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Environmental and Energy Study Institute

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CONGRESSIONAL BRIEFING

After COVID: A Lower Carbon Future for Commercial Aviation

Briefing Series: By Air, Land, and Sea: Navigating the Climate Future

Wednesday, November 18, 2020

About EESI...

EESI
Environmental and Energy Study Institute

NON-PROFIT

Founded in 1984 by a bipartisan Congressional caucus as an independent (i.e., not federally-funded) non-profit organization

NON-PARTISAN

Source of non-partisan information on environmental, energy, and climate policies

DIRECT ASSISTANCE

In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop "on-bill financing" programs

SUSTAINABLE SOCIETIES

Focused on win-win solutions to make our energy, buildings, and transportation sectors sustainable, resilient, and more equitable

...About EESI

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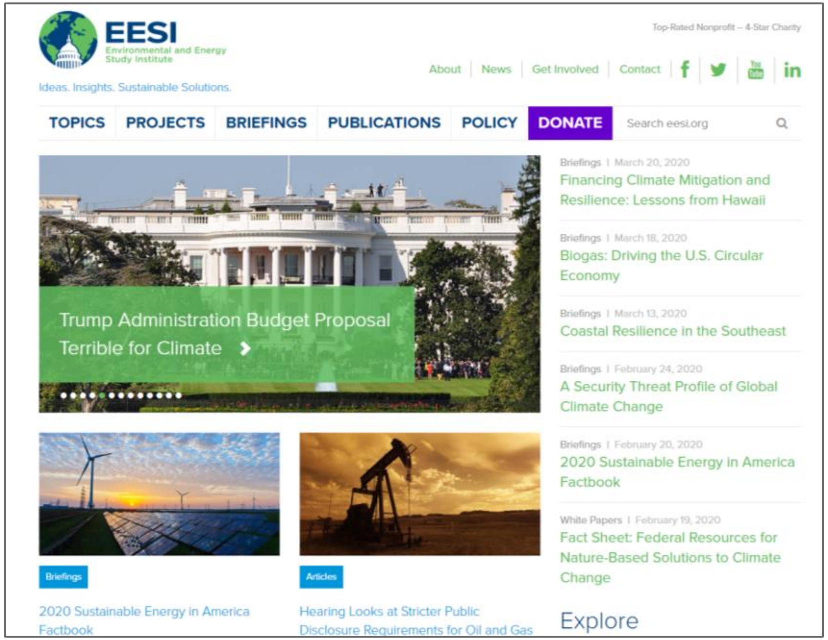

HILL BRIEFINGS

Video recordings and written summaries of Congressional briefings

CLIMATE CHANGE SOLUTIONS

Bi-weekly newsletter with all you need to know including a legislation tracker

SOCIAL MEDIA (@EESIONLINE)

Follow us on Twitter, Facebook, LinkedIn, Instagram, and YouTube

FACT SHEETS

Timely, science-based coverage of climate and clean energy topics

Sustainable Aviation Fuels: A Market Opportunity

Chris Tindal

Assistant Director, Commercial Aviation Alternative Fuels Initiative (CAAFI)

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COMMERCIAL AVIATION
ALTERNATIVE FUELS INITIATIVE

First flight from continuous commercial production of SAF, 10 March 2016

Fuel from World Energy - Paramount (HEFA-SPK 30/70 Blend).

Only facility offering continuous production of SAF at present.
Other batch production is occurring due to extreme customer interest.

CAAFI - Public/Private Partnership

A reflection of the 26+B usg U.S. Jet "market pull"

CAAFI Sponsors

AEROSPACE INDUSTRIES ASSOCIATION

FEDERAL AVIATION ADMINISTRATION

ACI NORTH AMERICA
AIRPORTS COUNCIL INTERNATIONAL

Airlines for America
We Connect the World

An aviation industry coalition established to facilitate and promote the introduction of alternative aviation fuel

Goal is development of non-petroleum, drop-in, jet fuel production with:

* *Equivalent safety & performance*
* *Comparable cost*
* *Environmental improvement*
* *Security of energy supply for aviation*

