EXAMINING R&D PATHWAYS TO SUSTAINABLE AVIATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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C O N T E N T S

March 24, 2021

Page

Appendix II: Additional Material for the Record

EXAMINING R&D PATHWAYS TO SUSTAINABLE AVIATION

WEDNESDAY, MARCH 24, 2021

House of Representatives,
Subcommittee on Space and Aeronautics,
Committee on Science, Space, and Technology,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 11:01 a.m., via Webex, Hon. Don Beyer [Chairman of the Subcommittee] presiding.

SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Examining R&D Pathways to Sustainable Aviation

Wednesday, March 24, 2021
11:00 a.m.
Cisco WebEx

PURPOSE

The purpose of the hearing is to examine research and technology approaches to sustainable aviation, including activities for improving the energy efficiency and reducing the climate and environmental impacts of civil and commercial aviation; inform research and development priorities to achieve emissions reduction goals for the aviation sector; and other issues.

WITNESSES

- **Dr. Karen A. Thole,** Department Head and Distinguished Professor, Department of Mechanical Engineering, Pennsylvania State University
- **Dr. R. John Hansman, Jr.,** T. Wilson Professor of Aeronautics & Astronautics and Director, MIT International Center for Air Transportation, Massachusetts Institute of Technology; Chair, FAA Research and Development Advisory Committee (REDAC); Co-director, FAA Center of Excellence for Alternative Jet Fuels and Environment (ASCENT)
- **Mr. Steve Csonka,** Executive Director, Commercial Aviation Alternative Fuels Initiative (CAAFI)

OVERARCHING QUESTIONS

- *What is the impact of aviation on CO_2 emissions and the overall environment?*
- *What are the recommended options, or "pathways," for reducing the aviation sector's impact on climate change, and on what timescales can they be realized?*
- *What research and development (R&D) questions and issues need to be addressed to make maximum progress toward more sustainable aviation in the near-term, mid-term, and long-term?*
- *What is needed to inform R&D priorities for sustainable aviation?*
- *How should factors such as workforce, global cooperation, and industry competitiveness be considered in the context of efforts to achieve sustainable aviation?*

BACKGROUND

Aviation and Climate Change

Globally, aviation contributes some 2.5% to annual CO_2 emissions.[1] In addition to CO_2, aviation emissions include aerosols and particulates, including nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide (CO), partially combusted or unburned hydrocarbons (HC), and particulate matter (PM).[2] The Environmental Protection Agency (EPA), in its annual inventory of greenhouse gas (GHG) sources and sinks, reports that GHG emissions from aviation comprised 2.6% of total GHG emissions and 3.2% of overall CO_2 emissions in the U.S. in 2018.[3]

The products of aircraft engine combustion react with different portions of the atmosphere than do those of other forms of transportation because most (70-90%) of overall aircraft emissions are released above an altitude of 3,000 feet.[4] Complex interactions with the upper troposphere and lower stratosphere can produce other types of warming mechanisms. For example, the EPA inventory of GHGs does not include water vapor, but water vapor—30% by mass of aircraft emissions—emitted at altitude can form contrails and contribute to cloud formation, which can lead to a net warming effect.[5]

While aviation's share of overall CO_2 emissions is small, and approximately 10% of U.S. transportation emissions, the EPA GHG inventory shows that aviation emissions have consistently increased at a faster pace than any other area of transportation in recent years.[6]

Trends

Through advances in engine, airframe, and propulsion design and manufacturing and other technology developments, aviation has achieved significant gains in energy efficiency. Over the past seventy years, overall engine efficiency has doubled, as has the power-to-mass ratio of aircraft, allowing modern aircraft to travel further on less fuel.[7] Overall, the aviation industry achieved an average annual fuel efficiency improvement of 2% from 2009-2019.[8]

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[1] Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, National Academy of Sciences, 2016, pp 15-16.
[2] Federal Aviation Administration (FAA), "Aviation Emissions, Impacts, and Mitigation: A Primer." 2015. Available at: https://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/primer_jan2015.pdf.
[3] Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990—2018." 2020. Available at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.
[4] Federal Aviation Administration (FAA), "Aviation Emissions, Impacts, and Mitigation: A Primer." 2015. Available at: https://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/primer_jan2015.pdf.
[5] One recent study found that non-CO_2 products of aviation contribute approximately two-thirds of the net warming effect of aviation (Lee, D.S. et al., "The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018." *Atmospheric Environment*, Volume 244, January 1, 2021. Available at: https://www.sciencedirect.com/science/article/pii/S1352231020305689#.)
[6] Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990—2018." 2020. Available at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.
[7] Epstein, Alan, "Aeropropulsion: Advances, Opportunities, and Challenges," *The Bridge*, Volume 50, Issue 2, National Academy of Engineering, Summer 2020. Available at: https://www.nae.edu/File.aspx?id=234402.
[8] https://aviationbenefits.org/media/167219/fact-sheet_3_tracking-aviation-efficiency_3.pdf.

Aviation's increased efficiencies have occurred in an environment of steady growth in passenger air travel. Whether measured by revenues, passengers, or miles, air travel has grown consistently every year after the 2008 financial crisis through 2019.[9] At these levels of growth, one estimate finds that commercial air travel has increased four times faster than fuel efficiency improvements.[10] The Federal Aviation Administration's (FAA) 2020 aerospace forecast, pre-pandemic, projected 2.0% growth in passengers and 2.5% growth in revenue passenger miles annually for U.S. aviation from 2020 through 2040.[11] Global air travel is expected grow faster and nearly triple by 2050. Even with projected further improvements in fuel efficiency, the U.S. Energy Information Administration projected in 2019 that global jet fuel consumption would continue to increase annually through 2050 at a rate faster than the rate of consumption of any other liquid fuel.[12]

Sustainable Aviation Goals and Emissions Standards

In 2009, the global aviation industry[13] agreed to industry-wide goals of improving fuel efficiency by an average of 1.5% per year from 2009 to 2020, achieving carbon-neutral growth from 2020 onward, as well as an aspirational goal to reduce net emissions from aviation by 50% from 2005 levels by 2050.[14]

The International Civil Aviation Organization (ICAO),[15] agreed in 2016 that member States would work toward achieving 2% annual improvements in aviation fuel efficiency until 2020, with aspirational goals of continued 2% annual fuel efficiency improvements through 2050 and carbon-neutral growth from 2020 onward.[16] In 2017,[17] ICAO adopted new aircraft CO_2 emission standards, after negotiations with industry and stakeholders including representatives from EPA and FAA, to achieve the fuel efficiency goals.[18] The ICAO standards apply to newly developed aircraft designs starting in 2020, and to aircraft in production starting in 2028. To ensure FAA-

[9] Federal Aviation Administration, "FAA Aerospace Forecast: Fiscal Years 2020-2040." March 26, 2020. Available at: https://www.faa.gov/data_research/aviation/aerospace_forecasts/.
[10] Graver, Brandon, Dan Rutherford, and Sola Zheng, "CO_2 Emissions from Commercial Aviation 2013, 2018, and 2019" International Council on Clean Transportation, October 2020. Available at: https://theicct.org/publications/co2-emissions-commercial-aviation-2020.
[11] Federal Aviation Administration, "FAA Aerospace Forecast: Fiscal Years 2020-2040." March 26, 2020. Available at: https://www.faa.gov/data_research/aviation/aerospace_forecasts/.
[12] U.S. Energy Information Administration, "EIA Projects Energy Consumption in Air Transportation to Increase through 2050." November 6, 2019. Available at: https://www.eia.gov/todayinenergy/detail.php?id=41913.
[13] Collective commitments were made by the Airports Council International (ACI), Civil Air Navigation Services Organization (CANSO), International Air Transport Association (IATA), International Business Aviation Council (IBAC) and International Coordinating Council of Aerospace Industries Associations (ICCAIA) on behalf of the international air transport industry.
[14] https://www.atag.org/our-activities/climate-change.html.
[15] ICAO, a specialized agency of the United Nations and has 193 member states, is a global forum used to adopt and implement international aviation standards.
[16] ICAO, "Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change," Resolution A40-18, 2019. Available at: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf.
[17] ICAO, "ICAO Council Adopts New CO2 Emissions Standards," March 6, 2017. Available at: https://www.icao.int/Newsroom/Pages/ICAO-Council-adopts-new-CO2-emissions-standard-for-aircraft.aspx
[18] Lattanzio, Richard K., "IN FOCUS: Aviation and Climate Change," January 11, 2021, Congressional Research Service. Available at: https://www.crs.gov/Reports/IF11696.

certified aircraft meet the new ICAO standards, EPA initiated a rulemaking process to the first U.S. standards for aircraft CO_2 emissions,[19] which was published as a Final Rule on January 1, 2021. [20] The standards would apply to all passenger jets, as well as propeller planes above a certain mass. FAA is now required to issue regulations to enforce the standards and apply them when certifying U.S.-manufactured engines. According to EPA, the Rule will have no net effect on fuel use or emissions, as aircraft in operation today already meet the standards.[21]

In support of the 2016 goals discussed above, ICAO established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA),[22] which attempts to use market-based measures to achieve environmental goals. The Committee on Aviation Environmental Protection (CAEP), [23] which assists the Council in formulating new policies and adopting new Standards and Recommended Practices (SARPs) related to aviation's environmental impact.

Means of Reducing Aviation Emissions and Associated Current Federal Activities

Efforts to reduce aviation's carbon emissions generally fall under one of three approaches: new or improved aircraft **technologies** that increase fuel economy or otherwise reduce the amount of hydrocarbon-derived energy necessary to fly; alternative jet **fuels** that burn more efficiently or cleanly or whose sourcing results in fewer lifecycle emissions than petroleum-based jet fuel; or efficiencies in aircraft and airport **operations**, including air traffic management and ground transportation.

In the federal government, the National Aeronautics and Space Administration (NASA) and the FAA lead civil R&D activities along all three approaches. FAA's Office of Environment and Energy develops, recommends, and coordinates national aviation policy relating to environmental and energy matter, including emissions and noise.[24] FAA's Research, Engineering and Development budget includes funding for research to meet our aviation sustainability goals. NASA's Aeronautics Research Mission Directorate (ARMD) conducts a number of early-stage technology development and demonstration programs for sustainable aircraft technologies and to provide data to inform future standards and regulation development.[25] In addition, the aerospace industry invests in research and development activities to improve aviation efficiencies and environmental impacts.

[19] Prior to 2021, EPA had no CO_2 emissions standards for aircraft, but did impose standards on fuel venting, hydrocarbons, CO, and NO_x.
[20] EPA. "Control of Air Pollution from Airplanes and Airplane Engines: GHG Emission Standards and Test Procedures - Final Rulemaking." December 2020. Available at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/control-air-pollution-airplanes-and-airplane-engines-ghg.
[21] Joselow, Maxine, "Greens Sue EPA Over Airplane Rule that Doesn't Cut CO2," *E&E News,* January 15, 2021. Available at: https://www.eenews.net/eenewspm/stories/1063722741/
[22] ICAO, "Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)." Available at: https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx
[23] ICAO, "Committee on Aviation Environmental Protection (CAEP)." Available at: https://www.icao.int/environmental-protection/pages/caep.aspx
[24] FAA, "Environment and Energy Research & Development." Available at: https://www.faa.gov/about/office_org/headquarters_offices/apl/research/
[25] NASA, "Aeronautics Research Mission Directorate (ARMD) Programs." Available at: https://www.nasa.gov/aeroresearch/programs

Technologies

In 2016, the National Academies of Sciences, Engineering, and Medicine issued a report, *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*,[26] which recommended, "for developing propulsion and energy system technologies that could reduce CO2 emissions from global civil aviation and that could be introduced into service during the next 10 to 30 years…a national research agenda that placed the highest priority on four approaches." Three of the four (unranked) approaches fall under the "technology" category:

- Advances in aircraft–propulsion integration
- Improvements in gas turbine engines, and
- Development of turboelectric propulsion systems.

The final approach—advances in sustainable alternative jet fuels—is discussed below. The report also identified two systemic challenges to such advancements: first, cost considerations of new systems in a highly competitive commercial environment; and, second, the need for highly disciplined system integration to introduce new technology because "commercial aircraft are composed of many distinct systems that are carefully integrated and regulated to maximize performance and safety."

Research and development efforts to address the recommended approaches are being carried out at the FAA and NASA and also in partnership with U.S. industry. At FAA, the Continuous Lower Energy, Emissions and Noise (CLEEN) Program is the principal environmental effort to accelerate the development of new aircraft and engine technologies and sustainable alternative fuels that reduce aircraft emissions, noise, and fuel burn.[27] Through the CLEEN Program, the FAA partners with industry to develop technologies that will expedite integration of these technologies into current and future aircraft.

NASA's ultra-efficient transport strategic thrust is focused on developing a sustainable flight demonstrator (SFD) that could test a number of early-stage sustainable aviation technologies, including a new airframe design such as a transonic truss-braced wing, a small core gas turbine, electrified aircraft propulsion, and a high-rate composite manufacturing. The goal of NASA's effort is to mature early-stage technologies to the point where industry can make them operational and economically viable.[28]

NASA is also developing the X-57 Maxwell All-electric Flight Demonstrator.[29] The X-57 will determine airworthiness of electrified aircraft technologies by demonstrating the performance of a complex, integrated all-electric aircraft through ground and piloted flight tests. In February

[26] National Academies of Sciences, Engineering, and Medicine. 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*. Washington, DC: The National Academies Press. Available at: https://doi.org/10.17226/23490.
[27] FAA, Continuous Lower Energy, Emission, and Noise (CLEEN) Program," Available at: https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/
[28] Gipson, Lillian, "NextGen Aircraft Design is Key to Aviation Sustainability", *NASA,* April 6, 2020. Available at: https://www.nasa.gov/aero/nextgen-aircraft-design-is-key-to-aviation-sustainability
[29] NASA, "NASA Armstrong Fact Sheet: NASA X-57 Maxwell," September 13, 2018. Available at: https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html

2021, the X-57 Maxwell began performing ground tests of the fully integrated aircraft, taking a critical step closer to its first flight.[30]

Sustainable Aviation Fuels

Sustainable aviation fuels are drop-in replacements for conventional jet fuel that are required to meet current jet fuel specifications either on their own or when blended with conventional jet fuel. SAFs are essentially chemically equivalent to petroleum-based jet fuels, and thus produce similar CO_2 emissions in the process of combustion, but their production processes have a lower carbon footprint than the extraction and refinement of fossil fuels. Depending on the specific feedstock and conversion stock, SAFs can reduce the lifecycle CO_2 emissions relative to conventional jet fuel by 41 to 89%.[31] As a result of federal R&D efforts in this area, there are now eight certified alternative fuel pathways enabling several airlines to buy and use SAFs.

Of the almost 20 billion gallons of aviation jet fuel used in the U.S. per year, SAFs comprise roughly less than one percent. [32] Production volume and price are barriers to increased SAF adoption. In particular, the price of SAF is currently higher than petroleum-based Jet A fuel and presents a challenge to SAF's greater commercial viability, considering that fuel accounts for roughly 24% of the operating cost of an airline.[33]

With jet fuel demand set to double pre-pandemic levels by 2050, and airlines increasingly pledging to reduce emissions, industry and federal SAF R&D efforts are exploring how to not only reduce cost but also decrease overall fuel consumption and cut carbon emissions to nearly zero, including through the development of carbon-negative fuels. This will require: reducing the cost of and improving value propositions for SAF already approved or far along the certification process, or poised to enter a fast track certification process; expanding opportunities in additional fuel production pathways; and ultimately targeting the development of fuel molecules that offer improvements in fuel properties and higher energy density.[34]

The Department of Energy's (DOE) Bioenergy Technology Office (BETO), in collaboration with U.S. National Laboratories are actively conducting R&D to meet the technical needs to overcome such hurdles preventing SAF deployment. Research efforts include DOE and the National Renewable Energy Laboratory's (NREL) wet waste flight demonstration project, which recently released findings outlining a biorefining process using the unused energy of food waste and other wet waste to produce SAF that is both compatible with existing jet engines and capable

[30] NASA, "NASA to Begin High-Voltage Ground Testing on All-Electric x-57," February 25, 2021. Available at: https://www.nasa.gov/centers/armstrong/news/newsreleases/2021/21-01NR.html
[31] National Academies of Sciences, Engineering, and Medicine. 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*. Washington, DC: The National Academies Press. Available at: https://doi.org/10.17226/23490.
[32] Overton, Jeff, "New Legislation Sets Policy Menu for Sustainable Aviation Fuels," EESI, December 8, 2020. Available at: https://www.eesi.org/articles/view/new-legislation-sets-policy-menu-for-sustainable-aviation-fuels
[33] IATA, "Economic Performance of the Airline Industry, 2018. Available at: https://www.iata.org/contentassets/f88f0ceb28b64b7e9b46de44b917b98f/iata-economic-performance-of-the-industry-end-year-2018-report.pdf
[34] DOE, "Sustainable Aviation Fuel: Review of Technical Pathways," September 2020. Available at: https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

of supporting net-zero carbon flight.[35] Such research is aiming to provide airlines with additional sustainable fuel options that are as safe and effective as conventional jet fuel, environmentally superior, and commercially viable.

The FAA's Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), a cooperative cost-sharing partnership of universities and private sector entities, is sponsoring research into alternative jet fuels and the environment. ASCENT is focused on exploring ways to produce SAFs at commercial scale and discovering science-based solutions that will benefit the aviation industry.[36]Examples of their current research include domestic and international alternative jet fuel supply chain analysis; alternative jet fuel testing and evaluations for certification; and aircraft technology modeling.

DOE, NASA, and FAA are all among the federal government agency members of the Commercial Aviation Alternative Fuels Initiative (CAAFI). CAAFI is a public-private partnership formed in 2006 by the FAA with aviation industry associations to explore alternative jet fuels. CAAFI enables the commercial aviation sector to engage the emerging alternative fuels industry to build relationships, share and collect data, identify resources, and direct research and development focused on the deployment of alternative jet fuels.[37] Today, CAAFI comprises numerous federal agencies, airlines, manufacturers, airports, and fuel producers to support coordination and cooperation in advancing and accelerating alternative fuel approvals, research, and commercial agreements.

Operations

Efficiencies in aircraft and airport operations and air traffic management can reduce overall aviation fuel burn by 1-2%.[38] The Next Generation Air Transportation System (NextGen) is the FAA-led modernization of America's air transportation system.[39] FAA NextGen Environment and Energy program is finding ways to minimize the impacts of aviation from noise, carbon emissions, air quality, energy, and the climate.[40] The approach is composed of: improved scientific knowledge and integrated modeling, aircraft technology maturation, sustainable aviation jet fuels, air traffic management modernization and operation improvements, and policies, environmental standards and market-based measures.

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[35] NREL, "From Wet Waste to Flight: Scientists Announce Fast-Track Solution for Net-Zero carbon Sustainable Aviation Fuel, March 15, 2021. Available at: https://www.nrel.gov/news/program/2021/from-wet-waste-to-flight-scientists-announce-fast-track-solution-for-net-zero-carbon-sustainable-aviation-fuel.html
[36] ASCENT, "The Aviation Sustainability Center." Available at: https://ascent.aero/
[37] Commercial Aviation Alternative Fuels Initiative (CAAFI), "About CAAFI." Available at: http://www.caafi.org/about/caafi.html
[38] Ryerson, Megan S., Hansen, Mark, and Bonn, James, "Time to burn: Flight delay, terminal efficiency, and fuel consumption in the National Airspace System," November 2014, *Transportation Research Part A: Policy and Practice,* Volume 69. Available at: https://doi.org/10.1016/j.tra.2014.08.024.
[39] FAA, "Modernization of U.S. Airspace." Available at: https://www.faa.gov/nextgen/
[40] FAA, "Environment and Energy." Available at: https://www.faa.gov/nextgen/cip/eande/

European Approach to Sustainable Aviation

The European Union (EU) is making significant efforts to reduce CO_2 emissions. The EU Emission Trading system (EU ETS) is the cornerstone of the EU's policy to combat climate change in a by creating a cap-and trade system for emission across industries, including aviation, with the goal of reducing emissions by 40% by 2030 as compared to emission levels in the 2004-2006 timeframe. [41] [42]

In February 2021, as part of the European Green Deal adopted in December 2019, which highlights the importance of boosting development of alternative fuels, the European Commission announced[43] that it will finance the European Partnership for Clean Aviation.[44][45] This program will be a joint undertaking between the EU and the aviation industry to develop new aircraft powered by clean fuel sources. The program will have three main thrusts: hybrid electric and full electric concepts; ultra-efficient aircraft architectures; and disruptive technologies to enable hydrogen-powered aircraft.[46] The goal is to introduce a new fleet of medium sized aircraft in the 2030s to Europe to meet their sustainable aviation goals. Since the onset of the pandemic, individual countries, including Germany, France, and the UK have also announced their own measures to invest in efforts to enable development of clean aviation technologies.

[41] EU, "EU Emissions Trading system (EU ETS)." Available at: https://ec.europa.eu/clima/policies/ets_en
[42] EU, "Reducing Emissions from Aviation." Available at: https://ec.europa.eu/clima/policies/transport/aviation_en
[43] European Parliament, "Sustainable Aviation Fuels," November, 2020. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659361/EPRS_BRI(2020)659361_EN.pdf
[44] *Ibid*
[45] *Ibid*
[46] EURACTIV, "A New Partnership for Clean Aviation," March 9, 2021. Available at: https://www.euractiv.com/section/aviation/opinion/a-new-partnership-for-clean-aviation-ahead/

Chairman BEYER. Great, thank you. Good morning. Welcome to the first meeting or hearing of our Subcommittee on Space and Aeronautics, "Examining R&D Pathways to Sustainable Aviation." So good morning. Welcome to our distinguished witnesses. Thanks for being here. I also want to welcome our new and returning Subcommittee Members to this first hearing. I also want to say happy birthday to the Ranking Member Dr. Brian Babin. I think you were 63 years old, Dr. Babin, something like that, yesterday?

Mr. BABIN. Absolutely. Absolutely. Thank you so very much, Mr. Chairman.

Chairman BEYER. OK. These are exciting times, Dr. Babin's birthday, humans are going back to the Moon in preparation to Mars for advancing scientific discovery and transforming the future of aviation. There's so much. And I really look forward to working with Ranking Member Babin and Ranking Member Lucas and our wonderful Chair, Chairwoman Eddie Johnson, on supporting a strong and bright future for America's space and aeronautics programs.

One of the immediate challenges is the climate crisis, and today, we're considering aviation's role in how to address it. Typically, aviation only contributes about 2.5 percent global CO_2 emissions, and that seems low, especially compared to, say, cars. However, with pre-pandemic global air travel growing at annual rates of three to five percent, it shouldn't come as a surprise that aircrafts'—aviation's global CO_2 emissions increased from 710 million tons in 2013 to 905 million tons in 2018, and it's supposed to triple by 2050.

Now, to its credit, the aviation industry has taken consistent steps to improve aircraft efficiencies, in part to reduce fuel costs. There are 70 to 80 percent more efficient aircraft engines, than there were those old turbocraft jet aircrafts in the 1950's, and efficiencies are expected to continue at one or two percent annually. But while these are important, they're not going to be sufficient to meet aviation's carbon challenge.

The good news, in 2009 the industry adopted the goal of reducing aviation's carbon emissions by 50 percent of 2005 levels by 2050, but that's going to need new technologies, increased efficiencies, and cleaner sources of energy. And I think we all believe that Federal Government R&D (research and development) is essential for the testing, demonstrating, and maturing solutions.

So today, potential approaches include electrified aircraft, alternative airframe designs, more efficient energies, and, obviously, alternative jet fuels. Some companies are investing in one or more of these options. Europe, for example, is betting on hydrogen as a cleaner aviation solution.

So how do these approaches compare, how do they contribute, what are the potential impacts on noise, air quality, cost, infrastructure, reliability, and safety? It's important we get these priorities right because, unlike cars or cell phones, changes to aircraft and aviation require very long timelines to develop, test, demonstrate, certify, and scale throughout the system.

A 2016 National Academies report on "Commercial Aircraft Propulsion and Energy Systems Research, Reducing Global Carbon Emissions" recommended priorities in aircraft-propulsion integra-

tion, improvements in gas turbine engines, development of turbo-electric propulsion systems, and advances in sustainable alternative jet fuels. So where does that research stand today? What more needs to be done?

So bottom line, today, we need the cold, hard facts on the strengths, limitations, feasibility, and timelines of the pathways to sustainable aviation. In short, we need smart and strategic R&D. And sustainable aviation is not only essential for our climate; it's a competitive advantage and a cooperative opportunity. And given the devastating impacts of the pandemic to the aircraft industry, it's more important than ever that we build back better.

[The prepared statement of Chairman Beyer follows:]

Good morning, and welcome to our distinguished witnesses. Thank you for being here.

I also want to welcome our new and returning Subcommittee Members to our first Space and Aeronautics hearing of the 117th Congress.

These are exciting times. From returning humans to the Moon in preparation for Mars to advancing scientific discovery and transforming the future of aviation, there is much that lies ahead of us. I look forward to working with you and Ranking Member Babin on supporting a strong and bright future for America's space and aeronautics programs.

Today we're considering the future of aviation and how we can ensure that the U.S. remains the leader for next generation aircraft and what R&D it will take to get us there.

With the climate crisis and as countries move to create parameters for permissible aircraft—like Norway determining that all short-haul flights will be entirely electric by 2040—being a participant in the global marketplace of the future will require sustainable aviation.

That means U.S. aviation won't have a competitive future without addressing climate impacts.

Currently, aviation contributes about 2 1/2 percent to global CO_2 emissions. In the U.S., transportation is the most greenhouse gas intensive sector and in 2018 aviation accounted for 5 percent of all U.S. emissions.

Pre-pandemic global air travel was growing at average annual rates of 3-5 percent and is expected to rapidly return as we get the pandemic under control.

It should come as no surprise that aviation's global CO_2 emissions increased from 710 million tons in 2013 to 905 million tons in 2018, with a projected tripling by 2050.

And that's just looking at CO_2.

According to the United Nations Intergovernmental Panel on Climate Change, aviation's total climate change impact could be from two to four times that of its past CO_2 emissions alone.

To its credit, the aviation industry has taken consistent steps to improve aircraft efficiencies, in part to reduce fuel costs. Aircraft engines are 70-80 percent more efficient today than the turbojet aircraft of the 1950s, and efficiencies are expected to continue at 1-2 percent annually.

But on their own, these improvements, while important, are not sufficient to meet aviation's future challenge.

In 2009, the industry adopted goals to reduce aviation's carbon emissions by 50 percent of 2005 levels by 2050.

Meeting even modest sustainability goals will require new technologies, increased efficiencies, and cleaner sources of energy. Federal government R&D is essential for testing, demonstrating, and maturing solutions.

Today, potential approaches include electrified aircraft, alternative airframe designs, more efficient engines, and alternative jet fuels. Some companies are investing in one or more of these options. Europe is betting on hydrogen as a cleaner aviation solution.

How do these approaches compare and how would they contribute to meeting aviation's climate challenge? What are their potential impacts on noise, air quality, cost, infrastructure, and reliability and safety?

The R&D opportunities are many, but it's important we get the priorities right.

Because unlike cars or cell phones, changes to aircraft and aviation require long timelines to develop, test, demonstrate, certify, and scale throughout the system.

A 2016 National Academies report on "Commercial Aircraft Propulsion and Energy Systems Research, Reducing Global Carbon Emissions" recommended priorities in aircraft-propulsion integration; improvements in gas turbine engines; development of turboelectric propulsion systems; and advances in sustainable alternative jet fuels.

Where does that research stand today? What more needs to be done?

Bottom line: we need the cold, hard facts on the strengths, limitations, feasibility, and timelines of the pathways to sustainable aviation.

In short, we need smart and strategic R&D.

