Addressing Aviation Environmental Challenges through Technology and Fuels

Presented to: Aircraft Noise & Emissions Symposium

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Outline

- **Background**
- **Fuels**
- **Aircraft Technology**
- **Conclusion**

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Efforts Relating to Aircraft Emissions

Understanding Impacts

- Particulate Matter (PM) measurements and modeling
- Improving atmospheric impact modeling capabilities
- Evaluating current aircraft, commercial supersonic aircraft, unmanned aerial systems, and commercial space vehicles

Mitigation

- Vehicle operations
- Alternative fuel sources
- Modifications to fuel composition
- Aircraft technologies and architecture
- Engine standard (CAEP PM standard)
- Policy measures (CORSIA)

Efforts Relating to Jet Fuel

Coordination

- Public-Private
- Interagency
- State & Regional
- International

Testing

- Support certification testing
- Improve certification process
- Emissions measurements

Analysis

- Environmental sustainability
- Techno-economic analysis
- Future scenarios

ASCENT Center of Excellence (COE)

Lead Universities:

Washington State University (WSU)*

Massachusetts Institute of Technology (MIT)

Core Universities:

Boston University (BU)

Georgia Institute of Technology (Ga Tech)

Missouri University of Science and Technology (MS&T)

Oregon State University (OSU)*

Pennsylvania State University (PSU)*

Purdue University (PU)*

Stanford University (SU)

University of Dayton (UD)

University of Hawaii (UH)*

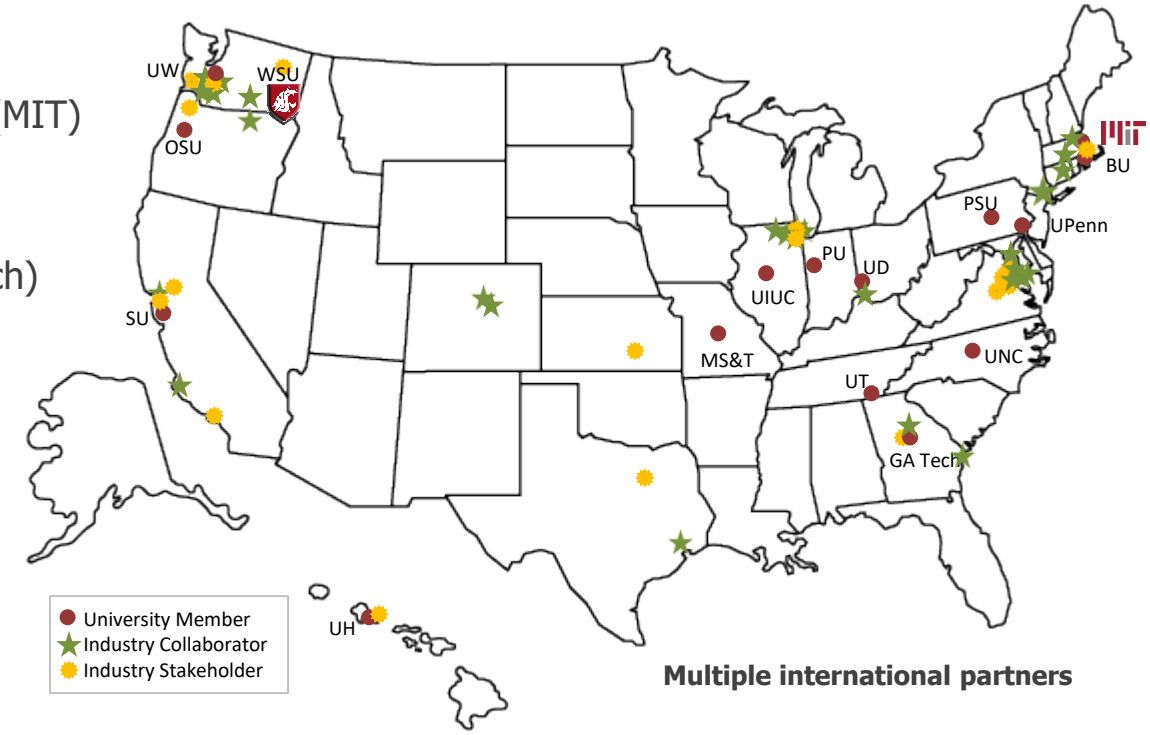
University of Illinois at Urbana-Champaign (UIUC)*

