Sustainable Aviation Fuel Grand Challenge

SAF Grand Challenge Roadmap

Flight Plan for Sustainable Aviation Fuel

U.S. DEPARTMENT OF ENERGY

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

USDA

EPA

Prepared by the U.S. Department of Energy, U.S. Department of Transportation, and U.S. Department of Agriculture, in collaboration with the U.S. Environmental Protection Agency.

Disclaimer

This work was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, its contractors or subcontractors.

Acknowledgements

This roadmap is the result of a memorandum of understanding among the U.S. Department of Agriculture, Department of Energy, and Department of Transportation. Extensive inputs were obtained from four workshops and discussions with federal government agencies, national laboratories, academia, nongovernmental organizations, and industry stakeholders. The Biomass Research and Development Board's Sustainable Aviation Fuel Interagency Working Group provided valuable insights to the roadmap. The Commercial Aviation Alternative Fuels Initiative provided additional opportunity for stakeholder outreach and feedback.

Development and drafting of the roadmap was led by an interagency team including:

William Goldner, U.S. Department of Agriculture
Justin Bredlau, U.S. Department of Agriculture
Nathan Brown, U.S. Department of Transportation, Federal Aviation Administration
Zia Haq, U.S. Department of Energy
Craig Brown, National Renewable Energy Laboratory
With key contributions on regulatory policy by Diana Galperin, U.S. Environmental Protection Agency.

Major writing and editing contributions were provided by:

Kevin Craig, U.S. Department of Energy
Steve Csonka, Commercial Aviation Alternative Fuels Initiative
Jay Fitzgerald, U.S. Department of Energy
James Hileman, U.S. Department of Transportation, Federal Aviation Administration
Beau Hoffman, U.S. Department of Energy
Kristin Lewis, U.S. Department of Transportation, Volpe Transportation Systems Center
Anna Oldani, U.S. Department of Transportation, Federal Aviation Administration
Valerie Reed, U.S. Department of Energy
Ian Rowe, U.S. Department of Energy
Mark Rumizen, U.S. Department of Transportation, Federal Aviation Administration
Mark Shmorhun, U.S. Department of Energy
James Spaeth, U.S. Department of Energy
Ryan Steinbach, U.S. Department of Transportation, Office of the Assistant Secretary for Aviation and International Affairs
Art Wiselogel, U.S. Department of Energy
Michael Wolcott, ASCENT/Washington State University.

Key support, review, and comment was received from representatives of the following organizations:

Commercial Aviation Alternative Fuels Initiative

U.S. Department of Agriculture
- National Institute of Food and Agriculture
- Agricultural Research Service
- Economic Research Service
- Natural Resources Conservation Service
- Rural Development
- Office of the Chief Economist, Office of Environmental and Energy Policy
- Office of the Under Secretary for Research, Education, and Economics/Office of the Chief Scientist

U.S. Department of Defense
- Defense Logistics Agency–Energy
- U.S. Air Force
- Office of the Secretary of Defense

U.S. Department of Energy
- Office of Energy Efficiency and Renewable Energy
- Bioenergy Technologies Office
- Loan Programs Office
- Vehicle Technologies Office

U.S. Department of Transportation
- Office of the Secretary of Transportation
- Office of the Assistant Secretary for Aviation and International Affairs
- Federal Aviation Administration
- Office of Policy, International Affairs, and Environment
- Volpe Transportation Systems Center

U.S. Environmental Protection Agency: Office of Transportation and Air Quality
NASA: Aeronautics Research Mission Directorate
Idaho National Laboratory
National Renewable Energy Laboratory
Pacific Northwest National Laboratory
Argonne National Laboratory
Sandia National Laboratories
Oak Ridge National Laboratory.

Critical administrative support and event coordination was provided by:

Richard Coaxum, The Building People
Brian Cooper, The Building People
Melissa Ladd, BCS
Seth Menter, BCS
Stacey Young, The Building People.

Special thanks to Kathy Cisar, Michael Deneen, and Elizabeth Stone at the National Renewable Energy Laboratory for crucial editorial review, graphics support, document formatting and layout support.

List of Acronyms

ASCENT	Center of Excellence for Alternative Jet Fuels and Environment
ATJ	alcohol-to-jet
CAAFI	Commercial Aviation Alternative Fuels Initiative
CI	carbon intensity
CO_2	carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FOG	fats, oils, and greases
GHG	greenhouse gas
HEFA	hydroprocessed esters and fatty acids
ICAO	International Civil Aviation Organization
LCFS	Low Carbon Fuel Standard
MSW	municipal solid waste
NGO	nongovernmental organization
OEM	original equipment manufacturer
RD&D	research, development, and demonstration
RDD&D	research, development, demonstration, and deployment
SAF	sustainable aviation fuel
USDA	U.S. Department of Agriculture

Executive Summary

"Flight Plan for Sustainable Aviation Fuel"

The Sustainable Aviation Fuel (SAF) Grand Challenge[1] is a U.S. government-wide approach to work with industry to reduce cost, enhance sustainability, and expand production to achieve 3 billion gallons per year of domestic sustainable aviation fuel production that achieve a minimum of a 50% reduction in life cycle greenhouse gas emissions (GHG) compared to conventional fuel by 2030 and 100% of projected aviation jet fuel use, or 35 billion gallons of annual production, by 2050.