Sustainable aviation is not only essential for our climate, it's a competitive advantage and a cooperative opportunity. And given the devasting impacts of the pandemic to the industry, it's more important than ever that we build back better.

Thank you and I look forward to our witnesses' testimony.

Chairman BEYER. So thank you. I look forward to our witness testimonies. And let me—I recognize the Ranking Member of the Space Subcommittee, Dr. Brian Babin.

Mr. PERLMUTTER. I think he decided to abandon us.

Chairman BEYER. Well, you know, failing that, Representative Lucas, Ranking Member of the big Committee, I'd be happy to recognize you.

Mr. LUCAS. Well, I'll only pretend to be the esteemed doctor until he's able to return to us, but thank you, Mr. Chairman, for holding this hearing.

Oklahoma is no stranger to being on the cutting edge of aviation. From the daring test pilots such as Tom Stafford and Gordo Cooper to other pioneering aviators like Jerrie Cobb, Oklahoma is well-represented by those who pushed the boundaries of flight. To this very day, Oklahoma's connection to aviation remains strong as the home of Tinker Air Force Base and FAA's (Federal Aviation Administration's) Mike Monroney Aviation Center.

The aviation industry is a vital part of our Nation's economy. It contributes $1.8 trillion annually to the economy and is directly or indirectly responsible for more than 10 million jobs.

The Science Committee has jurisdiction over several areas of Federal aviation research, ranging from our drafting the research title of each FAA reauthorization to our oversight of NASA's (National Aeronautics and Space Administration's) aeronautics research mission directorate. The research carried out by NASA and FAA is then utilized by industry partners who integrate this knowledge into their existing fleets.

Global air travel generates an estimated 2 to 3 percent of global greenhouse gas emissions. While we saw a reduction in the number of flights in the last year and a corresponding decrease in emissions, we know that these numbers will eventually rebound and increase. One estimate is that there will be roughly 10 billion passengers flying more than 12 trillion miles annually by 2050.

Today's hearing comes 2 weeks after we held a Full Committee hearing on the science of climate change. As that hearing made clear, we should focus on investing in research and development efforts, including R&D to give the aviation industry the tools they need to reduce emissions from flight. What we shouldn't do is allow ourselves to be subject to burdensome and unequal international mandates at the expense of our economic growth.

The good news is that the aviation industry is already making progress in reducing emissions. Multiple domestic and international aircraft manufacturers have already made commitments

to voluntarily reduce emissions. And we also will hear today about the research community and industry are teaming up to create innovative new ways to reduce emissions. For instance, we can help reduce emissions by researching new aircraft designs and the use of lighter materials to help reduce aircraft weight.

Additionally, research is ongoing about the use of a variety of farm-produced commodities which could be blended into existing fuels and potentially reduce emissions.

I thank our witnesses for being here today, and I look forward to a productive discussion about how we can support research and development efforts, which will assist our aviation industry in the years to come.

Thank you, Mr. Chairman, and I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you for holding this hearing, Mr. Chairman.

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I thank our witnesses for being here today and look forward to a productive discussion about we can support research and development efforts which will assist our aviation industry in the years to come.Thank you, Mr. Chairman, and I yield back.

Chairman BEYER. Thank you, Mr. Big Chair Ranking Member.

This is the first time I've done this, so I get things out of order. So what we also say this hearing will come to order. I brought my special gavel today. And without objection, the Chair is authorized to declare recess at any time.

And I also want to note that the Committee is meeting virtually, so please keep your video feed on as long as you're present in the hearing. You're responsible for your own microphones. That is, our wonderful staff is not going to turn them on and off for you. And obviously, please keep them muted unless you're speaking. And if you have documents you wish to submit for the record, please

email them to the Committee Clerk, whose email address was circulated prior to this hearing.

So now let me yield the chair to my good friend, Dr. Brian Babin, who is the Ranking Member of this Space Subcommittee. Dr. Babin?

Mr. BABIN. Thank you, Mr. Chairman. Can you hear me?

Chairman BEYER. Yes.

Mr. BABIN. Can you hear me?

Chairman BEYER. Yes, perfectly, Brian. Thank you, yes.

Mr. BABIN. OK, good. It still shows that I'm muted on my computer. That's what was confusing me a while ago, and I apologize.

But I guess before my opening statement I also want to just say thank you for what you said a while ago, Mr. Chairman. You and I have worked together for a number of years on this great Committee, and I really want to congratulate you on your chairmanship, and I'm looking forward to working with you, continuing to do that, and getting some great things done for our country and our space program. So with that I'll start my opening statement. Thank you, Mr. Chairman.

If I had to hazard a guess, most of our constituents fly budget airlines, not business class, and certainly not private aviation. Roughly 1/3 of the cost of a flight comes from fuel, and nearly half for budget airlines. The less fuel you burn, the less emissions you produce. Passengers want cheap tickets, and we all want less emissions. Both lead to the same free-market forces that drive airlines to purchase efficient aircraft.

This incentivizes aircraft manufacturers to produce more efficient aircraft and engines with little government intrusion into the market. Flights today are 50 percent more efficient than they were back in 1990, and each new generation of aircraft is 15 to 25 percent more efficient than the last. Separately, our Nation's airline industry already committed to carbon-neutral growth by 2030, and Boeing pledged to deliver aircraft capable of flying on 100 percent biofuels by 2030 on their own.

This isn't to say that there's not a role for the government to play in advancing aviation sustainability. The FAA conducts research to certify new technologies that are safe, and NASA develops high-risk, high-reward technologies that the private sector is willing—or unwilling or unable to undertake.

But we should be mindful of government intrusion into the market. The U.S. and Europe are embroiled in a nearly decade-long dispute over government aircraft subsidies. And last fall, the World Trade Organization (WTO) allowed Europe to implement over $4 billion in tariffs on U.S. products over a disagreement about the FAA and NASA research and development grants and subsidies. This followed a 2019 ruling by the World Trade Organization that allowed the United States to impose $7.5 billion in tariffs on Europe over European Union loans to Airbus. Earlier this month, those tariffs were put on hold for a few months pending additional negotiations. And as we look toward supporting our Nation's aviation sector, we should maintain the principles that made us the world leader in aviation: free enterprise and free markets.

Another thing we must consider is the impact on safety, which should be everyone's highest priority. Environmental research and

development within FAA's RE&D (research, engineering, and development) account increased over 190 percent from 2008 to 2021. Over that same time, the budget for safety research decreased.

Unfortunately, we may be seeing the results of these policy decisions. In order to compete with the new Airbus A320neo, Boeing designed the 737 Max to be more fuel-efficient and produce less emissions. The existing 737 airframe was modified by adding larger and more efficient engines. Because of the larger size, the engines had to be moved forward and higher on the airframe to maintain ground clearance. Doing so altered the aircraft's aerodynamics and required a new maneuvering characteristic augmentation system, or MCAS, which we are familiar with over in Transportation. MCAS has caused the aircraft to pitch downwards in certain configurations and was featured prominently in the National Transportation Safety Board's Safety Recommendation Reports.

Similarly, the *Wall Street Journal* published an article last Friday highlighting a recent incident involving an engine breaking apart over Denver. The article noted several other incidents of engine failures and engine cover damage over the last 5 years, one of which led to the first U.S. airline passenger fatality in nearly a decade. I'm not saying these accidents were caused by efforts to green aviation, but we should be reminded of Hoover Institute economist Dr. Thomas Sowell, who said "there are no solutions, only tradeoffs."

As we discuss the benefits of sustainable aviation today, we should also discuss its costs, either at the potential expense of safety or to other areas of our economy. Upending existing infrastructure, promoting land-use change and monocrops, raising commodity and food prices, increasing transportation costs, increasing taxes, and the impact of diluting the value of retirees' savings to pay for all of it should all be reviewed very carefully and very critically.

Green aviation not only requires a whole-of-government approach, but it also requires a whole-of-society approach. Luckily, the United States is the leader in aviation and science. Our industry and research communities are second to none. With FAA, NASA, DOE (Department of Energy), and other agencies providing fundamental basic research and industry-leveraging, market-based incentives, I am sure that we can meet any challenge presented to us.

And with that, I'll yield back, Mr. Chairman. Thank you.

[The prepared statement of Mr. Babin follows:]

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Chairman BEYER. All right. Thank you, Dr. Babin, very much.

At this time I'd like to—well, before doing that, any other Member who would like to have an opening statement—please—in the record, just please submit it in writing and we will include it.

[The prepared statement of Chairwoman Johnson follows:]

Good morning. I would like to begin by welcoming Chairman Beyer as the new Chairman of the Space and Aeronautics Subcommittee for the 117th Congress. I also want to welcome back Ranking Member Babin and all the Subcommittee Members. I am excited about the future of space and aeronautics and I look forward to working with you.

The climate crisis is affecting nearly every aspect of our existence-weather, shelter, commerce, natural resources, energy, environment, and so much more.

Research is imperative to understanding and mitigating climate change impacts, and addressing climate change is an important priority for our Committee.

We held our first Full Committee climate hearing last week. And I'm pleased, Chairman Beyer, that today's hearing will examine aviation's role in reducing carbon emissions.

Aviation is one of the few industries that has provided a positive trade balance. Pre-pandemic, U.S. civil aviation accounts for about 5 percent of gross domestic product, including both direct and catalytic sectors, $1.8 trillion in economic activity, and nearly 11 million jobs, including 285,000 jobs in my own state of Texas.

Even closer to home, Dallas is a hub for domestic and international air travel, and I believe that developing innovations to enable sustainable aviation is the industry's future.

Aviation's infrastructure is immense and changes throughout the system take time, in part, due to the need to meet high safety requirements for passenger air travel.

That's why research and development is essential for advancing sustainable aviation technologies.

However, the improvements that will lead to cleaner and more efficient aviation can't happen on their own. The people and workforce that bring the ideas from the labs and into the engines and aircraft are instrumental. To that end, our investments in R&D are also investments in sustaining our human capital leadership in aviation going forward.

I thank our witnesses for being here and I look forward to your testimony.

Thank you, and I yield back.

Chairman BEYER. At this time I'd like to introduce our witnesses. Our first witness is Dr. Karen Thole or Thole. Karen, you can fix it for me. Dr. Thole is the Department Head and Distinguished Professor of the Department of Mechanical Engineering at Pennsylvania State University. She co-chaired the 2016 National Academies' study "Commercial Aircraft Propulsion and Energy Systems: Reducing Global Carbon Emissions." Her area of expertise is gas turbine heat transfer and using additive manufacturing to develop innovative cooling technologies. At Penn State she established two research laboratories that were both awarded the distinction of being Centers of Excellence in aerodynamics and heat transfer. She received—Dr. Thole received a bachelor of science degree and a master of science degree in mechanical engineering at the University of Illinois and her doctorate in mechanical engineering at the University of Texas Austin, so she's a Longhorn. So, Dr. Thole, welcome.

Our second witness is Dr. John—R. John Hansman, Jr., a T. Wilson Professional of Aeronautics and Astronaut—Astronautics at the Massachusetts Institute of Technology. Dr. Hansman is also the Director of the MIT (Massachusetts Institute of Technology) International Center for Air Transportation, and he additionally serves as the Chair of the FAA Research and Development Advisory Committee and Co-Director of the FAA Center of Excellence for Alternative Jet Fuels and Environment, also known as ASCENT. Dr. Hansman's research focuses on applying information technology on operational aerospace systems. He received his bachelor of science degree in physics from Cornell University and a master of science and a doctorate in some little college in Massachusetts called MIT. So welcome, Dr. Hansman.

Our third witness is Mr. Steve Csonka, the Executive Director of the Commercial Aviation's Alternative Fuels Initiative, CAAFI, a public-private partnership working on the development and commercialization of sustainable aviation fuels (SAF). Previously, Mr. Csonka had positions—held positions at GE Aircraft Engines, American Airlines, and GE Aviation where he focused on a range of aircraft lifecycle activities, including conceptual analysis, design, manufacture, test, and certification, among other areas. He received his bachelor of science degree in aerospace engineering from Parks College of St. Louis University and a master of science degree in aerospace engineering from the University of Cincinnati. So welcome, Mr. Csonka.

So as our witnesses should know, you have five minutes each for your spoken testimony. Your written testimony has—will be included in the record for the hearing, and I think most of us re-

ceived your written testimony ahead of time, which I spent a long time with last night, fascinating. And when we—you have completed all three spoken testimonies, we will begin with questions, so each Member will have five minutes to question the panel. So let's start with Dr. Thole. Dr. Thole, the floor and the microphone are yours.

TESTIMONY OF DR. KAREN A. THOLE, DEPARTMENT HEAD AND DISTINGUISHED PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, PENNSYLVANIA STATE UNIVERSITY

Dr. THOLE. Chairman Beyer, Ranking Member Babin, and distinguished Members of the Subcommittee, thank you for this opportunity to testify. As was stated, my name is Karen Thole, and the opinions expressed in my testimony today are that of my own and do not represent views of the Pennsylvania State University.

Throughout my testimony, I will use information from the 2016 National Academies' low carbon aviation study, which was commissioned by NASA and which I cochaired. Resulting from the 2016 Academies report, the Chief Technology Officers of seven of the world's major aviation manufacturers jointly signed an agreement on a unified commitment to reduce commercial aviation emissions by half in 2050 relative to the levels in 2005.

As Chairman Beyer has already mentioned, commercial aviation is responsible for between 2 and 2.5 percent of the total global CO_2 emissions, of which 90 percent comes from large single-aisle and twin-aisle aircraft. Resulting from the 2016 Academy report, four research approaches for sustainable aviation were recommended: 1, advances in aircraft propulsion integration; 2, improvements in gas turbine engines; 3, development of turboelectric propulsion systems; and 4, advances in sustainable alternative jet fuels.

This past year, hydrogen has entered into the discussion for aviation and is being explored by U.S. industries and aggressively by the European Union. In my opinion, with strong support we can develop solutions starting with the use of sustainable alternative jet fuels progressing to turboelectric and hybrid electric propulsion systems followed by the use of hydrogen either for fuel cells or for producing synthetic fuels.

In the near term, we should promote sustainable alternative jet fuels. These fuels already exist as a drop-in option certified for use in jet engines at up to 50 percent blend with kerosene, and with further development it may be possible to achieve 100 percent. Given our third panelist has expertise in this area, he can further elaborate.

In agreement with the 2016 study, I believe the United States needs to invest in the development of new aircraft architectures that take full advantage and the potential benefits of turboelectrics and of hybrid electric propulsion systems. The Committee strongly recommended the development of turboelectric systems, which differ from all-electric and hybrid concepts because no additional batteries or fuel cells are required, both of which can add significant weight.

Turboelectric propulsion systems do require high power generators, cabling, and power electronics. Unlike other propulsion sys-

tems—electric propulsion systems, they do make beneficial concepts such as distributed propulsion more feasible. Some hybrid electric propulsion systems may also be feasible in my opinion.

Key to improvements, however, for both turboelectrics and hybrid electrics are continued improvements in both propulsive efficiency and in thermal efficiency of gas turbine engines, which is likely to produce the power by—the power for both. Many efficiency improvements can also be synergistic with the needs of our military's propulsion needs.

Today's engines have propulsive efficiencies of up to 70 percent and thermal efficiencies of up to 55 percent, both of which still have the potential to increase, which dramatically reduce fuel requirements. To improve propulsive efficiency, research is needed to make both evolutionary improvements, as—such as reducing fan pressure ratios and revolutionary improvements such as going beyond the traditional tube-and-wing platform.

To support improved thermal efficiencies, we need to shrink engine cores while meeting or even increasing thermal efficiencies. Added to those recommendations in 2016, research is needed on developing high-temperature materials and coatings, as well as for 3-D metal printing. We need to be able to integrate reliable sensors to support high-fidelity simulation tools to reduce both development, time, and risks.

Despite the ongoing discussions related to hydrogen as an aviation fuel, there are significant techno-economic and safety concerns. However, the United States needs to develop a long-term strategy on hydrogen for aviation to make sure we do not lag our foreign competitors. In that regard, Mr. Chairman, please make no mistake we are in a race particularly with China in the aviation industry, and whoever wins will have an economic and possibly military advantage that will result from a talented workforce. We need to invest now to make sure the United States is well-positioned to develop sustainable solutions and maintain our leadership in the aviation industry through strong partnerships between Federal agencies, industries, and universities.

Thank you.

[The prepared statement of Dr. Thole follows:]

Statement of

Karen A. Thole, PhD, ASME and AIAA Fellow
Distinguished Professor and Department Head
Department of Mechanical Engineering
Pennsylvania State University

before the

Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U.S. House of Representatives
March 24, 2021

Examining R&D Pathways to Sustainable Aviation

Executive Summary

Chairman Beyer, Ranking Member Babin and distinguished members of the Subcommittee, thank you for the opportunity to testify. My name is Dr. Karen Thole and I hold the title of Distinguished Professor and Department Head of Mechanical Engineering at the Pennsylvania State University. My expertise is in gas turbine heat transfer in which I have researched innovative cooling technologies that have gone from theory to application. My research laboratories have been given the distinction of being Centers of Excellence in aerodynamics and heat transfer for two gas turbine manufacturers. The opinions expressed in my testimony today are that of my own and do not represent views of the Pennsylvania State University.

Commercial aviation is responsible for between 2.0 and 2.5 percent of the total global CO_2 emissions of which 90 percent comes from large single-aisle and twin-aisle aircraft. In response to a request from the National Aeronautics and Space Administration (NASA), the National Academies of Sciences, Engineering, and Medicine (NASEM) convened a committee in 2015 to develop a national research agenda for reducing CO_2 emissions from commercial aviation [1]. In 2016, the National Academies published the committee's report, which led the Chief Technology Officers of seven of the world's major aviation manufacturers to jointly sign an agreement on a unified commitment to reduce commercial aviation emissions by half in 2050 relative to levels in 2005 [2]. This briefing provides a summary and an update on the four research approaches that were recommended by the 2016 National Academies report for sustainable aviation: (1) advances in aircraft-propulsion integration; (2) improvements in gas turbine engines; (3) development of turboelectric propulsion systems; and (4) advances in sustainable alternative jet fuels. I co-chaired the National Academies committee with some of my remarks below taken from the 2016 National Academies report.

It is my opinion that sustainable alternative jet fuels are a viable direction to provide a near- and mid-term reduction in CO_2 emissions. Despite the ongoing discussions related to hydrogen as an aviation fuel, there are significant technoeconomic and safety concerns identified in the 2016 National Academies report that did not make hydrogen a viable solution within the 2050 timeframe. Last

November, however, the Department of Energy released their Hydrogen Program Plan that provides a framework and coordinated effort for a hydrogen transition in the United States. Also, late last year, Airbus announced that they are developing a new zero-emission blended wing aircraft concept powered by two hybrid turbofan engines that will use hydrogen. Unlike the European Union, which has an aggressive hydrogen-powered aviation plan, the U.S. is missing a long-term strategy for using hydrogen in the aviation sector to reduce CO_2 emissions.

In agreement with the 2016 study, I believe we need to invest in new aircraft architectures that take full advantage of the potential benefits of turboelectrics and of hybrid electric propulsion systems. Key to both turboelectrics and hybrid electric systems are continued improvements needed in propulsive and thermal efficiencies, especially for small core gas turbines. Many propulsive and thermal efficiency improvements can also be directly applied to conventional gas turbines which is synergistic with meeting the needs for military propulsion. These improvements in efficiency can happen by using all of our available new tools such as advanced manufacturing and materials, machine learning, and sensor technologies.

In my opinion, provided there is strong research and development support, we are likely to see a range of innovative solutions emerge for creating sustainable aviation starting with the use of sustainable alternative jet fuels progressing towards hybrid electric propulsion followed by the use of hydrogen either for fuel cells or for producing synthetic fuels. It is obvious that we are racing with China and the European Union to develop these solutions because of the climate as well as economic benefits. Heavy investments are needed now to support ongoing research efforts and the education of a new workforce equipped with the latest technological tools to advance the U.S. aviation industry so that it will be sustainable and competitive.

Overview of Carbon Emissions Resulting from Aviation

Commercial aviation, like every means of mass transportation, releases carbon dioxide (CO_2) into the atmosphere. Relative to other means of mass transportation, however, commercial aviation is the most challenging because of technical, economic, and policy changes required not only for new technologies and infrastructure but also because of the high safety standards that are implemented in this industry.

The primary human activities that release carbon dioxide (CO_2) into the atmosphere are the combustion of fossil fuels (coal, natural gas, and oil) to generate electricity, the provision of energy for transportation, and as a consequence of some industrial processes. Although aviation CO_2 emissions only make up approximately 2.0 to 2.5 percent of total global annual CO_2 emissions, research to reduce CO_2 emissions is urgent because new technology requires a long time to propagate into and through the aviation fleet; because of the ongoing impact of global CO_2 emissions; and because of the international race to develop new products to meet increasingly stringent safety requirements.

Typical passenger capacity for different aircraft range between general aviation with fewer than 6 passengers to large aircraft including single-aisle with more than 100 passengers and twin-aisle with more than 200 passengers. Within these classes of aircraft, 90 percent of the CO_2 emissions from global commercial aircraft are generated by large aircraft (single- and twin-aisle). Therefore, any technologies for reducing the carbon emission from commercial aircraft will need to be applicable to and effective at this scale aircraft and must be widely deployed.

CO_2 emissions from a commercial aircraft can be reduced in the following ways:

- Reduce the energy required to fly by the aircraft by reducing its weight and/or drag;
- Improve the efficiency with which the energy is converted from fuel into thrust;
- Reduce the carbon intensity of the energy required—in other words, reduce the net amount of carbon that is emitted into the atmosphere to generate a given amount of energy.

In response to National Aeronautics and Space Administration (NASA), the National Academies of Sciences, Engineering, and Medicine convened a committee in 2015 to develop a national research agenda for reducing CO_2 emissions from commercial aviation [1]. To simplify the writing throughout the remainder of the paper, I will refer to this report as the 2016 National Academies report. Four high priority research approaches were identified to develop propulsion and energy system technologies that could reduce CO_2 emissions from global civil aviation and that could be introduced into service during the next 10 to 30 years:

- Advances in aircraft-propulsion integration;
- Improvements in gas turbine engines;
- Development of turboelectric propulsion systems; and
- Advances in sustainable alternative jet fuels.

For each of these approaches, several specific research projects were recommended by the committee. Considerations were given for each as to the breadth of applicability, ease of integration, technical and economic risks, and impact. The breadth of applicability, for instance, was compared between drop-in sustainable fuels that are applicable to all current and future jet aircraft, while improved technologies for fully electrical propulsion systems are more applicable only to future generations of small aircraft. During the study committee's work, significant discussions were given to the all-electric and hybrid-electric propulsion systems, particularly because these concepts have already been demonstrated and are even flying for small general-aviation aircraft. However, significant challenges exist in directly scaling these concepts to meet the demands of large aircraft given their sizes and long flight distances. Alternatively, the committee strongly recommended the development of turboelectric systems, which differ from the all-electric and hybrid concepts because no additional batteries or fuel cells are required. Turboelectric propulsion systems require high power generators, cabling, and power electronics, and like other electric propulsion systems they make beneficial concepts such as distributed propulsion much more feasible. In 2021, gas turbine manufacturers are actively evaluating all of these designs including the benefits for a family of parallel hybrid architectures that do require large, advanced batteries. Development and demonstration of these technologies in concert with NASA will accelerate their deployment.

In response to the findings of the 2016 National Academies report, the Chief Technology Officers of seven of the world's major aviation manufacturers jointly signed an agreement on a unified commitment titled, "The Sustainability of Aviation" at the 2019 Paris Airshow [2]. Through the Air Transport Action Group, the aviation industry set an ambitious target to reduce CO_2 emissions by 2050 to half of the levels that occurred in 2005. Prior to the COVID-19 pandemic, the emissions of CO_2 were rising by approximately 1% per year over the previous decade with no growth in 2019 [3]. The governmental policies during the COVID-19 pandemic drastically altered the energy demand around the

world, particularly commercial aviation. The daily global CO_2 emissions decreased by 17% by early April 2020 compared with 2019 levels [3].

The strategy outlined in The Sustainability of Aviation agreement included three strategies, which are similar to those proposed by the 2016 National Academies report:

- Continue to develop aircraft and engine design and technology;
- Support the commercialization of sustainable, alternate aviation fuels; and
- Develop radically new aircraft and propulsion technology to enable a new generation of aviation.

In recent times the use of liquid hydrogen (H_2) as an aviation fuel has gained international attention. With three times the energy density of kerosene, H_2 promises not just net carbon neutrality, but zero CO_2 emissions. The potential exists for H_2 to be generated in the gaseous state using green electricity produced from renewable energy sources such as solar, wind, geothermal, biogas, nuclear, and other hydroelectric sources unlike now where most H_2 is produced from fossil fuels such as coal and natural gas using processes that release CO_2 into the atmosphere. In considering ease of integration into commercial aviation, the impact on aircraft design and performance, and additional and economic considerations, the case for making use of H_2 as a fuel source for large aircraft is difficult to defend. Added to these challenges are the nearly insurmountable safety challenges. The 2016 National Academies committee assessed the viability and decided not to classify hydrogen fuel technologies as a high priority. Nonetheless, the development of a national research plan and modest support for this technology remains appropriate to ensure the U.S. global leadership in aerospace propulsion.

Through the remainder of this document, the needed research approaches suggested by the 2016 National Academies report along with The Sustainability of Aviation agreement will be discussed along with the potential of using liquid hydrogen (H_2) as an aviation fuel. After the required research is described, additional information is provided on the international competition and workforce needs for the aviation industry.

Research Priorities Required for Sustainable Aviation

Advances in Aircraft-Propulsion Integration. Two high-priority research projects were identified in the 2016 National Academies report for integration that requires a design disruption beyond discrete improvements to individual component technologies. Research is needed to make both evolutionary improvements in reducing the fan pressure ratio in nacelles and to make revolutionary improvements beyond the traditional tube-and-wing platform that would enable distributed propulsion concepts and boundary layer ingestion configurations. Unducted fans avoid weight and drag penalties, but the inability to contain airfoil components and high noise levels result in the majority of aircraft being powered by turbofans with ducted fans. In turbofans, the fan is placed in a duct (nacelle) where improvements in propulsive efficiency can be gained by reducing the fan pressure ratio because it lowers the fan's exhaust velocity. Reducing the fan pressure ratio can be accomplished by increasing the fan diameter, decreasing the core of the gas turbine engine inside the duct, or using distributed propulsion. These solutions require a change in the airframe configuration since we have already exhausted the maximum nacelle size because of the constraints of mounting the engine to the wings with respect to the landing gear heights on existing airframe architectures. An optimal balance is needed

between these solutions with that of the additional weight and drag induced. Other possible integration systems exist, including embedding the engine within the wings.

The specific high priority research projects for this approach were as follows: (1) develop nacelle and integration technologies to enable ultrahigh bypass ratio propulsors and (2) enable concepts that allow the ingestion of the boundary layer that develops on the aircraft body such that the velocity defect in the aircraft wake will be reduced. By reducing the velocity defect through boundary layer ingestion, the required thrust is reduced and thereby the amount of energy consumed is also reduced. It is my opinion that these research issues are unanswered and that the timeframe to conduct relevant research and testing in this area requires that we provide a concerted level of funding now to advance airframe architectures beyond tube-and-wing designs.

Improvements in gas turbine engines. Turbine engines are the devices that convert the energy in fuel into shaft power, which is then converted to propulsive power. The commercial and military aircraft designed in the last 40 years are primarily powered by gas turbine engines, either turbofans or turboprops. It is also important to note that gas turbines meet 40% of the U.S. demand for electricity and that many of the technologies developed for aviation applications can directly be used to make electrical power generation more sustainable. There are some notable differences, however, between the two applications including weight and volume limitations being only relevant to aviation and a wider variety of fuel types, for example H_2, being only relevant to power generation.

