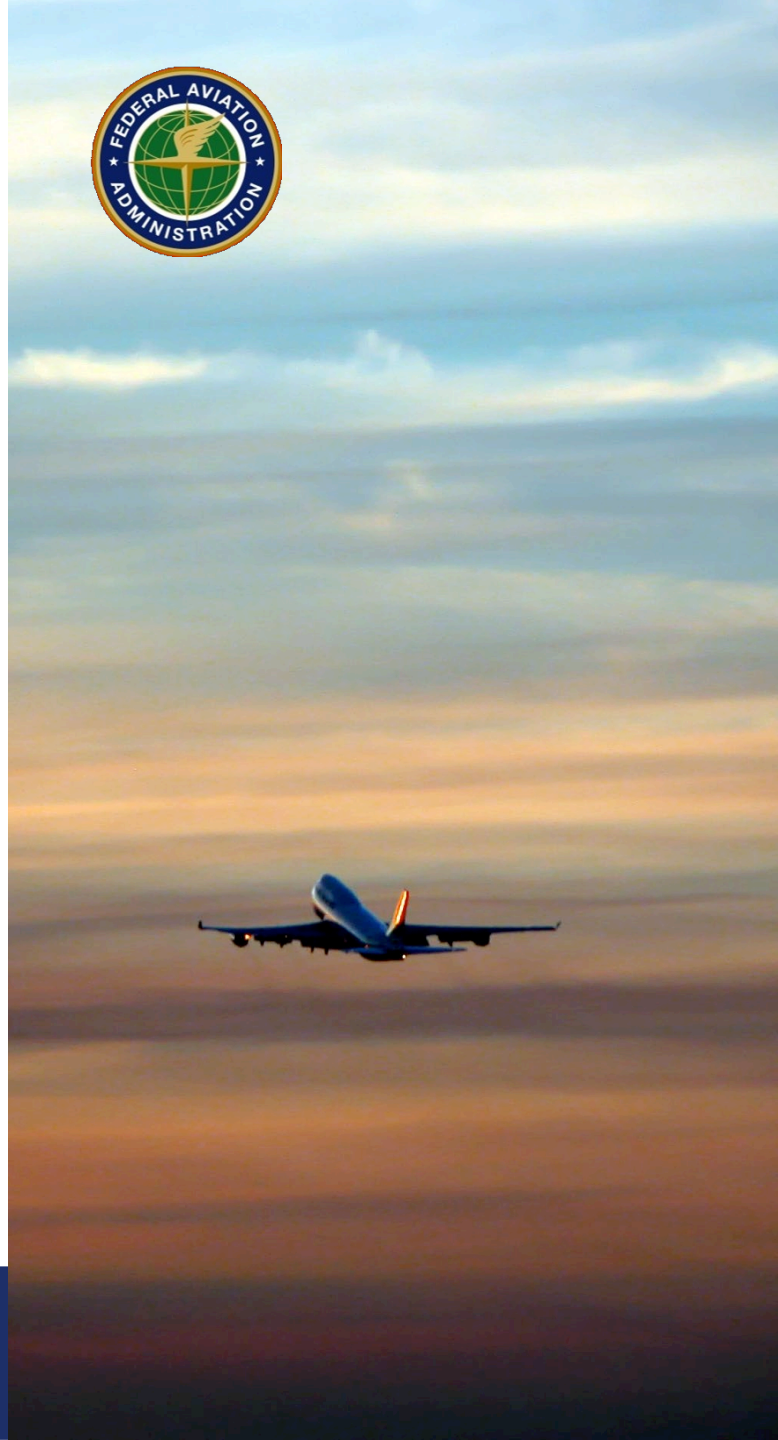
Sustainable Aviation Fuels (SAF)

