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...

**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
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
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”

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

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

Beginner’s Guide to Sustainable Aviation Fuel
Business Aviation made similar commitments

GOAL 1: +1.5%/2.0% annual efficiency

GOAL 2: CORSIA

GOAL 3: -50%

Emissions trajectory if we were still operating at the same efficiency levels as in 1990

Through new technology, improved operational measures and more efficient infrastructure, the industry has avoided 8.5 billion tonnes of CO₂ since 1990

Savings already achieved

Where emissions would be if efficiency does not improve from today.

With constant efficiency improvement through the pillars of technology, operations and infrastructure.

With gradual introduction of radical new technologies and sustainable alternative fuels.
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)
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
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

U.S. SAF Procurements*

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.
Worldwide SAF production capacity forecast
Announced intentions*

Year-end Production Levels (Mgpy)

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~59+M</td>
<td>~72+M</td>
<td>~746+M</td>
<td>~830+M</td>
<td>~990 M</td>
<td>1 B+</td>
</tr>
</tbody>
</table>

* Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified.
SAF offtake agreements
Beyond numerous demonstration programs

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

* 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

Up to 5 M gpy from 2016 (LAX)
Second 5-year agreement from 2020, 30/70 blend
1.8M g over 12 months

Misc Flights, e.g. SFO
Biports on demand, et al.

Halmstad
Arlanda
Bromma
Goteborg
Leeuwarden
SAF offtake agreements – pg 2

Beyond numerous demonstration programs

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

* Initial 34M gpy capacity

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

Neat quantities not announced
SAF offtake agreements – pg 3

Beyond numerous demonstration programs

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

gevo*

gevo* + Air Total

gevo* + Atlantic

gevo* + ACI Jet

gevo* + SAS

gevo* + Viva

gevo* + Queensland Government

gevo* + DELTA

gevo* + TRAFIGURA

neat quantities

Up to 1M gpy, 5 yrs+ / France & EU supply;

Various Business Aviation airports FBOs

10M gpy, from 2022/2023
term/blend unspecified

Unspecified SAF distribution rights
SAF offtake agreements – pg 4

Beyond numerous demonstration programs

*1 Sierra *

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

* 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
Beyond numerous demonstration programs

SAF offtake agreements – pg 5

- Southwest
- FedEx
- jetBlue
- Qantas
- KLM
- Suncor
- Mitsubishi
- LanzaTech
- Virgin Atlantic
- ANA
- Freedom Pines
- UK DfT F4C Funding: ATJ Development

neat quantities

3 M gpy each, 7 yrs (Bay Area, CA)

10M gpy, 10 yrs (JFK)

4M gpy, 10 yrs (LAX)

24M gpy, 10 yrs

SAF Supply collaboration

Freedom Pines, supply from 2022, 10M gpy nameplate

UK DfT F4C Funding: ATJ Development

* 100M gpy by 2024 from 4 facilities
Beyond numerous demonstration programs

Long-term supply negotiation (from 2023). Fueling all domestic flights by 2030.

Detail tbd; Montreal East pilot facility approaching completion
Airline commitments of greater ambition

Obtain 30% of jet fuel from alternative sources by 2030; 06Nov’17

First U.S. Airline to Pledge to Reduce Own Emissions by 50% (vs. 2005) by 2050; 13Sep’18. $40M SAF Investment Fund; 27Oct’19

Commits to flying 100 M passengers on SAF by 2030; 23Sep’19

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

Net-zero carbon by 2050, offsetting all domestic emissions by 2020; 10Oct’19

Net-zero carbon by 2050, CNG from 2020 on all emissions, $33M investment in SAF by 2030, matching of customer offsets; 25Nov’19

Reduce its net emissions by 50% from 2019 by the end of 2025, and achieve carbon neutrality by 2045 at the latest; 09Mar’20

SAF corresponding to the total jet consumption used in all SAS domestic flights, by the year 2030; 14Nov’19

Net Zero by 2040, and 100% renewable operations by 2025

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.
Commitments of Greater Ambition
Airlines using passenger booking options to offset cost

- **BRA**
  - 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% CO2 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
  - On select flights, CHF80 to offset carbon, 5% of which goes to SAF via Compensaid

- **SWISS**
  - 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
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
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
SAF: from a diverse set of world-wide feedstocks
Wastes, residues, purpose grown, circular-economy byproducts
Thank You
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


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
Technology Readiness Level, TRL

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.

Industry role in advancing technology for specific applications

NASA Aeronautics role in helping to “buy down” technology risk
Technology to Help Enable the Next Generation of Subsonic Transports

Small Core Gas Turbine
5%-10% fuel burn benefit

Electrified Aircraft Propulsion
Up to 5% fuel burn and potential maintenance benefit

High Rate Composites
4-6x manufacturing rate increase

Transonic Truss-Braced Wing
7%-10% fuel burn benefit
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

ARMD is advancing these key technologies to create market opportunities
Turbofan Engine Overview

Fan: Provides bulk of engine thrust

Low Pressure Compressor (LPC): Connects to fan & compresses intake air

High Pressure Compressor (HPC): Further compresses air to high pressures to add energy for combustion

High Pressure Turbine (HPT): Spins faster & powers the HPC

Low Pressure Turbine (LPT): Spins slower & powers the fan & LPC

Combustor: Ignores compressed air & fuel to add more energy to power turbines

“Bypass” air flow

“Core” air flow
Hybrid Thermally-Efficient Core Technologies

NASA has engaged industry to determine candidate technologies

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

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

**Combustor**
- Advanced cooling strategies
- Ultra compact combustor

**HPT & LPT**
- Power extraction for more electric airplane systems

**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
➢ 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

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

Phase III (2014-2016)
➢ M=0.745 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

TRL 1
2008 - 2011
2015
2016
2017
2018
2019
2020+
TRL 6
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
- 1631 team members
- 1170 different people
- 20-50 students per team
- 191 different proposing Principal Investigators
Thank you
What did you think of the briefing?

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

Materials will be available at:
www.eesi.org/111820transportation

Tweet about the briefing:
#eesitalk   @eesionline

Wednesday, November 18, 2020