With the exception of fully electric, even the majority of the hybrid propulsion and turboelectrics aviation propulsion systems use a gas turbine as the power plant. Given this need, the 2016 National Academies report stated it is imperative that if we are to reduce our CO_2 emissions, significant research attention is needed for improving the overall efficiency of gas turbine engines, which is the product of the propulsive efficiency (conversion of shaft power to propulsive power) and motor thermodynamic efficiency (conversion of fuel flow power to shaft power), which is often referred to as thermal efficiency. Today's aircraft operate with propulsive efficiencies of up to 70 percent and thermal efficiencies of up to 55 percent, both of which have steadily improved over many decades given innovations, significant testing, and improved design tools. Of note is that an aircraft in flight produces 15 percent fewer grams of CO_2 per kilowatt-hour than that of the world's electric grid. To achieve these efficiencies, today's turbine engines operate at temperatures much above the melting temperatures of the turbine components through the use of highly advanced cooling technologies. It is not clear as to the theoretical limits of what can be achieved in terms of increases in efficiencies from a practical consideration; however, the 2016 National Academies report estimates that further improvements of up to 70 percent for the thermal efficiency and of 90-95 percent for propulsive efficiency may be achievable. The report defines a number of research projects to move towards these goals.

Not discussed in the 2016 National Academies report is an important illustration as to the impact of innovation that increases overall efficiencies. In 2016, Pratt & Whitney introduced a Geared Turbofan (GTF), for which the company has already received 10,000 new engine orders. The GTF operates by de-coupling the fan from the turbine, thereby allowing each to operate with optimal performance. The disruptive technology introduced by the GTF has led to a reduction of about 100 gallons in aviation fuel for every flight hour relative to legacy engines [4]. In turn, this reduction in fuel leads to CO_2 savings of

about 3600 metric ton per year per aircraft, which equates to removing 800 cars from the road for one year or removing 2,000 cars from the road for the life of the aircraft. Technology disruptions are also illustrated by CFM International (a joint venture between Safran Aircraft Engines and GE Aircraft) in which it launched an engine program in 2008 called LEAP-X. The LEAP-X makes use of advanced aerodynamics and new material technologies including ceramic matrix composites, which enable higher temperatures. The LEAP-X has also taken advantage of advanced manufacturing, particularly 3D metal printing, which has enabled a new fuel nozzle design. In 2019, LEAP production rose to 1,736 engines with orders and commitments reaching 1,968 even amid the 737 MAX grounding, and there is a stable backlog of 15,614 engines [5].

During the power extraction in the turbine section of a gas turbine, the blades spin at tens of thousands of revolutions per minute while experiencing gas flow temperatures exceeding their melting temperatures. The stresses experienced by the spinning blades can be equated to hanging approximately five sports cars from a single blade. Current convention is to manufacture these blades by growing single crystal alloys, which is an art that fewer countries can do than the number of countries that can make nuclear weapons. The ability to cast turbine blades is a competitive advantage that the U.S. retains, but this process comes with manufacturing times on the order 90 weeks at a cost of over one million dollars to cast a set of developmental test blades. Metal 3D printing technology is being embraced by turbine manufacturers, particularly for turbine development, and in some cases for the production of static parts such as the LEAP-X fuel nozzle. In contrast to the time and costs for conventional methods, a set of development turbine blades made using metal 3D printing can be done in a matter of a few weeks at a cost of less than $30,000. Metal 3D printing, however, is still in its infancy since we need to show similar performance between cast and printed; and we need high temperature materials that can be used for metal 3D printing. One other opportunity that metal 3D printing offers is the ability to embed sensors in turbine components where it may otherwise not have been possible or where it was not possible to retain sensors due to the harsh environments. Integrating sensors, too, is in its infancy but is beginning to emerge. The opportunities of additive and the research priorities for the gas turbine industry were addressed through a second National Academies study completed in 2020 on advances needed for aviation and power generation gas turbines, which was commissioned by the Department of Energy [6]. There is a great deal of synergy between the 2016 and 2020 National Academies reports with regards to the research approaches needed for turbines.

In response to the needs of the aviation community, NASA is working with gas turbine manufacturers through the Hybrid Thermally Efficient Core (HyTEC) Program, which is aimed at achieving a 5 to 10% fuel burn reduction relative to the 2020 best in class, reducing the engine core size to facilitate hybridization, lowering environmental impacts, and reducing end-user costs. They have set forth goals to extract power up to four times that of the current state-of-the-art turbofan engine at altitude and allow more electrified aircraft systems with optimized electric power availability.

The high-priority research projects defined by the 2016 National Academies report for improving gas turbines were all focused on improving efficiency. Research to increase propulsive efficiency should be focused on turbofans since they power the vast majority of the aircraft. This research should seek to reduce the pressure loss of the gas flow as it passes through the fan and, as already mentioned, reducing the fan pressure ratio while taking into account overall system weight and noise. Research to

improve the thermal efficiency of gas turbines should focus on the development of materials and coatings that will enable higher engine operating temperatures. This development will make it possible to increase compressor exit and turbine inlet temperatures.

Improved aircraft efficiency means that turbine engine cores will shrink because aircraft will be able to use propulsion systems with less power. High efficiency is harder to achieve, however, given manufacturing constraints and tolerances. The 2016 National Academies report therefore also recommends research to develop technologies to improve the efficiency of engines with small cores. Area of particular interest include turbomachinery aerodynamic performance, manufacturing, thermal management, combustion, and the lifespan of turbine airfoils.

In my opinion all of high-priority research projects identified above are of value. To support research to improve turbomachinery aerodynamic performance, manufacturing, thermal management, combustion, and the lifespan of turbine airfoils, we need advanced development tools that enable trade-off studies between size and efficiency as cores shrink; reduction of cooling and secondary flows that allows higher temperatures; continued emission studies of current combustion systems while shrinking the combustor to reduce weight; actuation and sensors for advanced control strategies; evaluating alternative thermodynamic cycles as compared to today's simple Brayton cycle and concurrently the development of compact, efficient heat exchangers needed for advanced cycles. In addition to the high priority research projects listed in the 2016 National Academies report, emphasis should be placed on developing materials that allow 3D metal printing which reduce time and costs of development as these are critical to the U.S. Research emphasis is needed on also developing the latest high-fidelity simulation tools, machine learning, and 3D printing all of which can support the digital thread.

Electric Propulsion. The study committee evaluated the use of numerous electric propulsion architectures that fell into three primary groupings: all electric; hybrid electric; and turboelectric. The all-electric system uses only batteries while the hybrid systems and turboelectric systems all use gas turbine engines as the power source. The hybrid systems use the gas turbine engines to charge batteries, which also provides energy for propulsion during one or more of the phases of the flights. The turboelectric configurations do not rely on batteries for propulsion energy during any phase of the flight. Rather, they drive electric generators that power the propulsion system. All three architectures are compatible with the use of a distributed propulsion system that uses many, small individual motors instead of just two large engines, as is typical of conventional commercial aircraft.

Given the current and projected performance of characteristics of batteries in 2015 when the National Academies study committee convened, the committee elected not to recommend the all-electric and hybrid electric architectures as high research priorities because of the gap between the specific power requirements needed for large single-aisle and twin-aisle aircraft and what was available or projected to be available for batteries. It was unlikely that either an all-electric or hybrid electric propulsion system could be fully FAA certified during the subsequent 10 to 30 years, which was the timeline for the 2016 National Academies report. Potential applications (and time frames) for all-electric and hybrid concepts were based largely on projected advances in battery energy storage technology. Jet fuel is an excellent way to store energy, with an equivalent specific energy of approximately 13,000 Wh/kg. A regional or single-aisle aircraft is conceivable with batteries having a specific energy of "only" 800 Wh/kg for a

hybrid system (or 1,800 Wh/kg for an all-electric system). Even so, these levels far exceed both the current state of the art Lithium ion batteries (200-250 Wh/kg) and the committee's projection of how far the state of the art would advance during the subsequent 20 years (400-600 Wh/kg). Of course, smaller general aviation aircraft designed for short-range missions can and have been designed with less-advanced batteries. In 2021, the specific energy capabilities are still consistent with those given by the 2016 National Academies report.

Turboelectric concepts are not dependent upon energy storage technologies, but to reduce CO_2 emissions these concepts need to take full advantage of the aircraft-propulsion integration using boundary layer ingestion and distributed propulsion as previously described. Turboelectrics, in general, have lower efficiency than conventional gas turbine propulsion because of the particular energy conversion and transmission losses such that the advantages that it offers through boundary layer ingestion and distributed propulsion must outweigh the inefficiencies of the turboelectric architecture.

The recommended research projects include: turboelectric aircraft system studies to establish metrics and the development of megawatt-class research facilities that allow relevant ground-based testing in support of this size class. In response to these needs, NASA developed a test bed, referred to as the NASA Electric Aircraft Testbed (NEAT), to design develop, assemble and test electric aircraft power systems from a small one person aircraft up to 20 MW airliners, which allows ground-based testing of a full-scale electric aircraft powertrain [7]. Ongoing studies are taking place in the NEAT.

Sustainable Alternative Jet Fuels. Drop-in sustainable jet fuels have aggregate properties that are essentially equivalent to those of conventional (petroleum-based) jet fuels and, as such, are fully compatible with existing aircraft and the existing infrastructure such as pipelines and airport fuel systems. Sustainable alternative jet fuels are a family of drop-in fuels intended to lower the net life-cycle carbon emissions of commercial aviation. Jet fuels need to meet current specifications either on their own or when blended with conventional jet fuel such that these are "drop-in" replacements can be directly used as jet fuel with no impacts on performance. Alternative refers to the fact that these are produced primarily from non-petroleum sources of hydrocarbons (particularly agricultural and wood product) using a broad range of biochemical and thermochemical conversion processes. Sustainable refers to the ability to reduce net life-cycle carbon emissions relative to conventional jet fuel and in terms of environmental, societal, and economic factors.

Sustainable alternative jet fuels were endorsed by the 2016 National Academies study as one of the high research priorities and it is my opinion that this particular area is one that is best positioned to providing a near- to mid-term impact in reducing CO_2 emissions. Unlike hydrogen, which will be discussed below, existing aircraft have already been powered by sustainable alternative jet fuels since 2019 for United Airlines flights from Chicago to Los Angeles. United has committed $40M in investments to accelerate the production of sustainable alternative jet fuels, and it has agreed to purchase up to 10 million gallons over the next two years. Delta also entered into an agreement to purchase 10 million gallons per year and set aside $2M for research. Given Dr. Csonka will also testify at this hearing, more details will be provided by him as to the current state of sustainable alternative jet fuels.

Specific research projects recommended by the 2016 National Academies study included: modelling and analyses of the sustainable alternative jet fuel development; feedstock development; conversion processes and scale-up in production; and fuel testing and certification. These are, for the most part, ongoing research projects that are taking place.

Hydrogen as an Energy Source in Aviation. As was mentioned, the 2016 National Academies committee specifically assessed the possibility of using H_2 fuel for aviation propulsion and decided that research in this area was not a high priority for large aircraft that could become operational in the subsequent 10 to 30 years. Today, however, numerous discussions are taking place on the potential of hydrogen for both ground-based power generation (producing electricity) as well as aircraft propulsion.

Almost all of today's hydrogen is produced by natural gas or coal using processes that discharge CO_2 into the atmosphere. Using hydrogen produced in this way as a jet fuel results in no net reduction in atmosphere CO_2. In the future, there is a growing potential for making hydrogen from water using hydrolysis from green electricity to the extent that available green electricity exceeds total electrical demand on a particular power grid. The amount of H_2 that would have been required to meet the 2019 energy needs for jet fuel equates to approximately 14% of the world's electricity, which means that a significant amount of excess electricity would be required to meet the demands for H_2 as an aviation fuel if all were produced using green electricity [9]. To implement this fuel solution, significant infrastructure is required to produce, liquefy gaseous H_2 to the required liquid state for engines, and to distribute the hydrogen to airports through pumping or some other means. Liquefying H_2 costs are projected to be between 30 and 50 percent of the input energy costs. In addition to the infrastructure costs, entire aircraft fleets would need replacing.

In September 2020, Airbus reported that the company is developing a new zero-emission blended wing aircraft concept referred to as ZEROe [10]. A key part of this concept is that it would be powered by two hybrid turbofan engines using hydrogen as their energy source. To implement hydrogen as a fuel, aircraft designs would need to radically change. The fuel tanks need to be highly insulated for the liquid hydrogen to be maintained at -400F and need to be three times larger than existing fuel tanks on today's aircraft [9]. These storage requirements in turn add to the weight and drag of the aircraft which puts into question the overall efficiency that sets the amount of required fuel. Although these concerns are not necessarily insurmountable, the most compelling challenge is one of safety for the passengers who would be surrounded by highly flammable liquid H_2.

In my opinion, overcoming the technoeconomic and safety challenges in using H_2 as an aviation fuel are challenging in the timeframe in which we are looking for solutions to reduce CO_2 emissions (that is, by 2050). There are other opportunities for the aviation sector, however, including the recycling of atmospheric CO_2 into synthetic fuels using renewable energy, which offers an energy concept with no net CO_2 emission. Provided the right investments were made now, the European Union's Clean Sky Program estimates that hydrogen as a fuel source either through fuel cells, combustion in gas turbine engines or as building blocks for synthetic liquid fuels could result in a first short-range hydrogen-powered demonstrator by 2028. It is my opinion, that the U.S. needs to develop a longterm strategy for hydrogen specifically for the aviation sector to remain competitive.

Workforce Challenges and International Competitiveness

The 2016 National Academies report focused on technology. Two related areas of great importance are workforce challenges and international competitiveness.

The U.S. civil aviation industry accounts for more than $1.6 trillion in annual economic activity, supports 10.6 million direct and indirect jobs (contributes 5.1% to GDP), and is one of only a few industry sectors to generate a positive U.S. trade balance—$60 billion in 2019. In 2019, aviation manufacturers directly employed more than 600,000 highly skilled workers, accounting for nearly half of the total aerospace and defense industry workforce [11].

Supporting research in the priority areas already discussed is prudent to reduce CO_2 emissions. Academic institutions, industry, and federal agencies such as NASA, FAA, DOD, and DOE all have a critical role. Academic institutions have historically contributed in advancing technologies to low levels of technology readiness, but today's research at some of the leading universities in which significant financial investments in facilities and personnel have been made provide opportunities to move to higher levels of technology readiness. In the area of gas turbine research, for example, Georgia Tech, Ohio State, Notre Dame, Penn State, Purdue, Texas A&M, and Virginia Tech have made significant investments that have, in turn, resulted in multi-year committed research funding with one or more specific industry partners. These university-industry relationships have led to further research support from federal agencies because of the collaborative efforts and because of the technology transfer that has led to direct impacts on the products. It is my opinion that these partnerships must continue to be supported by the federal government because the investments being made ensure technology transfer and a pipeline of talented employees.

Now more than ever, however, the aviation industry requires a highly educated, diverse, and talented workforce who are not only knowledgeable in the fundamental, traditional areas such as turbomachinery, combustion, gas turbines, airplane design, and controls but equally as knowledgeable on how to use emerging technologies such as, for example, design for additive manufacturing, machine learning, hybrid propulsion systems, high-fidelity computational simulations, and sensor development. The students being educated today need to understand how to apply these tools in order to advance the industry, which can also positively impact our military propulsion capabilities. A lack of diversity in aviation is also holding back our abilities to achieve our goals because diverse thought leads to better solutions. As was mentioned, numerous universities have invested in facilities where students are educated through critical hands-on experiences that will make them successful aviation engineers in the aviation field; however, there are many more universities in which talented students are not being exposed to the opportunities that aviation provides. In addition, many subjects related to aviation require multiple years of study to master. Research support for graduate students from federal agencies as well as industry, which is generally provided one year at a time, often falls short on continued student support to allow that student to master these interdisciplinary subjects. These are the reasons that it is important that the federal government increase the support for dedicated graduate fellowships directed towards aviation, which can be done by expanding the existing fellowship programs offered by NASA and by DOD, for example.

In 2017, the total U.S. spending on research and development totaled $549B, while China came in at $496B. Together, these account for nearly half of the world's global research and development [12]. The rapid growth of China's committed efforts to research funding is clearly indicated in the growing

number of patent families (unduplicated measure of global inventions) granted to inventors, of which over half were awarded to China, while the U.S. had only 6.8%. China is also demonstrating rapid growth in the number of paper submissions to academic journals. In 2000, China published only 5% of all papers while the U.S. published 28%. In contrast in 2018, China published 21% of all papers which was higher than the 17% of papers published by the U.S. In 2015, the number of university degrees awarded by China in science and engineering was 2.2 times higher than the U.S. It is no secret that China's research and development strategy is to become the world's leader in science and technology by 2050, which was announced by the "Made in China 2025" plan in 2015 [13]. And, in China's plan, the aviation market is prominently placed. It is for these reasons that as a professor, I have been approached on multiple occasions by Chinese faculty indicating that if I were to collaborate with them in gas turbine heat transfer on joint research programs, an "open spigot of money" would be made available. I have declined such opportunities because I am fortunate to have outstanding support from my industry collaborators and the federal government, but for faculty who want to work in this area and are not so fortunate, China is a viable source of support.

The Clean Sky program funded by the European Union clearly communicates their plan to develop hydrogen as an energy source, which they believe will be disruptive to the industry [14]. Their recent study indicated that hydrogen as a primary energy source for propulsion, either for fuel cells or direct combustion in gas turbines or as a building block for synthetic liquid fuels could power aircraft with entry into service by 2035 for short range aircraft reducing the climate impact by 50 to 90 percent.

It is important to mention that over the last 15 years, there is only one federal program that has provided continual support of research in gas turbines, mostly directed for power generation, and that program is DOE's Advanced Turbines Program including the University Turbine Systems Research Program. Since 2017, NASA has begun offering multi-year research grants through its University Leadership Initiative to support university research in aviation and aeronautics. In both cases, these programs emphasize the close collaboration with industry, and in both cases, they do not have sufficient funds to support the development of many innovations which could otherwise be achieved through greater investments in research. The FAA ASCENT Program has also been critical to funding university research projects at 16 U.S. universities specifically targeted at aviation sustainability.

To remain competitive, it is imperative that the U.S. invests heavily now because of the need for a new cadre of students equipped with new tools to fill the workforce needs and because of the race to develop the best products and solutions for making aviation sustainable.

References

[1] *Commercial Aircraft Propulsion and Energy Systems Research: Reducing the Global Carbon Emissions,* National Academies of Sciences, Engineering, Medicine, https://www.nap.edu/23490

[2] https://www.globenewswire.com/news-release/2019/06/18/1870056/0/en/The-Sustainability-of-Aviation-A-Statement-by-the-Chief-Technology-Officers-of-seven-of-the-world-s-major-aviation-manufacturers.html

[3] Le Quere, C. et al., 2020, "Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement" https://www.nature.com/articles/s41558-020-0797-x

[4] https://www.forbes.com/sites/lorenthompson/2020/12/02/pratt--whitneys-geared-turbofan-is-poised-to-emerge-from-the-pandemic-in-great-shape/?sh=56ca1bb41655

[5] https://www.flightglobal.com/engines/cfm-to-build-10-737-max-engines-weekly-for-2020/136959.article

[6] *Advanced Technologies for Gas Turbines*, National Academies of Sciences, Engineering, and Medicine https://www.nap.edu/25630

[7] https://www1.grc.nasa.gov/aeronautics/eap/larger-aircraft/test-capabilities/nasa-electric-aircraft-testbed-neat/

[8] https://simpleflying.com/sustainable-aviation-fuel-airlines/#:~:text=United%20and%20Delta%20down%20for,the%20acceleration%20of%20biofuel%20production.

[9] https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html

[10] https://aviationweek.com/aerospace/program-management/opinion-leave-hydrogen-dirigibles?elq2=b819bb75ca34481cb52d69866d40cbd5

[11] https://www.faa.gov/air_traffic/publications/media/2016-economic-impact-report_FINAL.pdf

[12] https://ncses.nsf.gov/pubs/nsb20201/preface

[13] https://knowledge4policy.ec.europa.eu/foresight/topic/expanding-influence-east-south/industry-science-innovation_en

[14] https://www.cleansky.eu/publication/hydrogen-powered-aviation

Biographical Sketch

Dr. Karen A. Thole is a Distinguished Professor and head of the Department of Mechanical Engineering at The Pennsylvania State University. Dr. Thole is an ASME Fellow and an AIAA Fellow. She is internationally recognized as a leader in gas turbine heat transfer. Her research has taken innovative cooling technologies from theory to application, which has allowed increases in turbine thermal efficiencies. Dr. Thole has established two research laboratories at Penn State with the most recent housing a unique one stage test turbine. Both laboratories have been awarded the distinction of being Centers of Excellence in aerodynamics and heat transfer for two different gas turbine manufacturers. Dr. Thole has been recognized for her technical contributions by numerous best paper awards, the ASME George Washington Medal and the AIAA Air Breathing Propulsion Award. She has also been recognized for her work in mechanical engineering education and diversity including being selected as a U.S. White House *Champion of Change,* by ASME's Edwin F. Church Medal and by ABET's Claire L. Felbinger Diversity Award. She holds two degrees in Mechanical Engineering from the University of Illinois, and a PhD from the University of Texas at Austin.

Chairman BEYER. Thank you. Thank you, Dr. Thole, very much. It will provoke many questions, which is good.

I now recommend—or recognize MIT's Dr. John Hansman.

TESTIMONY OF DR. R. JOHN HANSMAN JR., T. WILSON PROFESSOR OF AERONAUTICS & ASTRONAUTICS AND DIRECTOR, MIT INTERNATIONAL CENTER FOR AIR TRANSPORTATION, MASSACHUSETTS INSTITUTE OF TECHNOLOGY; CHAIR, FAA RESEARCH AND DEVELOPMENT ADVISORY COMMITTEE (REDAC); CO-DIRECTOR, FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS AND ENVIRONMENT (ASCENT)

Dr. HANSMAN. Chairman Beyer, Ranking Member Babin, and Members of the Committee, thanks for the opportunity to talk about this important topic today.

As you guys have already noted, the impact of aviation on the environment is an increasing concern worldwide in that the aviation community is really highly motivated both in market reasons and international strategic reasons to improve its sustainability. There's lots of things we can talk about. I'm going to briefly discuss a few key areas today.

First, you know, the first thing that motivates understanding how we mitigate aviation environmental impacts is understanding the mechanisms of impact, and modeling the impacts is sort of a full system level. So you mentioned greenhouse gas emissions. There was other impacts that we need to understand, for example, contrails. But we have to look at it in terms of the system level. You have to think about all—how we fly the airplanes, where we fly them. As you mentioned, aviation contributes about 2 to 3 percent of the greenhouse gas emissions, but they are injected high in the atmosphere where they have a higher impact, so you have to think about where you fly, what the markets are around the world. These things are not necessarily symmetric. And you have to think about it in terms of the lifecycle. So, you know, it may make sense to use, for example, hydrogen as a fuel but only if you get it from a sustainable source.

The other thing I just mentioned as a fundamentalist that we need to think about aviation as a potential platform to monitor climate change mechanisms and risks both in terms of how we operate the airplanes but also as aviation platforms. And when you think about mitigations, I'm just going to separate them into three sort of timeframes. In the near term in the next 5 to 10 years we're going to have to figure out how to use the airplanes we have today more efficiently. You can't quickly—you know, even if you had a new technology, airplane technology, it's going to take 20 or 30 years to migrate into the fleet.

So given that you have to use the existing airplanes, there's two sort of approaches that—one of them has already been mentioned. So drop-in sustainable aviation fuels are clearly important and can be used in our existing airplanes. Right now, we're limited to blends of less than 50 percent sustainable aviation fuels, so there's a need to get to 100 percent so we can fully use that. The other thing you need to think about—again, this is a lifecycle and a sys-

tem-level impact—is where do those fuels come from and do you have sustainable aviation fuel pathways that make sense from an overall societal standpoint?

The second thing you can do in the near term is to fly the airplanes more efficiently. From a greenhouse gas emissions standpoint, most of the fuel is burned [inaudible] altitude improves or oceanic flight, so there are things that we can do to operate the airplanes more efficiently at altitude in terms of improving air traffic control, using the technologies of, for example, space-based surveillance to allow more direct routings to allow airplanes to be at their optimal speeds and altitudes.

We can also slow down a little bit. It turns out we burn probably a little bit more fuel than we need to from the speeds. In the terminal area, arriving and departing, the main opportunity for efficiency is going to be not only efficiency but local air quality and noise.

In the midterm we can think about new airplanes. And again, this is going to be 10 to 20 years out there. And the main thing we can do in R&D is to enable and de-risk new technologies and new configurations. NASA has shown in some other studies, the N+3 studies, for example, that there are potential for 50 to 70 percent improvement in fuel efficiency from new configurations, but these are too risky for industry to take on by themselves. [inaudible] been mentioned, I would say that the battery-based systems are going to be probably limited for short-range operations, but either hybrid systems or fuel cells may have some potential.

Also in the midterm we need to think about how we scale up the sustainable aviation fuels to the full level. In the far term hydrogen might be an option. It's appealing because you don't have to basically put the carbon back into the fuel to make a synthetic electro fuel, but it's a tough problem. It's got a couple key areas. One is really the safety issue, so, you know, as we know from the images of the Hindenburg that, you know, hydrogen is explosive. You have to think about how do you protect a hydrogen airplane from, for example, a lightning strike and how do you inert the fuel? [inaudible] infrastructure of hydrogen. We have—there are design issues because of the way hydrogen is held and stored. And we also have to think about the indirect impacts of something like hydrogen. Hydrogen puts out more water vapor, so does that create, for example, more contrails where the contrails may actually have a knock-on effect.

So there's a lot we can do, and I'm looking forward to the discussion.

[The prepared statement of Dr. Hansman follows:]

Statement of

R. John Hansman, Jr.
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Director, MIT International Center for Air Transportation
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before the

Committee on Science, Space and Technology
U.S. House of Representatives

March 24, 2021

Chairman Beyer and Members of the Committee:

Thank you for the opportunity to comment on *R&D Pathways to Sustainable Aviation*. I am a Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology. I Chair of the FAA Research and Development Advisory Committee (REDAC) and am also Co-Director of the FAA Center of Excellence for Alternate Jet Fuels and the Environment (ASCENT). I should note that while my testimony is informed by my participation in the REDAC and ASCENT, due to time constraints my comments have not been coordinated with my colleagues so I am speaking as an individual today.

The impact of aviation on climate change is an increasing concern for the air transportation community. While aviation represents only 2-3% of anthropogenic Green House Gas (GHG) emissions they occur higher in the atmosphere where they have a stronger impact than ground based emissions. Aircraft can also influence atmospheric warming through contrails from water vapor emissions. In addition to climate level impacts, aviation sustainably also includes considerations of the impact on local communities near airports in terms of noise, and emissions of small particles, nitrous oxides (NOX) and other landing and takeoff.

Addressing and improving the sustainability of aviation is a critically important to the nation and requires investment in Research and Development. Aviation is important both in terms of its direct, indirect, induced and catalytic economic effects but also through enabling international collaboration which will be critical to addressing global level climate change phenomena. Improving the environmental performance of our aircraft and operations are also an important competitive factor as the rest of the world increases its focus on environmental performance.

There is growing interest in from airlines, other operators and manufacturers in improving the sustainability of their operations in response to public perception and growing market pressure.

I will briefly discuss some of the important R&D needs below and frame the discussion in terms of the likely timeframe that this R&D would have impact.

Understanding and Modeling Environmental Impacts of Aviation

In order to inform policy and prioritize R&D in environmental mitigations it is important to understand the full systems level and life cycle impact of adverse aviation mechanisms. This requires research on aviation environmental impact mechanisms as well as modeling at a systems level. There are models such as the FAA Aviation Environment Design Tool that do a good job at representing well established mechanisms of fuel burn, emissions and noise but these should be enhanced and expanded to include mechanisms such as aviation induced cloudiness as well as full life cycle impacts and system level effects.