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

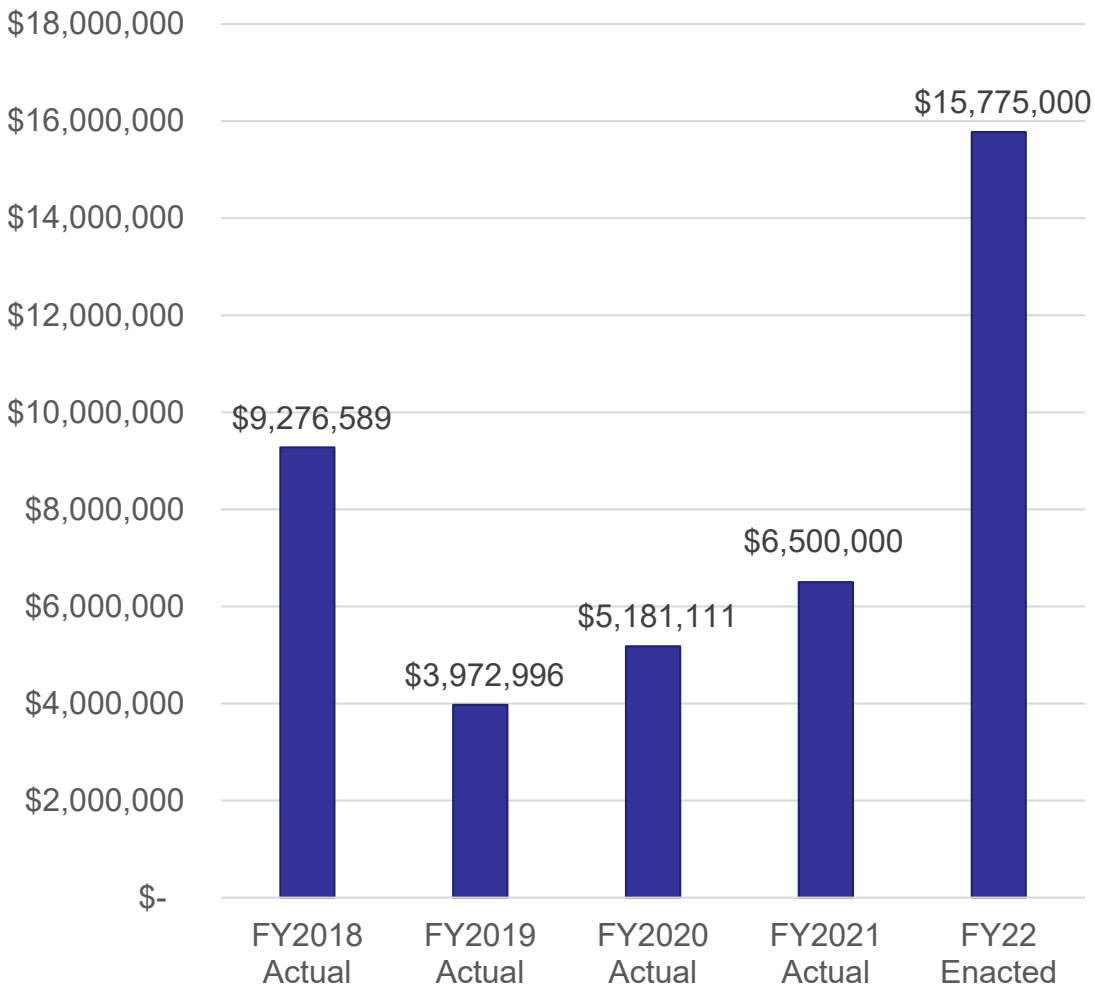
Analysis
environmental and economic sustainability

- Lifecycle emissions
- Cost reduction
- Supply potential
- Supply chain opportunities

Coordination
support SAF integration

- Public-private partnership – *CAAFI*
- U.S. interagency cooperation
- International cooperation – *ICAO*

