Sustainable Aviation Fuels (SAF)

Update to FAA REDAC E&E Subcommittee

To: E&E REDAC Subcommittee
By: Nate Brown & Anna Oldani
Date: March 22, 2022
SAF: Opportunities & Challenges

- Drop-in – same infrastructure, engines & aircraft
- Reduce lifecycle emissions – critical to aviation de-carbonization
- Viable tech – seven approved pathways, two co-processing
- Scalable feedstocks – wastes & residues, biomass, sugars, oils
- Widely accepted by airlines, business, and general aviation
- Broadly supported by governments to meet climate, energy security, rural economic development goals

- Production costs – conversion infrastructure, feedstock availability
- Incentives – lack production support
- Certification – time and resource intensive
- Blend limits – capped at 50%
- Sustainability – ensure credibility of GHG reductions
**FAA SAF Program Focus**

**Testing**
- accelerate SAF development
  - Test fuels
  - Improve testing methods
  - Conduct evaluation
  - Streamline approval

**Analysis**
- environmental and economic sustainability
  - Lifecycle emissions
  - Cost reduction
  - Supply potential
  - Supply chain opportunities

**Coordination**
- support SAF integration
  - Public-private partnership – CAAFI
  - U.S. interagency cooperation
  - International cooperation – ICAO
New Projects/Directions:

- Conduct SAF testing to go beyond the current 50% SAF blending limit in all aircraft
- Identify means to cost effectively reduce lifecycle GHG emissions from SAF production and use through supply chain analysis
- Quantify effects of SAF on non-volatile Particulate Matter emissions and evaluate non-carbon climate benefits
Agenda

Testing
• ASTM Status

Analysis
• Novel SAF Production
• Supply Chain Tools & Analysis

Coordination
• ICAO CAEP FTG & LTAG-TG
• Federal
• Commercialization
Agenda

Testing

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**Testing: ASTM Qualification Status**

*Through FAA support, seven alternative fuels* have been annexed in ASTM D7566.

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**Exploratory Discussions**

- OMV Re-Oil
- Forge?
- Juniper?
- Vertimass
- REVO?

- Vertimass & Green Lizard

**Management Go-Ahead confirmed, no new updates**

- Virent SK (inactive)
- Virent SAK

- Second batch of 30 L delivered to UDRI 01/12 to support ASTM ballot to increase HEFA cycloalkane limit

- Initiating Phase 2 testing

- Taking initial steps to kick project off with D4054 Clearinghouse

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**Tier 1**

- Global Bioenergies
- Indian CSIR-IIP

**Tier 2**

- ATJ-SKA (Byogy, Swedish Biofuels)
- HFP-HEFA (Green Diesel) (on hold)
- Shell IH²

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**Federal Aviation Administration**

*Fuels approved via ASTM D4054 and annexed under D7566 are considered *synthetic blend components* (SBC). Current annexes require that SBCs be blended with conventional jet fuel. Once blended, the fuel meets ASTM D1655 criteria for aviation turbine fuel.*
Testing: ASTM D1655 Status

Additional recent activity on co-processing routes

- **ASTM Task Force** formed to increase Lipids co-processing feedstock blend from 5% to 30%

- **ASTM Task Force** formed to co-process pyrolysis oil from used tires
  - Phillips66 Led Task Force Meeting Oct 21

- **ASTM Task Force** formed to co-process hydroprocessed biomass
  - ExxonMobil generating data to support a second ballot
ASCENT CLEEN Phase III Support

- **ASCENT 25/65a** – Stanford and University of Dayton prescreening test methods
  - CLEEN Phase III GE 100% SAF Task Force & SAF Testing
- **ASCENT 31** – UDRI fuel analysis
  - CLEEN Phase III Boeing Material Compatibility & GE SAF Testing
- **ASCENT 33** – Illinois fuels database
  - CLEEN Phase III GE 100% SAF Task Force
- **New ASCENT** – Beyond 50% SAF blends
  - CLEEN Phase III GE 100% SAF Task Force
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Analysis: Novel SAF Production

ASCENT 01, 52 and 80 at WSU and MIT are evaluating new technologies for hydrogen and power-to-liquid (PtL) fuels

- **Assess new concepts** in both green hydrogen and power-to-liquid (PtL) technologies for aviation
  - Renewable hydrogen for fuel production:
    - Provides immediate reduction in carbon footprint of aviation
    - Enables SAF use through low carbon fertilizers and fuel production

- **Quantify uncertainty and variability** in data for lifecycle and techno-economic evaluations