University of North Carolina at Chapel Hill (UNC)

University of Pennsylvania (UPenn)

University of Tennessee (UT)*

University of Washington (UW)*



Multiple international partners

Advisory Committee - 58 organizations:

5 airports
4 airlines
7 NGO/advocacy
9 aviation manufacturers
11 feedstock/fuel manufacturers
22 R&D, service to aviation sector

*** Denotes USDA NIFA AFRI-CAP Leads and Participants & Sun Grant Schools**

For more information:
https://ascent.aero/

Federal Aviation Administration

ASCENT COE Details

Timeline:

- In 2004, FAA established PARTNER Center of Excellence
- In 2013, FAA established Center of Excellence for Alternative Jet Fuels and Environment, a.k.a. Aviation Sustainability Center or ASCENT, continues PARTNER with expanded efforts on alt fuels

Budget Direction:

- FY2018 & FY2019 budget: FAA directed to use $15M in RE&D funds for ASCENT COE

	Report 1	Report 2	Report 3
Time period	9/2013 – 9/2015	10/2015 – 9/2016	10/2016 – 9/2017
Research Projects	50	54	43
Publications, Reports, and Presentations	137	119	110
Students involved	131	112	105
Industry partners	63	70	72

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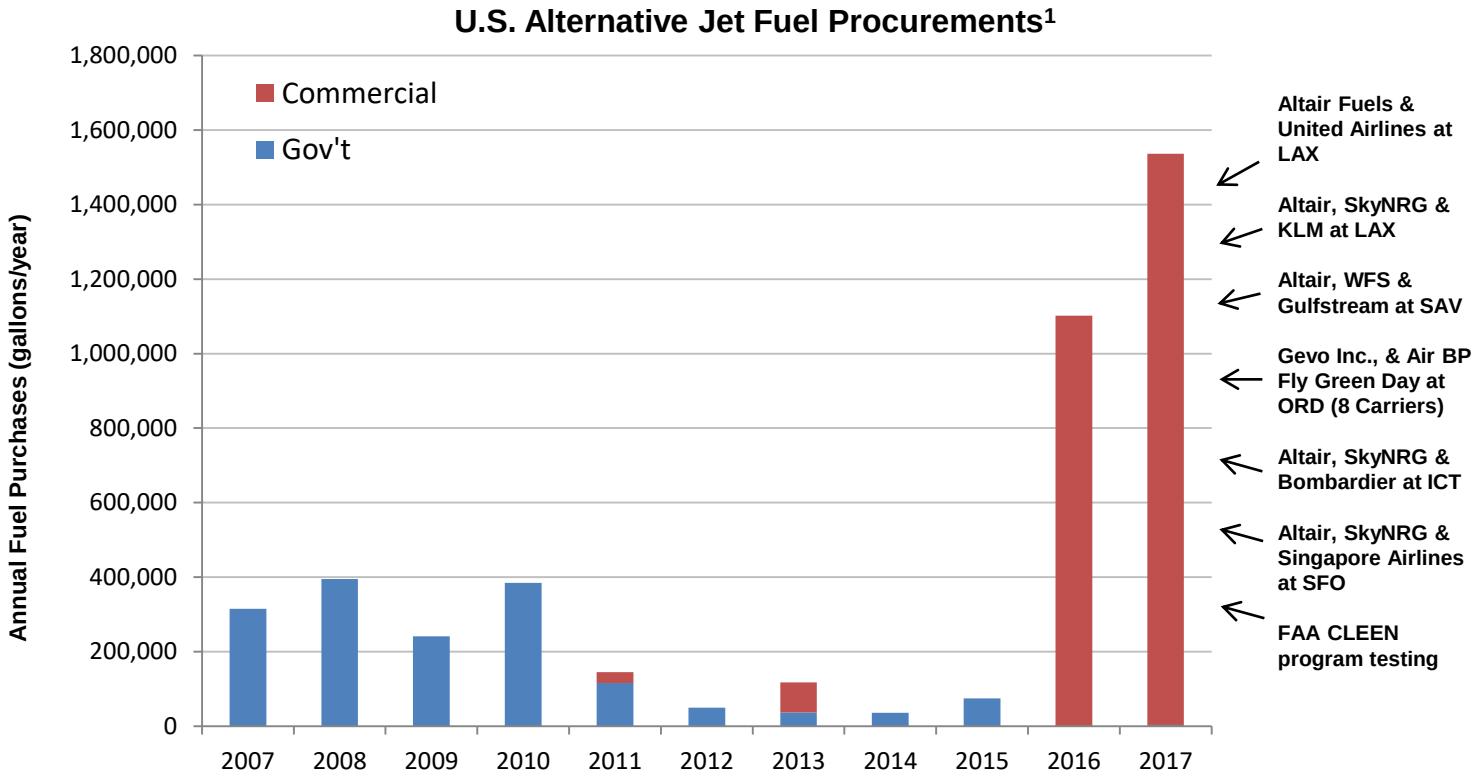
Where do we stand?