SAF Funding Levels



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

- **ASTM Status**

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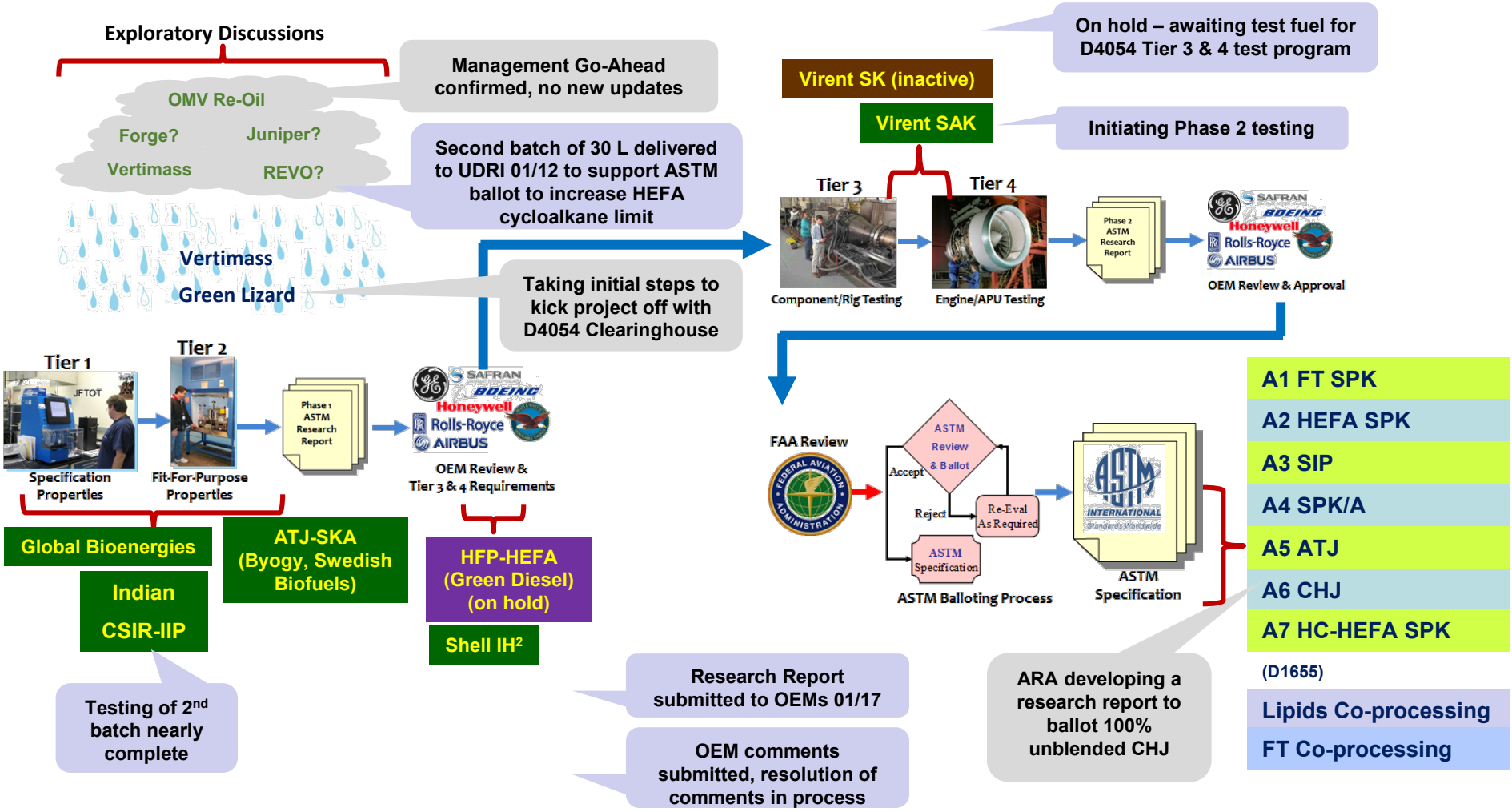
Testing: ASTM Qualification Status

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



*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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- **Supply Chain Tools & Analysis**

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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 CO_2 emissions reductions.
- LTAG-TG Fuels Sub Group focused on fuel production and lifecycle GHG emissions projections out to 2070.