- **Provide recommendations** for alternative uses and future directions as resource availability changes with time
  - Waste/biomass may not be sufficient in the future → PtL may be viable solution
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Frontiers in Energy Research SAF Topic

• **Online Journal SAF Research Topic**
  – Central point for ASCENT SAF research
  – Submissions closed
  – 21 Articles; 84 Authors
  – ~20k views; 1,349 downloads

• **Topics:**
  – Feedstocks;
  – Conversion;
  – Cert/Qualification Testing;
  – Economics;
  – Environment;
  – Policy

• **Editors:** WSU; FAA; DOE; USDA; Volpe; Lanzajet

**Selection of Paper Titles:**
- Oilseed Cover Crops for Sustainable Aviation Fuels
- Production and Reduction in Greenhouse Gas Emissions Through Land Use Savings
- Production of Sustainable Aviation Fuels in Petroleum Refineries: Evaluation of New Bio-Refinery Concepts
- Building Structure-Property Relationships of Cycloalkanes in Support of Their Use in Sustainable Aviation Fuels
- Economic Impacts of the U.S. Renewable Fuel Standard: An Ex-post Evaluation
- Cumulative Impact of Federal and State Policy on Minimum Selling Price of Sustainable Aviation Fuel

https://www.frontiersin.org/research-topics/19527/sustainable-aviation-fuels
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ICAO Fuels Task Group (FTG) and Long Term Aspirational Goal Task Group (LTAG-TG) Fuels Sub Group

- FTG working across five subgroups with a focus on maintaining the fuels-related sections of Annex 16 Vol IV (CORSIA).

- LTAG-TG final report will inform 41st ICAO Assembly in October 2022 on feasibility of a long-term global aspirational goal for international civil aviation CO₂ emissions reductions.

- LTAG-TG Fuels Sub Group focused on fuel production and lifecycle GHG emissions projections out to 2070.

For additional information on the CAEP Task Groups
FTG: https://www.icao.int/environmental-protection/Pages/CAEP-FTG.aspx
LTAG: https://www.icao.int/environmental-protection/Pages/LTAG.aspx
Lifecycle GHG Emissions and Sustainability

- FAA and ASCENT 01 / Volpe / ANL provided key data and leadership to determine how SAF and Lower Carbon Aviation Fuels (LCAF) are credited within CORSIA

- **CAEP/12**
  - Meeting approved LCAF LCA methodology to be published
  - Meeting approved additional guidance for LCAF sustainability criteria

- **CAEP/13**
  - Continue to develop induced land use change (ILUC) emissions for SAF
  - Continue to develop default core LCA values for SAF
  - Begin to evaluate impact of Soil Organic Carbon, biomass sequestration, and Carbon Capture Utilization and Sequestration (CCUS)
  - Develop LCA methodology for PtL fuels
  - Continue to monitor low LUC farming practices
  - Evaluate global production of SAF, with a focus on timeframe through 2030

For additional information on CORSIA Eligible Fuels
[https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx](https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx)
Future Fuel Production

• FTG:
  – Ongoing work to project SAF production led by FAA, ASCENT 01/52, Volpe, ANL
  – Assembled global near-term SAF production database
  – Will examine SAF potential across various world regions

• LTAG-TG:
  – Quantified SAF potential from waste CO/CO$_2$ gases & atmospheric CO$_2$
  – Quantified infrastructure costs, documented challenges for hydrogen use
  – Evaluated fuel volumes, GHG emissions, investments, etc. across all fuel types

• LTAG-TG report approved in recent CAEP/12 meeting

<table>
<thead>
<tr>
<th>Fuel Category</th>
<th>Fuel Types in Category</th>
</tr>
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<tbody>
<tr>
<td>Sustainable Aviation Fuels (SAF)</td>
<td>Biomass-based fuel</td>
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<tr>
<td></td>
<td>Solid and liquid waste-based fuels</td>
</tr>
<tr>
<td></td>
<td>Gaseous waste-based fuels</td>
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<tr>
<td></td>
<td>Atmospheric CO$_2$-based fuels</td>
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<tr>
<td>Lower Carbon Aviation Fuels (LCAF)</td>
<td>Lower carbon petroleum fuels</td>
</tr>
<tr>
<td>Non-drop-in fuels</td>
<td>Electricity</td>
</tr>
<tr>
<td></td>
<td>Cryogenic hydrogen</td>
</tr>
</tbody>
</table>
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SAF Grand Challenge

• A U.S. executive agency initiative led by the U.S. Departments of Transportation (DOT), Energy (DOE), and Agriculture (USDA)

• Commitment to:
  – 1) leverage existing government activities in research, development, demonstration, deployment, commercialization support, and policy;
  – 2) accelerate new research, development, demonstration, and deployment support; and,
  – 3) implement a supporting policy framework.