- Commercial flights on alternative jet fuels are expanding
- 1.5 million gallons in 2017 from two commercial producers, many commercial user, multiple U.S. airports



Notes:
1. Includes procurements of fuel by U.S. government, U.S. airlines, manufacturers, and foreign carriers delivered to U.S. airports

Where are we headed?

Potential for 250 million gallons/year in five years

Commercial Aviation Alternative Fuels Initiative

A public – private coalition for commercial aviation to engage the emerging alternative fuels industry and government

- **Communicate the Value Proposition of Sustainable Aviation Fuels (SAF)**
- **Enhance the Fuel Qualification Approach**
- **Implement Frameworks & Share Best Practices**
- **Develop the U.S. SAF Supply by Aligning Efforts to Enable Commercial Deployment**

CAAFI®
COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

CAAFI Administrative Leadership Team:

- Steve Csonka, CAAFI Executive Director
- Chris Tindal, CAAFI Assistant Director
- Kristin Lewis (Volpe)
- Peter Herzig (Volpe)
- Nate Brown (FAA)
- Rich Altman, CAAFI Executive Director Emeritus

CAAFI Team Leads:

- C/Q: M. Rumizen (FAA)
- Sustainability: J. Hileman (FAA) & N. Young (A4A)
- Business: J. Heimlich (A4A)
- R&D: M. Lakeman (Boeing), S. Kramer (P&W), & G. Andac (GE)

CAAFI Steering Group: AIA, ACI-NA, A4A, GE, Boeing, P&W, ASCENT, DOE, USDA

Coordination Activities:

U.S. Agency Efforts Across the Supply Chain

Feedstock Production	Feedstock Logistics	Fuel Conversion	Conversion Process Scale-up/Integration	Fuel Testing / Approval (Fuel Performance; Environment Assessment)	Enable Production	End User/ Buyer
Agriculture: Biomass Crop Assistance Program & Crop Insurance Program		Energy & Defense: R&D grants	Agriculture & Energy: R&D grants	FAA & Defense: C/Q Fuel testing	Agriculture, Navy, & Energy: Defense Production Act and Biorefinery Program	Airlines: fuel purchases
Agriculture: Feedstock Development Center Grants				FAA, Defense, & NASA: Enviro Analysis		Agriculture & Defense: Farm to Fleet
	Energy: R&D				EPA: Renewable Fuel Standard	FAA: Guidance for Airports
					Agriculture, Energy, FAA: Farm to Fly 2.0	FAA: ICAO CORSIA