To reduce aviation greenhouse gas emissions, the aviation sector is pursuing a combination of aircraft technology, operational improvements, offsetting, and sustainable aviation fuel. This approach is reflected in the *United States 2021 Aviation Climate Action Plan*,[2] which lays out the U.S. government strategy to build on sector-wide industry commitments to foster innovation and drive change across the entire U.S. aviation ecosystem and meet a goal of net-zero GHG emissions from U.S. aviation by 2050. SAF is "drop-in" liquid hydrocarbon jet fuel produced from renewable or waste resources that is compatible with existing aircraft and engines. The plan recognizes that SAF offers a critical near-term solution to reduce greenhouse gas emissions and decouple aviation's growth from its carbon emissions.

Developing innovative technologies to produce SAF will enable the United States to meet its domestic climate goals for the U.S. economy and position it as a global leader in the emerging SAF market. The United States also has the potential to be an exporter of SAF technology and fuels to support other countries in their efforts to decarbonize aviation globally. Finally, SAF supports long-term viability of the U.S. airline and aerospace industries and is a critical component of U.S. strategy in the United Nations' International Civil Aviation Organization (ICAO).

SAF are hydrocarbon fuels and thus emit carbon dioxide when combusted in the aircraft engine. The extent to which any particular SAF provides emission reductions depends on the life cycle emissions profile, taking into account the production, transportation, and combustion of the SAF, as well as indirect effects associated with these. The SAF Grand Challenge requires fuels to reduce emissions by at least 50 percent on a life cycle basis compared to jet fuel, and has workstreams and actions dedicated to increasing the emissions reductions possible from the production, blending, and distribution of SAF. Additional benefits are expected as some types of SAF reduce emissions that impact air quality and contribute to the formation of contrails, which also impacts climate change.

[1] DOE. 2021. "Memorandum of Understanding: Sustainable Aviation Fuel Grand Challenge." Sept. 8, 2021. https://www.energy.gov/sites/default/files/2021-09/S1-Signed-SAF-MOU-9-08-21_0.pdf.
[2] FAA. 2021. *United States 2021 Aviation Climate Action Plan*.

Based on the joint *Billion-Ton Report* from the U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA), about 1 billion dry tons/year of biomass can be grown or collected sustainably.[3] DOE estimates that this amount of biomass could be converted into 50–60 billion gallons of advanced biofuels without impacting agriculture, trade, or current uses of biomass. Further, as ground transport electrifies, SAF presents a potential market for existing biofuels. In addition to biomass sources, waste gaseous sources of carbon are potential SAF feedstocks. Combined, there is sufficient feedstock to meet the projected needs of the U.S. aviation industry if cost, sustainability, and production barriers can be addressed.

Successful implementation of the SAF Grand Challenge will require close collaboration of agencies across the federal government— particularly DOE, USDA, U.S. Department of Transportation (DOT) and its Federal Aviation Administration (FAA), and U.S. Environmental Protection Agency (EPA). The roles for these agencies have been spelled out in the SAF Grand Challenge memorandum of understanding. DOE is researching and developing sustainable fuel production technology, providing support for technology scale-up and advancing environmental analysis of SAF. USDA is developing feedstocks suitable for SAF and supporting commercialization. DOT has capabilities in fuel qualification and certification, U.S. and international standard-setting, transportation infrastructure, and stakeholder outreach. EPA is working directly with all three agencies on existing regulations that can support SAF production. Working within the structure of the interagency Biomass Research and Development Board,[4] an interagency working group on SAF has been established to enable coordination with representatives of a broader set of government agencies.

SAF Grand Challenge Roadmap Overview

An interagency team led by the DOE, DOT, and USDA worked with EPA, other government agencies, and stakeholders from national labs, universities, nongovernmental organizations (NGOs), and the aviation, agricultural, and energy industries to develop this SAF Grand Challenge Roadmap.

The roadmap outlines a whole-of-government approach with coordinated policies and specific activities that should be undertaken by the federal agencies to support achievement of both the 2030 and 2050 goals of the SAF Grand Challenge. This roadmap ensures alignment of government and industry actions and coordinate government policies to achieve the goals of the SAF Grand Challenge. This includes coordination in the formation and execution of plans in research, development, demonstration, and deployment (RDD&D) such as modeling and analysis to ensure sharing of approaches, tools, assumptions, and insights across agencies' research centers at the DOE national laboratories, FAA's Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), and USDA's Agricultural Research Service, Forest Service, and National Institute of Food and Agriculture.