Aviation also provides a platform to monitor and forecast key climate change risks. The global aviation system continuously probes the global atmosphere and operational flight data can be used to identify change signatures. Focused airborne monitoring systems such as the stratospheric solar electric observing platform being developed by Harvard and MIT can be used to monitor key risks such as Antarctic and Greenland ice breakup, tropical storm evolution, wildfire risk and convective storm driven ozone depletion over the US.

Near Term Mitigations (0-5 years)

Sustainable Aviation Fuels (SAF) and environmentally focused operations represent the most significant opportunities for near term mitigation as they can be implemented in the existing fleet of aircraft. There has been significant interest in “drop-in” SAFs which can be used in current aircraft engines as a direct replacement for fossil fuels. Currently SAF must be blended with traditional fuels to a maximum of 50% SAF due to concerns about low aromatic content and fuel system seals. There is general consensus in the SAF community that research should be done to enable 100% SAF as a near term mitigation. Research is also required to scale up and enable new SAF pathways including “electro” fuels and “bio” fuels considering the full life cycle impacts.

R&D to support more environmentally efficient operations is also a near term mitigation opportunity. Most environmental impacts scale with fuel burn so efforts to improve fuel efficiency have compounding GHG and emissions benefits. Since most fuel is burned during the cruise phase of flight, efforts to allow with more flexible ATC routing in high altitude sectors and oceanic airspace and better flight planning including contrail avoidance will have the greatest impact. At lower altitudes environmentally focused operations have the potential to reduce noise impacts and local air quality impacts during approach and departure.

Mid Term Mitigations (5-20 years)

New aircraft and propulsion systems with significantly lower environmental footprints will play an important role in sustainable aviation. The long time to develop and certify these aircraft and the even longer time to replace the active fleet make this a mid-term or later strategy. As the NASA N+3 program demonstrated, game changing reductions in fuel burn, NOx emissions and noise are possible with innovative transport aircraft and propulsion system configurations. Federal R&D will be critical to accelerating and enabling the transition from the current from current tube and wing aircraft configuration.

The R&D goal should be to enable and de-risk innovation and the transition to significantly cleaner aircraft. This should be focused at both the fundamental research level and at providing the processes and basis for certification and operational approval of fundamentally new aircraft. There is a role for demonstrator aircraft programs if they enable broad innovation and risk reduction but they need to be more than simple demonstrations of a single concept.

Electrification may also play a role as a mid-term mitigation but full electric aircraft will be limited in range and payload to levels similar to automobiles due to the limitations on battery specific energy (energy per unit weight) which are particularly important for aircraft. Development of ultra-high specific energy batteries focused on aviation would enable a broader range of electrification but need to satisfy safety concerns and have a sustainable life cycle including battery disposal.

Hybrid-electric propulsion (fueled with SAF) may be have a role in some aircraft if the hybrid-electric system can “buy its way onto the airplane” through increased performance or fuel efficiency.

Sustainable Aviation Fuel will continue to be important in the mid-term and research to assure the ability to scale SAF production will be important as aviation will be competing with other energy users for sustainable fuels. This will likely include increased use of “electro” fuels and development of scalable bio feedstock pathways that do not compete for food or water resources.

Far Term Mitigations (20+ years)

The ultimate objective of sustainable aviation should be a fully decarbonized aviation system. This implies that the future aviation system will need to source all its energy from sustainable electric energy. This energy will be carried on future aircraft either in batteries or advanced “electro” SAFs. One attractive fuel is hydrogen as it is simpler to generate from electricity than “drop in” electro SAF which requires adding carbon into the fuel.

Hydrogen has long been considered as an aviation fuel due to its very high specific energy but has not been practical due to a number of challenges including safety, aircraft design challenges due to fuel volume or pressure, and lack of a hydrogen distribution infrastructure which is why this would be a far term

mitigation. If hydrogen fueled aircraft become practical, they will have the highest impact on long haul flights which consume a large fraction of aviation fuel and have a limited set of airports which would require a hydrogen refueling infrastructure. Enabling R&D for hydrogen would consider both combustion and fuel cell approaches and would address safety concerns like fuel inerting to prevent explosions from lighting strikes or electrical shorts. In addition the potential impact of hydrogen fuel on other climate change mechanisms need to be investigated. For example hydrogen based propulsion will generate water vapor and the contrail behavior of hydrogen based propulsion aircraft are unknown.

I have only scratched the surface of what needs to be done. I am encouraged that the Committee is addressing this important issue which will become a dominant issue driving air transportation. I am happy to answer any questions you might have.

R. John Hansman is the T. Wilson Professor of Aeronautics & Astronautics MIT, where he is the Director of the MIT International Center for Air Transportation. He conducts research in the application of information technology in operational aerospace systems. Dr. Hansman holds 6 patents and has authored over 250 technical publications. He has over 5800 hours of pilot in-command time in airplanes, helicopters and sailplanes including meteorological, production and engineering flight test experience. Professor Hansman chairs the US Federal Aviation Administration Research Engineering & Development Advisory Committee (REDAC) as well as other national and international advisory committees. He is a member of the US National Academy of Engineering (NAE), is a Fellow of the AIAA and has received numerous awards including the AIAA Dryden Lectureship in Aeronautics Research, the ATCA Kriske Air Traffic Award, a Laurel from Aviation Week & Space Technology, and the FAA Excellence in Aviation Award.

Chairman BEYER. Dr. Hansman, thank you very much.

And I now recognize Mr. Steve Csonka for your five minute testimony.

TESTIMONY OF MR. STEVE CSONKA, EXECUTIVE DIRECTOR, COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE (CAAFI)

Mr. CSONKA. Thank you, Mr. Chairman. Esteemed Members of the Committee and Subcommittee, thank you for your general interest in aviation sustainability and your specific interest in sustainable aviation fuels, or SAF, and that's the nomenclature I'll use for the rest of this discussion with SAF being the sole focus of my remarks today.

I'm going to dive right into the three themes that are representative of questions extended to me by Committee staff with respect to SAF.

First, big question, how does SAF fit into the larger landscape of approaches and pathways to enable more sustainable aviation? I believe SAF represents the only viable approach for achieving any near-term, substantive, in-sector net carbon reduction. Further out in time, we might see more radical tech incorporated at rates that offset traffic growth driven by the aviation value paradigm. In the meantime, SAF scaling and usage can deliver a direct and proportional reduction in net carbon. SAF incorporation has no impact on any other parallel approaches to enable or improve sustainability via advancements in technology, operations, or infrastructure.

Second question, what are the opportunities and challenges of SAF for reducing the aviation sector's carbon emissions? The opportunities include the fact that SAF is a drop-in fuel. It obviates the need for significant investments outside of the fuel production itself. Two, SAF are not hypothetical. We started using them commercially 5 years ago. Three, SAF are proven to lower net carbon emissions. Four, SAF will be free of sulfur and likely have lower levels of certain hydrocarbons responsible for tailpipe soot and criteria pollutants that affect air quality. Five, SAF can be produced from a very wide range of processes and feedstocks which recycle carbon from our biosphere or feedstocks from 24/7 waste streams of various human and circular economy industrial activities.

On the other side of the spectrum, the challenges include SAF being a very nascent industry. We're just getting started, and every new facility is high on the cost curve. Given the nascent state, SAF production generally cannot compete with the cost of PETROJET at the current range of oil prices. The carbon reduction afforded by SAF is not yet broadly monetizable, and as a result of the inability of free-market economics to change this paradigm, policy is likely needed to affect change.

Industrial system cost reductions are typically achieved through the continued introduction of new technology, utilization of lower-cost inputs, and via learning curve improvements and tech and supply chain scaleup. However, none of these can be achieved without initiating the first steps of expansion, again, likely only available through policy support and regulation.

Third and finally, what research could be undertaken or accelerated by NASA and FAA to support SAF development and utiliza-

tion to further reduce aviation environmental impacts? NASA has expertise in measurement analysis and characterization of the atmosphere and atmospheric impacts of aviation emissions constituents. Questions associated with SAF in these areas include, one, quantifying the impact of different hydrocarbon molecules in jet fuel, the resulting combustion constituents, and their contribution to greenhouse gas agents. Two, further work can be done on physical emissions measurements both on ground test and flying aloft using different formulations of SAF with varying chemistry. Three, work can be done to address the impacts and benefits of elimination of certain hydrocarbon compounds known to have difficulty in achieving full combustion and responsible for soot, PM (particulate matter), HAPS (hazardous air pollutants), and other things we care about.

On the FAA side, they've been using several impactful programs to advance the modeling and understanding of ways to expedite SAF development and use, including the programs of ASCENT, CLEEN (Continuous Lower Energy, Emissions and Noise), and CAAFI. R&D associated with SAF in these areas includes, one, continuing to make progress on the modeling, referee test models, small-quantity fuel screening, clearinghouse assistance to continue to reduce the cost and time associated with industry qualification of additional SAF pathways. Using such models and knowledge development will help us move more quickly in the direction of higher allowable SAF blends or 100 percent SAF formulations that have been brought up a couple of times.

Second, removing supply chain barriers through analysis, tool development, and facilitating broader industry engagement and collaboration. All of these efforts by NASA and FAA should foster more interest on the part of commercialization entities to consider SAF production by creating a better realizable value proposition than exists today.

In summary, the opportunity for SAF is great. While the challenges for scaling remain abundant, the research capabilities of NASA and FAA and other agency partners are critical to enabling SAF maturation and improving aviation sustainability. Thank you for your attention, and I look forward to addressing your questions.

[The prepared statement of Mr. Csonka follows:]

Congressional Testimony Transcript
Committee: House of Representatives, Science, Space, and Technology
Subcommittee: Space and Aeronautics
Hearing Title: Examining R&D Pathways to Sustainable Aviation
Date: 24 March 2021
Witness Name: Steven J. Csonka
Position: Executive Director, Commercial Aviation Alternative Fuels Initiative (CAAFI)
President, Csonka Aviation Consultancy, LLC

Start of Oral Testimony:
Esteemed members of the Committee and Subcommittee, thank you for your general interest in aviation sustainability, and your specific interest in sustainable aviation fuels (or SAF), with SAF being the sole focus of my remarks today. I'm going to dive right into 3 themes representative of questions extended to me by subcommittee staff.

- How do SAF fit into the larger landscape of approaches and pathways to enable more sustainable aviation?
    1. I believe SAF represents the only viable approach for achieving any near-term substantive in-sector net carbon reduction. Further out in time, we might see more radical tech incorporation at rates that offset traffic growth driven by the aviation value paradigm. In the meantime, SAF scaling and usage can deliver a direct and proportional reduction in net carbon. SAF incorporation has no impact on any other parallel approaches to enabling improved sustainability via advancements in technology, operations, or infrastructure.

- What are the opportunities and challenges of SAF for reducing the aviation sector's carbon emissions?
    1. Opportunities include:
        1. SAF are drop-in fuels, obviating the need for significant investments outside of the fuel production itself.
        2. SAF are not hypothetical. We started using them commercially 5 years ago.
        3. SAF are proven to lower net carbon emissions.
        4. SAF will be free of sulfur, and likely have lower levels of certain hydrocarbons responsible for tailpipe soot and criteria pollutants affecting air quality.
        5. SAF can be produced from a very wide range of processes and from feedstocks which recycle carbon from our biosphere, or feedstocks from 24x7 waste streams of various human and circular-economy industrial activities.

    2. On the other side of the spectrum, challenges include:
        1. SAF being a very nascent industry. We're just getting started and every new facility is high on the cost curve.
        2. Given its nascent state, SAF production generally cannot compete with the cost of petro-jet at the current range of oil prices. The carbon reduction afforded by SAF is not yet broadly monetizable, and as a result of the inability of free market economics to change this paradigm, policy is likely needed to affect change.
        3. Industrial system cost reductions are typically achieved through the continued introduction of new technology, utilization of lower-cost inputs, and via learning

curve improvements and tech and supply-chain scale-up. However, none of these can be achieved without initiating the first steps of expansion, again, likely only achievable through policy support or regulation.

- Third and finally, what research could be undertaken or accelerated by NASA and FAA to support SAF development and utilization to further reduce aviation environmental impacts.

  NASA has expertise in measurement, analysis, and characterization of the atmosphere and atmospheric impacts of aviation's emissions constituents. Questions associated with SAF in these areas include:

  1. Quantifying the impact of different hydrocarbon molecules in jet fuel, their resulting combustion constituents, and their contribution as green-house-gas agents;
  2. Further work can be done on physical emissions measurements, both on ground test and flying aloft, using different formulations of SAF with varying chemistry;
  3. Work can be done to address the impacts & benefits of elimination of certain hydrocarbon compounds known to have difficulty in achieving full combustion, and responsible for soot, PM, or HAPS production.

  FAA has been using several impactful programs to advance the modelling and understanding of ways to expedite SAF development and use, including ASCENT, CLEEN, and CAAFI. R&D associated with SAF in these areas include:

  1. Continuing to make progress on the use of modelling, referee test models, small-quantity fuel screening, and clearinghouse assistance to continue to reduce the cost and time associated with industry qualification of new SAF pathways. Using such models and knowledge development will help us move more quickly in the direction of higher allowable SAF blend levels or 100% SAF formulations;
  2. Removing supply chain barriers through analysis, tool development, and facilitating broader industry engagement and collaboration.

  All of these efforts by NASA and FAA should foster more interest on the part of commercialization entities to consider SAF production, by creating a better, realizable value proposition than exists today.

In summary, the opportunity for SAF is great, while the challenges for scaling remain abundant. The research capabilities of NASA and FAA, and other agency partners, are critical to enabling SAF maturation, and improving aviation sustainability. Thank you for your attention and I look forward to addressing your questions.

End of Oral Testimony

Start of Additional Written Testimony

The entire jet-powered aviation enterprise has identified a basket of measure as the means to achieve carbon-neutral growth and long-term aspirational reductions in net carbon emissions[1]. These include technological advancements (which include the development of sustainable aviation fuels, or SAF), improvements in operations and infrastructure, and the use of market-based mechanisms. Commensurate with the goals, the industry also requested the assistance from world-wide governments to remove system inefficiencies and to help accelerate new technology development and incorporation (which is typically already being done with aircraft, engine, and systems technologies), but had not yet been done with SAF. Such support has primarily come from only the U.S. and E.U., but only at amounts that have served to initiate SAF deployment, not scale it broadly.

SAF in general is a low-net-carbon replacement for petroleum derived jet fuel. It is jet fuel produced synthetically from carbon and hydrogen sources that originate from biomass and other circular economy sources initially (waste streams), and then perhaps in the longer term from electrolyzed hydrogen and reformed carbon dioxide generated using renewable energy. The reuse or recycling of carbon from our biosphere, instead of continuing to pull it out of the earth in the form of petrochemical fuels, enables us to stop increasing the level of net CO2 emissions growth, and then perhaps enable future reductions, depending on level of incorporation.

SAF represents the only viable approach for achieving any level of deep net carbon reduction in-sector. This is reinforced by the fact that ~93% of carbon emissions come from aircraft flights of >80 seats and flying more than >500km. Even if we were able to double the rate of historical efficiency improvement offered by the incorporation of engine and aircraft technologies in new design introductions, and completely removed the system inefficiencies driven by operations and infrastructure shortfalls, we would still have an increasing footprint of carbon emissions based on historical traffic growth levels. This growth is driven by the continued burgeoning demand for safe, efficient, long-range, high-speed transport of goods and people offered by aviation. Only the reductions in net carbon affiliated with SAF usage allow us to cap physical emissions and move in the direction of annual reductions. Further, while progress is being made with hybrid aircraft, electrified aircraft, and use of hydrogen as a primary fuel source for aircraft, such technology pursuits are today primarily targeted at vehicles with <80 seat and <500km range whose carbon emissions comprise a small fraction of aviation's impact. These radically new technologies remain far from being technically feasible (let alone cost feasible) for use in commercial fleets, likely for several more decades. Such systems cannot achieve levels of sufficient energy per unit volume or per unit mass to even be considered in conceptual aircraft design studies, let alone for system demonstration in test vehicles and rigs, often missing the targets of today's technologies by 1 to 2 orders of magnitude. This is not to say that such technologies are not eventually critical, and should continue to be researched, but for near term reductions that enable longer-term significant reductions, SAF will be key.

The opportunities and challenges of SAFs for reducing the aviation sector's carbon emissions are many. The opportunities include:

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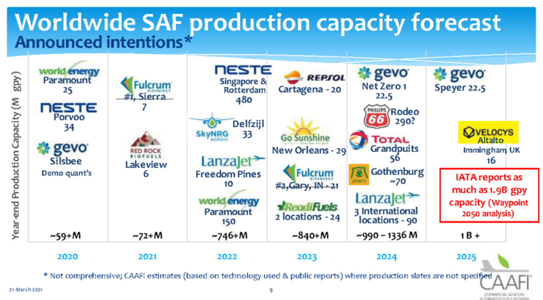
[1] Climate change (atag.org)

- SAF are not hypothetical. We started using them commercially 5 years ago, and have many pathways and opportunities to increase their production.
- Three facilities continuously produce SAF today. Several facilities are being built, and many others are being engineered or are in various stages of planning. The industry will perhaps achieve the first 1% of jet fuel worldwide usage coming from SAF within 5 years.



- SAF are drop-in fuels. No investments are required for replacing aircraft, retrofitting airports, retrofitting or adding fuel transport infrastructure, or requiring completely new and significant power infrastructure. Based on this view, it would appear that the development of SAF is likely to represent the lowest societal cost to deep decarbonization of aviation. Any incremental cost comes in the form of the new SAF production facilities themselves, as well as some infrastructure required to enable fuel blending and integration with existing distribution systems (e.g. fuel tanks, blending systems, transfer racks, and terminal stations). Further, the industry is currently moving in the direction of defining 100% SAF formulations which will reduce and perhaps eliminate the need that currently exists for blending neat SAF with conventional jet fuels.
- SAF are proven to lower net carbon emissions. Most of the pathways being pursued achieve greater than 50% lifecycle reductions in net carbon. Today, fuels are being delivered for use with 70+% reductions, and approaches have been identified to continue moving in the direction of 100% reductions (net zero carbon fuels), and even beyond, to net carbon negative fuels.
- SAF will be free of sulfur, and likely to have significantly reduced polycyclic aromatics, resulting in significant reductions in tailpipe criteria pollutants (particulate matter, CO, UHC, and HAPS) which affect air quality, as well as contribute to contrail production[2].
- SAF can be produced from a very wide range of biochemical and thermochemical processes, with a wide range of feedstocks, including fats, oils, greases, sugars and starches, lignocellulose, a wide range of 24x7 waste streams from various human activity and circular-economy production concepts.

The challenges include:

- SAF is a nascent industry, arguably 12 years old, competing against a petroleum baseline initiated in 1859 and enjoying 162 years of optimization and tremendous scale.

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[2] IPCC and other academic studies suggest aviation also produces other exhaust constituents responsible for radiative forcing responsible for planetary warming, beyond just CO_2, including: PM, NOx, water vapor, contrails, and persistence contrails which can form cirrus, all of which combined may have twice the radiative forcing impact as CO_2 alone.

- SAF production generally cannot compete with the cost of petro-jet at today's oil price. The carbon reduction afforded by SAF is not yet fully monetized, and as a result of the failure of free market economics to change this paradigm, policy is needed to affect change.
- Given appropriate policy support, either through incentive or regulation, SAF will still need to pursue significant supply chain development and cost reductions. Such cost reductions are typically achieved through the continued introduction of technology, utilization of low-cost feedstocks, and via learning curve improvements and tech and supply-chain scale-up. These reductions cannot commence without an initial push of commercialization, again, likely needing to come from policy support.

I have often referred to aviation's intent to use SAF as simply requiring the establishment of an entirely "new industrial sector," replete with its own technology development, supply chain development, demonstration and deployment activities, building of new refineries, enabling distribution infrastructure, and key commercial players. Although we passed the 5-year anniversary of continuous production of SAF from the first facility[3] on 10Mar'21, this sector should not be viewed as anything but a nascent sector. There is no doubt that foundational progress has been made to enable this sector to reach its initial penetration of 1% of jet fuel utilization by 2025, but the industry is clearly thinking more holistically than that. Initially, to a program that represents a major fraction of aviation's 2050 aspirational reduction goal (-50% from 2005 levels), to even more aggressive goals that are now being announced by airlines on a continuing basis. These more aggressive goals are in line with societal consensus goals of achieving net-zero carbon in 2050 or earlier, or in line with Paris commitments, with some advocating for net-zero carbon in 2030.

What is needed to accelerate and achieve these broad goals for SAF development and commercialization, specifically from the perspective of Agency assistance? … A full range of R&D and demonstration and deployment efforts across the full set of various supply chain models that have demonstrated technical feasibility, and economical promise.

- Interagency collaboration has been shown to be effective in such cases, as the concept of a "new industrial sector" include the remits of USDA, DOE, DOI, DOC (NSF), and DOT/FAA, with DOD's branches being both SAF consumers as well as active researchers in pathway development and certification.
- Several years ago, these agencies, including OS&TP, worked with aviation and fuel industry focals to develop a Federal Alternative Jet Fuel R&D strategy[4] (FAJFRDS). The strategy outlines essential R&D needed to enable this sector to flourish. Since then, some of the work elements have been completed or are ongoing, but many remain, or today would be expanded to areas of discovery since then. The Strategy outlines goals in 4 general areas:
    - Feedstock Development Production and Logistics
    - Fuel Conversion and Scale-up
    - Fuel Testing and Evaluation
    - Integrated Challenges

  The Strategy included 82 specific work elements, in near, mid, and long term efforts, assigned to the above identified Agencies, either individually or collectively. It also included

[3] World Energy's Paramount, CA plant (previously AltAir) delivering continuous quantities of SAF to Los Angeles International Airport via contracting with United Airlines.
[4] Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf (caafi.org)

a focus on multi-agency collaboration for more optimal coordinated research. A recent report on SAF from the DOE's Offices of Energy Efficiency & Renewable Energy, and Bioenergy Technologies Office[5] both outlines similar R&D needs, as well as the value of interagency and industry collaboration. The recently formed SAF Interagency Work Group, operating under the auspices of the USDA/DOE Biomass Research and Development Board is currently undertaking an update and refresh of the FAJFRDS.

Finally, Subcommittee staff have also discussed the potential need for a more formalized SAF Interagency Agreement, including development of a Strategic Plan that coordinates the involvement with industry and academia, across Federal Agencies, resources, and programs, including workshops, execution of aligned and integrated R&D and demonstration and deployment efforts. It also suggested the development and funding of appropriate budgets, and reporting of such needs and progress to Congress. Many of the elements of that proposed Interagency Agreement align with the needs and approach of the previously derived FAJFRDS, and are viewed by this author as being pertinent to making significant and optimized progress with SAF development and commercialization.

The aviation industry remains extremely interested in the development of SAF. At present, there are greater than 350 M gallons per year committed to offtake agreements with airlines, representing greater than $6.5 B in commitments, and such commitments are continuing to expand. However, in order to see the expansion of SAF commensurate with the societal demands for sector-wide carbon reductions, much work remains to get to the point of having SAF be competitive with petroleum-derived jet fuel. CAAFI will continue to work on the foundational elements that allow for future progress, and stands ready to collaborate with policy makers on effective approaches for governmental support, should they choose to do so.

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End of Additional Written Testimony

[5] https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

External Biography

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BIO – short

Steve is a commercial aviation professional with broad, strategic airline, aviation OEM, and SAF experience since 1985. Over his career, Steve has been a strong industry advocate who has worked in roles of developing pragmatic solutions to the challenges of aviation growth, and that interest led him to accepting the current CAAFI Executive Director role in 2012. CAAFI (the Commercial Aviation Alternative Fuels Initiative, www.caafi.org) is industry partnership fostering the development and commercialization of sustainable aviation fuels (SAF). CAAFI engages in public-private-partnership activities designed to assist in bringing together the group of participants needed to stand up an entirely new industrial sector.

Steve also continues to serve in leadership, steering committee, consultancy, and BOD roles with multiple aviation industry organizations in areas of applying technology and business concepts to enable commercial progression with SAF, both through the work of CAAFI, as well as independent activities through his consultancy.

BIO – Long

Steve Csonka is an ardent advocate for the aviation industry who seeks pragmatic solutions to the challenges of aviation growth. Built upon strong technical experience that spanned the breadth of the commercial aircraft/engine life-cycle, Steve's capabilities and initiative have led to his various engagements in business development and long-term, strategic planning for the aviation enterprise over the past fifteen years. Such work has focused on the nexus of future product requirements, technology progression, and industry value propositions, including aspects of policy, advocacy, regulatory affairs, and environmental impact.

Steve's overall industry engagement led to his current role as Executive Director of CAAFI (the Commercial Aviation Alternative Fuels Initiative, www.caafi.org) where he leads this Public-Private Partnership working toward the development and commercialization of sustainable alternative jet fuels (SAJF). He has been in this role since 2012, directing the CAAFI efforts of its 1200+ members and 500+ organizations who share the industry vision of enabling the decoupling of net carbon growth from expected sectoral growth. CAAFI engagement occurs through several work teams and public-private initiatives, and it seeks to be a force multiplier for a wide range of efforts required to achieve significant uptake of low net-carbon SAJF.

Steve is a commercial aviation professional with 35 years of broad, strategic airline and aviation OEM experience (GE Aircraft Engines, American Airlines, GE Aviation, and CAAFI). He holds BS and MS degrees in Aerospace Engineering. He has served in leadership, steering committee, and BOD roles with multiple aviation industry organizations (AIA, ICCAIA, IATA, GAMA, ICAO/CAEP, ATAG, Carbon War Room) in areas of technology and environmental progression. His CAAFI role has also led to appointments to advisory/leadership roles with the USDA/DOE BRDB TAC, the USDA/DOT/DOE/Industry *Farm-to-Fly 2.0* initiative, USDA/NIFA/AFRI CAP projects, and study committee work of the National Research Council.

Chairman BEYER. Thank you, Mr. Csonka, very much.

At this point I'd like to ask unanimous consent to include Congresswoman Julia Brownley of California on our Space Subcommittee for the purposes of this hearing. If there's no objection, Ms.—Julia, yesterday, by the way, gave a very passionate argument for SAF at a Ways and Means Committee Member hearing, so great to have you with us, Julia.

Ms. BROWNLEY. Thank you.

Chairman BEYER. Let me begin by asking Dr. Thole. You—in fact, all three of you have talked about hydrogen and the difficulty with it, the safety, problems to be overcome. Why has Europe chosen hydrogen and charged forward with that when we've been so reluctant?

Dr. THOLE. That's a great question, Chairman Beyer. You know, I mean, I think that they are being pushed by Airbus, which is one of their manufacturers, and they have made a decision to go that direction. There are a lot of advantages of hydrogen. You know, the fuel—or the energy density content of hydrogen is superior, and it can be made using green electricity, although currently it's not, so there are a lot of advantages there. And I think Europe sees the advantages, and they are putting a lot of money into it.

And so I can't really explain their rationale for doing this, but, you know, as I see it, I think there are a lot of challenges. There are a lot of challenges just from considering that the amount of space that hydrogen would require on an aircraft is three times larger than what we would—what we currently have. We have to store liquid hydrogen at minus 450 degrees Fahrenheit, which is a challenge in itself. And——

Chairman BEYER. And I guess all the opponents would have to do is say "Hindenburg."

Dr. THOLE. And Hindenburg, correct.

Chairman BEYER. Dr. Thole, you—let me pivot because you talked a lot about design disruption. You know, the larger picture, moving away from SAF, and you totally confused me by talking about fan pressure ratio and nacelles and revolutionary improvements in traditional tube-and-wing platform and boundary layer ingestion configurations. Can you simplify that for us humble Members of Congress——

Dr. THOLE. Yes, so——

Chairman BEYER. And the potential there?