Subgroup	Task Number	Task Title
ILUC	S.01.01	Computation of induced land use change emissions for SAF for use in CORSIA
	S.01.02	Low ILUC risk practices
	S.03	Co-processing of esters and fatty acids in petroleum refineries – just ILUC calculation
	S.04.02	Methodology refinements – ILUC
Core LCA	S.01.03	Feedstocks classification
	S.02	Computation of default core LCA emission values for SAF for use in CORSIA
	S.03	Co-processing of esters and fatty acids in petroleum refineries – methodology for conducting LCA and default core LCA values
	S.04.01	Methodology refinements – core LCA
Emission Reductions	S.04.03	Methodology refinements – Emission Credits
	S.11	Double counting
	S.12	ILUC Permanence
All FTG	S.05	CORSIA Package Updates
Sustainability	S.06	Sustainability criteria
	S.07	SCS Requirements
Technology and Production	S.08	Technology evaluation
	S.09	Fuel Production Evaluation
	S.10	Guidance on Potential Policies and Coordinated Approaches for the Deployment of SAF

CAEP/12 work programme shown here. CAEP/13 programme expected to be similar.

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

Federal Aviation Administration

Lifecycle GHG Emissions and Sustainability

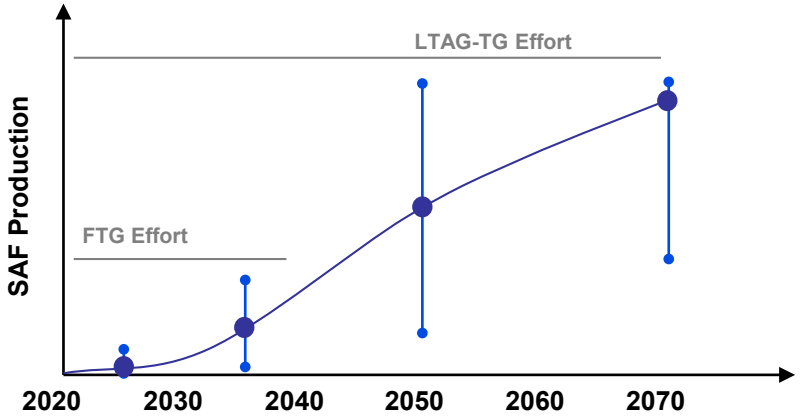
- FAA and ASCENT 01 / Volpe / ANL provided key data and leadership to determine how SAF and Lower Carbon Aviation Fuels (LCAF) are credited within CORSIA

- **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

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



Fuel Category	Fuel Types in Category
Sustainable Aviation Fuels (SAF)	Biomass-based fuel
	Solid and liquid waste-based fuels
	Gaseous waste-based fuels
	Atmospheric CO_2-based fuels
Lower Carbon Aviation Fuels (LCAF)	Lower carbon petroleum fuels
Non-drop-in fuels	Electricity
	Cryogenic hydrogen

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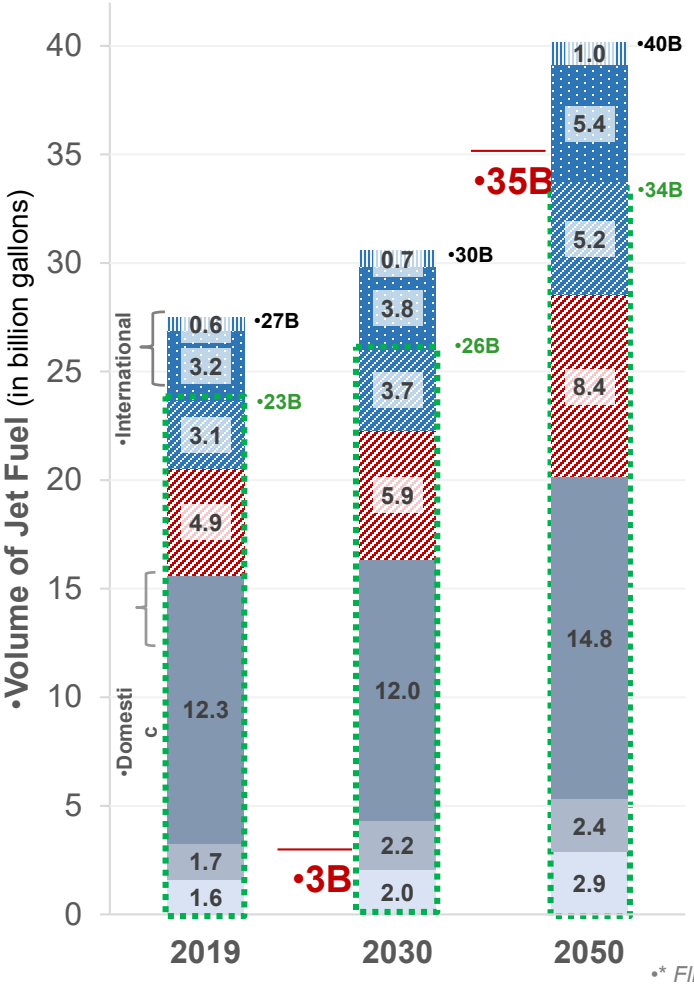
SAF Grand Challenge

- **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



•Geographic Scope:

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
- •Jet Fuel Uplift within the United States

•Data Sources and Assumptions:

- •2019: BTS T-2 (International operations reported by US carriers)
- •2030-2050: CO_2 emissions based on FAA Aerospace traffic Forecast, after technology and operations improvements. Assuming breakdown of flows (departures from US, arrivals in US and foreign-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. CO_2 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

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

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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- Federal
- **Commercialization**

Commercial Aviation Alternative Fuels Initiative (CAAFI)

A public/private partnership of FAA, A4A, AIA & ACI-NA

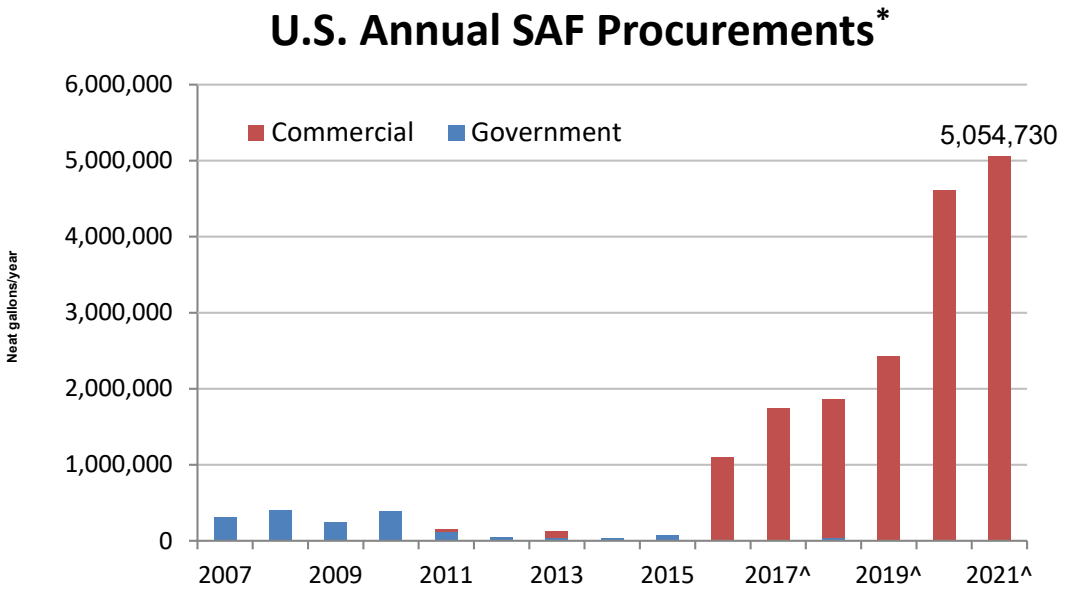
- **2022 Work Plan**
  - Convening a broad exchange of information among SAF stakeholders
  - Providing information resources and credible expert technical support
  - Coordinating and aligning with U.S. Government Agencies' activities in support of the SAF Grand Challenge
  - Facilitating ongoing efforts 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

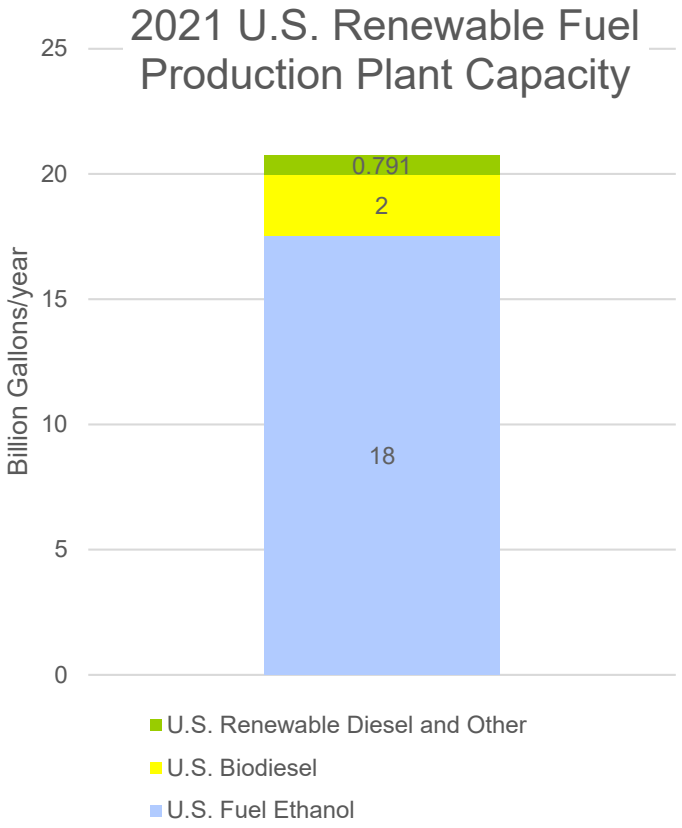
Initiation under way, still early, but growing

- 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



*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.

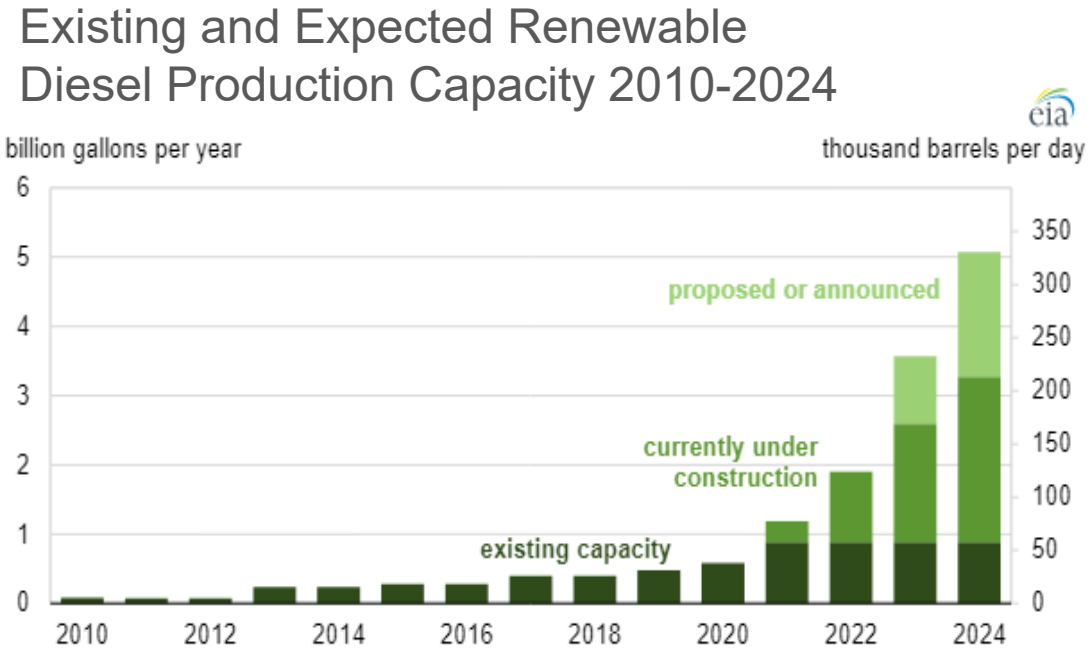
Existing & expected U.S. renewable fuel production