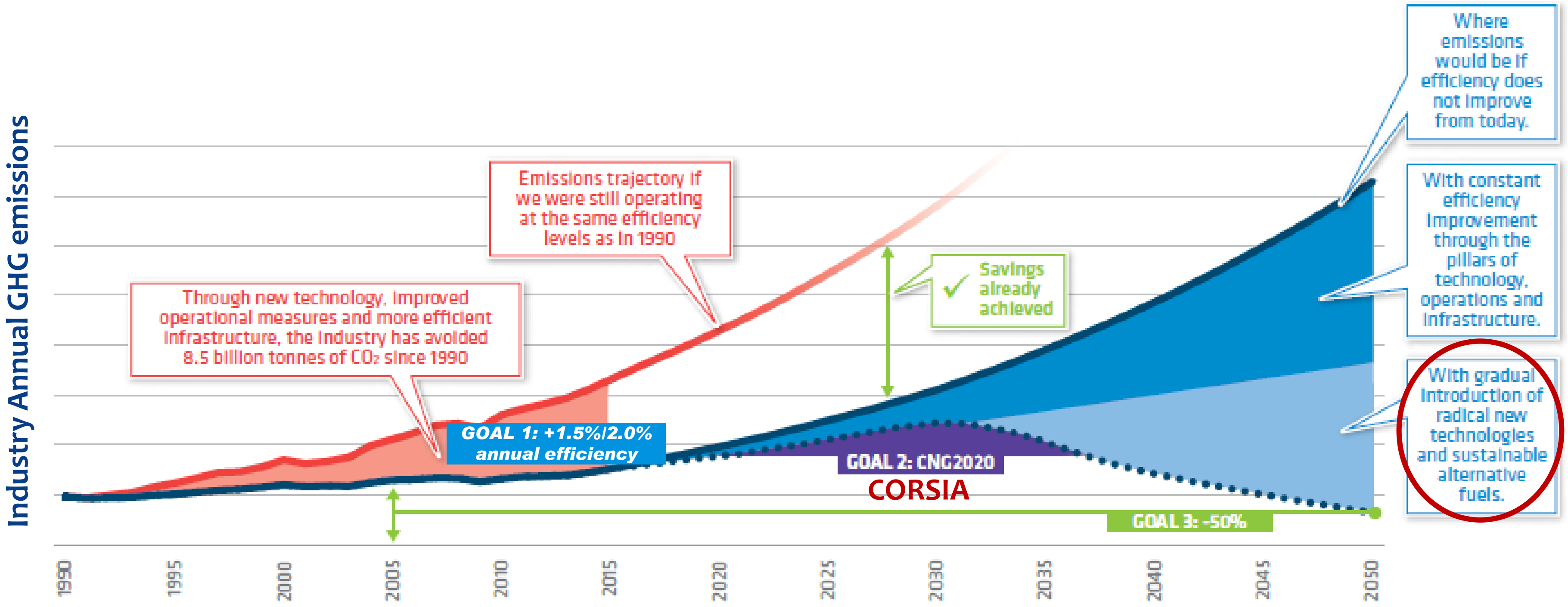
Synthetic jet fuels, primarily from renewable sources

Enables its diverse stakeholders to build relationships, share and collect data, identify resources, and direct research, development and deployment of alternative jet fuels

www.caafi.org

CAAFI

SAF a key component of the Technology Pillar; enabler for GHG containment strategy



Courtesy of ATAG: www.atag.org/our-publications/latest-publications.html
Beginner's Guide to Sustainable Aviation Fuel
Business Aviation made similar commitments

COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

SAF (Sustainable Aviation Fuel)

a.k.a. aviation biofuel, biojet, alternative aviation fuel

Aviation Fuel: Maintains the certification basis of today's aircraft and jet (gas turbine) engines by delivering the properties of ASTM D1655 – Aviation Turbine Fuel – enables drop-in approach – no changes to infrastructure or equipment, obviating incremental billions of dollars of investment

Sustainable: Doing so while taking Social, Economic, and Environmental progress into account, especially addressing GHG reduction

How: Creating synthetic jet fuel with biochemical and thermochemical processes by starting with a different set of carbon molecules than petroleum … a synthetic comprised of molecules essentially identical to petroleum-based jet (in whole or in part)

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SAF Progress - Technical

* SAF are becoming increasingly technically viable
  * Aviation now knows we can utilize numerous production pathways
    (7 approved, 6 in-process, >15 in pipeline)
  * Enabling use of all major sustainable feedstocks
    (lipids, sugars, lignocellulose, hydrogen & carbon sources, circular-economy byproduct streams)
  * Utilizing thermo-chemical and bio-chemical conversion processes to produce pure hydrocarbons, followed by standard refinery processes
  * Following blending with petro-jet, SAF is drop-in, indistinguishable from petro-jet
  * Some future pathways expected to produce SAF blending components that will need less, or zero, blending
  * Expanding exploration of renewable crude co-processing with refineries
  * Continuing streamlining of qualification – time, $, methods

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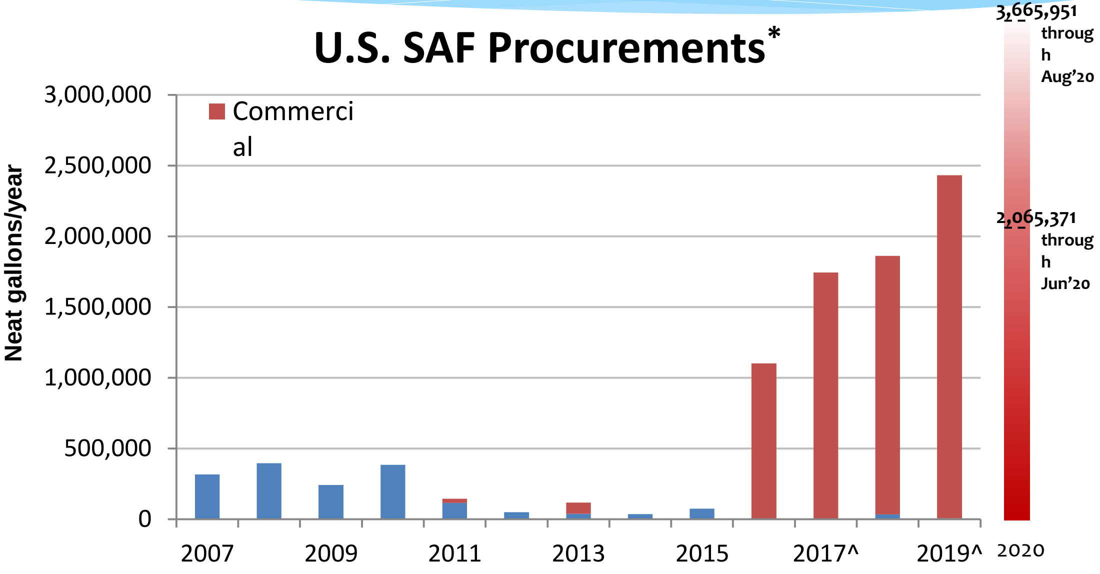
Where we stand on U.S. SAF consumption
Initiation under way, still early

* Four years of sustained commercial use
* Commercial & General Aviation engaged
* Two facilities in operation
* Two facilities under construction, others in development
* Cost delta still a challenge, with policies favoring renewable diesel
* In spite of that … we still have $6.5 B in airline offtake commitments for >350M gpy … with more in development



Credit: FAA

*Reflects voluntarily reported data on use by U.S. airlines, U.S. government, manufacturers, other fuel users, and foreign carriers uplifting at U.S. airports.

^2017-2019 calculation includes reported EPA RFS2 RINs for jet fuel.

CAAFI® COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

Worldwide SAF production capacity forecast

Announced intentions*

Year-end Production Levels (M [illegible]y)

2020

world energy Paramount 25

NESTE Porvoo 34

gevo Silsbee Demo quant's

TOTAL La Mede ?

~59+M

2021

Fulcrum BIOENERGY #1, Sierra 7

RED ROCK BIOFUELS Lakeview 6

~72+M

2022

NESTE Singapore & Rotterdam 480

SkyNRG NORDIC Delfzijl 33

LanzaJet Freedom Pines 10

world energy Paramount 150

~746+M

2023

gevo Luverne 10

Go Sunshine (drive clean, save green) New Orleans 29

Fulcrum BIOENERGY #2,Gary, IN 21

ReadiFuels 2 locations 24

~830+M

2024

PHILLIPS 66 Rodeo 290?

TOTAL Grandpuits 56

preem Gothenburg ~70

LanzaJet 3 International locations 90

~990 – 1336 M

2025

VELOCYS Altalto Immingham, UK 16

1 B +

* Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified

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SAF offtake agreements

Beyond numerous demonstration programs

world energy

Paramount *

- Initial 40M gpy nameplate facility With 25M gpy SAF capacity

neat quantities

+ UNITED	=	Up to 5 M gpy from 2016 (LAX)
+ World Fuel Services, Gulfstream	=	Second 5-year agreement from 2020, 30/70 blend
+ Shell, amazon Prime Air	=	1.8M g over 12 months
+ SkyNRG Nordic, AIRFRANCE, FINNAIR, KLM	=	Misc Flights, e.g. SFO
air bp, SAS, OSLO AIRPORT, Shell, Lufthansa Group, VistaJet	=	Bioports on demand, et al. — Halmstad, Arlanda, Bromma, Goteborg, Leeuwarden

* 24Oct'18: Moving forward with $350M Paramount expansion to enable 306M gpy total capacity & jet capacity of 150M gpy; Fuel production expected by YE'22

SAF offtake agreements – pg 2

Beyond numerous demonstration programs

NESTE

Porvoo *

- Initial 34M gpy capacity

+ air bp + SAS, AIRBUS, Lufthansa, KLM, ZÜRICH AIRPORT, FINNAIR, Emirates, Alaska, jetBlue, American Airlines =

Neat quantities not announced

Porvoo SAF Q4'18 restart supplied to:

Swedish Airports - SAS;

Mobile, Hamburg – Airbus;

Frankfort – Lufthansa;

Amsterdam – KLM;

Zurich – WEF;

Helsinki – Finnair;

Stockholm – Emirates, Swedavia;

SFO - American, Alaska, and JetBlue

+ Signature FLIGHT SUPPORT NETJETS =

SFO, London – Signature FBO

* Moving forward with significant expansion at Singapore and feasibility study at Rotterdam to enable ~480M gpy by 2023

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COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

SAF offtake agreements – pg 3

Beyond numerous demonstration programs

gevo*

* 3-4 facilities, utilizing ethanol conversion bolt-on approach

neat quantities

\+ AVFUEL / AIR TOTAL = Up to 1M gpy, 5 yrs+ / France & EU supply;

\+ AVFUEL ATLANTIC ACIJET = Various Business Aviation airports FBOs

\+ SAS VIVA EnergyAustralia Queensland Government =

\+ DELTA = 10M gpy, from 2022/2023 term/blend unspecified

\+ TRAFIGURA = Unspecified SAF distribution rights

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SAF offtake agreements – pg 4

Beyond numerous demonstration programs

neat quantities

Fulcrum BIOENERGY

#1 Sierra *

* Initial 11M gpy nameplate facility, remainder at 2-3X in size

+ CATHAY PACIFIC = 37.5M gpy

+ UNITED = 90-180 M gpy

+ air bp = 50 M gpy

10 yr agreements

+ JAPAN AIRLINES, JOIN, Marubeni = Project Development, License, and Offtake

* Per statements made at ABLC 2020

#2 Gary, IN @ 3x capacity

Then replication in Houston, UK, WA state, CA state, Australia

Additional sites aligned with investor airlines' US focal cities previously discussed

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SAF offtake agreements – pg 5

Beyond numerous demonstration programs

				neat quantities
RED ROCK BIOFUELS	+	Southwest	=	3 M gpy each, 7 yrs (Bay Area, CA)
	+	FedEx	=	
SG Preston	+	jetBlue	=	10M gpy, 10 yrs (JFK)
	+	QANTAS	=	4M gpy, 10 yrs (LAX)
SkyNRG NORDIC	+	KLM	=	24M gpy, 10 yrs
	+	Shell	=	SAF Supply collaboration
LanzaTech * capturing carbon fueling growth	+	ANA SUNCOR MITSUI & CO.	=	Freedom Pines, supply from 2022, 10M gpy nameplate
LANZAJET	+	virgin atlantic	=	UK DfT F4C Funding: ATJ Development

* 100M gpy by 2024 from 4 facilities

CAAFI COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

SAF offtake agreements – pg 6

Beyond numerous demonstration programs

neat quantities

preem Gothenburg Refinery	+	SAS	=	Long-term supply negotiation (from 2023). Fueling all domestic flights by 2030.
SAF+ CONSORTIUM	+	Air transat	=	Detail tbd; Montreal East pilot facility approaching completion

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Airline commitments of greater ambition

	FedEx	Obtain 30% of jet fuel from alternative sources by 2030; 06Nov'17
	UNITED	First U.S. Airline to Pledge to Reduce Own Emissions by 50% (vs. 2005) by 2050; 13Sep'18. $40M SAF Investment Fund; 27Oct'19
	SpiceJet	Commits to flying 100 M passengers on SAF by 2030; 23Sep'19
	AIRFRANCE	Horizon 2030: offset 100% of domestic CO2 from 2020; reduce 2030's CO2/pax-km by 50% from 2005; R&D for French SAF industry; 01Oct'19
oneworld NZC'50	IAG INTERNATIONAL AIRLINES GROUP	Net-zero carbon by 2050, offsetting all domestic emissions by 2020; 10Oct'19
	QANTAS	Net-zero carbon by 2050, CNG from 2020 on all emissions, $33M investment in SAF by 2030, matching of customer offsets; 25Nov'19
	FINNAIR	Reduce its net emissions by 50% from 2019 by the end of 2025, and achieve carbon neutrality by 2045 at the latest; 09Mar'20
	SAS	SAF corresponding to the total jet consumption used in all SAS domestic flights, by the year 2030; 14Nov'19
	amazon Prime Air	Net Zero by 2040, and 100% renewable operations by 2025
	norwegian	Improve carbon efficiency by 45% by 2030 (16-28% SAF usage, or up to 500M liters)

Multiple airlines now committing to net zero carbon by 2050 (NZC'50).
Pressure to look at more progress by 2035.

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Commitments of Greater Ambition

Airlines using passenger booking options to offset cost

BRA Braathens Regional Airlines: Customer option to pay for incremental price of SAF of €29.50 on any flight

SAS: Customer option to pay for incremental price of SAF in 20-min blocks of flight time for €10 / block (up to 80% CO_2 reductions); fuel being allocated to future flights

Lufthansa: Compensaid – calculates specific cost of SAF for specific flights and enables customer to pay for incremental price

SWISS: On select flights, CHF80 to offset carbon, 5% of which goes to SAF via Compensaid

FINNAIR: Customer option to pay for incremental price of SAF for 3 categories of flight: intra-Finland (€10), intra-EU (€20), International (€65); fuel being allocated to future flights

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Other commitments of greater ambition

Norway's government introduces 0.5 % blending mandate for advanced aviation biofuels from 2020; 04Oct’18

Netherlands committed to transition all military aircraft to 20/80 AJF blend by 2030 and 70% by 2050; 23Jan’19

France, in alignment with EU Green Deal goals, announces SAF targets: 2% of SAF from 2025, 5% in 2030 and 50% in 2050; 27Jan’20

DG Move have now put together a comprehensive "roadmap" as a potential way forward for an integrated approach for policy intending to foster SAF commercialization in the European Union - ReFuelEU

Sweden's government introduces GHG reduction mandate for jet fuel, from -0.8% in 2021 to -27% in 2030; Fossil free by 2045; 11Sep’20

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ALTERNATIVE FUELS INITIATIVE

SAF progress – Significant commercial pull !

* First facilities on-line, producing SAF at various run-rates
* Commercial agreements being pursued, fostered by policy and other unique approaches
* Line of sight to first billion gallons, but reflecting only 1% of market need
* Making progress, but still significant challenges – only modest production: focus on enabling commercial viability
* Potential for acceleration a function of engagement, offtakes, first facilities' success replication, policy, …
* … and additional technologies that lower production cost, lower capital, enable byproduct revenue

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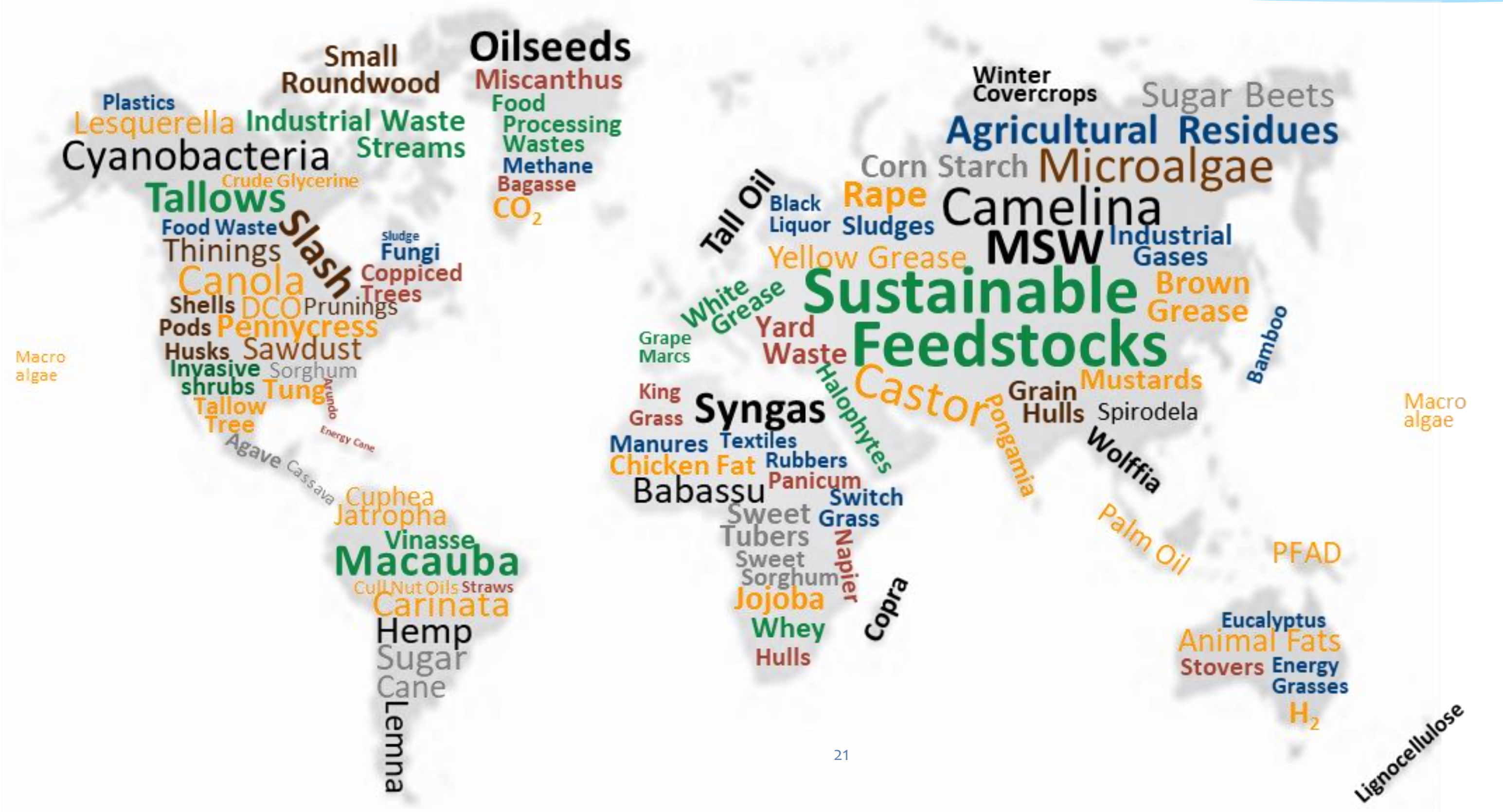
SAF: from a diverse set of world-wide feedstocks

Wastes, residues, purpose grown, circular-economy byproducts



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Thank You

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FUELING SOLUTIONS FOR
SECURE & SUSTAINABLE AVIATION

NASA Aeronautics Research Mission Directorate
Overview for the Environment & Energy Study Institute (EESI)

Barbara Esker, Deputy Director
Advanced Air Vehicles Program
November 18, 2020

NASA Aeronautics Strategies for Research

https://www.nasa.gov/sites/default/files/atoms/files/sip-2019-v7-web.pdf

Safe, Efficient Growth in Global Operations

- Achieve safe, scalable, routine, high-tempo airspace access for all users

Innovation in Commercial Supersonic Aircraft

- Achieve practical, affordable commercial supersonic air transport

Ultra-Efficient Subsonic Transports

- Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy.

Safe, Quiet, and Affordable Vertical Lift Air Vehicles

- Realize extensive use of vertical lift vehicles for transportation and services including new missions and markets

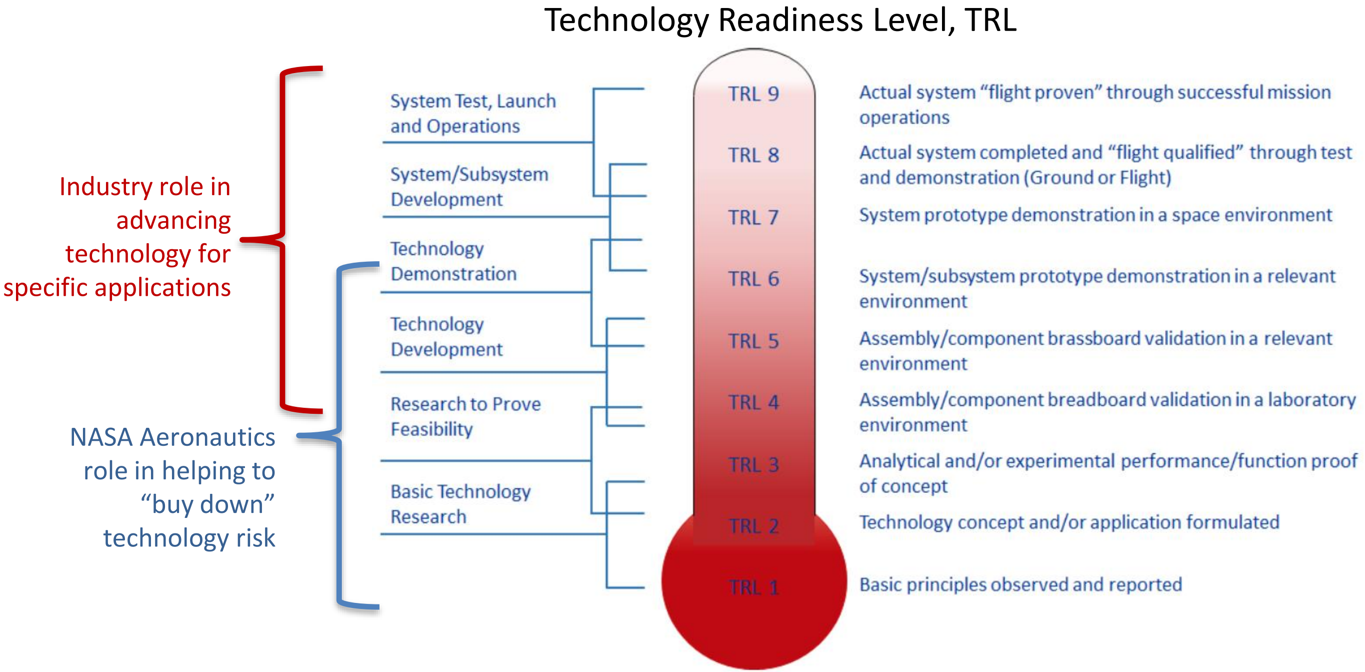
In-Time System-Wide Safety Assurance

- Predict, detect and mitigate emerging safety risks throughout aviation systems and operations

Assured Autonomy for Aviation Transformation

- Safely implement autonomy in aviation applications

NASA Aeronautics Strategies for Research



Additional points –

- NASA & FAA coordination so that the right technical data and insights are available to support eventual certification and regulatory decisions
- Infusion of technology into a fleet takes time. Technology availability is only one piece of a broader business decision.

Technology to Help Enable the Next Generation of Subsonic Transports

Four Key Subsonic Transport Technologies

Create new "S" curve for the next 50 years of subsonic transports

Electrified Aircraft Propulsion

- Improved efficiency/emissions
- Mild hybrid systems promising for early 2030s

Small Core Gas Turbine

- Increased gas turbine efficiency
- Facilitates airframe integration – conventional or EAP

Transonic Truss-Braced Wing

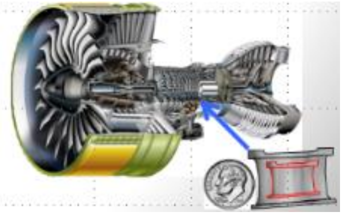
- Increased aerodynamic and structural efficiency
- Propulsion system integration and high-rate production

High-Rate Composites

- Critical to U.S. competitiveness via reduced delivery time
- Reduced time/cost to market with increased performance

Electrified Aircraft Propulsion

synergistic



Small Core Gas Turbine

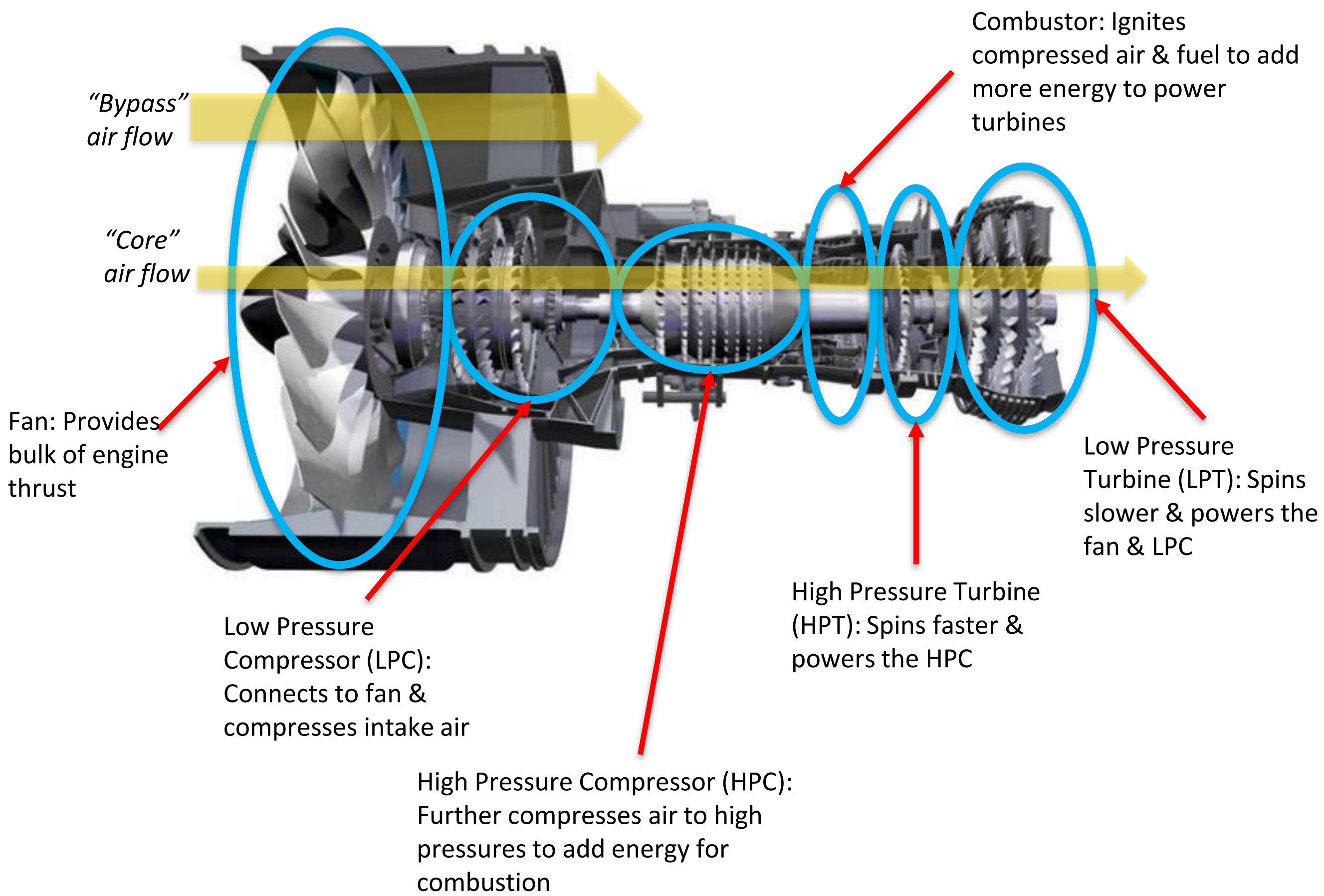
High-Rate Composites

synergistic

Transonic Truss-Braced Wing

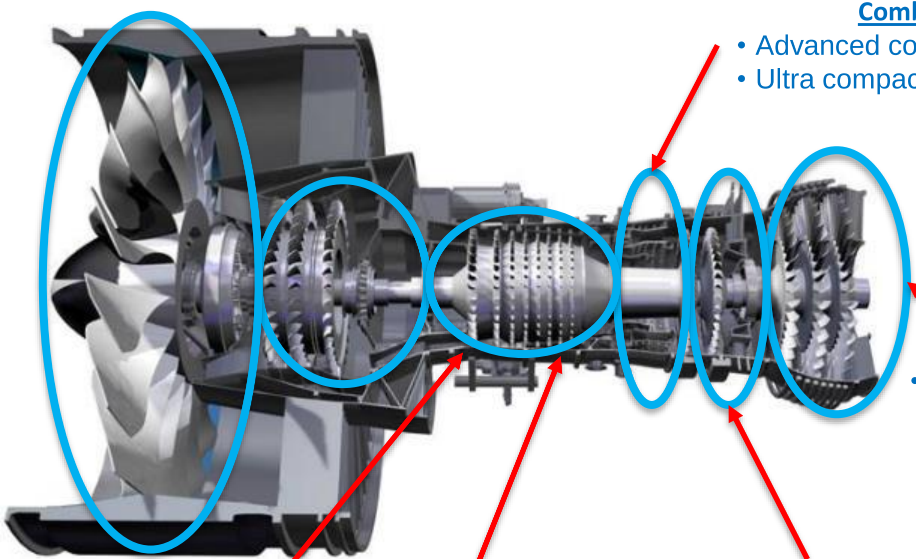
ARMD is advancing these key technologies to create market opportunities

Turbofan Engine Overview



Hybrid Thermally-Efficient Core Technologies

NASA has engaged industry to determine candidate technologies



Combustor
- Advanced cooling strategies
- Ultra compact combustor

HPT & LPT
- Power extraction for more electric airplane systems

HPC – Front Block
- Compressor operability, performance characterization, & aeromechanics
- Advanced casing treatments

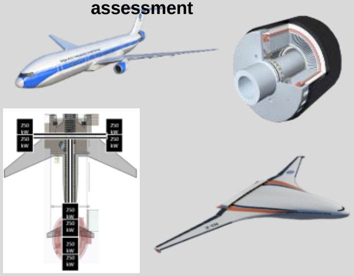
HPC – Rear Block
- Stator performance & stability at higher pressure ratios

HPT
- CMC turbine blade development
- Advanced cooling strategies
- Advanced aero technologies
- Advanced materials and coating

System Level
- Advanced thermal management

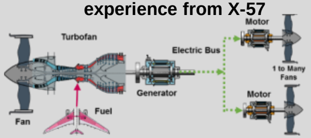
Transport-Class, Electrified Aircraft Propulsion Advancing Technical & Integration Readiness

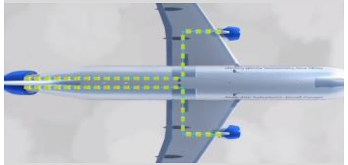
0 **Early conceptualization & identification of KPP's/ technology gaps; component advancement; ground test capability gap assessment**



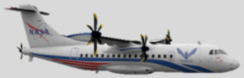
1 **Ground testing of Key electrical components (work is ongoing but must accelerate)**

2 **Integrate in a flight system (likely existing airframe) – leveraging experience from X-57**





3 **Flight Experiments in relevant environment**



- **Key data informing product decisions**
- **Knowledge to support certification**
- **Learning to inform further fundamental research**

2009-2015
TRL 1-2
NASA in-house & NASA-sponsored university/industry efforts advancing MW motors & inverters for EAP

2016-2018+
TRL ~3
NASA in-house & industry efforts raise the TRL level of motors and inverters

2018-2020
TRL ~4
NASA in-house & industry efforts leading to ground demo of TRL 4 level end-to-end power system

2021-2023
TRL 5-6
Flight demo of end-to-end MW EAP power system with application to transport aircraft.

New project: Electrified Powertrain Flight Demonstration (EPFD) Project

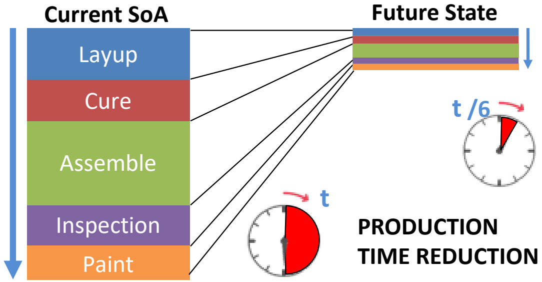
To reduce the technology risks of a MW-class electrified powertrain by demonstrating key elements in a relevant flight environment

Project planning and formulation efforts underway

High Rate Composite Manufacturing

Game-changing manufacturing/delivery rate needed to meet single aisle demand

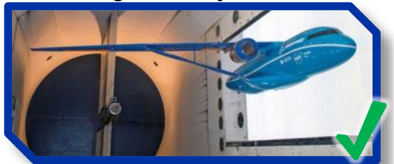
- Goal: enable 4-6X manufacturing rate increase for composite airframe structures (~15 ➔ ~100/month)
- Shift from focus on weight to balance rate, cost, & weight
- Demonstrate high-rate manufacturing concepts at full scale (TRL/Manufacturing Readiness Level (MRL) 3+)
  - Evolving State of the Art (SoA) thermosets
  - Thermoplastics
  - Resin Transfer Molding
  - Materials, processes, and architectures
- Demonstrate model-based engineering tools for efficient design, development, and certification
- Partner with Industry and FAA for realistic requirements
  - Leverage industry expertise and efforts



Rapid prototype and evaluation of manufacturing concepts, down-select at smaller scale, and mature concepts at larger scale

Transonic Truss-Braced Wing Technology

Non-linear Aeroelastics Test
- Verify modes & nonlinear behavior
- Validate high-fidelity finite element model



High-Speed Test (M=0.745)
- First high-speed performance test

High-Speed Test (M=0.745)
- Leverage first test & build knowledge

High-Speed Test (M=0.80)
- New design
- Higher cruise Mach

High-Lift System Test
- First high-lift TTBW test
- 8% scale model

TRL 1 — 2008 - 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020+ — TRL 6

Phase I – Phase II (2008-2014)
- Conceptual design studies (TRL 1)
- Reduce wing weight uncertainty (TRL 2)

Phase III (2014-2016)
- M=.745 High-Speed Design (TRL 2)

Phase IV (2016-2019)
- M=0.80 Design,
- High-Lift System Design (TRL 2)

Phase V (2020-2022)
- Buffet Test (TRL 4)
- High-Lift Test #2

University Leadership Initiative
Engaging the University Community

3 rounds of solicitations – seeking & awarding proposals addressing all Strategic Thrusts

- 13 awards with 47 universities
- 5 HBCUs and 5 MSIs
- 240 proposals submitted
- 191 different proposing Principal Investigators
- 1631 team members
- 1170 different people
- 20-50 students per team

Thank you

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Energy Study Institute

What did you think of the briefing?

Please take 2 minutes to let us know at:
www.eesi.org/survey

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