Dr. THOLE. So if we want to improve the efficiency of our power generation on our aircraft, there's a big advantage to reducing fan pressure ratio and to have high bypass ratio engines. And so, you know, when you fly on an aircraft, right, and you look at the really big engines, you—they're huge. And right now, we're limited with the traditional tube-and-wing and landing gear constraints such that the nacelle can't grow any larger. And as the nacelle grows, in addition, you have additional weight and you have additional drag. So really our bypass ratios of our engines are somewhat limited at this point.

The other alternative is to shrink the core engine, right, so we can shrink the core of the turbine, which allows more flow area, or perhaps we can develop a new overall aircraft propulsion integration system such that we could have distributed propulsion. And

that's another way to do it. And that's what—and a disruption would be required for that.

Chairman BEYER. Thank you. You know, I've long had an interest in this, and Senator Cardin and I have introduced legislation in the last Congress and will again, the *Cleaner, Quieter Airplanes Act*, to bolster the R&D we need for competitive future aviation sector. And this testimony is exactly what we need. And this is not accidental because I live about two miles from a national airport, so it's our number-one constituent complaint.

Dr. Hansman, Norway is on track for full electrification for short-haul stuff by 2040. Do you see that electrification being—can we do that for short-haul? Should we be—where are we on electrification perspective?

Dr. HANSMAN. So if you say—if by electrification you mean full battery, it's really going to be short-haul, but the problem that we have with airplanes is that airplanes have to carry the battery, so the figure of merit that we think about is something we call specific energy, the amount of energy you can get per unit pound. And basically the battery technology has been improving, driven by the automobile interest, but, you know, we're sort of getting to the point where it's much harder, and once we get to the point that it's really not an issue for cars, it's going to be hard to get that specific energy up high enough that it really makes big airplanes practical, particularly on even medium hauls. So I think it's a desirable goal, but I think it's going to be tough to do anything practical, right, other than relatively very short-range airplanes at a sort of limited scale.

Chairman BEYER. OK, great. Thank you. My time is almost up, so let me yield now to our Ranking Member Dr. Babin if Brian is here.

Mr. BABIN. I am here. Can you hear me?

Chairman BEYER. Yes, good, good. I can hear you, and charge. The floor is yours.

Mr. BABIN. OK. All right. Thank you very, very much.

First off, I really appreciate the witnesses being here today. Dr. Hansman, the WTO recently ruled that Europe was allowed to implement $4 billion in tariffs against the United States, including aircraft tractors, ag products, and according to the World Trade Organization and the European complaint, this is based on NASA and FAA research and development subsidies, as well as tax breaks provided by the State of Washington. The U.S. has stated that it is now in compliance with the WTO order.

Similarly, Europe claims that they are now fully compliant with the WTO ruling that allowed the U.S. to impose $7.5 billion on European products despite the U.S. Trade Representative (USTR) arguing that they are not. NASA and FAA subsidies are small compared to the significant loan guarantees provided by European nations to Airbus.

Given the fact that U.S. industry funds most of the $15 billion annually spent on aviation research and development and that aviation is one of the largest sources of U.S. exports accounting for $148 billion in 2019 alone, is the small funding from NASA and the FAA worth the headache that it creates in terms of international trade and overall economic health of the U.S., Dr. Hansman?

Chairman BEYER. Dr. Hansman, you're muted for the moment.

Dr. HANSMAN. Sorry about that. Yes, I think there are some things that need to be funded by the either FAA or NASA. On the FAA side—and Steve talked about this a little bit—there's a need to fund those things that allow us to determine whether we can, for example, use synthetic or sustainable aviation fuels safely, so we have to think about the certification processes, so there's clearly a role there.

There's a general role for NASA to be doing fundamental research that enables the knowledge and understanding of the mechanism, so there's clearly benefit to us. If we want to move the system to a more sustainable system, it won't be done by the industry alone.

One of the things we did a few years ago, one of my students did a game theory analysis of, you know, what would incentivize improving the efficiency of airplanes? And it turns out it's very hard to take the risk and development time to do an airplane which would be fundamentally better. We know we can get 50 percent, 70 percent improvement in efficiency, OK, but this is too big a risk for an individual company to take on its own, so you need to do the underlying research to de-risk [inaudible] validation.

Mr. BABIN. OK. Well, thank you. Thank you very much.

And, Dr. Thole, the market has already responded to sustainable aviation challenges, and companies continue to pivot operations. Flights today produce 50 percent less CO_2 as the same flight did in 1990, and each new generation of aircraft leads to a 15 to 25 percent improvement in efficiency per passenger mile. The vast preponderance of the $15 billion a year spent on aviation efficiency research and development is funded by the private sector.

In January of 2021 the Boeing Company, a leading manufacturer of commercial jets, announced that they will begin delivering commercial airplanes capable of flying on 100 percent biofuel by the end of the decade. Airlines for America, the U.S. airline trade group, pledged to improve fuel economy by 1.5 percent a year, have carbon-neutral growth by 2020, and reduce CO_2 emissions by 2050 relative to 2005 levels.

In August of 2020, the energy company Phillips 66 announced plans to convert a facility in Rodeo, California, into the world's largest renewable fuels plant to support growing demands for these types of fuels. These impressive steps were taken by the U.S. private sector on their very own.

How can we maintain this positive momentum and focus academia and industry efforts to solve this challenge? What high-risk, high-reward research should NASA support that industry is unable or uninterested in conducting? And what are the highest-priority safety research areas tied to sustainable aviation that the FAA should focus on?

Dr. THOLE. I think during my talk I actually outlined some of those, so, for example, if we focus particularly on thermal efficiencies and improving thermal efficiencies, I think there are a lot of areas that we can work on in particular looking at high-temperature materials. The other thing I'd want to point out is—Mr. Babin is that——

Mr. BABIN. Yes, ma'am.

Dr. THOLE [continuing]. The amount of time to develop these new solutions is too long right now. It is—it takes a long time to develop new solutions. Part of that is because of our manufacturing requirements. The United States is one of the few countries in the world that can actually cast turbine blades, but those turbine blades come at a cost in terms of time and in terms of money. And I think that we need to develop better ways to do faster manufacturing and evaluate innovative solutions faster.

I think academia has a large role to play. We usually generally focus on lower technology readiness levels. We—for successful universities to work in this field, we work closely with industry. This is not a field that you fund through the FAA or NASA without a partnership between the Federal agency, the university, and industry. If you want to be successful in this field, you have to work with industry. And many of our universities do. So the dollars you spend in research are not going into esoteric studies. They're going into real studies.

Chairman BEYER. Thank you, Dr. Thole. And thank you, Dr. Babin.

Mr. BABIN. Thank you. My time is up, and I yield back. Yes, sir, Mr. Chairman. My connectivity and my video have gone down the tubes here, and I don't know how much time I've spent or have any left at all, so I apologize.

Chairman BEYER. That's all right. Thank you. Thank you, Dr. Babin.

Let me now recognize Dr. Bera from California.

Mr. BERA. Great. Great, thanks, Mr. Chairman. I may have—I've got poor internet connection right now as well, so let me know if my audio is not great.

A question for Dr. Thole. You talked a little bit about turbo-electric. If you can kind of expand on that compared to, you know, the battery-charged electric and then also the role of maybe hybrid technologies as, you know, I think about the car I bought 15 years ago, it was a hybrid vehicle, and the next car I'll buy will be all electric and, you know, what role hybrid technology may play. So, Dr. Thole.

Dr. THOLE. Yes, that's a great question. So there's a spectrum, right? There's the conventional gas turbines that operate today that—the next phase off of that is what I would call turbo-electrics. Turbo electrics do not require batteries or fuel cells, but they do require motor generators and all of the auxiliary equipment along with that, and what they enable is a concept that I talked about earlier which is distributed propulsion, and that can have significant benefits or at least we believe that it will have significant benefits in overall reducing the amount of fuel needs. So that's the turbo-electric class.

Then if you go to the next class, you have the hybrid electric class of engines or potential solutions. There are also a range of those. Generally, those still require a gas turbine as the power plant most likely, but perhaps a battery would be also put into the overall propulsion system to provide some power maybe during takeoff when more power is needed and so forth. So there are a lot of different hybrid electric architectures that are feasible, and com-

panies are looking at a range of different architectures right now to see the tradeoffs.

And then finally, you go to the last step, and the last step is maybe addressing your next car needs, and that's fully electric. And as already was mentioned I think by some of the other Committee Members, fully electric is a big challenge for large aircraft. And if you remember, 90 percent of the CO_2 emissions is coming from the large aircraft. To scale batteries and fuel cells to large aircraft, we do not see a path for that right now because if you look at the current energy density of batteries and what it would take to get there to implement solutions by 2050, there—it would require a major—you know, a major discovery, and we don't project that right now.

Mr. BERA. Maybe for——

Dr. THOLE. I hope that answers your question.

Mr. BERA. It does. And maybe for all the witnesses, then how should we be thinking about this as Congress? What are the investments we should be making if we're looking at turbo-electric as, you know, kind of the next step in reducing emissions and then, you know, the investments we might be thinking about making in hybrid electric if those are the more feasible paths and which of you——

Dr. THOLE. So the good news here is that both for turbo-electrics and hybrid electrics, considering that the gas turbine is still going to be the power plant, any investments that can be made in that area to increase the thermal efficiency is going to be—is going to impact both, the success of both.

In addition, the research that is needed to do the propulsion aircraft integration will also impact both areas, so I think that is a key area to invest in.

Dr. HANSMAN. Yes, I think the—one way to think of it is that these new hybrid electric or turbo-electric have to buy their way onto the airplane, so they either have to bring in [inaudible] efficiencies. So when we think about efficiency, there's something called the Breguet range equation, so you either have to improve the aerodynamics or you improve the energy consumption of the engines. So one of the nice things about particularly hybrid is you don't have to have a big engine for takeoff. Today, we [inaudible] because they have to be [inaudible] get away with a smaller engine so it might be more efficient. So we need to think about all of those pathways from the entire airplane system and how does the propulsion system improve the entire [inaudible].

Mr. BERA. Right. And, Mr. Csonka, if you want to add something?

Chairman BEYER. Mr. Csonka, you're muted for the moment.

Mr. CSONKA. My apologies. I would say the hybrid propulsion actually is the—a good first step that puts us on a pathway to expanding opportunities for other technologies down the road. So when you start the development of the hardware required to handle more electric power on the aircraft, you open the door up to the potential hybrid, and you potentially open the door up to further—more fully electric aircraft that don't appear to be on the horizon right now. So that's clearly where it has been a focus of NASA work over the last couple years, and that clearly would suggest

continued effort because it's a good first step for the—for pathways that lie in our future but still remain somewhat uncertain.

Mr. BERA. Great. And I see I'm out of time. Mr. Chairman, I'll yield back.

Chairman BEYER. OK. Thank you, Dr. Bera.

I now recognize the—Mr. Posey from Florida, who will be followed by Mr. Perlmutter. Mr. Posey, the floor is yours. And you are muted.

Mr. POSEY. All right. Thank you very much, Mr. Chairman, for holding this hearing.

I fully support the use of technologies to reduce emissions but have concerns for using feedstocks from crops and for the use of sustainable aviation fuels. My concern is that here we have, as in other parts of the world, we're devoting an increasing amount of land and resources to nonfood crops such as ethanol and now sustainable aviation fuels. You know, simply put, I think we should be growing crops for food and not for fuel.

I recently was shown a white paper on sustainable aviation fuels from the International Council on Clean Transportation (ICCT) March of 2021, and the paper contained the following statement that I'd like to share with you. "Increased demand for biofuels made from crops grown on dedicated cropland such as wheat or palm may displace commodity used for food and feed and increase the total agricultural area needed to meet the demand. The conversion of high-carbon stock forest, natural lands, and pastures to agriculture to meet the increased demand would release carbon from distributed biomass in soil and thereby would generate indirect emissions attributable to those biofuels." Those type of things often get forgotten and overlooked in the process.

Mr. Csonka, in your testimony you state, "Sustainable aviation fuels is not yet broadly monetizable and as a result of the inability of the free-market economics to change this paradigm, policy is likely needed to affect the change." Would one policy include a new renewable fuel standard (RFS) that would mandate volume production levels for sustainable aviation fuels, as happened with the ethanol fuels?

Mr. CSONKA. So let me address the first part of your question first. Yes, I understand ICC's position. I would suggest that that's somewhat of an alarmist position for an entity that's interested in other solutions for aviation. And what I would also say to you is that there are no crops being grown today for the production of SAF. It's fairly limited in supply.

But I think the more interesting perspective, Mr. Posey, is that we—the aviation industry is very attuned to the criticisms associated with things that have happen in the past with respect to sustainability of feedstocks, and so it may surprise you that, as we look at the use of waste streams alone, municipal solid waste, forestry waste residues, wood processing waste, ag waste, waste food production oils, industrial off gases, and some amount of oil coming from crops that actually don't contribute to indirect land-use change can supply the full amount of fuel that we need for aviation. That's without dedicated energy crops. And the aviation industry is clearly focused where we need to be with respect to dedicated energy crops on ones that address sustainability.

Secondly, with respect to the issue of policy, there are a lot of policy elements. Jet fuel actually does—is able to take advantage of RFS policy at it exists today, as well as tax treatment from a blenders tax credit perspective and things like the California low-carbon fuel standard (LCFS) and other mechanisms in other parts of the world. So the policy does exist.

Would the production of SAF benefit from refinements to those policies? Absolutely, and there is a clear effort right now in Congress to address perhaps the first challenge that the industry sees as trying to level the playing field between the production of sustainable aviation fuel and the production of renewable diesel. I just added up the statistics this morning. There are 6.9 billion gallons of renewable diesel capacity being planned today. That technology is completely applicable to the production of SAF. The issue for—the reason why that production is targeted to diesel is that diesel enjoys benefits from that policy that SAF doesn't, and so a blenders tax credit specific to aviation fuel is being proposed for renewable diesel to level that playing field and see some of that 7 billion gallons of fuel production come in the direction of sustainable aviation fuel.

Mr. POSEY. I see my time is expired, so I yield back. Thank you very much.

Chairman BEYER. Thank you, Mr. Posey. And, Mr. Csonka, thank you for that very clear description of where those biofuels are coming from. It was a fairly effective response to Dr. Babin's opening statement, so thank you.

I'd now like to recognize Mr. Perlmutter, who will be followed by Congresswoman Young Kim from California. So, Mr. Perlmutter, the floor is yours.

Mr. PERLMUTTER. Thanks, Mr. Chair.

And this is to Dr. Hansman and Mr. Csonka. And it's—I'm coming at it a little different angle here. I'll give you some background. I've been working on helicopter fuel systems for the last few years. We've seen in—there's—the fuel systems have been very fragile. If there have been accidents, the helicopter blows up, burns everybody. And we recognized this back during the Vietnam War, and the military changed their fuel systems. But commercially, we haven't really done much until just now. There have been some very well-known high-publicity kinds of accidents where people were killed, and I guess what I'm saying is I just—it's hard—and, Dr. Thole, you were talking about this. How long, given the fleets that are out there, will it take to retool and revamp our engine systems for sustainability? I'm just trying to get new fuel systems in helicopters for safety purposes.

So, Dr. Hansman, you started off talking about how long it will take to retool the entire fleet, so can you and Mr. Csonka and Dr. Thole expand on that for me, please?

Dr. HANSMAN. Sure. So if—one way to think of it is if a brand-new technology came in, so if you go back and look historically at the jet engine, when the jet engine came in, it took 20 to 25 years for most of the airplanes flying to be jet aircraft. So in—another way to think of it is a commercial transport airplane is like a factory, so you're not going to throw away that factory. In fact, we don't have the capability to reproduce it. So even if you had the air-

plane ready to go and certified, it would take 20 years to propagate into the system.

Now, let's step back and look at what it would take to get that airplane available. You need to design the airplane [inaudible] certification. One of the reasons—pardon me—why we are hesitant to go to new technologies is there's a huge risk in certification. If you go to a totally new technology, you don't necessarily know what will be—we need to do to make it fully safe, so it's easier to go to an existing—what Karen mentioned as a tube-and-wind configuration. We know how to do that. We know how to do the structures. We certainly know how to do the engines. So in order to stimulate a kind of revolution in—there are things we know we can do to make the airplanes much better, but nobody's going to take the risk. So this is really where we have to, as a collective, sort of go into that.

So, now, the sustainable aviation fuels or the alternative fuels are a little bit easier because they can be used, as Steve said, as a drop-in, but you need to make sure that they're safe, so one of the challenges to go to 100 percent today is to make sure you haven't introduced a problem like leaking C-fuels or whatever that come due to the chemistry of the fuels. So we need, you know, to look at it as sort of a long-term process, all of the steps. We need to do what we can in the short term, but we need to invest to get the risk down so we can make the changes in the long term.

Mr. PERLMUTTER. All right. So let me turn to Mr. Csonka for a second. So in my helicopter example, the military made changes 50 years ago. Commercially, we haven't made any changes, but now we're changing the fuel systems in new helicopters, but we still need to go retool the current fleets. So how would your drop-in fuels—I mean, what kinds of things do we have to worry about with your approach? And you're muted.

Mr. CSONKA. Yes. Yes, thanks. Thanks for the question. So the short answer is you have to take no changes with respect to the current or legacy or future fleet. The thing we have to keep in mind is that jet fuel is an extremely efficient, extremely safe fuel system. It's an energy system. And it's actually quite unparalleled. We've talked about hydrogen and other things, and there are tradeoffs associated with those. So jet fuel works.

I think a lot of the changes that you're talking about are actually changes to the infrastructure of the vehicle itself, to delivery systems, fuel protection systems, et cetera. The beauty of a SAF approach is that all of that stuff can happen in parallel with the continued introduction of sustainable aviation fuel. And the reason that that can happen in parallel is because these molecules that we're producing synthetically, they are identical to the molecules that you find in jet fuel. There are no differences. We're not introducing something new. We're not introducing an ethanol molecule to a gasoline pool or a fatty acid methyl ester to a diesel pool. These are jet fuel molecules. So drop in, no change is required, it continues to enable the safety and efficiency in the system that we've come to know and love.

Dr. THOLE. If I could also say something unless the time is up.

Chairman BEYER. Dr. Thole, go ahead, please.

Dr. THOLE. I—you know, I appreciate what Dr. Hansman said and, you know, he gave your timescale, but I also want to point to a counterexample. In 2016, Pratt & Whitney offered the gear turbofan. The gear turbofan reduces the amount of fuel needed by aircraft by about 100 gallons of fuel per hour, which is significant. Since 2016, there are already 10,000 engine orders for that engine. I can point to an equally successful program, the LEAP (Leading Edge Aviation Propulsion) program on the GE side, so the market is very hungry for this.

While it will take some time to infiltrate the entire market, there are some success stories out there that are recent success stories that aircraft, as Chairman Beyer pointed out, you know, airlines are spending a lot of money on fuel, and so with fuel savings, they're going to buy these new engines, for example. Thank you.

Mr. PERLMUTTER. Thank you very much. Thanks to our witnesses. I yield back.

Chairman BEYER. Thank you, Mr. Perlmutter.

I now recognize and welcome to the Science Committee and the Space Subcommittee Congresswoman Kim. The floor is yours.

Ms. KIM. Thank you, Chairman Beyer. I'd like to go directly to the questions and to all our witnesses. I want to thank you for joining us. This is a very enlightening session for me.

You know, NASA Aeronautics in southern California has played a leading role in the new X-Plane flight demonstrators, including electric propulsion and low boom supersonic flight demonstrators. As NASA prepares to launch a new transonic truss-braced wing flight demonstrator, how can a national subsonic demonstrator support and accelerate adoption of innovative new structures, composites, and propulsion systems for commercial aviation that can help increase efficiency and reduce emissions?

Dr. HANSMAN. So let me start on that. I think that the role of the X-Planes is to demonstrate the technology and provide a basis to de-risk it, to allow the industry to actually move forward on that. So the—the X-Planes, for example, the transonic truss-braced wing, it's not just that transonic wing, it's the set of tests that would be done on the airplane that would provide the basis. It would allow you to both design and certify airplanes in the future. So, again, it's—NASA is not a manufacturer. They're not trying to push an idea. They should be trying to do the knowledge discovery, the engineering that would support us in actually investing and making a new airplane configuration going forward.

So I think it's an important role because there is—you know, these things take a long time and they're expensive to do these big test airplanes and to do the engineering right and get the information.

Dr. THOLE. Yes, I think the only thing I would add is I think the role of NASA is really critical in making sure that this industry take risks and can demonstrate risky technologies. And I think that's where NASA, again, working with the industries and universities, can play a major role.

Ms. KIM. All right. I'll go to next question, actually, Dr. Thole, since you talked in your testimony, you remind us that China and the E.U. are also racing to develop sustainable aviation solutions. So what actions are currently taking place to ensure that the U.S.

is a leader in sustainable aviation technologies, and where are further investments needed to remain competitive?

Dr. THOLE. Yes, so I will start off by telling you a little story, and I put this in my testimonial. You know, I have been approached on numerous occasions by colleagues in China working at very highly respected universities asking for me to work with them directly. And I was opened and—you know, given an opportunity to have an open spigot of money on any research I wanted to do. And so, you know, I didn't take that money and—because I am fortunate to be—you know, be well-funded by the—by industry as well as by FAA, NASA, and the Department of Energy. And so what's very key and what's important for us to develop a competitive workforce in this area and for us to keep that—to keep universities working in the space is to make sure that NASA Aeronautics is funded at a heavy rate, the FAA, the ASCENT program, which I also am a part of, you know, is funded at a high rate and particularly also the U.S. Department of Energy. So those—you know, those Federal funding agencies play a key role in making sure that, you know, we do maintain some—you know, some—we maintain leadership in the aviation industry.

Ms. KIM. Thank you.

Dr. HANSMAN. Yes, I think—sorry.

Ms. KIM. Go ahead.

Dr. HANSMAN. No, I was going to say I think we need to think about this strategically, so as Karen indicates, we need to make this as a strategic investment. [inaudible].

Ms. KIM. Well, thank you. I wanted to put in the last thoughts and maybe if there was time I would like to hear your thoughts as well. You know, regarding the former U.S. Trade Representative Robert Lighthizer, he recently stated in an interview with Reuters that the U.S. and Europe should agree to cooperate in opposing any future hurtful subsidies used by China to buildup its commercial aircraft industry. And Mr. Lighthizer expressed frustration that current WTO rules would not prevent future subsidies by the European Union or China. So can you explain what can the U.S. do domestically to prevent predatory trade practices by other nations? Anyone can answer.

Dr. HANSMAN. I think we're not experts on WTO policies.

Dr. THOLE. I would agree. We're not—I'm not an expert in this, so I——

Ms. KIM. OK.

Chairman BEYER. Congresswoman Kim, that may be a better question for the record, but——

Ms. KIM. Yes.

Chairman BEYER [continuing]. We'll get you to ask it as a Ways and Means Committee.

Ms. KIM. I know my time is up, so if I can get an answer at a later time, that would be greatly appreciated. Thank you. I yield back.

Chairman BEYER. Thank you very much.

I now recognize Congresswoman Lofgren, Chairman of the House Administration Committee and many other things.

Ms. LOFGREN. Well, thanks very much, Mr. Chairman. This has been an interesting hearing.

And as everyone probably knows, I represent San Jose, California, and the San Francisco Bay area is very much on board with sustainable aviation fuel. In fact, I believe or have been told that two California airports, San Francisco and LAX, actually dispense most of the sustainable aviation fuel in use today.

Now, I think part of the reason for that is the California Air Resources Board addition of sustainable aviation fuels as an eligible credit generator to the carbon—low-carbon fuel standard program, but there are still, I think, a few other barriers. And I'm interested—I probably—Mr. Csonka, you might be best to answer this but maybe others have comments, too. What can be done to reduce the price of SAF's as it compares to conventional jet fuel? And would Federal policy creating something like the California credit be part of that price reduction?

Mr. CSONKA. Thank you very much. And yes, absolutely. First, I concur with your belief and statement that the introduction of fuel to California airports of SAF is directly attributable to the policy associated with low-carbon fuel standard. And so in the comments that I made earlier about the need for policy to change the paradigm that exists in the marketplace today with carbon reduction not being recognized or monetizable, the California low-carbon fuel standard clearly does that, and it's—it has absolutely been responsible for the introduction of that fuel.

There are other likely policy mechanisms that can come into play. Those—and there have been several think tanks and other folks who have looked at additional mechanisms for different kinds of policy support that could be brought into play. I'll refer you to the Atlantic Council's look at policy applicable to sustainable aviation fuel. But yes, a national LCFS system could address issues associated with potential shortfalls to the existing RFS policy. It can do some other things like level the playing field between all airlines with respect to whether one airline wants to be more progressive with SAF usage and another doesn't and helps create a level playing field there. So yes, there clearly are opportunities for mechanisms.

The reason that the industry is clearly behind the blenders tax credit at present is to address this disparity with respect to existing policy between diesel and jet fuel but also because it's near term. We understand economics associated with producing fuel in California under the LCFS and with the existing non-level playing field, and the blenders tax credit proposal addresses that issue specifically.

What becomes harder is something like what Congresswoman Brownley has proposed is a longer-term strategy for what actually moves us further in the direction of long term addressing these issues, and that's where it becomes very gray because we don't know, as an industry, what happens if RFS gets redone in some fashion. You know, what might happen at the Federal level to bring in new policy elements? And will significant regulation that requires multiple years be required to introduce that kind of legislation? So it's one of those things of, you know, a bird in the hand is worth two in the bush. That's why we have the focus on BTC today, and tomorrow, it becomes much less clear to us what appropriate policy mechanisms might be.

Ms. LOFGREN. I wonder if—you know, this has been a useful hearing for me to hear that, you know, a molecule is a molecule is the same as the other jet fuel, so what's the reason behind the current 50 percent blend limit?

Mr. CSONKA. So I said that all of the molecules in SAF are molecules that are currently found in jet fuel but not necessarily all of the molecules that are found in jet fuel. That's the difference. So we established initially a blending limitation to ensure that the full suite of molecules that we've been operating off of for the last six, seven decades still remains in jet fuel while we continue to learn more in this sector.

The good news is or the bad news is the first couple pathways were limited in how much—how identical they were to the jet fuel they were replacing. We've got a couple pathways now. One's already approved and a couple or more on the way that now are producing a nearly identical replication of the full suite of molecules that we find in petroleum jet fuel, so those create the basis for us over the next couple of years to increase the SAF blending limit from its 50 percent maximum level today to perhaps fully drop-in 100 percent synthetic fuels tomorrow. And we're working diligently on the foundation of that strategy.

Ms. LOFGREN. Well, my time is expired, but let me just say I think that is exciting news given the role that aviation plays in climate change.

So, Mr. Chairman, I yield back. Thank you very much.

Chairman BEYER. And thank you, Chairman Lofgren.

And now one of our greatest enthusiasts of SAFs, Congresswoman Brownley from California.

Ms. BROWNLEY. Thank you, Mr. Chairman, and I thank the Ranking Member also for allowing me to participate in today's hearing.

You know, I have been working on this issue and have reintroduced a bill that has a number of different policy mechanisms, including grants, tax credits, standards, as well as R&D funding.

And I'm grateful for Mr. Csonka here today. Full disclosure, he has been extraordinarily helpful to my office in crafting legislation, so I'm greatly, greatly appreciative.

And so, Mr. Csonka, my first question is to you. You know, as you know, my bill would fund a number of research priorities that industry experts have told me are important issues in need of more study. So one of these priorities is developing SAF that can be used without blending with fossil jet fuel. Another is studying the climate impacts of non-CO_2 greenhouse gas emissions from jet fuels like water vapor or contrails. What are these—why are these important research priorities for the industry?