[3] DOE. 2016. "2016 Billion-Ton Report." https://www.energy.gov/eere/bioenergy/2016-billion-ton-report.
[4] Biomass Research & Development. 2022. "Biomass Research & Development Board." https://biomassboard.gov/.

The roadmap lays out six action areas spanning all activities with the potential to impact the SAF Grand Challenge objectives of (1) expanding SAF supply and end use, (2) reducing the cost of SAF, and (3) enhancing the sustainability of SAF:

1. Feedstock Innovation (FI)
2. Conversion Technology Innovation (CT)
3. Building Supply Chains (SC)
4. Policy and Valuation Analysis (PA)
5. Enabling End Use (EU)
6. Communicating Progress and Building Support (CP).

Within each of the six action areas are workstreams that define critical topics to be addressed. Appendix A includes descriptions of granular activities within each workstream that can be pursued. During fiscal year 2023, public–private implementation teams will be formed around these action areas and workstreams. Throughout the remainder of the SAF Grand Challenge time frame, these implementation teams will further assist in developing and refining lists of goals, activities, and timelines commensurate with expected progress on action areas and workstream efforts, as well as identification of new needs.

This roadmap is the beginning of an iterative, collaborative, and necessarily dynamic process. Regular updates are anticipated as research advances, technologies progress, markets develop, and agencies progress toward the SAF Grand Challenge goals.

SAF Grand Challenge Actions and Impact

Meeting the two SAF Grand Challenge goals of 3 billion gallons of SAF per year by 2030 and 35 billion gallons of SAF per year by 2050 will require sets of activities that differ in focus to impact the two different periods. Key actions in support of 2030 and 2050 production and GHG reduction goals are identified on the following pages.

Key Actions To Support 2030 Production

Given the limited time—less than 8 years—to meet the 2030 goal, and considering the time required for SAF production infrastructure to be built, the path to meeting the 2030 goals requires an immediate focus on commercially ready conversion technologies and feedstocks. Lipid-based pathways (fats, oils, and greases) are expected to be the primary fuel pathway leading up to 2030, with a smaller contribution from waste, forest and agricultural residue, and alcohol pathways by 2030.

Workstreams Supporting Near-Term SAF Production Impactful to 2030 Goals

- **Build and support stakeholder coalitions through outreach, extension, and education** (Workstream SC.1) to set the stage for SAF supply chains to develop and sustain themselves and replicate with continuous improvement.
- **Maximize sustainable lipid supply for 2030** (Workstream FI.2) through a coordinated approach to lipid feedstock RDD&D to support rapid buildout of lipid pathway production.
- **Decarbonize, diversify, and scale current fermentation-based fuel industry** (Workstream CT.1) to address barriers to expansion of SAF supply via alcohol pathways.
- **Invest in SAF infrastructure** to support industry deployment (Workstream SC.4) and to allow industry to attract investment into production capacity.
- **Develop improved environmental models and data for SAF** (Workstream PA.1) to support optimization of existing policies and implementation of new policies that could be enacted.
- **Inform SAF policy development** (Workstream PA.3) with analysis of gaps and impacts of policies under consideration.
- **Stakeholder outreach and engagement on sustainability** (Workstream CP.1) to exchange data and information about best practices to reduce life cycle GHG emissions from agricultural and forest-derived feedstocks and optimize other environmental and social impacts.
- **Enable use of drop-in unblended SAF and SAF blends up to 100%** (Workstream EU.2) to simplify blending requirements, reduce cost of logistics, and facilitate supply.
- **Integrate SAF into fuel distribution infrastructure** (Workstream EU.4), including conducting infrastructure analysis to identify and address barriers to SAF supply to airports.

It is important to note that additional policy incentives may be necessary to achieve rapid scaling to meet the 2030 goal. This roadmap includes executive agency activities in support of policy analysis and tools to inform new policy implementation that will increase production of SAF and reduce aviation sector GHG emissions. President Biden, working with Congress**,** signed the Inflation Reduction Act (IRA) into law on August 16, 2022 (see text box below). This legislation provides powerful first steps to incentivize companies across the aviation industry and the fuel supply chain to move aggressively to shift toward a low-carbon future, and to hire American workers to get the job done.

SAF Provisions of the 2022 Inflation Reduction Act (IRA)

The Inflation Reduction Act of 2022, signed into law by President Biden on August 16, includes a two-year tax credit for those who blend SAF; a subsequent three-year tax credit for those who produce SAF; and a grant program of $290 million over four years to carry out projects that produce, transport, blend, or store SAF, or develop, demonstrate, or apply low-emission aviation technologies. To be eligible, the SAF must achieve, in general, at least a 50% improvement in GHG emissions performance on a life cycle basis as compared with conventional jet fuel. The tax credit—which starts at $1.25/gallon of neat SAF—increases with every percentage point of improvement in life cycle emissions performance up to $1.75/gallon.