• In order to:
  – Reduce the cost of SAF
  – Enhance sustainability of SAF
  – Expand SAF supply

• Goals:
  – U.S. SAF production of 3 billion gallons per year by 2030
  – 100% of aviation fuel demand by 2050 (projected 35 billion gallons per year)
SAF Grand Challenge Goals Relative to Projected Demand

**Volume of Jet Fuel (in billion gallons)**

- **2019:**
  - Domestic: 0.6 *3B*
  - International: 3.1
- **2030:**
  - Domestic: 1.7
  - International: 3.8
- **2050:**
  - Domestic: 1.6
  - International: 5.9

**Geographic Scope:**
- Domestic:在国内
- International:国際

**Legend:**
- International outside the US* (US Operators)
- International Arrivals (US Operators)
- International Departures (US Operators)
- International Departures (Foreign Operators)†
- Domestic Passenger
- Domestic Cargo
- Domestic General Aviation

**Data Sources and Assumptions:**
- **2019:** BTS T-2 (International operations reported by US carriers)
- **2030-2050:** CO₂ emissions based on FAA Aerospace traffic Forecast, after technology and operations improvements. Assuming breakdown of flows (departures from US, arrivals in US and foreign-based on 2019 CORSIA breakdown).
- **2019:** EPA GHG Inventory, international departures by foreign operators scaled based on 2019 traffic mix (FAA Data)
- **2030-2050:** FAA Modeling based on EPA GHG Inventory (Domestic) scope. CO₂ emissions based on FAA Aerospace traffic Forecast, after technology and operations improvements.
- **2019-2050:** General Aviation from FAA Aerospace Forecast (2020-2041).

*Flights between two different ICAO Member States (other than the United States) e.g., Germany -> UAE, UK -> China.
† Not in scope of Climate Action Plan, shown to facilitate comparisons for SAF Grand Challenge.*
### SAF Grand Challenge Roles (in MOU)

#### DOE
- Continue investments and develop expertise in sustainable technologies to develop cost effective low carbon liquid fuels and enabling coproducts from renewable biomass and waste feedstocks
- Continue a significant multi-year SAF scale-up strategy committed to in FY21
- R&D aimed at creating new pathways toward higher SAF production
- Advance environmental analysis of SAF
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

#### DOT/FAA
- Develop overall strategy to decarbonize aviation
- Coordinate ongoing SAF testing and analysis
- Work with standards organizations to ensure safety and sustainability of SAF
- Continue International technical leadership
- Promote end use of SAF
- Support infrastructure and transportation systems that connect SAF feedstock producers, SAF refiners, and aviation end users.
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

#### USDA
- Continue investments and build expertise in sustainable biomass production systems
- Decarbonize supply chains
- Invest in bio-manufacturing capability & workforce development
- Community and individual education
- Provide outreach & technology transfer to producers, processors and communities to accelerate adoption and participation
- Commercialization support
- Collaborate with EPA to expedite regulatory approvals of SAF with significant life-cycle GHG reductions

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Next Step: Develop SAF Grand Challenge Roadmap

[https://www.energy.gov/sites/default/files/2021-09/S1-Signed-SAF-MOU-9-08-21_0.pdf](https://www.energy.gov/sites/default/files/2021-09/S1-Signed-SAF-MOU-9-08-21_0.pdf)
SAF Grand Challenge Roadmap

• Define what needs to be done in next decade
  – to achieve a goal of 3 billion gallons of U.S. SAF production in 2030 and put us on a trajectory to 35 billion gallons/year by 2050

• Create a multi-agency plan for continuing, long-term, substantial federal assistance to:
  – research and development activities;
  – demonstration & deployment;
  – commercialization support;
  – workforce development;
  – outreach/technology transfer;
  – and policy.

• Engage USG and industry stakeholders to catalyze synergy and collaboration
SAF GC Roadmap – Action Area Definitions

Major Sections - Action Areas

1. **Feedstock Innovation** - Focus ongoing and future R&D on sustainable feedstock supply system innovations across the range of SAF relevant feedstocks and identify optimization to reduce cost, reduce technology uncertainty and risk, increase yield and sustainability, and optimize SAF precursors.