Mr. CSONKA. So the first one is I personally answered that in the last question which is if we know that we need to count on sustainable aviation fuels to deliver carbon reductions that the industry has signed up for, that policymakers might be interested in, we need to remove artificial barriers long term, right? So external fans or foes of what we're doing [inaudible] look at the 50 percent blending limit as a hurdle, a limitation on how much benefit we can actually get from SAF. And so we're interested in removing those

kinds of carriers and hurdles, letting the world know that, yes, we can go beyond the 50 percent blend level.

And so if we produce a fuel that delivers an 80 percent net lifecycle carbon reduction and we're able to use it at a 50 percent level to get a 40 percent reduction, if we're able to use it at a 100 percent as a full drop-in, we get that full 80 percent reduction. So that's why we're focused on that. And there is some more research and development activity that needs to occur that builds on work of the last five years through the National Jet Fuel Combustion Program and other work of NASA and FAA to continue to ensure that we move from the paradigm that we're in today, 50 percent maximum levels to 100 percent max levels.

Ms. BROWNLEY. I've got a couple more questions [inaudible].

Chairman BEYER. Go ahead.

Ms. BROWNLEY. So, you know, to all the panelists, I just wanted to ask a very quick question and that in your opinion do we need more research before SAF is ready to be deployed at scale? Just yes or no.

Dr. HANSMAN. Yes.

Mr. CSONKA. Yes.

Dr. THOLE. Yes. Yes.

Mr. CSONKA. Yes.

Ms. BROWNLEY. OK. And, you know, I guess I would like to delve into that deeper by your answers, but I don't think I have enough time, so I'll talk to you later about it.

And the last question before I run out of time here is, Dr. Thole, you talked about China and the European Union. I was just wondering if you could tell me, you know, where is—we sort of—I think in this hearing sort of disclosed and uncovered where the United States is with SAF at this particular point and where it might be going in the nearest future, so where is exactly China and the European Union on SAF production?

Dr. THOLE. Yes, I think I will have to defer to Steve on this one. He probably is more aware of that than I am in terms of——

Ms. BROWNLEY. So you have talked more about hydrogen and other technologies, where they are ahead?

Dr. THOLE. They—oh, yes, that's right. They have made a committed effort to hydrogen right now, a significant financial commitment, and they are plowing ahead.

Ms. BROWNLEY. OK. So——

Dr. THOLE. And China on the—you know, what China is doing is they are developing an aviation ecosystem, right? Everything from airframers to engine companies and everything in between, so——

Ms. BROWNLEY. Very good. So, Mr. Csonka, is China doing SAF production as part of their portfolio here? No, none?

Mr. CSONKA. They are not.

Ms. BROWNLEY. OK.

Mr. CSONKA. They've done some demonstration work only. Europe produces about half, America produces about half of what's being produced today.

Ms. BROWNLEY. Very good. Well, it looks like my time is up. Again, thank you, Mr. Chairman, for allowing me—this has been a great hearing, and I yield back.

Chairman BEYER. Thank you, Congresswoman Brownley, very much. And I'd really like to thank all of you.

Dr. Thole, we heard your name pronounced six different ways today, which is fun, but——

Dr. THOLE. That's OK. I think I've answered to all of them, so I hope it's OK. It's Thole. It's Thole, but that's fine.

Chairman BEYER. And I for one have been really impressed by the incredible range of knowledge that all three of you have brought to this, so I'm very, very grateful.

I would like to ask for unanimous consent to introduce a letter from BIO that was sent and has been reviewed by Republican staff, so if no concerns, it will be part of the record.

There—I think Members have two weeks to submit other additional statements, and we will try to get Congresswoman Kim an answer on USTR Lighthizer's concerns about China and its progress.

So with that, I want to thank you very much again for being part of this, and I bring this meeting to a close. Thank you all for your testimony. Have a good, good spring and goodbye.

[Whereupon, at 12:24 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Karen A. Thole

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Exploring R&D Pathways to Sustainable Aviation

Questions for the Record to:
Dr. Karen Thole

Answers Submitted by Dr. Karen A. Thole in Response to**:**
Chairman Byers' Questions

1. **Sustainable R&D and related activities needed to help meet aviation's climate challenge span multiple agencies and involve industry and academia. Do we need a national R&D strategy for sustainable aviation?**
    - **What, if any, test or laboratory facilities are needed to advance R&D onsustainable aviation technologies and fuels?**

Since the 2016 low carbon aviation study by the National Academies was completed, there has been considerable attention given to sustainable aviation by industry, academia and multiple federal agencies. The importance of developing solutions, particularly for the large aircraft, have been confirmed by the strong commitments made by industry to meet CO_2 reduction goals by 2050. Our nation, however, is in need of a roadmap and very focused approach that considers all of the aviation operations with accurate bookkeeping of the CO_2 impacts. This roadmap is not only critical to developing a defined R&D strategy, but also critical to the continued leadership position in the aviation industry that the U.S. has maintained through the decades.

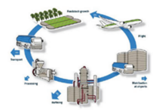
Similar to the manufacturing institutes that were launched during President Obama's administration, I propose a potential approach that identifies focused R&D hubs in key areas. These efforts will require particular focus areas suggested by the graphic below. For each of these efforts, there will be specific expertise needed and, in some cases, new large-scale facilities. FAA and NASA and perhaps other federal agencies could be the lead on each of the proposed R&D hubs. It is critical that close collaboration between the federal government, industry, and academia take place in these hubs with projects ranging from small to large scale and from low to high risk. Involving new industry entrants to these hubs will stimulate innovation and develop a strong aviation economy. In the graphic, proposed large-scale facilities for some of the R&D hubs are identified. In some cases, there are existing facilities either in the private sector or at NASA, including the NASA Electric Aircraft Testbed (NEAT), that will be needed for the hubs.

It is time now to invest in focused areas that are feasible to ensure reduced climate impact and maintaining leadership in aviation. And it is time that a roadmap be developed.

Sustainable Alternative Fuels R&D Hub

- Low-cost feedstocks and production
- SAF impacts at micro/macro scales
- Turbine transition from 50/50 to 100% SAF

Missing test facilities: facility that assesses SAF impacts on environment (contrails) and hardware (turbines)



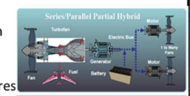
Fully Electric Small Aircraft R&D Hub

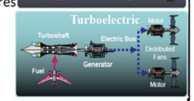
- Batteries / fuel cell capabilities
- Superconducting motors and generators
- Vehicle noise

Partial Hybrid / Turboelectric Large Aircraft R&D Hub

- Turboelectric system integration
- Electrical technologies
- Aircraft-propulsion integration
- Turbine efficiencies for small cores
- High temperature materials/coatings

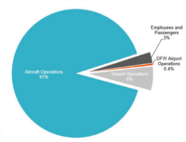
Missing test facilities: complete system that encompasses all components (turbine, battery, generators, propulsors)





Airport Operations R&D Hub

- Analysis of hydrogen to replace/augment energy sources for airport operations, ground support equipment, electricity generation, backup power
- Transportation and handling of fuel



2. **To what extent are the various trades among research and technology approaches in terms of carbon reduction, cost, infrastructure, noise, efficiencies, reliability, safety, and the fundamental science behind how various systems integrate, among other factors, well understood? What, if anything, is needed to improve such understanding?**

   The various trades among research and technology approaches are not well understood. The reason is because we are entering a new era with regards to the aviation industry. As one specific consideration, many communities are concerned about noise from current aircraft and helicopter operations, but as electrification of smaller aircraft becomes prevalent, we need to understand how the design choices lead changes in vehicle noise depending upon the number of lifting fans, fan geometry, and the use of ducts.

3. **In your prepared testimony and during the question-and-answer period of the hearing, you discussed the top R&D priorities for reducing carbon emissions from commercial aviation identified in the 2016 National Academies study that you co-chaired. What do you see as the primary factors affecting the pace of progress along those R&D pathways?**

   The primary factors affecting the pace of progress along the R&D pathways are the following: an aversion to high-risk approaches by our aviation community given the cost and time ramifications; a lack of federal support and cohesive approach; large-scale testing facilities (identified in addressing the first question); and meeting the workforce needs with highly qualified scientists and engineers who have skills that are different from those needed for current conventional approaches.

4. **What are your perspectives on the effectiveness of Federal government research coordination on sustainable aviation?**

   Support from the Federal government is critical in addressing sustainable aviation for the reasons mentioned in the answer to question 3. However, it is even more critical that the Federal government develop a cohesive long-term plan such as the one I proposed in addressing question 1. There are ongoing R&D efforts that are directed at sustainable aviation. However, it is now time to have a very focused approach whereby time spent and every dollar spent have an impact—especially with regard to large aircraft, one of the key contributors to the CO_2 emissions.

5. **Is there a role for the Federal government, or another entity, in being an "honest broker" on the feasibility and viability of sustainable aviation pathways?**

   There is a very important role for the Federal government in developing clear assessment methods to tracking the entire fuel life cycle starting with the fuel recovery and extraction to the product conversion to the fuel transportation to the emissions. An entire fuel life cycle needs to be considered in evaluating solutions. If we do not do the complete fuel life cycle, we are in danger of implementing solutions that could have serious consequences to our climate and society. As one specific example, the techno-economic and life cycle analyses are inconsistent across the SAF industry. However, the consistent message from most models is that the main cost drivers are feedstock costs, yields, and plant capital recovery. The Federal government has a role to play in standardizing these analyses.

6. **During the hearing it was stated that one of NASA's roles is to conduct basic R&D activities to minimize risk of new medium to long-term technologies for industry. To what extent should NASA's medium- and long-term aeronautics R&D portfolio be focused on meeting industry and international goals for reducing aviation's carbon emissions, and to what extent should that portfolio be targeting more aspirational or ambitious goals for carbon reduction beyond the current industry and international goals, such as complete decarbonization of aviation?**

   Because of the significant leaps required to reduce the largest CO_2 producer, namely the large single- and twin-aisle aircraft and because of the amount of time required to develop safe and feasible solutions, it is important that NASA's role remain focused on minimizing the risk of new medium- and long-term aeronautics in the R&D portfolio to reduce aviation's carbon emission. However, it is important that NASA collaborate with all of the federal agencies, industries, and universities to remain knowledgeable on how the complete decarbonization solutions could impact the aeronautics solutions.

7. **NASA's Aeronautics Research Mission Directorate is currently considering which concept topursue for its next X-plane demonstrator. What are the important factors to consider in this decision? What evaluation and analysis is needed to determine which concepts could have asubstantial impact on sustainable aviation R&D?**

I believe that NASA's Aeronautics Research Mission Directorate should direct their next X-plane demonstrator towards a partial hybrid propulsion system with a highly efficient turbine core having an integrated propulsion system. Such a demonstrator would be a critical and reasonable leap in identifying the following concepts: incorporation of two power producing systems (turbine and battery) to understand efficiencies of each and operations together on the flight mission; and integrated and distributed propulsion system to evaluate aircraft architectures.

8. **To what extent can near- and mid-term technology development efforts in support of lower-carbon solutions—such as sustainable aviation fuels, new engine or aircraft designs, hybrid electric aircraft—be scaled to eventually achieve decarbonization? Or, is the development pathway to decarbonization necessarily distinct from that of the low-carbon approaches? If so, how should the two be balanced in a sustainable aviation R&D portfolio?**

The development pathways to fully decarbonize are not distinct from that of the low-carbon approach in my opinion. However, as was stated previously, it is the Federal government's duty to develop honest broker assessment tools to track the progress towards low-carbon such that these analyses can be used to assess the potential of the low-carbon solutions towards decarbonization.

9. **In your prepared testimony, you recommended the U.S. develop a long-term strategy for hydrogen to remain competitive. Why should the U.S. invest in hydrogen-powered aviation R&D, given the technical challenges? Where should hydrogen fit within R&D priorities for sustainable aviation?**

In my testimony, I stated that the use of liquid hydrogen (H_2) as an aviation fuel has gained international attention. With three times the energy density of kerosene, H_2 promises not just net carbon neutrality, but zero CO_2 emissions. The potential exists for H_2 to be generated in the gaseous state using green electricity. However, in considering ease of integration into commercial aviation, the impact on aircraft design and performance, and additional and economic considerations, the case for making use of H_2 as a fuel source for large aircraft is difficult at best to defend. Added to these challenges are the nearly insurmountable safety challenges. To further elaborate, however, there are opportunities to consider the use of hydrogen for airport operations or for the production of sustainable alternative jet fuels. As such, it is my opinion, that the U.S. should identify all the feasible uses for hydrogen that can lead to further reductions in carbon emissions.

Questions for the Record to:

Dr. Karen Thole

Answers Submitted by Karen A. Thole in Response to**:**

Mr. Perlmutter

SAF Policy Considerations and Incentives

Colorado understands the benefits of sustainable aviation fuel so we can reduce greenhouse gas emissions, improve air quality, and bolster our economy. Denver International Airport (DEN) is just outside my district and wants to continue working with industry to collaborate on sustainableaviation fuel projects. We've also seen several U.S. aircraft and engine manufacturers announce efforts to make fleets 100% compatible with Sustainable Aviation Fuels. The current generation of large commercial aircraft are rated up to 50-50 blend of SAF and Jet-A; however, adoption of blended SAF remains low across the U.S.

- **What do you see as potential policy drivers for faster commercialization of sustainable aviation fuel? What are the hurdles?**

  Irrespective of the sustainable alternative fuel (SAF), there should be a regulatory-framework that can encompass new fuels and additives without legislative change. There needs to be a stable policy environment, de-risked technology, and acceptable economics to make SAF viable. Regulatory frameworks that incorporate market-based solutions (and are technology-neutral) that meet society's demands are important.

- **What can Congress do to incentivize airlines and airports to move to a 50-50 blend of Sustainable Aviation Fuels in the near term and adopt 100% over the longer term at the same time?**

  Two challenges to providing sustainable alternative fuels is the size of the jet fuel market, which is growing, along with the small number of SAFs that have been certified for a 50/50 blend, which today is eight. While the domestic available biomass in the United States can meet our aviation fuel needs, the price of SAF is costlier than conventional fuel and because fuel costs are typically between 20-30% of an airline's operating costs, we need an R&D plan that will drive costs down. Consider subsidies that would equate the airlines' costs of sustainable aviation fuels with that of current jet fuel prices. Also, consider the idea of providing tax incentives to airports that use their land to produce biofuels. The adoption of 100% will require assessment of the overall impacts on the turbine engine durability and operational efficiency so as not to increases costs. Finally, I suggest determining ways to achieve fast track approvals.

Questions for the Record to:

Dr. Karen Thole

- **Are there ideas which would help fledgling producers of Sustainable Aviation Fuel, such as cost-sharing grants, or loans? The Department of Energy and the USDA have some programs, but I'm hearing they may not be robust enough at this point.**

  Public-private partnerships and collaboration across agencies can accelerate cost reductions by ensuring that a diverse set of stakeholders identify barriers industrywide early on. More analyses are needed in bringing in the opportunities of using nontraditional raw materials such as deconstructed plastic and other waste materials, which could also reduce costs making SAF on parity with conventional fuels.

Military Follow Up

To follow up on my questioning with parallels to helicopter fuel systems, can each of you provide more detail on how DOD interest in SAF innovation and deployment can help advance the commercial transformation? With safer helicopter fuel systems we saw the military lead the design, engineering, and deployment of these safer fuel systems in the 1970s, but the commercial sector didn't finally standardize these safer fuel systems in newly manufactured helicopters until Congress required it in 2018. How do we shorten this lag time for SAF deployment?

DOD has an important role in shortening the lag time for SAF through de-risking technologies. For example, as we move from 50/50 blends to 100% SAF, we will need to assess turbine component durability as well as operational issues such as turbine seals. These problems will be common between commercial and military propulsion systems. Because of the more stringent propulsion demands for military applications, these issues will be even more pressing and, as such, the DOD can assist by identifying such issues and supporting continued technology R&D to address issues.

Questions for the Record to:

Dr. Karen Thole

Answers Submitted by Karen A. Thole in Response to**:**

Mr. Weber

1. **(See chart, attached) – I want to share a chart with you that shows just how much Europe has increased its investment in Aeronautics R&D, especially as part of its COVID relief spending. What was already a big gap in Aeronautics R&D between the U.S. and Europehas now become much larger – billions of dollars in difference each year. With the relatively small investments the U.S. makes through NASA Aeronautics and FAA R&D, are we doing enough to keep up with Europe's major investments in its domestic sector and companies? What are the consequences to the U.S. competitiveness and leadership in the aviation sector if this significant gap in R&D continues?**

   Thank you for sharing this particular chart showing the stark differences in funding in Aeronautics R&D between the U.S. and Europe. While I do not agree with Europe's increased funding directed towards hydrogen propulsion, I am in complete agreement that significant investments are needed to solve the long-term, challenging problems associated with aviation sustainability. This particular data is dramatic and there is no doubt on how this kind of financial commitment will impact the leadership role of the U.S. in aviation. We are all aware of the climate impact of aviation, but there is truly a race to develop feasible solutions that will have strong economic and workforce impacts.

2. **I represent many of the refineries that produce U.S. airports and airlines with jet fuel – fueling the majority of U.S. air travel. I would note that aviation represents just 2% of CO2 emissions, making aviation a remarkably efficient way to transport passengers and freight cargo relative to the billions of annual passengers and cargo the industry transports each year. Blending the jet fuel produced in my district with new SustainableAviation Fuel (SAF) feedstocks will be essential to meeting the aviation industry's commitments on efficiency – and with less than 1% of all fuel today incorporating SAF despite airplanes already being certified to fly up to a 50-50 blend. Would you agree that our oil and gas refineries and blenders play an essential role in increasing adoption of SAF?**

   Yes, I would agree that our oil and gas refineries and blenders play an essential role. Not only will these companies have an opportunity to invest in SAF giving them a wider product portfolio, but they already have the infrastructure for efficient transportation of fuels.

Questions for the Record to:

Dr. Karen Thole

3. **Proposals like the Green New Deal would impose regulatory costs for consumers on commercial air travel in the hopes of eventually eliminating the need for air travel in the next 10 years and instead encourage alternative sustainable travel options like high-speedrail. These proposals would not only result in over $1.5 trillion in lost economic activities attributed to the U.S. airline industries, but the U.S. would also lose competitive edge in advanced aviation and aeronautics technologies. What are some other proposals that would encourage sustainability for the aviation sector without detrimental economic consequences?**

   In considering these alternative modes of transportation, it is important to consider that the U.S. does not have the infrastructure necessary for high-speedrail and that those development costs, similarly, would need to be imposed on consumers if no additional government subsidies were provided. Until SAF production costs can be reduced at scale, it will be important for the U.S. government to carefully consider the need for subsidizing the additional costs relative to conventional fuels. Not only would we lose the competitive edge in advanced aviation technologies, but we would lose the need for a highly educated workforce which drives more than the aviation industry.

4. **The WTO tariffs on U.S. imports caused by NASA and FAA research subsidies result in higher costs to import aviation parts to the U.S. from Europe. Those parts are used at domestic manufacturing facilities in Alabama where Airbus has a plant that provides thousands of high-paying jobs for hard-working Americans. Should we promote free trade, or adopt the failed policies of the Soviet Union? With China seeking to export its own aircraft, which is almost entirely subsidized by the Chinese Communist Party, what kind of message are we sending to the international community if we are also subsidizing our industry? Should we rely on free market principles that made our nation the world- leader in aviation, and punish violators for violating those free market principles, or cave-in to the pressure and follow the lead of the Chinese Communist Party and subsidize our industry?**

   The obvious answer is that we should maintain our free market principles upon which our country and values have been built. These types of tariffs are not my area of expertise, but as a citizen and taxpayer, I am committed to retaining leadership by the U.S. in the aviation industry.

Responses by Dr. R. John Hansman Jr.

Responses to Questions for the Record
R. John Hansman
rjhans@mit.edu

Questions for the Record to:

Dr. John Hansman

Submitted by Chairman Beyer

1. Sustainable R&D and related activities needed to help meet aviation's climate challenge span multiple agencies and involve industry and academia. Do we need a national R&D strategy for sustainable aviation? What, if any, test or laboratory facilities are needed to advance R&D on sustainable aviation technologies and fuels?

A national strategy could be helpful but probably not critical if there is a clear national strategic goal for aviation sustainability. Test and laboratory facility needs will depend on which technology approaches are pursued.

2. You wrote in your prepared testimony of the importance of understanding systems-level and life cycle impacts of aviation environmental emissions and noise, and that the current state-of-the-art models, such as the FAA Aviation Environment Design Tool, need to be enhanced and expanded. Please discuss why such models are important and how they could be used to inform aviation's environmental impacts. Please identify the key open questions and challenges in modeling and understanding the life cycle impacts of aviation and systems-level effects. What is needed to advance modeling as you have described, and what plans, if any, does FAA or any other entity have to do so?

In order to determine the most effective approaches to mitigating the environmental impact of aviation it is important to understand and model the full life cycle impacts and the interactions between energy source generation, aircraft technology, fleet level operations and the environmental impact of the emissions and other environmental disturbances. Models need to include simulation of the effects of changes in technology or operations to determine the cost benefit of different options. This will be important in determining which sustainability approaches will be most effective and guiding national and industry investment as well as policy decisions.

3. Your testimony refers to environmentally focused operations that can be implemented within the existing aviation system. What operational efficiencies could be implemented and how and to what extent could they contribute to reducing aviation's carbon emissions and environmental impacts? o Are operational efficiencies that have been tested and demonstrated in research and pilot programs in wide practice today? If not, what are the impediments and how can they be overcome?

An initial list of potential operational mitigations are include in "Evaluation of potential near-term operational changes to mitigate environmental impacts of aviation" by Marias, Reynolds et. al. in the Journal of Aerospace Engineering https://doi.org/10.1177/0954410012454095. As an example which would have significant impact would be approaches to enable more efficient routings and

altitude assignments during long range cruise where a large fraction of aviation fuel and emissions occur. Airlines do a reasonable job of planning and flying fuel efficient routes but are limited by Air Traffic Control constraints and lack of surveillance in oceanic airspace. ATC modernization and operational procedures focused on routing flexibility and fuel efficiency in the oceanic, enroute and terminal area would have a significant impact.

4. What are your perspectives on the effectiveness of Federal government research coordination on sustainable aviation?

There has been good coordination on civil aviation led by the FAA Office of Environment and Energy at the ICAO level and with industry through the CLEAN Program and universities through the ASCENT Center of Excellence. NASA has been involved and is interested in being an even stronger partner. There is some coordination with the EPA and DOD although there may be opportunities to strengthen this.

5. Is there a role for the Federal government, or another entity, in being an "honest broker" on the feasibility and viability of sustainable aviation pathways?

I think that the key role of the Federal government will be to support research to enable and reduce the risk approaches to improve sustainability. This will include the modeling mentioned above but also core research on technology and operations. In addition the Federal government has a critical role in policy and regulation which will help industry justify investment and operational changes to improve sustainability. In the absence of an external Federal policy or regulatory stimulus only incremental changes in environmental performance are likely.

An additional need for an "honest broker" is in the life cycle accounting for any approaches which use market based approaches to carbon trading and offsets.

6. NASA's Aeronautics Research Mission Directorate is currently considering which concept to pursue for its next X-plane demonstrator. What are the important factors to consider in this decision? What evaluation and analysis is needed to determine which concepts could have a substantial impact on sustainable aviation R&D?

A key role of an X-plane demonstrator is to reduce risk to a level that would justify a manufacture to include the technology, configuration, or capability being demonstrated in a future aircraft. Part of an investment decision on a demonstrator should include an estimate of the probability that the results of the demonstration would impact a future aircraft design and how that change would impact the overall sustainability of civil aviation in the future.

7. During the hearing it was stated that one of NASA's roles is to conduct basic R&D activities to minimize the risk of new medium to long-term technologies for industry. To what extent should NASA's medium- and long-term aeronautics R&D portfolio be focused on meeting industry and international goals for reducing aviation's carbon emissions, and to what extent should that portfolio be targeting more aspirational or ambitious goals for carbon reduction beyond the current industry and international goals, such as complete decarbonization of aviation?

NASA should have a portfolio including medium and long term approaches. However NASA has the lead responsibility in the fundamental research to support long term approaches. NASA should be bold and have a part of their portfolio focused on innovative and "out of the box" approaches.

8. There is considerable interest in electric, hybrid electric, and turboelectric propulsion. What are the challenges in scaling this type of energy source into single-aisle and twin-aisle aircraft, which produce over 90 percent of aviation's CO_2 emissions?

Battery energy density is unlikely to be high enough to enable full electric for single-aisle and twin-aisle aircraft at any significant ranges. Hybrid electric, and turboelectric propulsion may have a role but would have to generate aerodynamic or fuel burn (specific fuel consumption) benefits to offset the additional weight and complexity to allow these technologies to "buy their way onto the airplane".

9. What, if any, R&D questions and issues need to be considered regarding the compatibility of sustainable aviation fuels with aircraft and engine components, materials, and related systems? Is ongoing research addressing these types of questions and, if not, which entity is best suited for this type of research?

A key near term objective is to increase the allowable percentage of sustainable aviation fuel which is currently limited by concerns on performance of fuel system and engine internal components and seals. This is an active area of research and requires coordination between FAA, manufacturers, operators and fuel producers.

10. After the hearing, we received the attached letter from the Alternative Fuels and Chemical Coalition. The letter suggests that the FAA has placed less emphasis, including funding, on activities related to setting policy goals and the safe integration of SAFs with aviation equipment and infrastructure. Can you comment on that?

I can't comment on the details of the letter but would note that policy incentives are probably the most effective way to stimulate more sustainable behavior. As the effective cost of fuel increases manufacturers and airlines will be able to justify more fuel efficient aircraft and flight procedures. As an example during the 2008 fuel price spike some US airlines were observed to fly slower cruise speeds to conserve fuel.

Questions for the Record to:

Dr. John Hansman

Submitted by Mr. Perlmutter

SAF Policy Considerations and Incentives
Colorado understands the benefits of sustainable aviation fuel so we can reduce greenhouse gas emissions, improve air quality, and bolster our economy. Denver International Airport (DEN) is just outside my district and wants to continue working with industry to collaborate on sustainable aviation fuel projects. We've also seen several U.S. aircraft and engine manufacturers announce efforts to make fleets 100% compatible with Sustainable Aviation Fuels. The current generation of large commercial aircraft are rated up to 50-50 blend of SAF and Jet-A, however adoption of blended SAF remains low across the U.S.

• What do you see as potential policy drivers for faster commercialization of sustainable aviation fuel? What are the hurdles?

Policy incentives to use sustainable aviation fuel would help incentivize the production and use. Enabling the use of 100% sustainable aviation fuel vs the current limit of 50-50 blend would also help although this is currently being addressed

• What can Congress do to incentivize airlines and airports to move to a 50-50 blend of Sustainable Aviation Fuels in the near term and adopt 100% over the longer term at the same time?

Any approaches which would make the SAF cost competitive with traditional petroleum derived fuels would help.

• Are there ideas which would help fledgling producers of Sustainable Aviation Fuel, such as cost-sharing grants, or loans? The Department of Energy and the USDA have some programs, but I'm hearing they may not be robust enough at this point.

This is not really my area of expertise.

Military Follow Up
To follow up on my questioning with parallels to helicopter fuel systems, can each of you provide more detail on how DOD interest in SAF innovation and deployment can help advance the commercial transformation? With safer helicopter fuel systems we saw the military lead the design, engineering, and deployment of these safer fuel systems in the 1970s, but the commercial sector didn't finally standardize these safer fuel systems in newly manufactured helicopters until Congress required it in 2018. How do we shorten this lag time for SAF deployment?

I am not aware of the full details but the full system should be considered in determining if retrofit or forward fit approaches to SAF compatible fuel systems make sense.