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

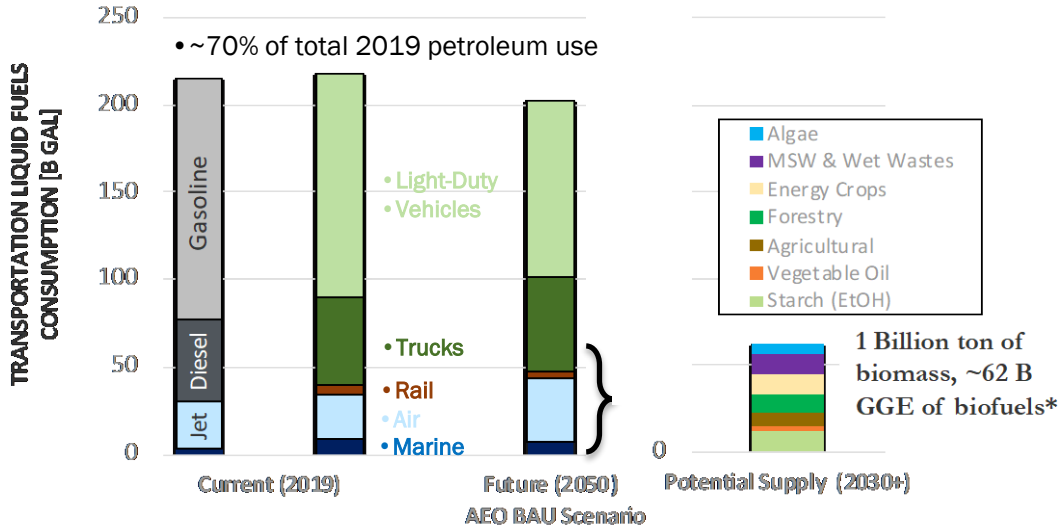
https://www.eia.gov/biofuels/renewable/capacity/

https://www.eia.gov/petroleum/ethanolcapacity/



Source: U.S. Energy Information Administration (EIA)
https://www.eia.gov/todayinenergy/detail.php?id=48916

Total Available Biomass for Renewable Fuels



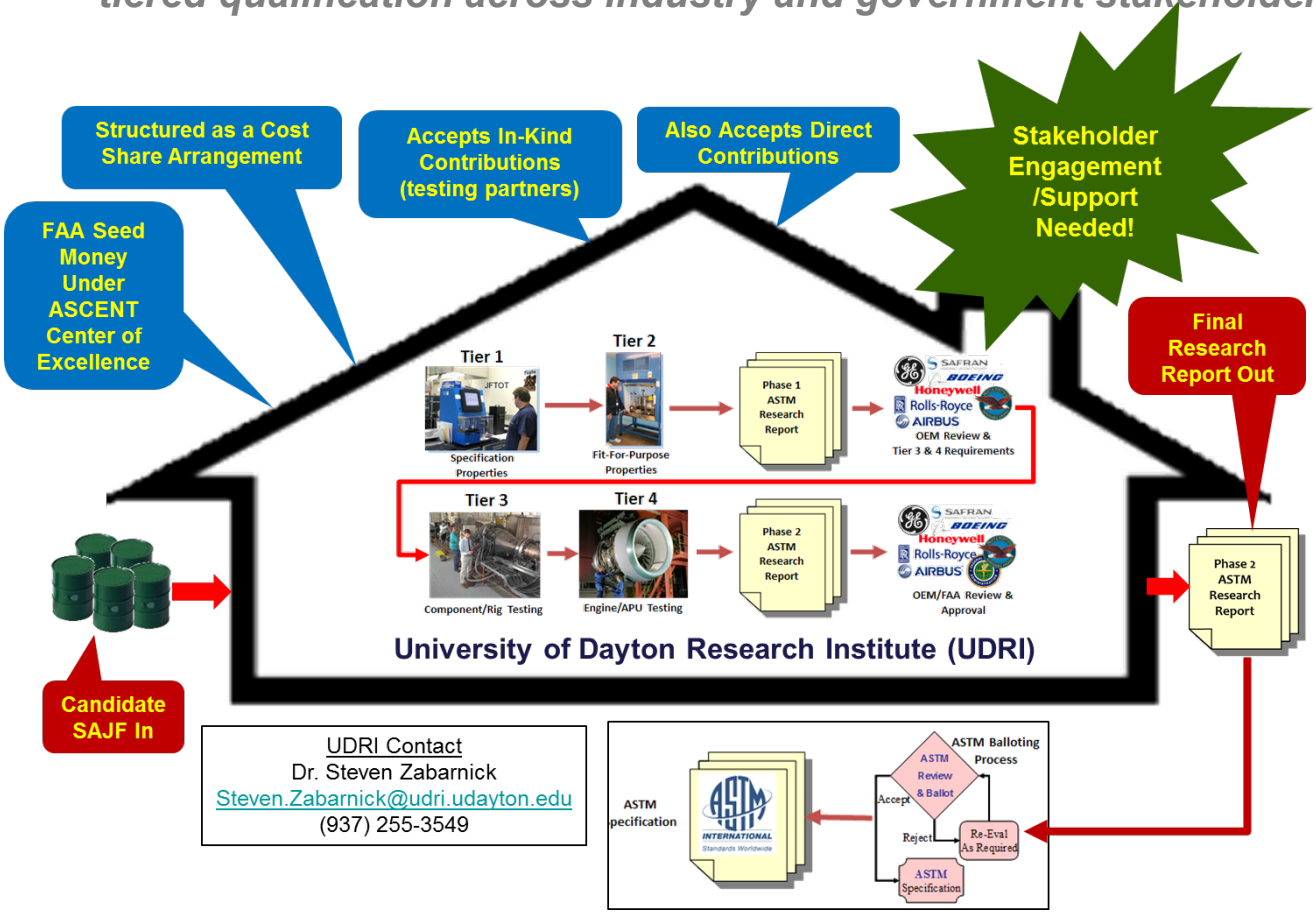
- Biomass can fully **supply future Aviation/ Maritime/Rail** (requires 75% of all feedstocks)
- Biggest market pull is **in sustainable aviation fuels** (SAF)
- Provides market for **current ethanol** (~17B gal, ~40% of corn production)
- Supports decarbonization of chemicals via **bioproducts**, and decarbonization of agriculture through healthy forests and sustainable agriculture
- **CO_2-to-fuels** remains to be explored

QUESTIONS

BACKUP SLIDES

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

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

Fuel Type	ASTM Data Review	Final Phase II Report	ASTM Specification (D7566)	Estimated gallons of fuel produced for testing	Estimated time from first review to approval	Composition
FT-SPK	09/2007	09/2008	09/2009	710,000[1]	3 years	Mostly normal/ iso-paraffins
HEFA-SPK	06/2008	05/2010	07/2011	626,000[2]	3 years	
SIP*	06/2011	04/2013	06/2014	16,000	3 years	
Gevo ATJ-SPK (isobutanol)	12/2010	04/2015	06/2016	93,100[3]	5 $^{1}/_{2}$ years	
Lanzatech ATJ-SPK (ethanol)	09/2016	07/2017	04/2018	50[4]	1 $^{1}/_{3}$ years	
ARA CHJ	06/2012	10/2018	01/2020	79,000	7 years	Wider range of molecules
IHI HC-HEFA**	02/2019	06/2019	04/2020	50	~1 year	40% cycloparaffin

**Approved at 10% volume*

***First Fast Track approval – approved at 10% volume blend limit*

ARA Applied Research Associates

[1]USAF fuel purchases in 2007 08 for fleetwide qualification

[2]USAF & Navy fuel purchases in 2009 11 for fleetwide qualification

[3]USAF, Navy and CLEEN fuel purchases in 2012 2014

[4]Only Tier 1 2 testing due to existing knowledge base and similarity to approved fuels

Testing: Beyond 50%

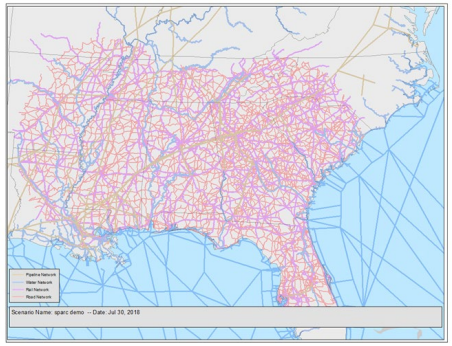
New ASCENT direction to support higher blend limits of alternative fuels

- 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:

- ASCENT: Washington State U., MIT, Purdue, U. Tennessee, U. of Hawaii, Penn State U.
- 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