2. **Conversion Technology Innovation** - Focus ongoing and future R&D on a multi-generational pipeline of conversion technologies to reduce cost of production while increasing conversion efficiency, sustainability, and volume of fuels produced.

3. **Building Regional SAF Supply Chains** – Support SAF production expansion through regional supply chains ensuring R&D transitions, field validation, demonstration projects, supply chain logistics, public-private partnerships, bankable business model development, and collaboration with regional, state and local stakeholders.

4. **Enabling End Use (e.g. Fuel Testing and Certification & Qualification)** - Facilitate the use of SAF by enabling the efficient evaluation of fuel engine performance and safety through advancement of certification and qualification processes, collection and analysis of data, addressing existing blend limits and understanding combustion emissions and impacts.

5. **Policy and Valuation Analysis** - Provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF including alignment of existing and new policies.

6. **Communicating Progress & Building Support** – Monitor and measure progress against SAF GC goals and communicate the public benefits of the SAF GC to critical stakeholders.
SAF GC Roadmap Outline

• Executive Summary
• Overview
• Major Action Areas
  1. Feedstock Innovation
     a) Workstream 1
     b) Workstream 2
     c) ...
  2. Conversion Technology Innovation
  3. Building Regional Fuel Supply Chains
  4. Fuel Testing, Certification & Qualification
  5. Policy & Valuation Analysis
  6. Communicating Progress & Building Support
• Appendices
  – Detailed activity breakdown
SAF Grand Challenge Roadmap Next steps

• DOT/FAA, DOE and USDA leading process
• Biomass Board SAF Interagency Working Group
• Status
  – Two brainstorming sessions held with federal experts in August
  – One session held with DOE national labs, ASCENT and USDA researchers in September
  – Industry/NGO stakeholder session in March
  – Writing/development underway
• Roadmap targeted for late Q2
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Commercial Aviation Alternative Fuels Initiative (CAAFI)
A public/private partnership of FAA, A4A, AIA & ACI-NA

• **2022 Work Plan**
  – Convening a broad exchange of information among SAF stakeholders
  – Providing information resources and credible expert technical support
  – Coordinating and aligning with U.S. Government Agencies’ activities in support of the SAF Grand Challenge
  – Facilitating ongoing efforts by ASTM International
  – Promoting harmonization of sustainability evaluation approaches and tools
  – Continuing and expanding international engagement
  – Leveraging the above efforts to advance the use and commercial production of SAF

• **In-person CAAFI General Meeting planned for June 1-3, 2022 in Washington, DC**
  – Feature a SAF Summit – request of the FAA’s MAC
  – Discussion of SAF Grand challenge
  – Future directions for SAF
Where we stand on U.S. SAF commercialization

Initiation under way, still early, but growing

- Six years of sustained & increasing commercial use
- 5.05 M gallons in 2021
- One commercial U.S. facility in operation
- Two facilities under construction (others in development)
- Cost delta with renewable diesel remains major challenge

U.S. Annual SAF Procurements*

*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.

^ 2017-2021 calculation incorporates data reported by EPA for RFS2 RINs for renewable jet fuel.
Existing & expected U.S. renewable fuel production

2021 U.S. Renewable Fuel Production Plant Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Billion Gallons/year</th>
</tr>
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<tbody>
<tr>
<td>2021</td>
<td>0.791</td>
</tr>
<tr>
<td>2020</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td></td>
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</table>

Source: U.S. Energy Information Administration (EIA)
https://www.eia.gov/biofuels/biodiesel/capacity/
https://www.eia.gov/biofuels/renewable/capacity/
https://www.eia.gov/petroleum/ethanolcapacity/

Existing and Expected Renewable Diesel Production Capacity 2010-2024

Source: U.S. Energy Information Administration (EIA)
https://www.eia.gov/todayinenergy/detail.php?id=48916
Total Available Biomass for Renewable Fuels

- Biomass can fully **supply future Aviation/ Maritime/Rail** (requires 75% of all feedstocks)
- Biggest market pull is in **sustainable aviation fuels** (SAF)
- Provides market for **current ethanol** (~17B gal, ~40% of corn production)
- Supports decarbonization of chemicals via **bioproducts**, and decarbonization of agriculture through healthy forests and sustainable agriculture
- **CO₂-to-fuels** remains to be explored
QUESTIONS
Clearinghouse Concept
Centralized testing through ASCENT 31 at UDRI – coordinates multi-tiered qualification across industry and government stakeholders

- **ASTM International** manages jet fuel specification
- Does not determine sustainability of fuel, only safety, performance
- Support evaluation through:
  - Data gathering & report review
  - OEM coordination