Responses by Mr. Steve Csonka

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON SPACE AND AERONAUTICS

March 24, 2021 Hearing Entitled: ***Exploring R&D Pathways to Sustainable Aviation***

Responses to, **Questions for the Record** directed to:

Mr. Steve Csonka
Executive Director, CAAFI (Commercial Aviation Alternative Fuels Initiative)
(all responses represent the views of the responder alone and do not reflect official views of CAAFI or any type of collective views of CAAFI sponsors)

Questions Submitted by Chairman Beyer

1. Sustainable R&D and related activities needed to help meet aviation's climate challenge span multiple agencies and involve industry and academia.

Yes, the breadth of needed research, development, demonstration, and deployment (R&DDD) activities needed for a robust response to the aviation challenge span a broad group of constituents and disciplines. For the development of Sustainable Aviation Fuels (SAF) alone, these disciplines need to encompass the full range of constituents' interests across the activities representing the full supply chains. CAAFI regularly refers to working with 10 different agencies in its work to-date (FAA/DOT, USDA, DOE, DOD, DOC/NIST, White House offices of OS&TP / NS&TC, NSF, NASA, EPA), in various public-private-partnership activities like the recently completed Farm-to-Fly 2.0 program.[1] The conclusions of that successful program include the following observations:

The successful development of SAF:

1) Must involve activities that span the purviews of multiple agencies.
2) Requires focus on high potential development opportunities specific to aviation.
3) Needs leadership and focus from the heads of the participating organizations, and the effective engagement from a few key committed personnel, to drive successful action.
4) Should be guided by lessons learned from F2F and F2F2, and similar public-private-partnership activities.
5) Can be significantly impacted by even modest amounts of dedicated funding.
6) In addition to seed funding, other types of financial support at all stages of development (research, pilot, and demonstration scale) are needed to ensure successful development and to achieve meaningful scale-up of new SAF production processes.

Within the 10 agencies mentioned above, CAAFI has worked with over 40 separate offices on aspects of SAF development, indicating the breadth over which development activities are warranted.

USDA Examples: the biological -*omic* sciences (genomics, proteomics, metabolomics, metagenomics and transcriptomics for both plant and microbial organisms), to breeding, agronomy, agriculture practices, precision ag, autonomous monitoring and extension, development of herbicides & insecticides, understanding the root biom, fundamentals of more sustainable agriculture (soil science, nutrient management, water and soil management, use of synergistic crops and production methods, use of buffers and perennials).

[1] F2F2_Final_Report_September2019.pdf (caafi.org)

DOE Examples: feedstock development, production and management, delivery, energy densification, conversion process development, defining and perfecting synergistic industrial processes, carbon management and sequestration, improvements in process, catalysts, …

The aviation industry worked with many of the above mentioned agencies in the development of a Federal Alternative Jet Fuels R&D Strategy[2], published in 2016, which outlined R&D efforts that were viewed as key to a successful SAF implementation. See also my previous written comments provided to the Subcommittee for the original hearing of 24Mar'21.

1a. Do we need a national R&D strategy for sustainable aviation?

Based on our experience to date, yes, a national strategy would provide the most effective approach to accelerating the development of SAF. A significant review of the state of SAF performed by DOE and published in 2020 drew similar conclusions.[3] A national strategy, operating under the oversight of engaged leadership should offer the best opportunity to align diverse efforts across multiple agencies, maximize effectiveness of spending, eliminate duplication, and create a manageable and responsible structure, answerable to leadership. At present, a SAF Interagency Work Group, established in 2020 under the auspices of the Biomass Research and Development Board[4] (BRDB) based on the vision of key leaders at FAA, DOE, USDA, and NASA, is serving the function of updating a national R&D strategy starting with an update of the FAJFRDS. However, the BRDB is not a recently mandated or directly funded activity, so questions remain around whether its effectiveness can be addressed with a new mandate, or whether another more robust approach might be warranted.

I note that Staff of the Energy Subcommittee of the House Committee on Science, Space, and Technology, in consultation with industry, had been developing a proposed SAF Interagency Agreement that established a SAF R&D Initiative, defined Initiative Activities, proposed an Initiative Office, Initiative Coordination, Annual Reporting, a request for funding to execute such activities, as well as an Advisory Committee, and thoughts on International Coordination and use of Public-Private-Partnerships. CAAFI was supportive of the perceived effectiveness of such an approach, and provided significant insight into needs and approaches to execution.

At present, key Agencies have signaled that they are working on a non-mandated, voluntary approach to executing a SAF R&D strategy, under a loosely described Aviation Grand Challenge, and perhaps still under the auspices of the BRDB. Additionally, Congresswoman Brownley's office, recognizing the challenges associated with SAF production, has introduced the Sustainable Aviation Fuel Act, with provisions to fund SAF R&DDD, as well as additional potentially-enabling policy elements. Irrespective of the exact approach, any formation of an integrated strategy and work plan would be welcomed by the industry.

1b. What, if any, test or laboratory facilities are needed to advance R&D on sustainable aviation technologies and fuels?

There are not many specific needs for dedicated facilities to advance R&D that don't already exist in some form in the National Labs, the dedicated research centers of USDA and DOE, or at academic

[2] Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf (caafi.org)
[3] Sustainable Aviation Fuel: Review of Technical Pathways Report (energy.gov), pp 49-53
[4] Home | Biomass Research & Development (biomassboard.gov)

institutions. Although the ABPDU at LBNL had done a great job with enabling significant research on biochemical conversion (fermentation) of feedstocks, when one considers the breadth of technologies in the thermochemical conversion world, such a PDU approach becomes a bit more complex perhaps, and difficult to execute. So, we have seen some fragmentation of various PDU approaches at the various National Labs (e.g. PNNL having a Hydrothermal Liquefaction System, a Catalytic Hydrothermal Gasification PDU, and an Upgrading PDU). It could be possible to accelerate R&D in some discrete areas using Centers of Excellence (say around product separations, catalyst development, chemical compound detection processes, manufacturing of unique industrial components associated with biofuel production). See also the last paragraph of my response to question 2 following.

2. You stated during the hearing that we are currently at a 50% blend limit for sustainable aviation fuels (SAFs) in aircraft flying today. What research or data collection is needed to allow for 100% SAF usage and is there a timeline for that in the U.S. right now?

After doing some significant thinking and planning about the topic for the last several years, on 05 Apr 2021, a Task Force of the ASTM D02.J community associated with SAF had its kickoff meeting. That industry group hopes to move the current max blend limit to greater than 50%, and in some cases enable fully synthetic formulations of jet fuel, using a range of possibilities:

- Using an existing, fully formulated synthetic blending component to move past the 50 percent blend now allowed (e.g., the current fuel pathways described under ASTM D7566 Annexes A4 and A6). In fact, the Navy continues to work with the developer of Annex A6 technology on a near term qualification of use of that fuel at 100% levels;
- Consider the blending of various blending components to produce a fully formulated fuel;
- Deriving an entirely new specification that would maintain compatibility with the most common ASTM specification (D1655) while using a process similar to the standard practice for evaluation of new turbine fuels (D4054), but for concepts that do not need blending;
- Moving toward a compositionally based specification rather individual definitions that now prevail.

With CAAFI and FAA being integral players in the D02.J activities, I have confidence that at least one of the approaches will emerge from the process before a discussed conceptual target date 2026.

One of the key needs for final approval of any new fuel type, or fuel blend, is the need to perform specific types of tests (engine or APU component, sector, full engine, or in-flight) which require quantities of fuel production well beyond what is available from a laboratory bench-top or pre-pilot rig. This is a key impediment, as the technology developer typically cannot find the funds necessary to build a pilot or demonstration facility, especially when success is not yet guaranteed. So, industry practitioners have considered the need to have a dedicated, re-configurable PDU resource that could be used for this purpose. Finding an owner and funding for such an approach has proved difficult, so this concept could use further consideration. At one point the Air Force had the basics of such a facility at WPAFB, but it was subsequently dismantled, since the building and resources had more targeted usage, and the industry did not have the continuous flow of producers wanting to move through the process at the time.

Additional fidelity from molecular inspection technologies is one area of needed technological development, to identify specific chemical species (and isomers) that might be present in SAF blending

components: e.g., GCxGC (2D, 3D, 4D, VUV, MS), FID, MS (TOF, HRT), NMR, IR, etc., or a research effort to identify/develop additional approaches combined with various interpretation methodologies.

3. After the hearing, we received the attached letter from the Alternative Fuels and Chemical Coalition. The letter suggests that the FAA has placed less emphasis, including funding, on activities related to setting policy goals and the safe integration of SAFs with aviation equipment and infrastructure. Can you comment on that?

   AFCC makes many good points in its intervention, even though I would not agree with all their observations. However, I would push back on the assertion made in this question: in my view, the AFCC did not suggest it was FAA placing less emphasis on topics associated with SAF, rather FAA is being restricted in such work by their appropriations and the congressionally mandated efforts and restrictions associated with such appropriations. AFCC has continued to make additional, incremental funding requests for R&D and the specific work associated with SAF, but such requests have not resulted in the increases which were suggested. FAA's Office of Environment and Energy (AEE), within the Office of Policy, International Affairs, & Environment (APL), continues to be a strong advocate for the development of SAF. AEE leverages about 25% of the total Research Engineering and Development (RE&D) funding appropriated to FAA (from two defined appropriations: RE&D Environment and Energy, and RE&D NextGen / Environmental Research) for the competing demands for research for the Divisions of Noise, Technology & Operations, Emissions, and Environmental Policy. From those Divisions and funding, FAA supports for the robust development of SAF through three programs: ASCENT, CLEEN, and CAAFI. All three programs are making significant progress, but AEE could certainly do more work on SAF with more RE&D funding that did not have restrictions associated with working on SAF R&D.

4. You mention in your prepared testimony that approaches have been identified to continue moving in the direction of 100% lifecycle reduction in net carbon through the use of SAFs in place of traditional jet fuels. Please expand on what these approaches entail. What, if any, are the any outstanding research questions that need to be answered before we can reach 100% lifecycle carbon reductions through the use of SAFs?

   Yes, the assertion is correct. Two things are required to reach 100% lifecycle carbon reductions through the use of SAFs: first, to achieve higher blend levels, and secondly, for the synthetic fuel component to achieve a deep reduction in net lifecycle greenhouse gas accounting, or carbon index of the fuel (CI). I addressed the question of higher blends above. Now I will address the topic of CI. There are many examples of SAF blending components achieving 60-70% reductions in CI. SAF CI scores can continue to be reduced by:

   - By utilizing waste feedstock streams (that would typically result in GHG emissions under normal disposal techniques, thus obviating such emissions);
   - By utilizing continuingly more efficient conversion processes (of new and existing conversion processes);
   - Using renewable power for production plant & equipment, or even using the feedstocks for such;
   - By using renewable hydrogen for fuel finishing;
   - By optimizing the supply chain to reduce transport emissions (distance or mode), or having the supply chain use renewable fuel and/or energy in its operations;

- By sequestering carbon in some fashion: in the soil associated with certain feedstocks; in the form of char used as a soil amendment; in the form of capturing CO_2 emissions from the conversion process and using such CO_2 for enhanced oil recovery or permanent storage;
- By moving in the direction of more advanced fuel production concepts, including Power-to-Liquid fuels which use renewable power to both capture CO2 directly from the atmosphere, convert the CO_2 to CO, and to split water to hydrogen (H_2), and then subsequently recombine the CO and H_2 to form SAF.

R&DDD on any/all of the above would allow continued advancements in reducing CI. The good news is that such work can be done through existing programs and expertise resident in many of the SAF-related activities of USDA, DOE, FAA, NASA, and DOD.

The above, and specifically the combination of the above approaches can result in low, zero, or even negative CI fuels[5]. Negative scores indicate that we have removed, or kept from being released in the first place, more CO_2 than is released during the burning of the fuel in the aircraft.

5. In addition to carbon emissions, aviation emissions, including those from sustainable fuels, involve contrails and particulate matter that affect warming and also air quality. To what extent are these factors well understood? What are the salient questions that need to be explored and what research is needed to address them as we look to wider use of SAFs?

These mechanisms are fairly well hypothesized (modelled), but uncertainty still exists around their exact physics and individual and inter-relational total impacts, as driven by the methodologies used to calculate the magnitude of each attributes impact, and the extended duration of the attribute which goes into the calculation of duration-dependent Effective Radiative Forcing impact. In general, the industry concedes that the non-CO2 effects are real, and they are order of magnitude equal or greater than the impact of CO2 alone. A recent estimate of such Radiative Forcing suggests the non-CO2 impacts are 2x the magnitude of the CO2 release alone.[6] However, uncertainty remains that could be aided through improvements in atmospheric measurements of chemical composition, doing more work on understanding the exact nature of chemical cycles involving NOx, HOx, halogens, and other chemical species in the upper troposphere and lower stratosphere, and more comprehensive modelling, all supported by various test programs.

The good news with respect to SAF usage is that they are proven to deliver a couple of positive effects:

- SAF have no sulfur, as is still prevalent in petro-jet fuel, so the reduction in emissions of sulfur oxides is directly proportional to the fraction of SAF blended in the fuel;
- For the paraffinic pathways that are already approved, such SAF have no, or very limited levels of poly-cyclic aromatic compounds that exist in petro-jet. These poly-cyclic aromatic compounds are a key driver in the production of soot and particulate matter (PM). For some of the future pathways we envision, that will also contain naphthenes (cycloparaffins and non-polycyclic aromatics), we have found that such naphthenes can replace the function of the poly-cyclic aromatics, thus reducing PM associated with combustion;

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[5] See for example: Negative-emission fuel agreement | Velocys

[6] The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018 - ScienceDirect

- SAF is typically a purer version of the hydrocarbons found in jet fuel, so we also see reductions in CO, and potentially in other emissions constituents, including some Hazardous Air Pollutants (HAPS).
- When there is less PM production in the exhaust plume, there are also perhaps fewer sources of nucleation for ice particles to form, resulting in reduced contrail generation, and perhaps persistence.

Unfortunately, we have not seen a good correlation for any potential NOx reduction associated with the use of SAF. NOx will need to be reduced via combustor technology, or with some type of post turbine treatment (low TRL).

So, while SAF has the potential to reduce many warming and air quality impacts, more work needs to be done on quantifying such impacts. Contrails can be avoided through use of dynamic routing of aircraft to avoid regions of supersaturation in the atmosphere. However, there will likely be a countervailing impact of higher fuel burn due to flying a more circuitous route, or flying at non-optimal altitudes. More research can be done on contrail formation and avoidance, including effective atmospheric measurement and modelling, getting such information into a cockpit to allow for flight profile changes (or perhaps actually having the aircraft performing dynamic assessments of atmospheric conditions), and addressing the impacts to air traffic control changes. More work needs to be done on defining when atmospheric conditions result in persistence of contrails, or for formation of induced cirrus. For instance, if contrails are not persistent, they are projected to provide global cooling in daylight. If they last into the night, they result in warming.

When and if such impacts are more well understood, future designers of aircraft, engines, and ATM systems can push the entire system in the direction of lowering total impact. Some studies have been done on this basis, concluding for instance that slowing the fleet and flying at lower elevations with quite different point designs for the aircraft (higher aspect ratio, low sweep wing configurations) will achieve the maximum level of GHG reduction possible, but at the cost to human productivity due to greater trip times.

Experience with the above elements, hence serving as a good foundation for additional R&D, lies with FAA ASCENT, NASA, and academia.

Questions Submitted by Mr. Perlmutter

SAF Policy Considerations and Incentives - Colorado understands the benefits of sustainable aviation fuel so we can reduce greenhouse gas emissions, improve air quality, and bolster our economy. Denver International Airport (DEN) is just outside my district and wants to continue working with industry to collaborate on sustainable aviation fuel projects. We've also seen several U.S. aircraft and engine manufacturers announce efforts to make fleets 100% compatible with Sustainable Aviation Fuels. The current generation of large commercial aircraft are rated up to 50-50 blend of SAF and Jet-A, however adoption of blended SAF remains low across the U.S.

1. What do you see as potential policy drivers for faster commercialization of sustainable aviation fuel? What are the hurdles?

   The primary impediment to broader commercialization of SAF is its lack of cost competitiveness with petro-jet. Cost competitiveness will likely be addressed through 4 primary elements: 1) an increase in the price of petro-jet as driven by oil price increases (e.g. reduction of petroleum industry incentives), or the introduction of carbon pricing policy; 2) a reduction in the cost of SAF by introduction of more productive conversion technology and use of lower cost feedstocks; 3) a reduction in the cost of SAF driven by learning curve improvements for operations, supply chains, and equipment; 4) Through policy intervention (incentives and/or mandates). One final element impacting pricing is whether existing policies create a level playing field between production of SAF, or the competitive production of renewable gasoline blend components or diesel fuel. At present, the incentives offered RFS, Federal tax policy, CA LCFS, and CA tax policy substantially favor the production of diesel. This is a major reason why we currently see the commercial exploration of ~7 B gpy production of renewable diesel in the U.S., and less than 400 M gpy SAF production, whereas the physical market for diesel is only 3x the size of jet fuel.

2. What can Congress do to incentivize airlines and airports to move to a 50-50 blend of Sustainable Aviation Fuels in the near term and adopt 100% over the longer term at the same time?

   Airlines are fully vested in the idea of using SAF. Recall it was the industry itself that voluntarily agreed to cap carbon from 2020, and to pursue long term reduction of carbon by 2050. SAF usage is an integral part of that plan. Recently, the A4A airlines have agreed to pursue net zero carbon by 2050, with a couple airlines adopting even more aggressive approaches, or by setting mid-term quantity-usage goals. SAF has proven viable in every sense but price. And, until we can establish a more robust SAF industrial sector, we cannot hope to achieve learning curve improvements that can reduce cost/price. Hence, the cost issue needs to be addressed through R&DDD and policy. There is currently a bill being developed by congress to introduce a Blenders Tax Credit specific to SAF which is intended to level the playing field with diesel. Whether more aggressive approaches might be used to address aviation, since it lacks the energy switching options available for ground transport, remains to be seen.

   Airports have a more limited role to play in the uptake of SAF. Airports do not purchase jet fuel. At present, SAF cannot be blended on airport. So, a primary role of airports might be to: 1) serve as a convening function of research activities related to how SAF can best be integrated with existing fuel delivery infrastructure; 2) to advocate for incentivizing policy changes at the state level; 3) to advocate for feedstock and supply chain analysis work that will assist with commercialization efforts of prospective producers.

The bottom line is that if Congress is able to lower or close the cost difference between petro-jet and SAF, using one of several mechanisms highlighted above, the airlines will acquire the SAF.

3. Are there ideas which would help fledgling producers of Sustainable Aviation Fuel, such as cost-sharing grants, or loans? The Department of Energy and the USDA have some programs, but I'm hearing they may not be robust enough at this point.

   Certainly, current financing programs of the various departments do help, and perhaps can be made more robust or less difficult/costly to obtain. It is nice to see DOE rejoining this space. One shortfall of current DOE and USDA programs is that they generally do not address the need for rote development of pilot and pre-commercial demonstration facilities, which are typically required to demonstrate feasibility before for the cost-sharing, grants, loans, bond programs, etc, are able to be utilized. This continues to be a significant challenge for prospective new technologies. Such a concept is also prone to risk of failure which some deem as being politically unacceptable, and hence perhaps the reason why more assistance is not available for this critical phase of development.

   Congress could also assist with the introduction of other investment and tax benefits, e.g.: 1) a robust Investment Tax Credit approach for the infrastructure needs associated with the whole supply chains of SAF production concepts; 2) allowing Master Limited Partnerships; 3) Extending the concept of carbon capture tax credits; 4) Enabling monetization of other environmental services (water quality, soil quality, nutrient management) offered by SAF supply chains.

Military Follow Up

4. To follow up on my questioning with parallels to helicopter fuel systems, can each of you provide more detail on how DOD interest in SAF innovation and deployment can help advance the commercial transformation?

   To date, the various agencies of DOD have been key players in the R&DDD of SAF. The Air Force played a key role in the initial experimental validation of SAF, and subsequent flight proving. When Air Force engagement waned in the last decade, The U.S. Navy undertook efforts to foster demonstration and deployment through programs like the Defense Production Act financial support of new production facilities, and the Great Green Fleet efforts to signal U.S. intent to producers and allies world-wide.

   A good example of this type of detailed technical collaboration is seen in the recently finalized six year efforts of the National Jet Fuel Combustion Program[7] (NJFCP), initiated by FAA through the Aviation Sustainability Center (ASCENT), and jointly executed with the U.S. Air Force Research Laboratory and NASA. The program built upon basic foundational research from the U.S. Air Force Office of Scientific Research and results from the engine-company-led Combustion Rules and Tools program initiated (but not completed) by the U.S. Air Force. Following NJFCP initiation, the effort was subsequently bolstered by support from the Office of Naval Research/NavAir, the Army Research Laboratory, and the Defense Logistics Agency – Energy. Working in conjunction with academia and gas turbine designers / manufacturers, the NJFCP has advanced the modelling, evaluation, and prediction of jet fuel combustion as it relates to specific chemical composition of various jet fuels and SAF formulations. It developed combustion-related generic test and modeling capabilities that have improved the understanding of the impact of fuel chemical composition and physical properties on combustion, enabling the acceleration of the industry's (commercial, military, business aviation) approval process of new synthetic jet fuels, at

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[7] See www.ascent.aero/project, projects 25-30

lower cost and with less fuel required. Benefits of this program are still in the process of being fully appreciated and implemented. One key result already showing benefit is the establishment of new fuel screening methodologies being performed by the University of Dayton in collaboration with new prospective SAF producers, and in consolidated testing and evaluation approaches of the University of Dayton Research Institute, enabling the implementation of a one-stop-shop Clearinghouse, and Fast Track fuel approvals under the ASTM D4054 Design Practice for the evaluation and approval of new SAF pathways.

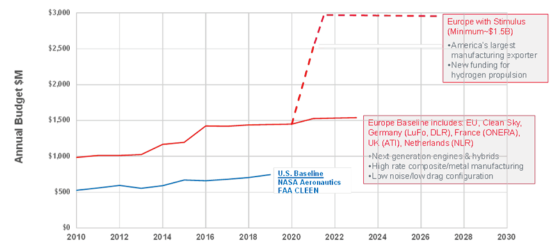
The DOD, also being a significant consumer of jet fuel (up to 14% of U.S. production capacity), could be in a position to be an early adopter of SAF production, facilitating a quick expansion of production capacity, given the appropriate direction from the government leadership.

5. With safer helicopter fuel systems we saw the military lead the design, engineering, and deployment of these safer fuel systems in the 1970s, but the commercial sector didn't finally standardize these safer fuel systems in newly manufactured helicopters until Congress required it in 2018. How do we shorten this lag time for SAF deployment?

   We do not currently see a significant lead/lag time associated with differences between military and commercial engagement on SAF. In R&D, the above response shows good synergism at present. In demonstration and deployment, DOD did in fact participate in the DPA program to facilitate SAF deployment (the first results of which are scheduled to enter production in the current quarter), but commercial deployment has also been occurring in parallel. In commercial aspects, much work was done in the last decade to align the purchase of jet fuel with commercial practices, with one net result being the DOD's significant acquisition of jet fuel using the commercial specification (ASTM D1655). The DOD still has not determined how to utilize other commercial methods, like long term purchase agreements, that might prove extremely beneficial in enabling entrepreneurs to close their business cases and financing, as enabled by the power of having a multi-year offtake agreement for their full production slate of SAF and other fuels and chemicals.

Questions Submitted by Mr. Weber

1. I want to share a chart with you (attached below) – that shows just how much Europe has increased its investment in Aeronautics R&D, especially as part of its COVID relief spending. What was already a big gap in Aeronautics R&D between the U.S. and Europe has now become much larger – billions of dollars in difference each year. With the relatively small investments the U.S. makes through NASA Aeronautics and FAA R&D, are we doing enough to keep up with Europe's major investments in its domestic sector and companies? What are the consequences to the U.S. competitiveness and leadership in the aviation sector if this significant gap in R&D continues?



I am not sufficiently qualified or knowledgeable enough to comment on your questions about the above, especially as they might relate to my area of expertise, SAF development. If I were a policy maker concerned about U.S. competitiveness in aviation, I guess I would ask the same thing of my colleagues. If there is any silver lining with respect to SAF development, we are seeing good cooperation from researchers and industry partners around the globe, and it is nice to see R&D coming into the SAF sector from the EU. And, I hope going forward that that fraction increases for the benefit of making aviation more sustainable and enabling the long-term health and resiliency of the U.S. aviation sector.

2. I represent many of the refineries that produce U.S. airports and airlines with jet fuel – fueling the majority of U.S. air travel. I would note that aviation represents just 2% of CO2 emissions, making aviation a remarkably efficient way to transport passengers and freight cargo relative to the billions of annual passengers and cargo the industry transports each year. Blending the jet fuel produced in my district with new Sustainable Aviation Fuel (SAF) feedstocks will be essential to meeting the aviation industry's commitments on efficiency – and with less than 1% of all fuel today incorporating SAF despite airplanes already being certified to fly up to a 50-50 blend. Would you agree that our oil and gas refineries and blenders play an essential role in increasing adoption of SAF?

Yes, absolutely, the oil and gas refiners, blenders, and pipeline transport entities have a key role to play in the eventual success of SAF. It will likely become very important to have their increased engagement in enabling the lowest cost and most efficient blending approaches possible. I believe two key issues for this group of constituents include: 1) determining ways to process more biocrude to SAF in existing refineries (co-processing); 2) enabling the installation of new terminals (or existing terminal infrastructure) coincident to pipelines that allow for SAF blending and shipping. On the co-processing topic, the aviation community has worked collaboratively with the petroleum industry to allow the use of

5% co-processing of lipids and Fischer-Tropsch biocrude into SAF in existing refineries, but it will likely be expedient to expand such usage and feedstocks. The refiners and technology licensors could also likely benefit from R&D funding targeting the removal of barriers to greater co-processing.

3. Proposals like the Green New Deal would impose regulatory costs for consumers on commercial air travel in the hopes of eventually eliminating the need for air travel in the next 10 years and instead encourage alternative sustainable travel options like high-speed rail. These proposals would not only result in over $1.5 trillion in lost economic activities attributed to the U.S. airline industries, but the U.S. would also lose competitive edge in advanced aviation and aeronautics technologies. What are some other proposals that would encourage sustainability for the aviation sector without detrimental economic consequences?

The concept of moving all long-range air travel to high-speed rail (or dirigible, boat, or tube travel) is fallacious, especially in large countries with significant land mass and where rail infrastructure and rights of way are not already ubiquitous. The aviation industry (airlines, business aviation, OEMs, airports, ANSPs) as a whole, agrees that the utilization of SAF as a primary means of reducing CO_2 emissions represents the lowest societal cost approach to decarbonizing aviation. And no other mode of transport offers the safety, flexibility, network, reliability, and human productivity associated with aviation. So, I'd encourage you to point to SAF as being an enabler for improving the sustainability of long-range, high-speed travel that is a cornerstone of the worlds' societies and economies.

4. The WTO tariffs on U.S. imports caused by NASA and FAA research subsidies result in higher costs to import aviation parts to the U.S. from Europe. Those parts are used at domestic manufacturing facilities in Alabama where Airbus has a plant that provides thousands of high-paying jobs for hard-working Americans. Should we promote free trade, or adopt the failed policies of the Soviet Union? With China seeking to export its own aircraft, which is almost entirely subsidized by the Chinese Communist Party, what kind of message are we sending to the international community if we are also subsidizing our industry? Should we rely on free market principles that made our nation the world-leader in aviation, and punish violators for violating those free market principles, or cave-in to the pressure and follow the lead of the Chinese Communist Party and subsidize our industry?