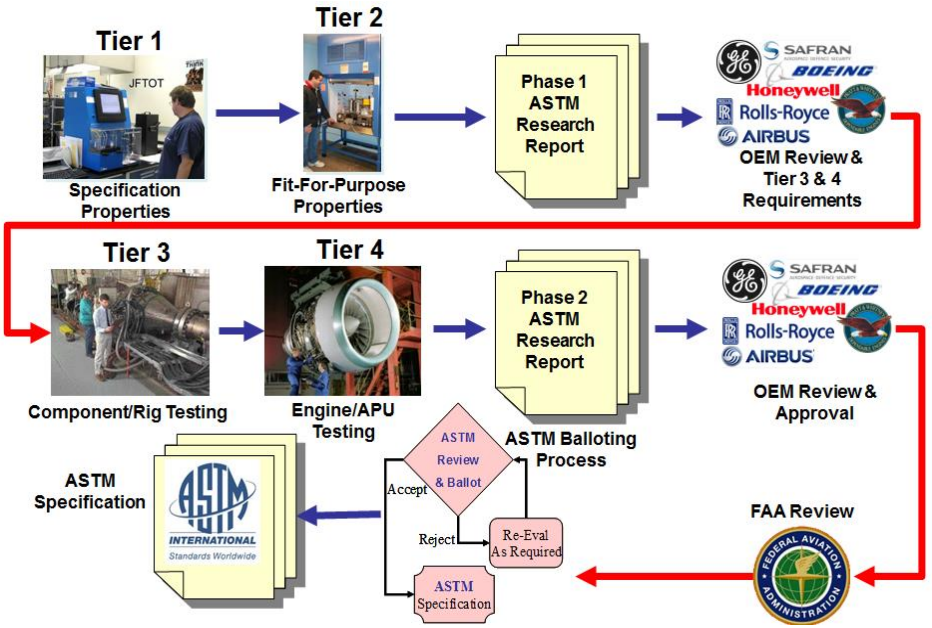
All: Coordination with Other Federal Agencies

Overview of FAA Testing Activities

Support ASTM International evaluation of alternative jet fuels and improve the evaluation process

- **Support ASTM certification & qualification testing activities to develop data for new approvals** (CAAFI, CLEEN, & ASCENT)
- **ASTM Clearinghouse** (CAAFI & ASCENT)
- **OEM Review Process** (ASCENT)
- **Data Gathering & Library** (ASCENT)
- **Streamline approval process via the National Jet Fuels Combustion Program** (ASCENT)

D4054 Alternative Jet Fuel Approval Process



Testing Activities Resulting in Fuel Certification

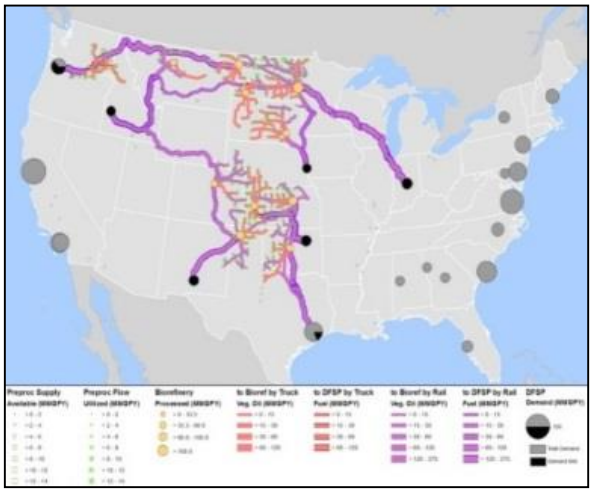
Alternative Jet Fuels are being Certified

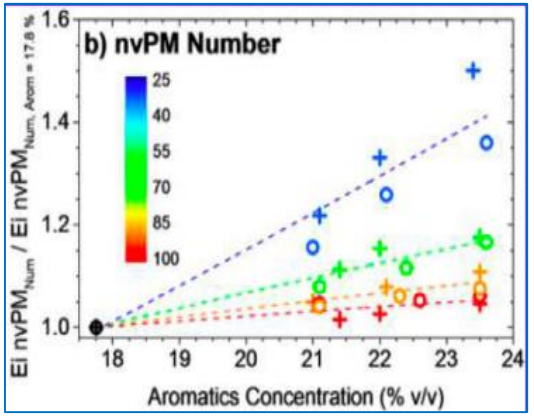
- **Created ASTM D7566 Specification (2009)**
- **5 fuels added to the ASTM specification (2009-present)**
  - Sixth approval Q2 2018
  - 6+ additional fuels under evaluation
- **Created ASTM D4054 Process and D4054 Users Guide**
- **Filled "testing gap"**
  - FAA funded testing of 7 fuels via first phase of CLEEN program
  - FAA funded testing of 5 fuels via second phase of CLEEN program
- **D4054 Clearinghouse established via ASCENT to simplify and accelerate approval process (2016)**
  - Facilitate funding from non-US government sources
  - Research report review support
  - Tier 1 & 2 testing for two fuels
  - EU, UK clearing houses in development