**FAA Seed Money Under ASCENT Center of Excellence**

**Structured as a Cost Share Arrangement**

**Accepts In-Kind Contributions (testing partners)**

**Also Accepts Direct Contributions**

**Stakeholder Engagement / Support Needed!**

**Final Research Report Out**

University of Dayton Research Institute (UDRI)

**Candidate SAJF in**

**UDRI Contact**
Dr. Steven Zabarnick  
Steven.Zabarnick@udri.udayton.edu  
(937) 255-3549

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Steve Zabarnick  
October 2019
# Testing: Fuel Approval

As a result of the investments made by FAA and others, time and fuel volume requirements for ASTM International approval have fallen over time.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>ASTM Data Review</th>
<th>Final Phase II Report</th>
<th>ASTM Specification (D7566)</th>
<th>Estimated gallons of fuel produced for testing</th>
<th>Estimated time from first review to approval</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT-SPK</td>
<td>09/2007</td>
<td>09/2008</td>
<td>09/2009</td>
<td>710,000¹</td>
<td>3 years</td>
<td>Mostly normal/iso-paraffins</td>
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<tr>
<td>HEFA-SPK</td>
<td>06/2008</td>
<td>05/2010</td>
<td>07/2011</td>
<td>626,000²</td>
<td>3 years</td>
<td>Most normal/iso-paraffins</td>
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<tr>
<td>SIP*</td>
<td>06/2011</td>
<td>04/2013</td>
<td>06/2014</td>
<td>16,000</td>
<td>3 years</td>
<td>Mostly normal/iso-paraffins</td>
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<tr>
<td>Gevo ATJ-SPK * (isobutanol)</td>
<td>12/2010</td>
<td>04/2015</td>
<td>06/2016</td>
<td>93,100³</td>
<td>5 ¹/₂ years</td>
<td>Mostly normal/iso-paraffins</td>
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<tr>
<td>Lanzatech ATJ-SPK (ethanol)</td>
<td>09/2016</td>
<td>07/2017</td>
<td>04/2018</td>
<td>50⁴</td>
<td>1 ¹/₃ years</td>
<td>Most normal/iso-paraffins</td>
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<tr>
<td>ARA CHJ</td>
<td>06/2012</td>
<td>10/2018</td>
<td>01/2020</td>
<td>79,000</td>
<td>7 years</td>
<td>Wider range of molecules</td>
</tr>
<tr>
<td>IHI HC-HEFA**</td>
<td>02/2019</td>
<td>06/2019</td>
<td>04/2020</td>
<td>50</td>
<td>~1 year</td>
<td>40% cycloparaffin</td>
</tr>
</tbody>
</table>

¹Approved at 10% volume  
²First Fast Track approval – approved at 10% volume blend limit  
³40% cycloparaffin  
⁴Only Tier 1/2 testing due to existing knowledge base and similarity to approved fuels

ARA = Applied Research Associates  
¹USAF fuel purchases in 2007-08 for fleetwide qualification  
²USAF & Navy fuel purchases in 2009-11 for fleetwide qualification  
³USAF, Navy and CLEEN fuel purchases in 2012-2014  
⁴Only Tier 1/2 testing due to existing knowledge base and similarity to approved fuels

Federal Aviation Administration
Testing: Beyond 50%

New ASCENT direction to support higher blend limits of alternative fuels

• ASTM D7566 limits most pathways to 50% by volume blending with conventional jet fuel
• Focus on drop-in fuels - compatible with existing and legacy systems
• Solicited feedback from OEMs & PIs on key research priorities
• New ASCENT project(s) will evaluate fuel properties that currently constrain blend volumes to support higher blend limits
Analysis: Supply Chain Research & Tools
Understand benefits, costs and potential supply

• Considering entire supply chain via analysis of:
  – Feedstock production
  – Techno-economics of pathways
  – Existing infrastructure
  – Community assets
  – Transportation routes and capacity
  – Economic Impacts

• Three regional studies:
  – Inland Pacific Northwest
  – Hawaii
  – Southeast/Tennessee

• Developing open source tools
  – FTOT - 2021.4 release in January
  – TEA models – article in Frontiers In Energy

• Support for ICAO CAEP

Research Team:
• U.S. DOT Volpe Transportation Center, DOE Argonne National Lab (ANL) & National Renewable Energy Lab (NREL)

https://ascent.aero/project/alternative-jet-fuel-supply-chain-analysis/
https://github.com/VolpeUSDOT/FTOT-Public