacelle configuration established

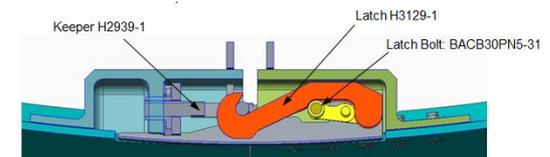
Engine performance and operability meet requirements

Acoustics meet requirements

Engine loads and dynamics acceptable with modified hardware

Control modifications in scope

	Strain Energy	Imbalance Sensitivity	Stability Margin
Fan	●	●	●
Low Rotor	●	●	●
High Rotor	●	●	●



Configuration selected that meets all criteria and satisfies FAA CLEAN goals

# HARDWARE FABRICATION

## Critical parts being tracked

Assembly need dates established

- Working with suppliers to meet dates
- Identified hardware critical path
- Critical suppliers under PO

Initial long-lead hardware delivered

Industrial management in place

Leverage GTF development tooling



Hardware Tracking

Plan supports August 2014 engine build





# SUMMARY

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Alternative fuel engine & rig evaluation near completion

No significant differences noted from test results

Critical CLEEN demonstrator hardware completed detail design phase

Cleared to initiate detail hardware fabrication phase

Completed successful fan rig test

Data matches well with predictions on fan rig 1

Scaled CLEEN hardware selected for fan rig 2

Industrial management plan in place

Critical parts identified

Engine assembly planning and test planning initiated

2014 looks to be an exciting year!!!