Overview of FAA Analysis Activities

Support better understanding of the environmental sustainability, economic costs, and potential supply of fuels from petroleum and alternative sources

- **ICAO Support** (ASCENT)
  - Greenhouse gas emissions life cycle analysis
  - Sustainability criteria
  - Alternative fuel production potential & policies
- **Supply Chain Development** (ASCENT, Volpe)
  - Opportunities & challenges for U.S. production
  - Regional supply chain studies (Pacific Northwest, Southeast, Hawaii)
  - Open source tools development (economic evaluation, environmental analysis, siting etc.)
- **Modeling Future Scenarios/Supply** (ASCENT, Volpe)
- **Reducing Emissions and Improving Performance through Fuel Composition Changes**





Analyses Supporting Industry and Government Efforts

Analyses being Used

- **Inclusion of alternative jet fuels in DOE Argonne National Lab GREET model**
- **Renewable Fuel Standard (RFS) "opt in" for Alternative Jet Fuels**
- **California Low carbon fuel standard (LCFS) "opt in" for Alternative Jet Fuels**
- **Inclusion of Sustainable Aviation Fuels and Lower Carbon Aviation Fuels within CORSIA**
  - Life cycle emissions methodology and values
  - Initial set of sustainability criteria
- **Fuel production forecasts widely used by ICAO**
- **Support DOE funding activities for conversion process development**
- **Economic analyses being used by industry (e.g., High Freeze Point - HEFA)**
- **Complementing USDA regional activities**
  - Increasing understanding of bottlenecks to production

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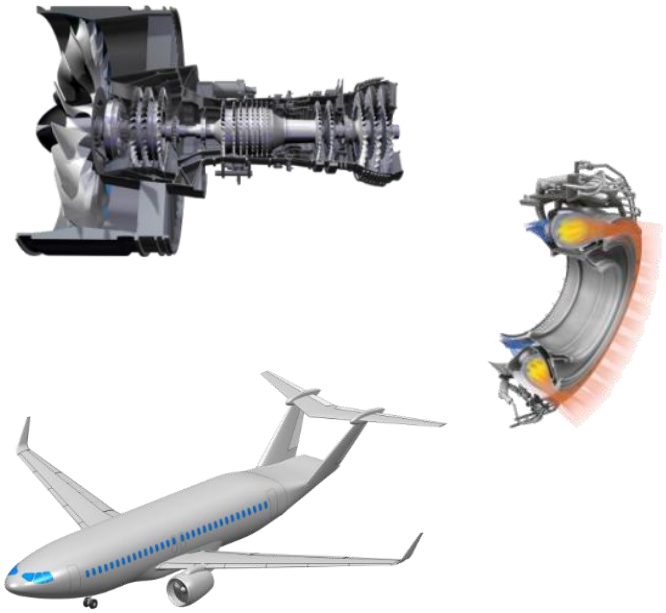
Continuous Lower Energy, Emissions & Noise (CLEEN)

- FAA led public-private partnership with 100% cost share from industry
- Reducing fuel burn, emissions and noise via aircraft and engine technologies and alternative jet fuels
- Conducting ground and/or flight test demonstrations to accelerate maturation of certifiable aircraft and engine technologies

	Phase I	Phase II	Phase III*
Time Frame	2010-2015	2016-2020	2021-2025
FAA Budget	~$125M	~$100M	TBD
Noise Reduction Goal	25 dB cumulative noise reduction cumulative to Stage 5 ***and/or reduces community noise exposure***		
NO_X Emissions Reduction Goal	60% landing/take-off NO_X emissions	75% landing/take-off NO_X emissions (-70% re: CAEP/8)	
Fuel Burn Goal	33% reduction	40% reduction	-20% re: CAEP/10 Std.
Entry into Service	2018	2026	2031

***Notional**



For more information on CLEEN program: http://www.faa.gov/go/cleen

CLEEN III Industry Day: https://faaco.faa.gov/index.cfm/announcement/view/32134

CLEEN III Solicitation: https://faaco.faa.gov/index.cfm/announcement/view/31885

CLEEN Details

Awardees:

- Aurora Flight Sciences (Phase II only)
- Boeing
- Delta Tech Ops, America's Phenix, MDS Coating Technologies (Phase II only)
- General Electric (GE) Aviation
- Honeywell Aerospace
- Pratt & Whitney
- Rohr, Inc. / UTC Aerospace Systems (Phase II only)
- Rolls-Royce

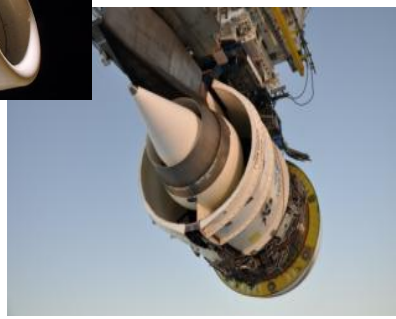
Phase I Technologies:

- **9 Technologies focused on**
  - Revolutionary Engine Design
  - Engine redesign
  - Wing technologies
  - Flight Management System Improvements
  - Improved Combustors

Phase II Technologies:

- **14 Technologies focused on**
  - Fuselage redesign
  - Engine redesign
  - Wing technology
  - Flight Management System improvements
  - Improved combustion

CLEEN Highlights



CLEEN Phase I

- GE TAPS II Combustor entered fleet in 2016 on LEAP engine
- Pratt & Whitney Gen 2 geared turbofan propulsor technology successfully engine tested
- Boeing ceramic matrix composite nozzle flight tested on a 787 aircraft

CLEEN Phase II

- GE TAPS III Combustor has achieved CLEEN goals on NOx reduction
- Aurora Flight Sciences tested key structural subcomponent that enables mass-efficient double bubble fuselage
- America's Phenix/Delta TechOps/MDS Coating Technologies currently conducting in-service flight evaluation of fan blade leading edge protective coating
- Boeing completed ground engine test of compact nacelle technology
- Rolls-Royce conducting full annular rig test for RQL low NOx combustion system
- Pratt & Whitney completed rig testing of advanced high pressure compressor technologies

CLEEN Phase I Benefits:

Demonstrated technologies that reduce noise, emissions and fuel burn

Boeing

Adaptive Trailing Edge
~ 2% fuel burn reduction
~ 1.7 EPNdB cum in some single and twin aisles

CMC Acoustic Nozzle
~ 1% fuel burn reduction
~2.3 EPNdB cumulative noise margin to Stage 4

Honeywell

Fuel Burn Technologies
CLEEN technologies contributed to ~5% fuel burn reduction as part of a 15.7% fuel burn reduction engine package

Pratt & Whitney

Geared Turbofan Technologies
CLEEN techs expand design space for engine with ~ 20% fuel burn reduction, > 20 EPNdB cumulative noise margin to Stage 4

For more information: http://www.faa.gov/go/cleen

General Electric

TAPS II Combustor (entered fleet in 2016)
> 60% margin to CAEP/6 LTO NOx was achieved

FMS/Engine and FMS/ATM Integration (Entered into service - LEAP engine on B737MAX, Airbus A320 Neo aircraft, and GE9X engine on 777X)
0.7-1.0% fuel burn reduction

Open Rotor
~26% reduction in fuel burn (re: 737-800)
~15-17EPNdB cumulative noise margin to Stage 4

Rolls Royce

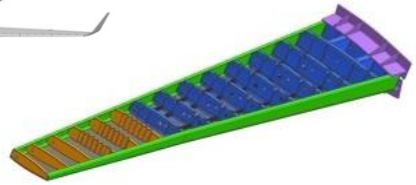
Ceramic Matrix Composite Turbine Blade Track
CMC blade tracks offer > 50% reduction in cooling flow and component weight.

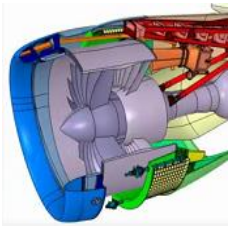
Rolls-Royce – Dual Wall Turbine Airfoil
Dual Wall turbine airfoils provide > 20% reduction in cooling flow and increased operating temperature capability.

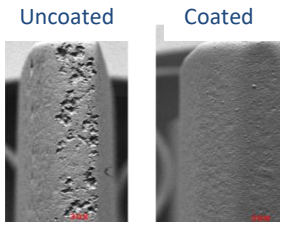
CLEEN tech will provide ~1% fuel burn reduction

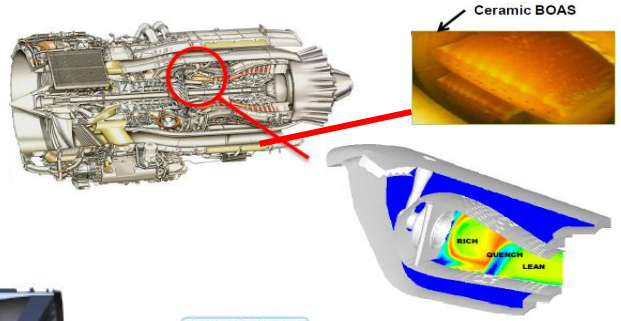
CLEEN Phase II Technologies

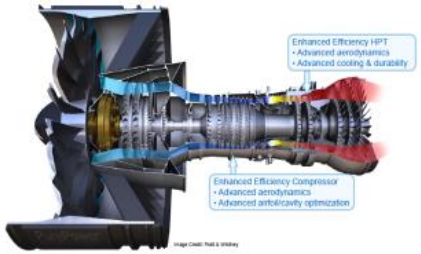
- Aurora Flight Sciences: D8 Double Bubble Fuselage ✓
- Boeing: Structurally Efficient Wing (SEW)
- Boeing: Compact Nacelle – Short Inlet / Acoustic Liners
- Delta Tech Ops/MDS Coating Technologies/America's Phenix: Leading Edge Protective Blade Coatings
- GE: TAPS III Combustor ✓
- GE: FMS Technologies
- GE: More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)
- GE: Low Pressure Ratio Advanced Acoustics & Liners
- Honeywell: Compact Combustor System
- Honeywell: Advanced Turbine Blade Outer Air Seal (BOAS) System
- Honeywell: Advanced Acoustic Fan Module (TBC)
- Pratt & Whitney: High Pressure Compressor Aero-Efficiency Techs
- Pratt & Whitney: High Pressure Turbine Aero-Efficie & Durability Techs
- Rolls Royce: Advanced RQL Low NOx Combustion System
- UTAS: Nacelle Technologies











✓ Completed technologies

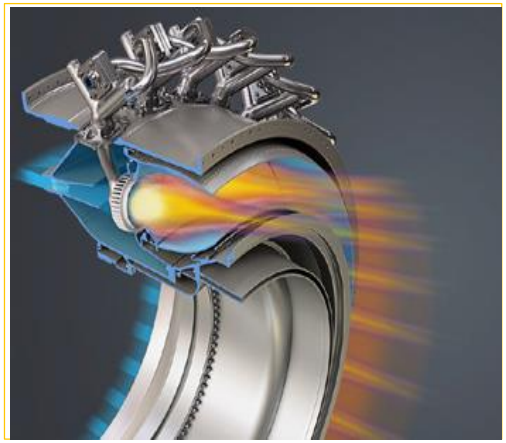
Technology & Emissions Reduction

- Visible smoke emissions have been eliminated

DC-8, 1958

Boeing 787, 2012

- 50% reduction in CAEP Nitrogen Oxides (NOx) emissions standard since 1995
- CLEEN Program - Low NO_X Combustors
  - GE TAPS II Combustor,
    LTO Nox: 55% below most recent CAEP std
    PM: 90% below CAEP visibility smoke limit
  - CLEEN II combustor development ongoing with GE, Honeywell, RR