I am not sufficiently qualified or knowledgeable enough to offer cogent, insightful observations about your questions, other than to say that these are political issues that need political solutions. Politicians will offer subsidies when they feel it is expedient to do so, e.g., when competing with a non-free-market competitor. Given that there is no such thing as a world-wide free market (with everyone operating under the same rules and with the same value systems), then a free market will likely need policy driven adjustments from time-to-time to address greater societal needs.

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE BEYER

Biotechnology Innovation Organization

March 24, 2021

The Honorable Don Beyer
Chairman
Subcommittee on Space
and Aeronautics
Committee on Science, Space,
and Technology
U.S. House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515

The Honorable Brian Babin
Ranking Member
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The Honorable Eddie Bernice Johnson
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The Honorable Frank Lucas
Ranking Member
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Dear Chairman Beyer, Ranking Member Babin, Chairwoman Johnson, and Ranking Member Lucas:

The Biotechnology Innovation Organization (BIO) is pleased to submit a statement for the record to the United States House of Representatives Committee on Science and Technology Space and Aeronautics Subcommittee hearing entitled, "Examining R&D Pathways to Sustainable Aviation."

Introduction

BIO[1] represents 1,000 members in a biotech ecosystem with a central mission – to advance public policy that supports a wide range of companies and academic research centers that are working to apply biology and technology in the energy, agriculture, manufacturing, and health sectors to improve the lives of people and the health of the planet. BIO is committed to speaking up for the millions of families around the globe who depend upon our success. We will drive a revolution that aims to cure patients, protect our climate, and nourishes humanity.

Our members use technology to enhance cultivation and food production and produce sustainable biofuels, renewable chemicals, and biobased products. These breakthroughs provide a cost-competitive alternative to petroleum's value chain that spur economic development, create jobs, and improve environmental and public health. Companies are utilizing biological processes to convert biomass and

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[1] https://www.bio.org/

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waste feedstocks into everyday products while creating new markets for agricultural crops, crop residues, and waste streams – in addition to contributing to a circular economy.

Overview

BIO applauds the committee for holding this hearing on sustainable aviation.

To tackle the climate crisis, it is crucial to lead with science and U.S. innovation. We must incentivize the adoption of innovative and sustainable technologies and practices and streamline and expedite regulatory pathways for new technology solutions to reduce carbon in hard to abate sectors. In doing so, the federal government can support pioneering breakthroughs that reduce greenhouse gas emissions in manufacturing, transportation, and agricultural supply chains to build a stronger, more resilient, and environmentally sustainable economy.

One of these hard to abate sectors is aviation. Currently, the global aviation industry produces around two percent of all human-induced carbon dioxide (CO_2) emissions and 12 percent of CO_2 emissions from all transport sources.[2] In 2018, the United Nation's (UN) International Civil Aviation Organization (ICAO) forecasted these emissions would triple by 2050 and the International Council on Clean Transportation, found that emissions from global air travel may be increasing more than 1.5 times as fast as the UN estimate.[3]

Fortunately, the development and commercialization of sustainable aviation fuels (SAF) represents a viable solution to reduce emissions in aviation— which has no near-term alternative to liquid hydrocarbon fuels.[4]

Reducing Emissions through Innovation

Biofuels produced using biological systems provide a strong and immediate solution to reducing emissions from all forms of transportation, including aviation. Because of biotech innovations, the production of biofuels is becoming more efficient and environmentally sustainable. Biocatalysts, such as enzymes, lower energy requirements, increase reaction rates, can reduce the number of process steps necessary to make chemical transformations. Enzymes are selective, specific, and have a high catalytic rate; they are more efficient, producing chemical products with higher purity and fewer byproducts or wastes. Enzymes are enabling biofuel producers to convert corn stover, wheat straw, wood chips, sawdust, waste, and sugarcane bagasse into fuel, and to collectively increase biofuel yield and energy efficiency throughout the sector. Biocatalysts (e.g. bacteria) are enabling production of fuels from new waste and residue streams.

[2] https://www.atag.org/facts-figures.html
[3] https://www.nytimes.com/2019/09/19/climate/air-travel-emissions.html
[4] https://www.iata.org/contentassets/a33c39219430432fb241f7b9ac5a145c/environment.pdf

BIO[5] member[6] companies[7] have led the way in developing and deploying SAF with major airline companies around the world. However, to scale up production to levels needed to meet future growth of air travel and reduce emissions additional research and development (R&D) and incentivizes are needed.

Bolstering Government R&D Programs

Bolstering funding for the U.S. Department of Energy (DOE), U.S. Department of Agriculture (USDA) renewable energy programs, Federal Aviation Administration (FAA) and other government research programs is essential for the growth of SAF and the advanced biofuels industry.

DOE's Office of Energy Efficiency and Renewable Energy (EERE) invests in clean energy technologies that strengthen the economy, protect the environment, and reduce dependence on foreign oil. According to DOE's *Aggregate Economic Return on Investment in the U.S. DOE Office of Energy Efficiency and Renewable Energy*,[8] R&D investments provide significant economic benefits. A total taxpayer investment of $12 billion (inflation-adjusted 2015 dollars) in EERE's R&D portfolio has yielded more than $388 billion in net economic benefits to the United States.

The Bioenergy Technologies Office (BETO) within EERE funds vital research and development of technologies to convert our nation's biomass resources into clean, renewable fuels. Bolstering BETO will help fund vital research and development of technologies to convert our nation's biomass resources into clean, renewable fuels, as well as chemicals and industrial products. BETO Systems Development and Integration (SDI) program is working to establish first-of-a-kind integrated biorefineries, that are capable of efficiently converting a broad range of biomass feedstocks into commercially viable SAF.

USDA's Biorefinery Assistance Program provides loan guarantees for the development, construction, and retrofitting of commercial-scale biorefineries that produce advanced biofuels. This program has enabled companies to put steel in the ground for first-of-a-kind biorefineries that are producing aviation biofuels. [9]

FAA programs are also critical to support the research and development, commercialization, and deployment of Sustainable Aviation Fuel. FAA's Office of Environment and Energy's R&D Program provides scientific understanding, development of new technologies, fuels and operations, and analyses to support achieving the Next Generation Air Transportation System (NextGen) and the program's goals of environmental protection allow for sustained growth. The NextGen program is working with partners to develop solutions to reduce the

[5] https://news.delta.com/delta-enters-offtake-agreement-gevo-10m-gallons-year-sustainable-aviation-fuel-creates-long-term
[6] https://www.lanzatech.com/2018/10/04/virgin-atlantic-lanzatech-celebrate-revolutionary-sustainable-fuel-project-takes-flight/
[7] https://www.velocys.com/2019/10/10/negative-emission-fuel-agreement
[8] https://www.energy.gov/sites/prod/files/2017/11/f39/Aggregate%20ROI%20impact%20for%20EERE%20RD%20-%2010-31-17.pdf
[9] https://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2014/09/0195.xml

impacts associated with aviation noise and exhaust emissions and increasing energy efficiency and availability. In alliance with research institutions and industry stakeholders, the program will accelerate the maturation of engine and airframe technologies to reduce aviation noise, fuel use, and emissions. FAA's Center of Excellence (COE) is charged with discovering, analyzing, and developing science-based solutions to the energy and environmental challenges facing the aviation industry. Through COE, FAA has been supportive of alternative jet fuel testing and analysis efforts through the ASCENT. This program is working collaboratively with its 16 main universities and five affiliate universities.

Streamline and Expedite Regulatory Pathways for Breakthrough Technology Solutions

Unclear, protracted regulatory pathways are one of the largest barriers to the deployment of innovative solutions that can address climate change. Uncertainty surrounding the approval of pathways and registration for advanced and cellulosic biofuels are also hindering the development of SAF.

The U.S. Environmental Protection Agency's (EPA) delays in approving biofuel pathways and facility registrations have led to an erosion of the Renewable Fuel Standard (RFS) as Congress intended. Developing and producing these fuels and attracting investment to sustainable fuel projects has been curtailed because of EPA's actions. This hampers the growth of rural America and stymies the development of the bioeconomy. Bringing these innovative technologies online will be critical to commercializing SAF and creating a resilient, healthier transportation sector in a post-COVID economic recovery.

Congress should exercise its oversight authority over EPA to ensure the Agency interprets the RFS broadly and accommodates all pathways and approve facility registrations that could fall within the existing statute. Specific areas that would have an impact immediately to accelerate the production of SAF are related to biological carbon capture and utilization (CCU), the interpretation and eligibility of "renewable biomass", the use of biointermediates, and life-cycle and tracking methodologies for sustainable fuels from waste agricultural residues such as corn kernel fiber. This would have immediate benefits for reducing greenhouse gas emissions in the aviation and agricultural sectors by create more demand for waste feedstocks and renewable biomass.

Incentives

Long-term tax incentives have been incredibly important to our companies that are making significant investments to create new agricultural supply chains, build infrastructure for liquid biofuels, and develop innovative new technologies. These credits have enabled our industry to create new jobs, contribute to rural prosperity, and diversify our nation's energy supply. New, long-term tax incentives are needed to drive new green energy breakthroughs and enable alternatives to become fully established.

As the House Select Committee on the Climate Crisis noted in its Climate Crisis Action Plan, "Congress should strengthen the sustainable aviation fuels tax credit to include a life-cycle carbon intensity requirement and extend it for at least five years to provide market certainty. Congress should consider the potential benefits of separating the sustainable aviation fuel tax credit from the broader biodiesel tax credit."[10]

Enacting a long-term SAF specific tax credit will attract significant investment to the sector, address existing structural and policy disincentives, and ramp up domestic SAF production to meaningful levels.

Health Benefits

The benefits of SAF go beyond reducing greenhouse gas emissions. Based on findings in a cooperative international research program led by National Aeronautics and Space Administration (NASA). and involving agencies from Germany and Canada, using biofuels to help power jet engines reduced particle emissions in their exhaust by as much as 50 to 70 percent.[11]

COVID-19 has highlighted the impact air pollution has on human health and the need to increase the use of biofuels in the transportation sector to improve air quality. Prior to COVID-19, the World Health Organization[12] found that 4.2 million deaths[13] every year occur because of exposure to ambient air pollution. Since then, numerous studies have found that long-term exposure to levels of tiny particulate matter were linked to a significant increase in the mortality rate for COVID-19[14].

Increasing the use of SAF to reduce contrails, particulate matter, and mass emissions compared to conventional fossil jet fuels will improve air quality and human health near airports and reduce the climate impacts of aviation at high altitude.[15]

Conclusion

BIO is committed to working with the Committee, Congress, and the Administration to address the climate crisis. Policy that advances pioneering technology like SAF will lead to breakthroughs reducing emissions in the aviation sector. By supporting science and innovation, we can return our Nation and the world to health and prosperity by taking bold and drastic action to address the climate crisis.

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[10] https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf
[11]: https://www.nasa.gov/press-release/nasa-study-confirms-biofuels-reduce-jet-engine-pollution
[12] https://www.who.int/health-topics/air-pollution#tab=tab_1
[13] https://www.who.int/gho/phe/outdoor_air_pollution/burden/en/
[14] https://www.newscientist.com/article/2241778-are-you-more-likely-to-die-of-covid-19-if-you-live-in-a-polluted-area/
[15] https://www.nature.com/articles/nature21420

LETTER SUBMITTED BY ALTERNATIVE FUELS & CHEMICALS COALITION

Alternative Fuels & Chemicals Coalition

Advocating for Public Policies to Promote the Development & Production of Alternative Fuels, Renewable Chemicals, Biobased Products, and Sustainable Aviation Fuels

March 24, 2021

The Honorable Don Beyer
Chairman
House Subcommittee on Space and Aeronautics
U.S. House of Representatives
Washington, DC 20515

The Honorable Brian Babin
Ranking Member
House Subcommittee on Space and Aeronautics
U.S. House of Representatives
Washington, DC 20515

The Honorable Eddie Bernice Johnson
Chairwoman
House Committee on Science, Space and Technology
U.S. House of Representatives
Washington, DC 20515

The Honorable Frank Lucas
Ranking Member
House Committee on Science, Space and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Chairman Beyer, Chairwoman Johnson, Ranking Member Babin, Ranking Member Lucas, and Members of the Subcommittee:

Alternative Fuels and Chemicals Coalition (AFCC) appreciates the opportunity to submit statement for the record to the United States House of Representatives Committee on Science, Space and Technology and the Subcommittee on Space and Aeronautics hearing held on March 24, 2021, called, "Examining R&D Pathways to Sustainable Aviation."

Introduction

AFCC is a collaborative government affairs effort organized by the Kilpatrick Townsend & Stockton law firm and American Diversified Energy. AFCC was created to address policy and advocacy gaps at the federal and state levels in renewable chemicals, bioplastics/biomaterials, cell-cultured food ingredients, single cell protein for food and feed, enzymes, alternative fuels, biobased products and sustainable aviation fuels (SAF) sectors. AFCC member companies work on feedstocks, renewable chemicals, food, feed, fiber, bioplastics and biomaterials, and biofuels impacting the biobased economy.

AFCC applauds the House Subcommittee on Space and Aeronautics in holding the hearing on sustainable aviation.

The COVID-19 pandemic has had an unprecedented impact on the aviation industry. Passenger volume in the United States decreased 95% in April 2020 and as of November 2020 domestic air travel was still 60%, and passenger volume forecasted to recover by early 2024[1]. Despite the impacts of COVID-19, the global

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aviation industry recommitted to meeting its environmental targets at an International Air Transport Association (IATA) Board of Governors meeting in June 2020[2]. The aviation sector faces unique challenges as it tries to accomplish its ambitious climate goals, as well as responding to customer and investor-driven desires to decarbonize. SAF is the only near-term technology option for reducing aviation's carbon emissions. Numerous conversion pathways have been approved and there are multiple SAF production facilities in operation, under construction or planned in the United States. Congress supporting legislative polices would accelerate SAF development.

The Benefits of Sustainable Aviation Fuels (SAF)

AFCC member companies[3,4,5,6,7] are leaders in the production and deployment of SAF with major airline companies around the world. However, to scale up production to levels needed to meet future growth of air travel and reduce emissions additional research and development (R&D) and policies incentivizing the development of sustainable supply chains are needed.

SAF is a jet fuel made from renewable sources such as municipal solid waste (MSW), construction and demolition (C&D) debris, crop residues, wood wastes, used cooking oil, animal tallow, algae, oilseeds – and even industrial smokestack emissions. SAF has been certified to the same safety standards and specification (ASTM D1655) as petroleum Jet-A. SAF typically is blended as a "raw" or "neat" aviation biofuel with Jet-A. SAF Offers Multiple Economic Opportunities to every state – and to local communities in almost every Congressional district and has the opportunity to create jobs and stimulate economic development through the production of SAF. This is because SAF can be produced from waste products that are readily available in all large and medium-size and many modest-size communities. These wastes often represent economic and environmental liabilities to these communities due to the logistics associated with their disposal. By using these waste materials to produce SAF, communities can turn these liabilities into job creators and economic assets. Here are the Advantages of SAF over conventional petroleum jet fuel:

- Reduces lifecycle greenhouse gas emissions 50% to 80% compared with petroleum jet fuel.
- Has zero sulfur (less than 5 parts per billion) compared to ultra-low sulfur Jet-A which contains 15 parts per million of sulfur.
- Has no aromatics such as benzene, toluene, and naphthalene, which cause smog.
- Has very little particulate matter (soot).
- Reduces carbon monoxide and unburnt hydrocarbon emissions.
- Offers better thermal stability and combustion characteristics. There are significant economic benefits to the use of SAF.

Tests conducted on military jets at Wright-Patterson Air Force Base in 2012 and the Naval Air Warfare Center Weapons Division at China Lake in 2013 found that SAF

can add 13% to performance, compared to fossil fuels. SAF lowers engine temperatures by 135 degrees, due to the absence of impurities, aromatics, and particulate matter found in conventional fossil fuels. When these impurities burn, they cause high temperatures to radiate throughout the engine, which accelerates metal fatigue. Preliminary data from these tests show that engine parts could last up to 10 times longer. SAF has, for the same volume, 7 percent less mass, which lowers the weight of a plane when fully fueled, making it possible for jets to fly faster, farther, or carry more payload. Each of these benefits translates into significant savings in reduced maintenance and extended engine life, greater reliability, less time on the ground and increased revenues (and improved military preparedness) due to better performance and the ability to fly farther and carry more payload.

Congress Should Amend the Clean Air Act for SAF Fuel Pathways to Generate RINs

The Alternative Fuels & Chemicals Coalition urges Congress to introduce legislation that would amend the *Clean Air Act* by adding the definition for *Forest Resid*uals, as proposed below, which **would not open** the Renewable Fuel Standard (RFS).

The amendment would allow dead and diseased wood to be removed from national forests and public lands which increase wildfire danger and destruction they cause. It also would allow biofuel producers to use zero-cost dead and diseased wood as feedstock for the production of sustainable aviation fuels. Lowering the cost of feedstocks will in turn lower the cost of production of SAF, which today represents barrier to entry and use of 100% SAF.

Amending the *Clean Air Act* would prevent opening the RFS, which has statutory restrictions on the use of woody biomass from national forests. This amendment would give direction from Congress to the EPA Administrator to use these diseased and dead wood as an acceptable pathway for the production of biofuels, generate RINs, and will have uses in the production of other high-value biobased products. Currently, the *Clean Air Act,* under the RFS promulgates use of tree residue, slash and pre-commercial thinning, and prevents the use of the entire tree which is diseased and beetled as feedstock to qualify under the RFS.

a. Definition of Forest Residuals

The definition that AFCC is proposing for "Forest Residuals" be added as a new paragraph (5) under Part C, Prevention of Significant Deterioration of Air Quality, Section 7479 Definitions, of the Clean Air Act of 1963 (P.L. 88-206), 42 USC 85, as amended in 1990 (P.L. 101-549), as follows:

The term "forest residuals"

"(5) *The term 'forest residuals' means diseased, dying, and insect-infested trees and underbrush, fallen trees, slash piles, discarded forest waste from timber sales and thinning operations, and small diameter branches and tree*

> *tops discarded by timber operations, to reduce the dangers, destruction, and occurrences of wildfires, which release large amounts of carbon dioxide, black carbon, brown carbon, and ozone precursors into the atmosphere, as well as volatile and semi-volatile organic materials and nitrogen oxides that form ozone and organic particulate matter, leading to harmful exposures to first responders, local residents, wildlife, and distant populations, as well as losses of forest resources, habitats, property, and lives."*

Our nation is facing unprecedented challenges as a result of the global health pandemic caused by COVID-19, with its impacts felt across all of society. The Department of Homeland Security has identified the biofuels sector as an essential, critical infrastructure workforce during the COVID-19 response. However, as motor vehicle and aviation fuel demand has plummeted, prices have slumped to record lows and alternative fuel producers are suffering heavy losses. Highly skilled jobs across the country are being lost at an alarming rate.

Drought, intensified by climate change, as well as insect infestations and disease have put national forests, public lands, private forest lands, and rural areas at increased risk of catastrophic wildfire. Removing decayed and diseased forest residuals for use as feedstock for value-added products in the production of sustainable aviation fuels would alleviate the buildup of residual forest waste and mitigate the damage and costs of future wildfires.

b. Congress Oversight for the Environment

Congress should exercise its oversight authority over Environment Protection Agency (EPA) to ensure the Agency interprets the RFS broadly and accommodates all pathways[8] such as wood waste from national forests causing hazardous fires and approves rapidly the facility registrations that could fall within the existing statute – and exercising the current regulatory authority EPA has to approve biofuel pathways. Specific areas that would have an impact immediately to accelerate the production of SAF are related to biogenic carbon capture, storage, and utilization, the interpretation and eligibility of "renewable biomass", and the use of agricultural intermediates.

Furthermore, EPA needs to adopt the most recent modeling for lifecycle greenhouse gas assessments for corn-based ethanol, biodiesel, sustainable fuels from waste agricultural residues such as corn kernel fiber, and for all other purposes using modernized tracking methodologies as set forth in the most recent Argonne National Laboratory's Greenhouse gases, Regulated Emissions and Energy use in Transportation, commonly referred to as the GREET modeling tool, to improve the way in which these assessments are conducted and ensure greater accuracy, so that more projects can advance that produce ethanol, biofuels, and SAF, reducing the nation's reliance on fossil fuels. This would have immediate benefits for reducing greenhouse gas emissions in the aviation and agricultural sectors by creation of more demand for waste feedstocks and renewable biomass.

Congressional Intentions for Research and Development for Advancing SAF

Government funding for SAF programs in the U.S. Department of Agriculture (USDA), Federal Administration Agency (FAA), and the U.S. Department of Energy (DOE) will ensure programs are continuously funded through grants and loan guarantees.

AFCC strongly recommends continue and increased funding for research, engineering, and development of alternative aviation biofuels. The Federal Aviation Administration (FAA) agency plays an important role in bringing alternative fuels such as SAF from the lab to the airport. Activities include setting policy goals, ensuring that the fuels can be safely integrated with aviation equipment and infrastructure. In the past, FAA program funding included specific appropriations for these activities. In recent budgets, the emphasis has changed to place less emphasis on this economically critical area. AFCC provides funding requests for research dollars to FAA in appropriations request as shown on its website[9] for FY2021 and work is underway for FY2022.

AFCC strongly supports continued funding for the Office of the Assistant Secretary, Development and Technology, FAA Centers of Excellence (COE) Program for alternative jet fuels and environment research since it is considered the largest DOT program attempting to develop new sustainable alternative fuels. Centers of air transportation excellence established under section 44513 of Title 49 are funded by the Airport and Airway Trust under section 48102(a) of title 49. Since its inception, FAA made a major commitment to support multiyear and multimillion dollar research efforts, ensuring coordination and innovation across the university teams that make up the various COEs. This investment has resulted in significant advancements in aviation science, technologies, and technology transfer. There are currently six active established FAA COEs, each with specific research areas. The goal is for each center to become a national resource 20 in a particular area of transportation. The COE program has included over 70 academic institutions and over 200 industry and government affiliates. Through their collaborative efforts, they have conducted research in areas critical to the FAA and the flying public.

Furthermore, increasing – and NOT eliminating – funding for the production of Alternative Fuels for General Aviation – these programs aimed at improving the sustainability and competitiveness of the U.S. transportation system in today's increasingly environmentally conscious world need to be protected as they compete with other priorities. AFCC has a strong focus on alternative feedstocks and fuels for aviation, which are typically derived from biological and renewable resources, and are sustainably produced in the U.S. Their adoption promotes the use of home-grown agricultural crops, helping our farmers, advancing innovation, creating jobs, and in turn building the nations biobased economy. There is growing international demand for these biofuels and mandates in the EU and other areas of the world may require their use in overseas flights and in the U.S. military. Adoption of alternative fuels supports the USA's leadership in green technologies

and AFCC strongly recommends funding research for a cleaner and healthier environment.

Increasing funding for DOE RD&D in next-generation biofuels and other alternative fuels is important, especially since there is uncertainty and slow turnover of electrification of aviation which therefore requires the need for continued scientific exploration of SAF to reduce carbon intensity of liquid fuels burned in the U.S. As a result, Congress should increase funding for DOE's Energy Efficiency Renewable Energy (EERE) funding for research, development, demonstration, and commercialization of SAF – particularly next-generation biofuels made from non-food (cellulosic wood, dead and diseased trees, municipal solid wastes and other non-food sources) which would build a cleaner and more resilient aviation domestic sector.

The loan guarantee programs in both federal agencies, USDA Biorefinery Assistance Program[10] and DOE Loan Program Office[11], provide loan guarantees for the development, construction, and retrofitting of commercial-scale biorefineries that produce advanced biofuels, and these federal programs have enabled companies to put steel in the ground for first-of-a-kind biorefineries that are setup to produce sustainable aviation fuels.

Level the Playing Field for SAF: Tax Incentives, Renewable Fuel Standard, Low Carbon Fuel Standard

AFCC and its member companies have made long-term significant investments in the development of infrastructure for the production of SAF which are based on renewable resources, innovative technologies, are in the process of creating new supply chains and modernizing existing ones, and creating jobs – towards this end the U.S. government needs to ensure long-term tax incentives are available for SAF producers, which will assist in paying dividends towards their capital investments.

Sustainable aviation fuel producers will need support to scale up the production of their alternative fuels. Today, sustainable aviation fuels are eligible for the biodiesel and renewable diesel tax credit in Section 40A of the tax code. On December 27, 2020, President Trump signed the Consolidated Appropriations Act, 2020, into law. This bill retroactively extended the tax credit, which had expired, through 2022. Therefore, the tax credit expires in 2022, Congress should strengthen the sustainable aviation fuels tax credit to include a life-cycle carbon intensity requirement and extend it for at least five years to provide market certainty and should consider the potential benefits of separating the sustainable aviation fuel tax credit from the broader biodiesel tax credit. The House Select Committee on the Climate Crisis report[12] summarized this concept in its report.

Under the existing RFS, sustainable aviation fuel generates fewer credits per gallon than biodiesel. Similarly, the California Low Carbon Fuel Standard does not cover aviation, but users of sustainable aviation fuel can opt in and obtain credits. Neither program currently mandates the production or consumption of certain volumes of sustainable aviation fuel. Congress should amend the Renewable Fuel Standard or

craft a future federal Low Carbon Fuel Standard to provide a credit multiplier for sustainable aviation fuels that meet an ambitious emissions reduction threshold. This will provide fuel manufacturers additional market certainty and financial incentive to scale up production of sustainable aviation fuels.

Leveling the playing field for SAF producers and enacting a long-term SAF specific tax credit will attract significant investment to the sector, address existing infrastructure and policy disadvantages, and will dramatically increase U.S. SAF production facilities which will provide meaningful volumes of sustainable aviation fuels – since SAF continues to be a nascent industry in our sector.

Conclusion

AFCC looks forward to working with the Space and Aeronautics Subcommittee and Science, Space and Technology Committee in finding solutions to climate change – including building and rebuilding America's energy, transportation, and manufacturing infrastructure to be cleaner and more resilient to climate impacts, and offer an opportunity to propel the U.S. economy forward. The aviation sector faces unique challenges as it tries to accomplish its ambitious climate goals, as well as responding to customer and investor-driven desires to decarbonize. SAF is the only near-term technology option for reducing aviation's carbon emissions. Numerous conversion pathways have been approved and there are multiple SAF production facilities in operation, under construction or planned in the United States. Congress supporting legislative polices would accelerate SAF development. Legislation targeting the use of *Forest Residuals* for the production of ground transportation biofuels, SAF, renewable chemical, biobased products and mitigating wild fires.

Sincerely,

Rina Singh, PhD.
Executive Vice President, Policy
Alternative Fuels & Chemicals Coalition

1. Airlines for America, https://www.airlines.org/dataset/impact-of-covid19-data-updates/
2. IATA-International Air Transport Association Board of Governors is comprised of 25 global airlines, including U.S. passenger and cargo carriers, https://www.iata.org/en/about/priorities/

3. https://www.velocys.com/2019/10/10/negative-emission-fuel-

4. https://biofuels-news.com/news/vertimass-awarded-up-to-1-4-billion-to-optimise-renewable-jet-fuel/

5. https://bioenergyinternational.com/biofuels-oils/shell-signs-cellulosic-fuels-purchase-agreement-with-red-rock-biofuels

6. https://news.delta.com/delta-partners-northwest-advanced-bio-fuels-among-actions-toward-more-sustainable-future

7. https://news.delta.com/delta-enters-offtake-agreement-gevo-10m-gallons-year-sustainable-aviation-fuelcreates-long-term

8. https://www.energy.gov/sites/prod/files/2020/09/f78/beto-sust-aviation-fuel-sep-2020.pdf

9. https://7bdc9ed1-5541-4922-aeae-2573761cb763.filesusr.com/ugd/7694c1_f508d86629e5458dbdf3a2c01e9e1232.pdf

10. https://www.rd.usda.gov/programs-services/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance

11. https://www.energy.gov/lpo/loan-programs-office

12. https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf