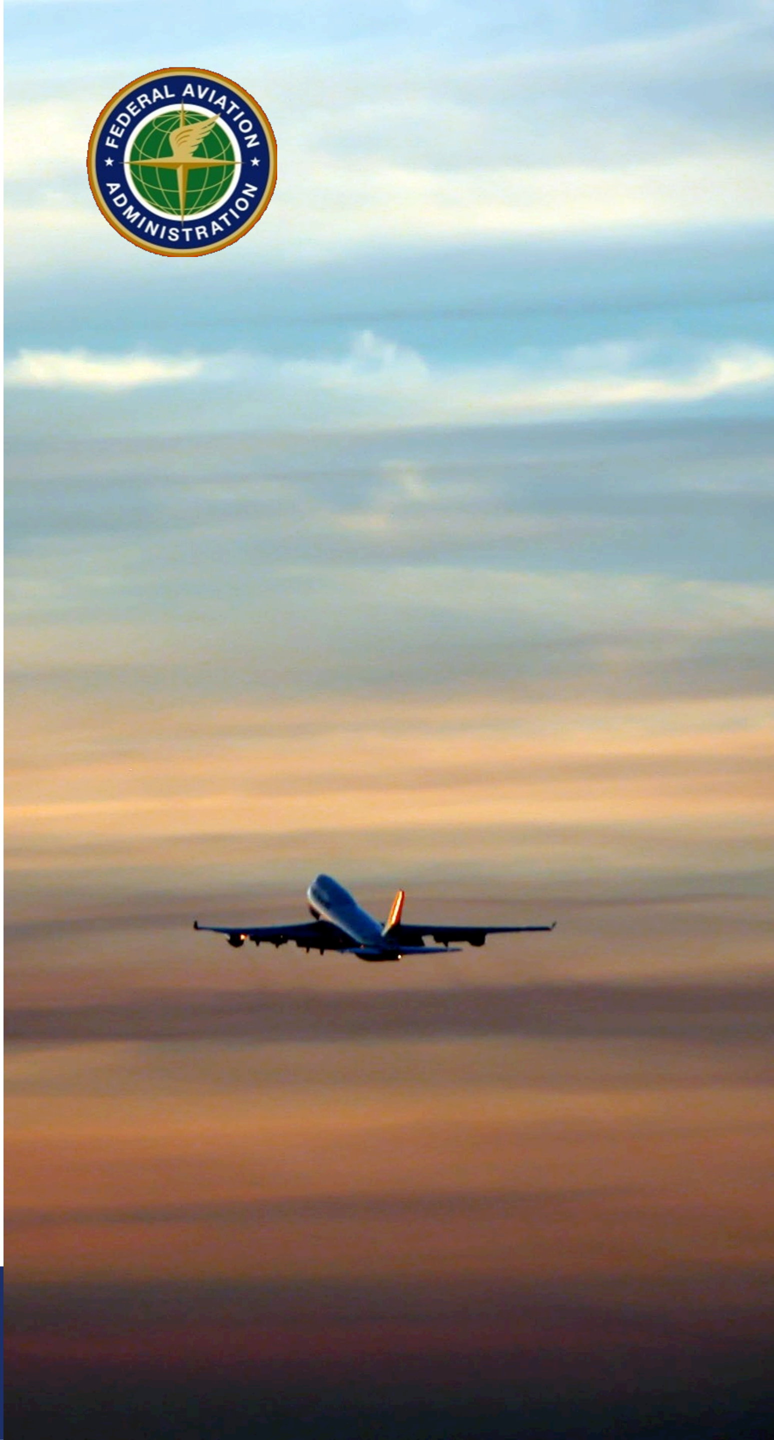
Sustainable Aviation Fuels (SAF)

Update to FAA REDAC E&E Subcommittee

To: E&E REDAC Subcommittee

By: Nate Brown & Anna Oldani

Date: September 15, 2021



Benefits of Sustainable Aviation Fuels (SAF)

- **SAF are "drop-in" liquid aviation fuels –** same infrastructure, engines & aircraft
- **SAF reduce lifecycle GHG and air quality emissions substantially** – critical to aviation de-carbonization
- **Viable technologies exist** – seven alternative fuel pathways currently approved for use, and two approved for co-processing with petroleum, more under evaluation for approval
- **Scalable feedstocks –** wastes & residues, biomass, sugars, oils and energy crops can all supply SAF
- **Widely accepted** by airlines, business, and general aviation
- **Broadly supported among federal agencies** as meeting critical goals - climate, energy security, rural economic development
- **Critical to international efforts** to address aviation emissions

Challenges to SAF commercialization

- **Cost and scale of production**
  - Availability of conversion infrastructure
  - Availability of feedstock supply
- **Lack of production incentives and support**
- **Time and resource intensive certification process**
- **Current blend limits capped at 50%**
- **Ensuring overall sustainability**
- **Credible accounting of GHG reductions for buyers**

FAA SAF Program Focus

Testing

accelerate SAF development

- Test fuels
- Improve testing methods
- Conduct evaluation
- Streamline approval

Analysis

environmental and economic sustainability

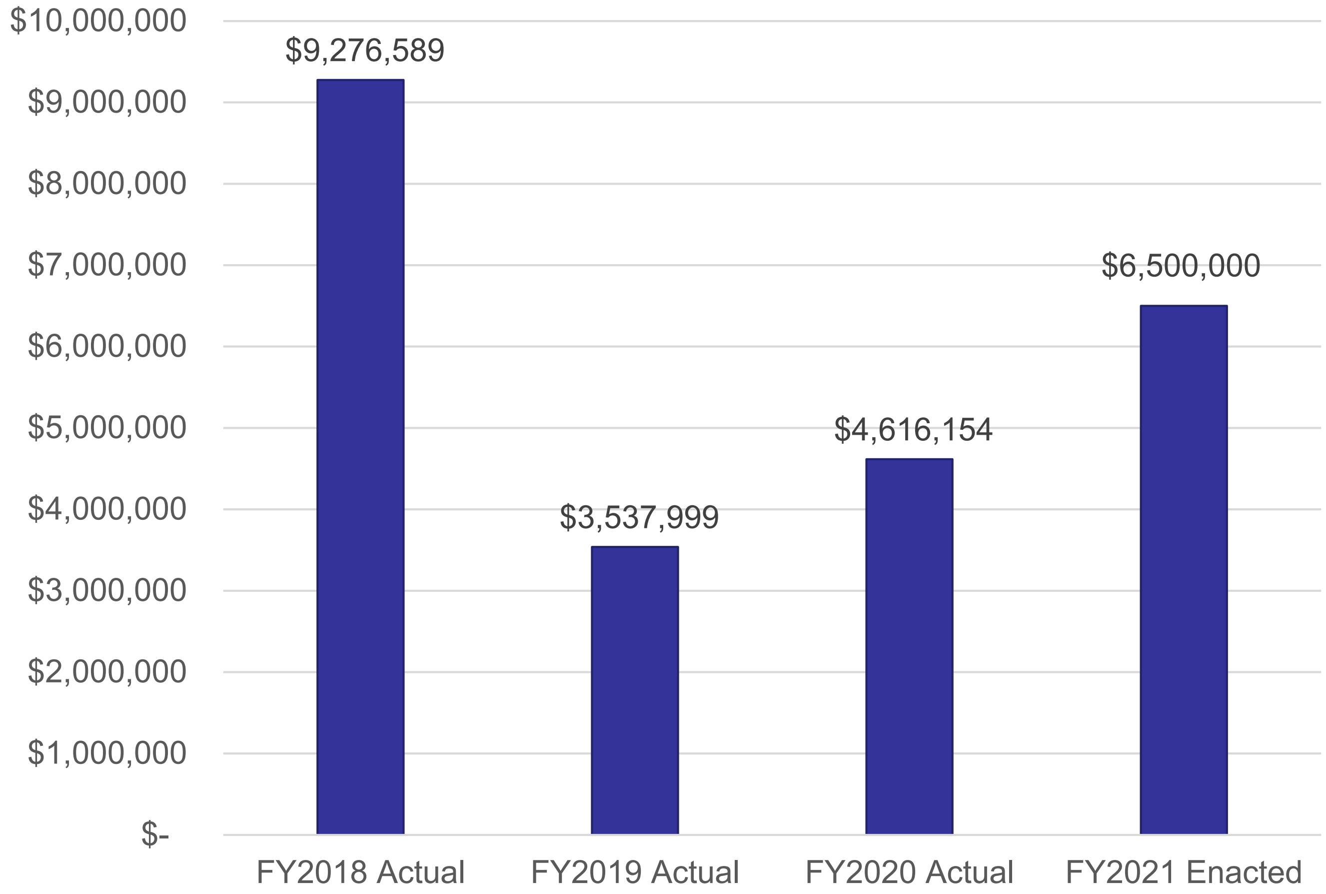
- Lifecycle emissions
- Cost reduction
- Supply potential
- Supply chain opportunities

Coordination

support SAF integration

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

SAF Funding Levels



Agenda

Testing

- Qualification Process
- ASTM Status

Analysis

- Novel SAF Production
- Supply Chain Tools & Analysis

Coordination

- ICAO CAEP FTG & LTAG-TG
- Federal
- Commercialization

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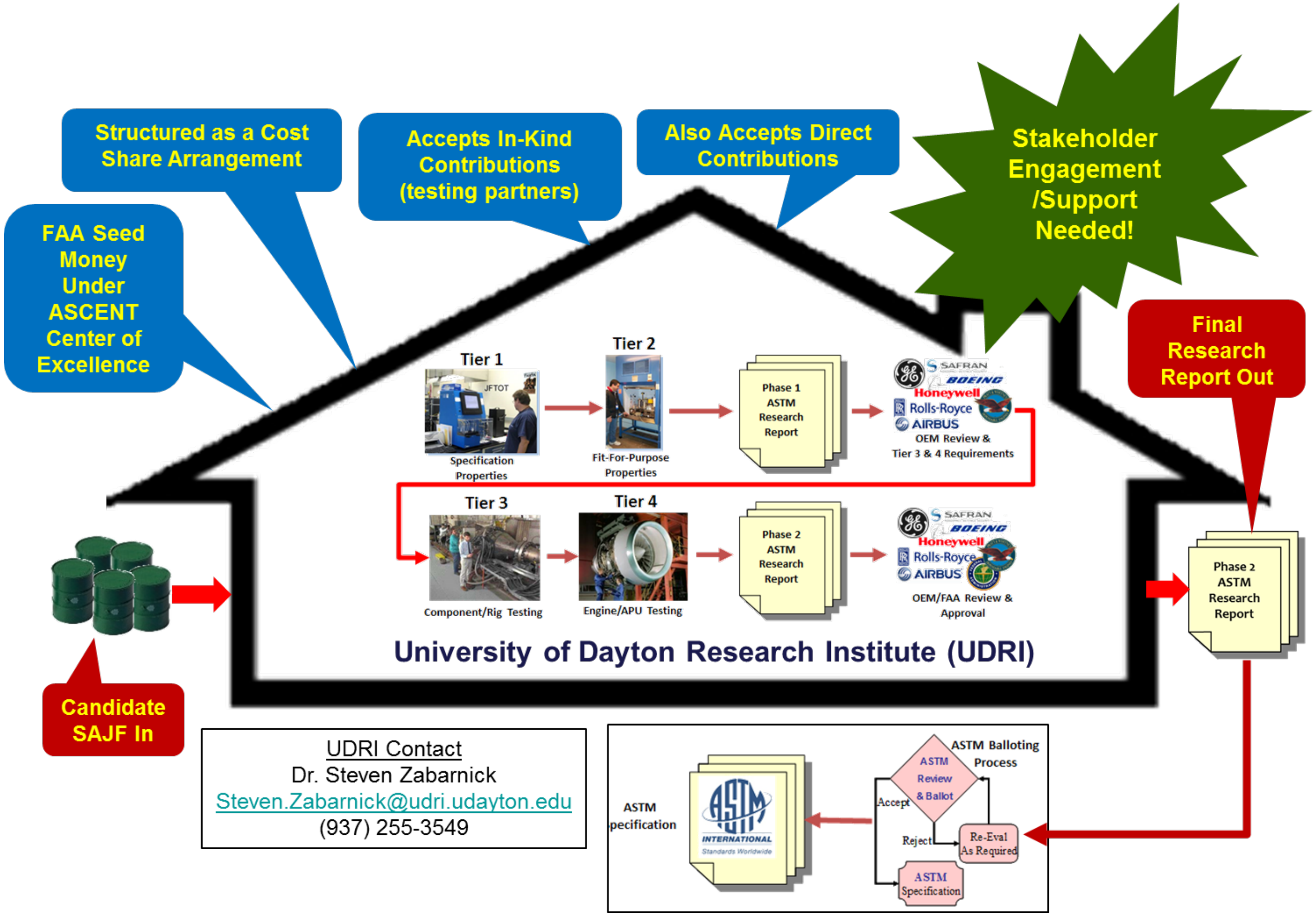
Testing: D4054 Clearinghouse

Centralized testing through 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
- **€5.9 M** cost share from EU partners for Clearinghouse testing support

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- **ASTM Status**

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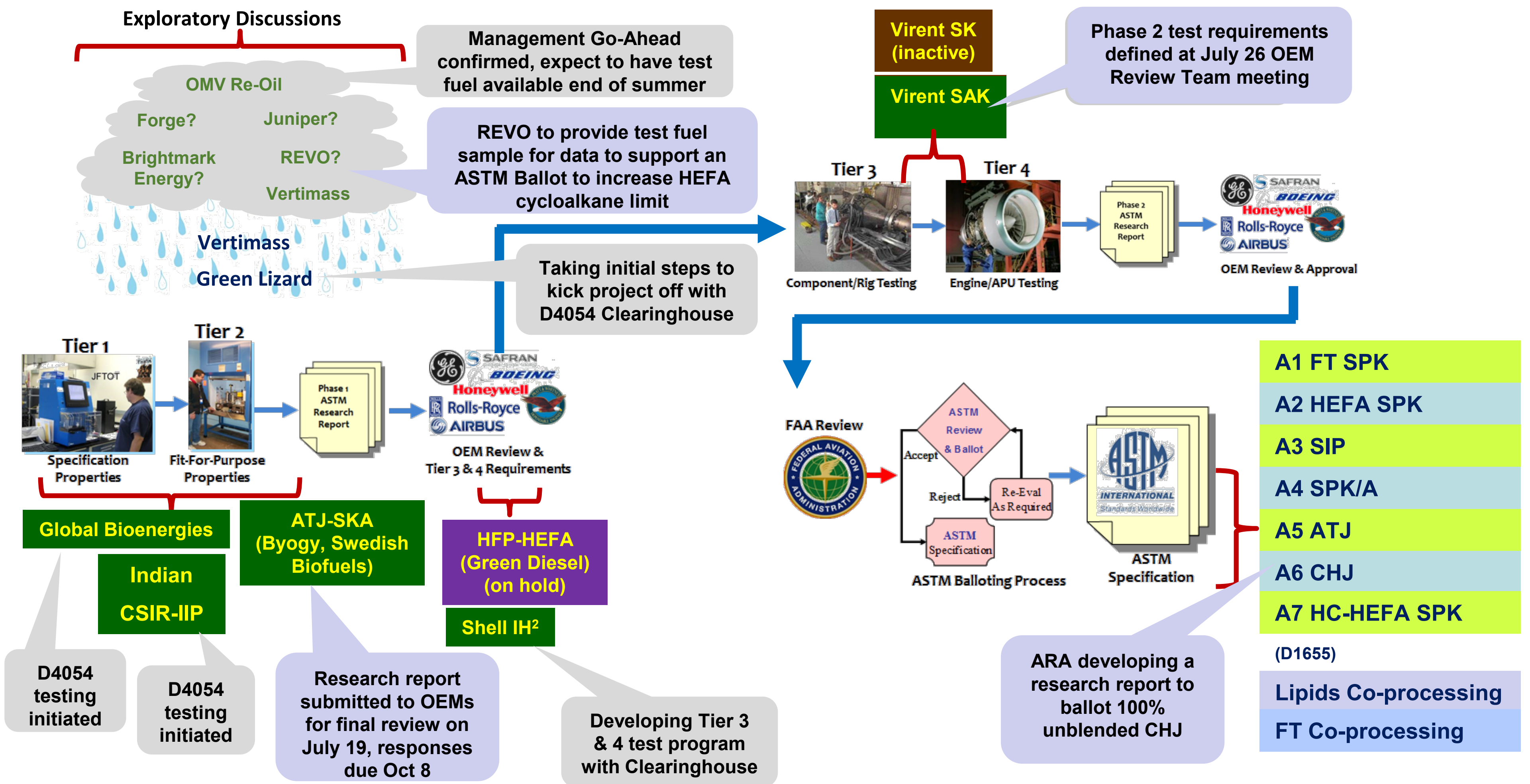
Testing: ASTM Qualification Status

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: 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

- Current ASTM D7566 specifications **limit most pathways to 50%** by volume blending with conventional jet fuel
- Need to ensure fuels are **drop-in compatible with existing and legacy systems**
- **Developing new ASCENT project(s)** to isolate fuel properties that constrain blend volumes and develop fuel evaluations that support higher blend limits

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Hydrogen Use in Aviation

- MIT and WSU through ASCENT COE Projects 1 and 52 have been examining potential paths for using renewable electricity in aviation[1]

- ***Hydrogen is the key to unlocking the potential of SAF***
- Using renewable hydrogen for fuel production would provide an immediate reduction in carbon footprint of aviation and enable the use of sustainable aviation fuels (low carbon fertilizers and fuel production)
- There are considerable waste and biomass resources in the U.S. that could be sustainably produced, at lower costs than either cryogenic hydrogen or power-to-liquids, and that would use today's infrastructure[2, 3]
- Makes logical sense to use these resources now and to leverage our current infrastructure. Could also use biomass with power-to-liquids.
- In the future, if we need more jet fuel than can be provided from waste and biomass resources, then power-to-liquid fuels could be a viable solution. It could be produced from renewable electricity via hydrogen as an intermediary while enabling us to use our existing infrastructure

1. See ascent.aero and look for Projects 1 and 52

2. For additional details on potential for wastes as a SAF feedstock, see: http://caafi.org/focus_areas/docs/US_WasteFeedstockPotential.pdf

3. DOE Billion Ton Study

Analysis: Novel SAF Production

New ASCENT Project 80 will evaluate costs and lifecycle GHG for hydrogen and power-to-liquid (PtL) fuels

- **Address recent interest** in both green hydrogen and PtL concepts for aviation
- **Intense electricity demand** must be factored into lifecycle and techno-economic evaluations
- **Provide recommendations** for alternative uses and future directions as resource availability changes with time

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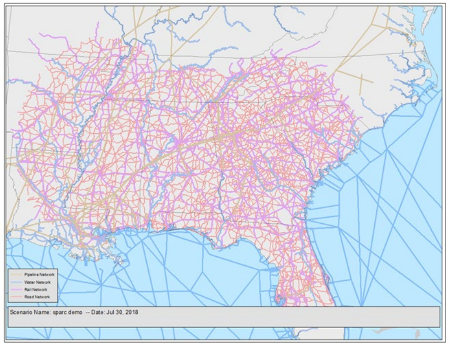
Analysis: Supply Chain Research & Tools

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 - 2021.3 release in September
  - 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)

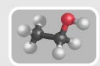
https://ascent.aero/project/alternative-jet-fuel-supply-chain-analysis/

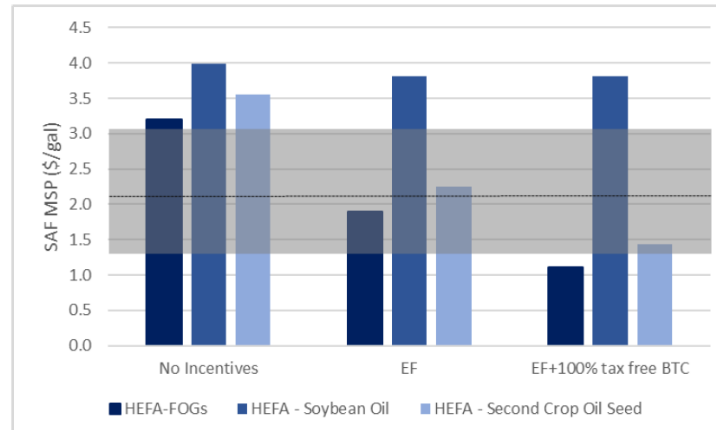
https://github.com/VolpeUSDOT/FTOT-Public

Analysis: Techno-economics

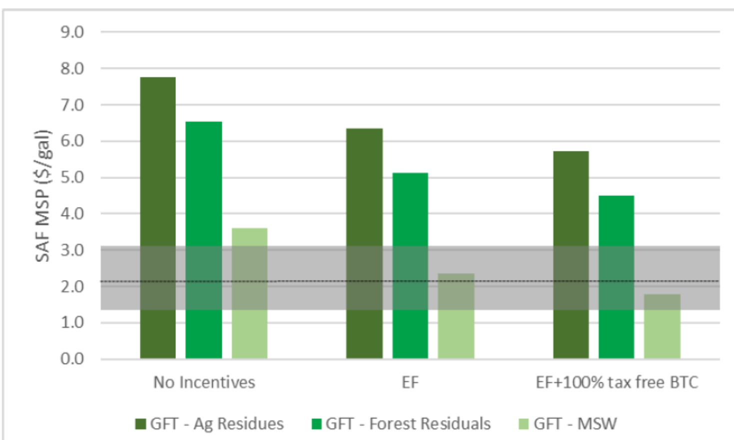
Understand SAF economics and the impact of proposed policy

- **WSU used TEA tools to model the impact of no incentives, existing federal (EF) incentives and a new SAF Blenders Tax credit on SAF minimum selling price (MSP)**

Process	Feedstock					
	FOGs	Vegetable Oil	Ag Residue	MSW	Forest Residue	Alcohol
HEFA						
GFT						
ATJ						



Price parity range for wholesale petroleum jet 2011-2020, EIA
Average SAF price parity with wholesale petroleum jet 2011-2020, EIA



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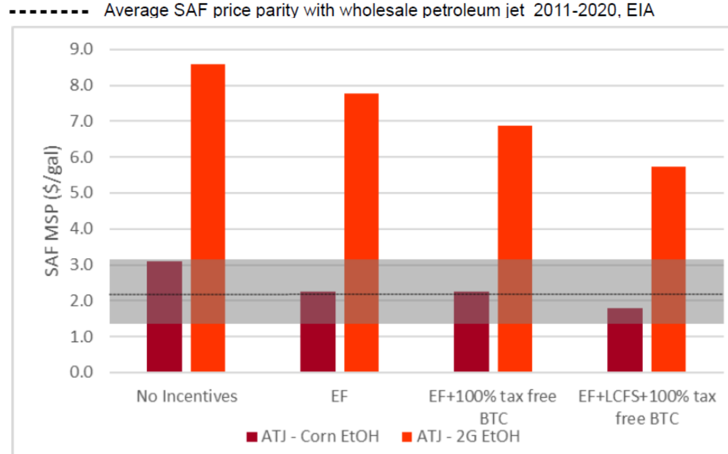

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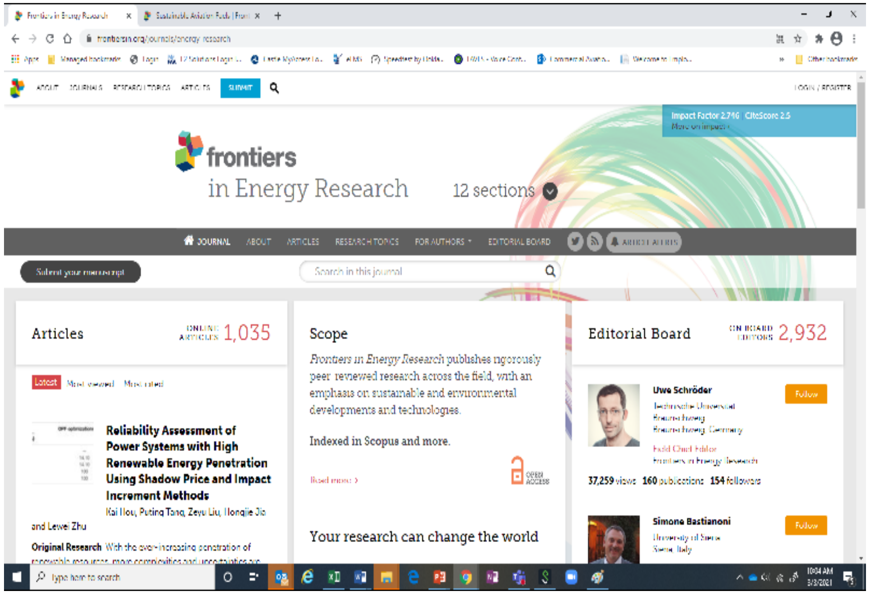
https://alliance-wsu.esploro.exlibrisgroup.com/discovery/fulldisplay/alma99900599451401842/01ALLIANCE_WSU:ResearchRepository

Frontiers in Energy Research SAF Topic

- **Online Journal**
- **SAF Research Topic**
  - Central point for SAF research
  - Will increase visibility of ASCENT Project 1 efforts
  - Open to other research
  - Variety of article types
- **Topics:** Feedstocks; Conversion; Cert/Qualification Testing; Economics; Environment; Supply Chain Analysis; Cost / Risk Reduction; & Policy
- **Editors:** WSU; FAA; DOE; USDA; Volpe; Lanzajet
- Anticipate **~30 articles**



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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 working to 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

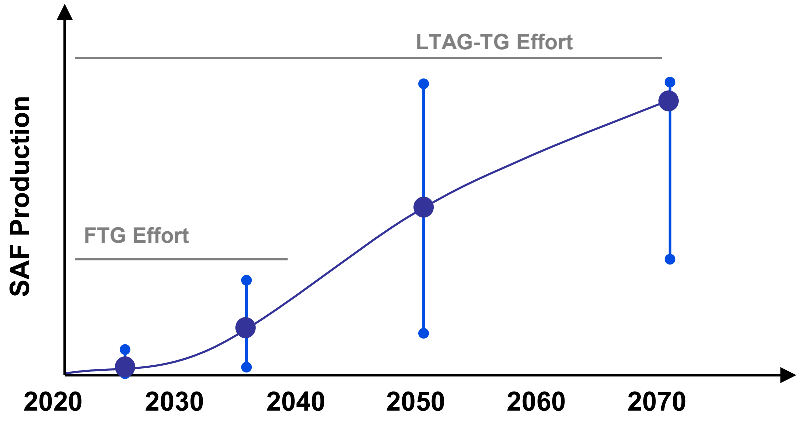
Lifecycle GHG Emissions and Sustainability

- FAA and ASCENT P1 / Volpe / ANL Team providing key data and leadership to determine how SAF and Lower Carbon Aviation Fuels (LCAF) are credited within CORSIA
- Continue to develop core life cycle emissions values for SAF made from waste CO emissions, jatropha, and co-processing of biomaterials with petroleum in today's refineries
- Continue to develop a life cycle analysis methodology for LCAF to determine fuel eligibility under sustainability criteria 1 and amount of crediting
- Sustainability criteria being developed for LCAF based on the list of SAF criteria – have also revised the SAF criteria
- Sustainability Certification Schemes have been approved by the ICAO Council and posted on the CORSIA Eligible Fuel website
- FAA continues to help convene a series of meetings with CAEP Members and Observers on LCAF to help overcome current impasse

For additional information on CORSIA Eligible Fuels
https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

Future Fuel Production

- FTG & LTAG-TG have considerable ongoing work to project future SAF production – being led by FAA and ASCENT P1/P52 / Volpe / ANL Team
- Assembled a global near-term SAF production database and are extending it to 2035-2070
- Quantified SAF production potential from waste CO/CO_2 gases and atmospheric CO_2
- Quantified infrastructure costs and documented additional challenges for hydrogen use by commercial aviation
- Evaluating fuel volumes, life cycle GHG emissions, investment requirements, etc. across all fuel types



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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Biomass R&D Board

- The Sustainable Aviation Fuels Interagency Working Group (AAF IWG)
  - Ensuring aviation biofuel research and development efforts reflect critical needs
  - Advancing a revised and coordinated federal research and development roadmap on sustainable aviation fuels
  - Developing and scaling best practices to foster the success of sustainable aviation fuels in commercial, business, and military aviation sectors.
- Originated the concept of a SAF "Grand Challenge"

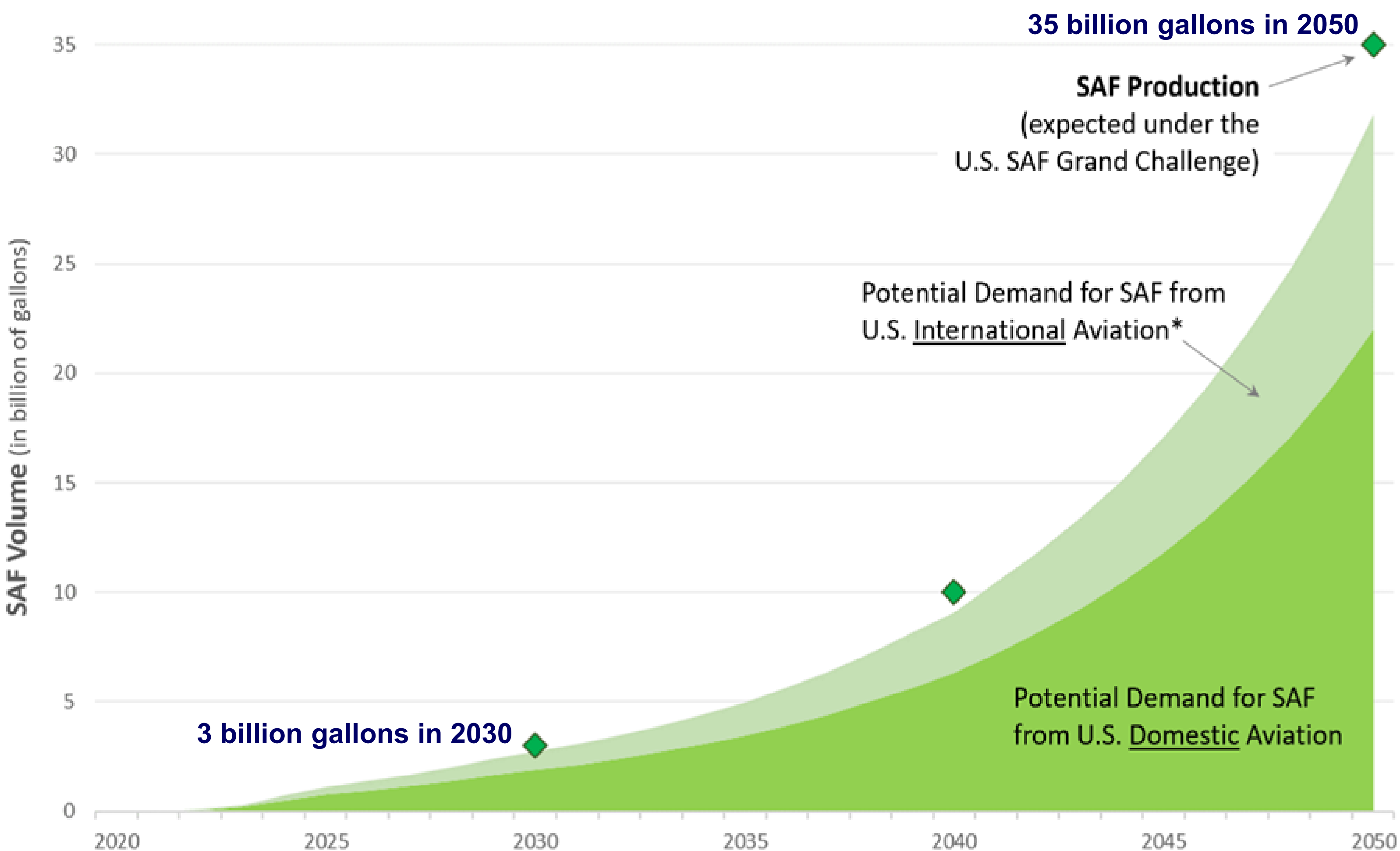
For additional information on SAF IWG:
https://biomassboard.gov/sustainable-aviation-fuels-interagency-working-group

The SAF Grand Challenge

U.S. government-wide effort to reduce the cost, enhance the sustainability, and expand the production and use of Sustainable Aviation Fuel (SAF) to meet 100% of aviation fuel demand by 2050

- **Establishes SAF as a key priority** in a broader set of actions by the U.S. Government and the private sector to **reduce the aviation sector's emissions in a manner consistent with the goal of net-zero emissions**
- Sets an **ambitious vision** and affirms to industry that the **USG is committed to SAF research, development, and deployment**
- **Announcement** and MOU signing with White House and agency Secretaries on September 9, 2021
- **Memorandum Of Understanding (MOU) among DOE, DOT and USDA** to jointly lead the initiative and commit resources to research, development, and deployment

SAF Grand Challenge Goals relative to Consumption



** Note: U.S. International Aviation defined as all flights from U.S. carriers. Difference between total SAF needs and SAF Production (expected under the U.S. SAF Grand Challenge) could serve potential demand from flights performed by Foreign operators departing the United States.*

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.
- Conduct R&D aimed at creating new pathways toward higher specificity of SAF Production.

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.

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
- Extension/outreach/ technology transfer
- Commercialization support

Next Step: Develop SAF Grand Challenge Roadmap

SAF Grand Challenge Roadmap

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

Roadmap will consider critical challenges

- **Regional Resources and Capacities**
  - Identigy opportunities and challenges for feedstock and fuel production in 7 U.S. regions
- **Expanding SAF supply and end use**
  - Technology barriers
  - Availability of feedstock supply (crop education/extension/workforce training)
  - Availability of infrastructure
  - Barriers to end use (e.g. timely certification for aviation use of SAF solutions; crediting of benefits)
- **Reducing the costs of production**
  - Technology Opportunities across the supply chain
- **Enhancing the sustainability of production**
  - Across the supply chain and via other activities (e.g. increasing blend limits to greater than 50%).
- **Gaps in analytical capability, tools or knowledge**
- **Gaps in financing, risk of investment**
- **Effective alignment of policy incentives**

SAF Grand Challenge Roadmap Status

- **6 month process**
- **FAA, DOE and USDA leading process**
- **Biomass Board SAF Interagency Working Group**
- **Status**
  - Outline in development
  - Two brainstorming sessions held with federal experts in August
  - Session planned for September 16 with DOE national labs, ASCENT and USDA researchers
  - Industry session(s) to follow
- **Draft roadmap targeted for end of year**

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Commercial Aviation Alternative Fuels Initiative (CAAFI)

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

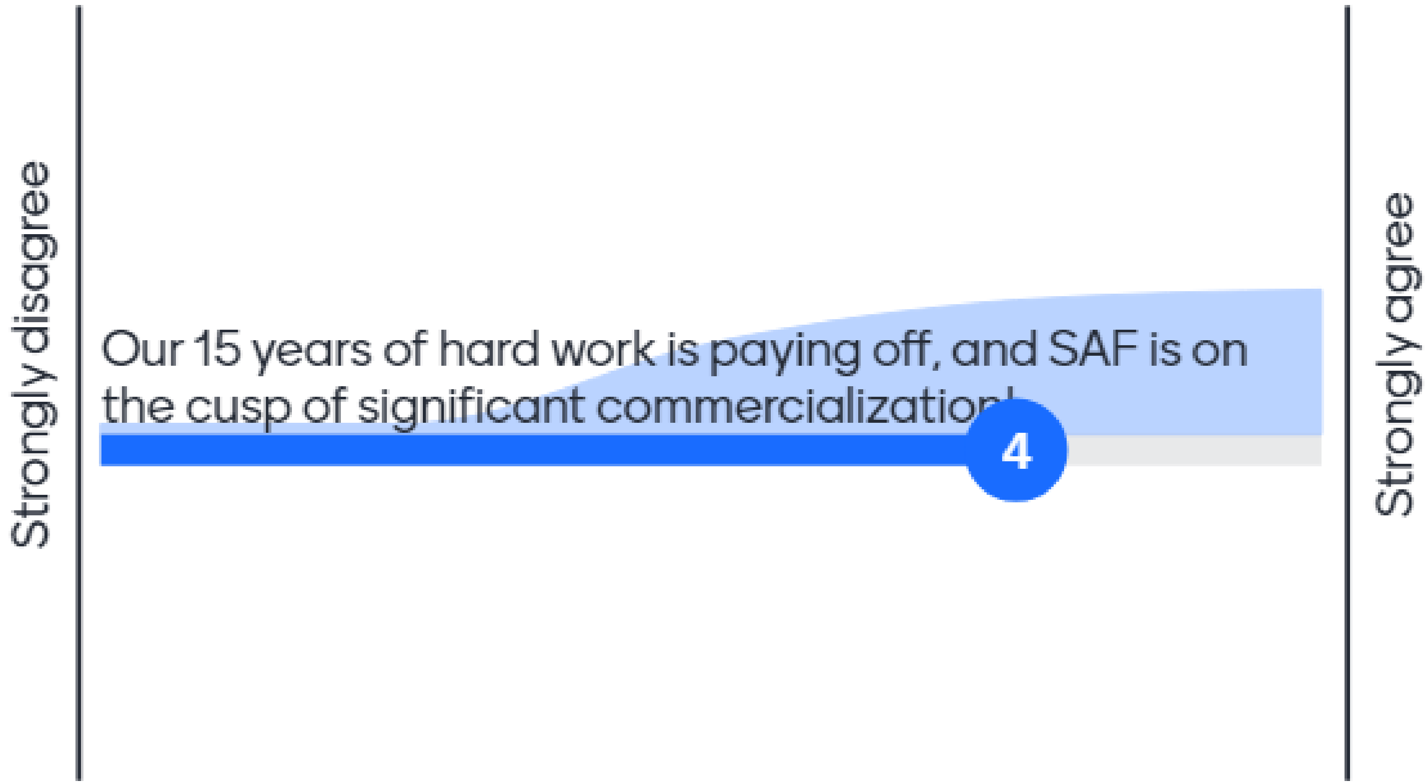
- **Continued outreach & coordination**
- **2021 Goals & Priorities**
  - Communicate the Value Proposition of SAF
  - Enhance the Fuel Qualification Approach
  - Align Efforts to Enable Commercial Deployment of U.S. SAF Supply
  - Implement Frameworks & Share Best Practices
- **Held Virtual Mini-symposium June 1-3, 2021**
- **In person CAAFI General Meeting planned for June 1-3, 2022 in Washington, DC**