Assessment of CLEEN Technologies

Analytical Evaluation:

- Conducted by Georgia Tech
- Evaluating impact on fuel burn and noise out to 2050
- Modeled most, but not all, Phase I and II CLEEN Technologies
- Evaluation of Phase I captured in two technical reports – results below

Key Results:

- 22 billion gallons of cumulative jet fuel saved - equivalent to 1.7 million cars taken off road between 2025 and 2050
- Contributes to 14% <u>decrease</u> in the land area exposed to DNL 65 dB and greater

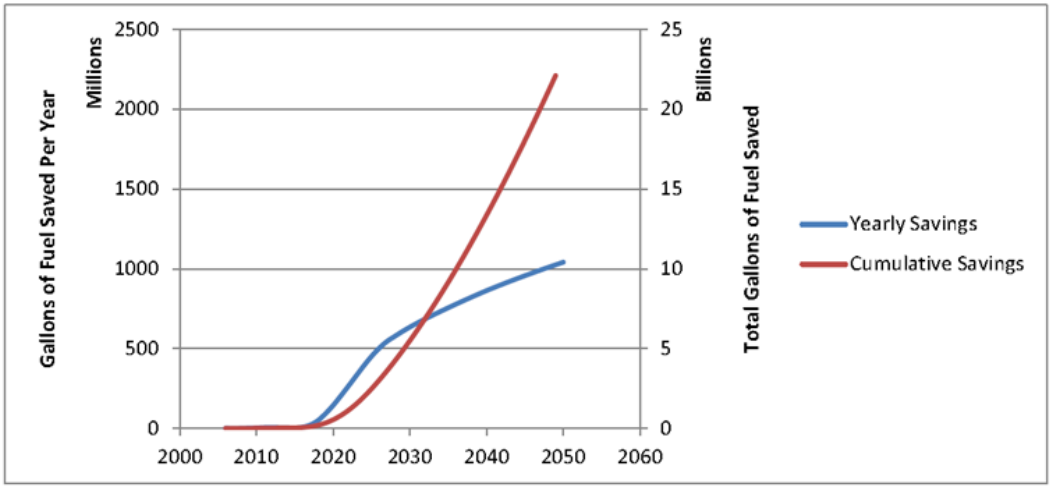


FIGURE 40: POTENTIAL FUEL BURN SAVINGS PROVIDED BY CLEEN TECHNOLOGIES MODELED IN THIS STUDY

https://ascent.aero/documents/2018/07/ascent-010-2015-annual-report.pdf/

http://partner.mit.edu/sites/partner.mit.edu/files/PARTNER-Project-36-final-report.pdf

CLEEN Phase III Overview

- **CLEEN Phase III:** Follow-on to CLEEN Phase I and Phase II Programs focusing on aircraft noise, emissions and energy (five year program with 100% cost share)

- **Purpose:**
  - Mature previously conceived noise, emissions and fuel burn reduction technologies for civil subsonic and supersonic airplanes from TRLs of 3-5 to TRLs of 6-7 to enable industry to expedite introduction of these technologies into current and future aircraft and engines
  - Assess jet fuels that could be compatible with the current fleet of aircraft (i.e., they are “drop-in” fuels) that could provide reductions in emissions or improvements in efficiency, including fuels that enable advancements in aircraft and engine design. This includes both conventional and alternative jet fuels.

- **CLEEN Phase III technologies expected to be on a path for introduction into commercial aircraft in the 2025-2031 timeframe**

CLEEN Phase III Outlook

- Notional CLEEN Phase III timeline (actual timeline in flux due to budget uncertainty)
- Market Survey: https://faaco.faa.gov/index.cfm/announcement/view/31002
- Industry Day: https://faaco.faa.gov/index.cfm/announcement/view/31885
- Industry Day Follow up: https://faaco.faa.gov/index.cfm/announcement/view/32134

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Conclusion

- Utilizing a comprehensive approach to address environmental challenges
- Working with a broad range of stakeholders to understand issues and develop solutions
- Placing **more focus on innovation** to overcome noise and emissions challenges
- Continue to seek partnerships for our R&D efforts