Virtual Mini Symposium Polling

Rate (and rank) these barriers to SAF commercialization? Scale of 1 - 10

Virtual Mini Symposium Polling

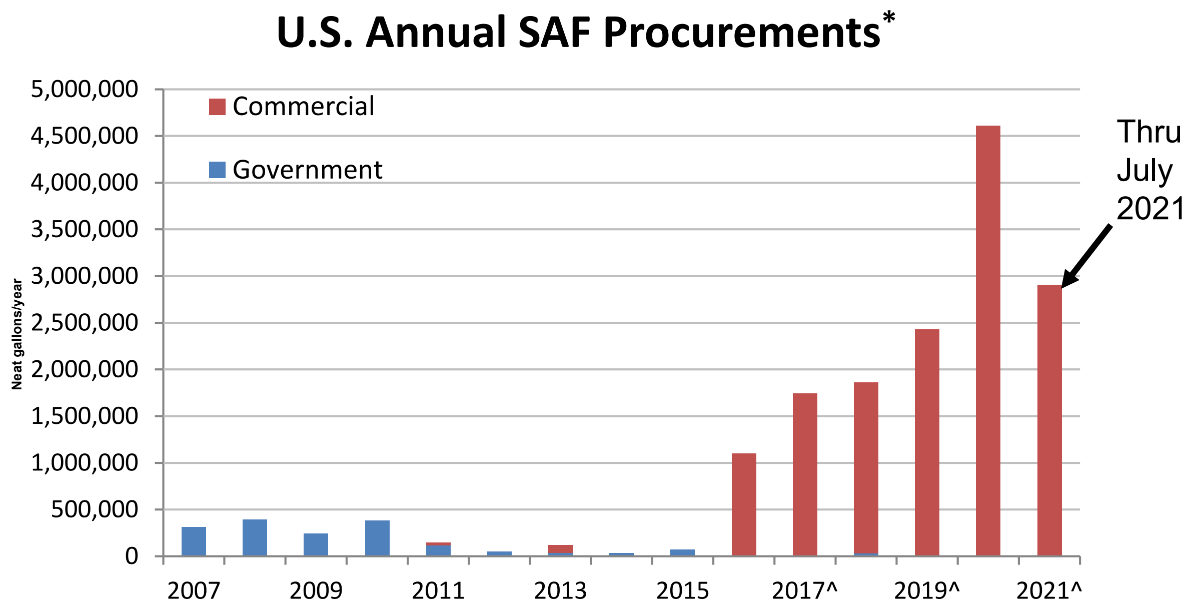
How do you feel about the following statement? Scale of 1 - 5



Where we stand on U.S. SAF commercialization

Initiation under way, still early, but growing

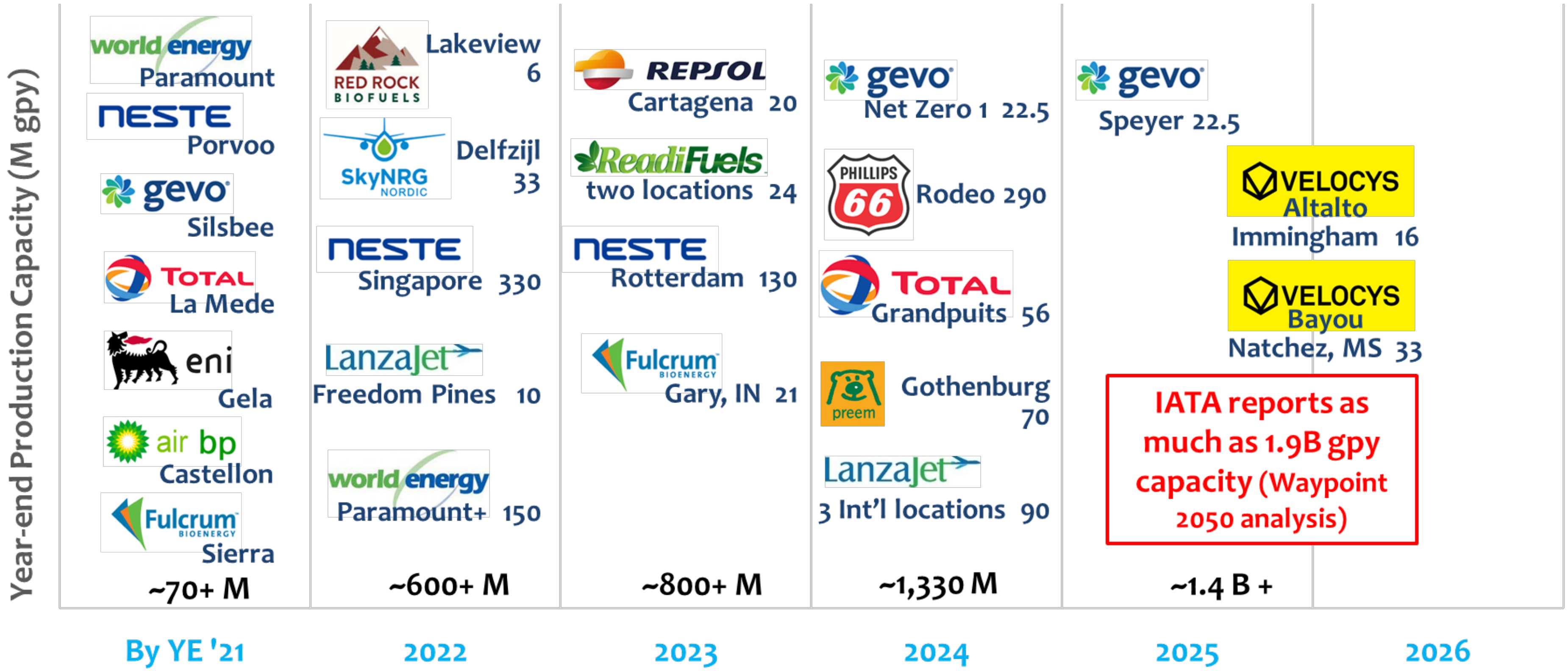
- Six years of sustained & increasing commercial use
- 4.6M gallons in 2020
- On track ~5M in 2021
- One commercial U.S. facility in operation
- Two facilities under construction (others in development)
- Cost delta with renewable diesel still a challenge



*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.

Worldwide SAF Capacity Forecast

*Announced intentions**



Credit: CAAFI

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

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QUESTIONS