Key Actions To Support 2030–2050 Production

The path to meet the goals beyond 2030 to 2050 requires a continuing focus on supporting ongoing innovation, including research, development, and demonstration (RD&D) of new feedstock and conversion technologies with potential for exponential growth in production capacity, greater emissions reductions, and reductions in cost of production and carbon intensity (CI) after 2030. This effort must occur simultaneously with the 2030-focused activities to develop a portfolio of solutions that can come into production after 2030 and be sequentially scaled to meet the ambitious fuel production needs through to 2050. Technologies in this portfolio are expected to result in a dramatic buildout and expansion of alcohol, waste-based, lignocellulosic, and waste and captured carbon gas pathways.

Workstreams Supporting Midterm and Long-Term Innovation Impactful to 2050 Goals

- **Conduct RD&D on scaling and sustainability of biomass, waste, and residue feedstocks** (Workstreams FI.3 and FI.6) to enable innovations in technologies and strategies that increase the availability of biomass and waste resources at reduced CI and cost. This includes addressing the social, environmental, and economic sustainability aspects of feedstock supply chains.
- **Conduct RD&D on feedstock logistics and handling reliability** (Workstreams FI.4 and FI.5) to increase efficiencies and decrease cost and CI of supply logistics from the producer's field to the conversion facility door.
- **De-risk scale-up through R&D and integrated piloting of critical pathways by 2030** (Workstreams CT.1–CT.4) to accelerate fuel conversion technology scale-up and improve financeability of critical conversion pathways that utilize the full potential of an expanded feedstock supply.
- **Build and support regional stakeholder coalitions through outreach, extension, and education** (Workstream SC.1) to continue to expand an SAF industry that improves environmental and economic performance while supporting job creation and social equity in multiple regions of the country.
- **Model and demonstrate sustainable regional supply chains for critical pathways by 2035** (Workstreams SC.2 and SC.3) to promote commercialization of SAF supply chains through process validation and risk reduction via access to critical data and tools that empower rapid, informed decision-making when evaluating SAF supply chain options.
- **Continue to invest in industry deployment** (Workstream SC.4) to help overcome barriers to project financing through creative financing, government loans and loan guarantees, and outreach.
- **Continue to inform SAF policy development** (Workstream PA.3) to enable aligned policy incentives that will support long-term SAF deployment.
- **Support SAF qualification** (Workstream EU.1) to accelerate fuel safety testing, evaluation, and specification activity; reduce the cost and time for new approvals; and expand the range of qualified fuels to include new critical pathways that will enable expansion of SAF supply.

Summary

The ultimate goal of the SAF Grand Challenge is to reduce GHG emissions in the aviation sector by supporting the creation of an environment where feedstock producers adopt best practices to reduce emissions, regional collaborations come together to maximize economic and social benefits in developing SAF, and fuel producers ultimately choose to produce and sell SAF to aviation industry end users. As previously noted, further legislative action to reduce cost and risk will likely be necessary to meet the goals. The SAF Grand Challenge Roadmap creates a coordinated approach to federal actions that will increase emissions reductions; de-risk technology, supply chains, and markets; and reduce barriers. This is being carried out with activities that support near-term production to meet 2030 goals, as well as ongoing innovation to support future production to meet 2050 goals. In addition, the roadmap provides a focus on setting up demonstrations of supply chains, investing in production infrastructure, collecting data and performing analysis to support markets for SAF through strong policies, and eliminating barriers to enable distribution and end use of SAF. Finally, the roadmap prioritizes engagement with stakeholders to build support and communicate on progress of the SAF Grand Challenge. In combination, these actions can support industry to build out and use a dramatically expanded U.S.-based SAF supply.

The Sustainable Aviation Fuel Grand Challenge Roadmap affirms that the □overnent, across multiple agencies, is committed to the substantial emissions reductions that can be achieved through SAF research, development, and deployment. It is a plan for continuing, long-term, and substantial assistance and action.

Table of Contents

Disclaimer ii
Acknowledgements iii
List of Acronyms vi
Executive Summary vii
SAF Grand Challenge Roadmap Overview viii
SAF Grand Challenge Actions and Impact ix
Table of Contents xiii
List of Figures xv
List of Tables xv
Introduction 1
Urgency of Action 2
Roadmap Overview 5
Roadmap Approach 5
Roadmap Action Areas 6
Feedstock Innovation 12
FI.1. Understand Resource Markets and Availability 14
FI.2. Maximize Sustainable Lipid (FOG) Supply for 2030 16
FI.3. Increase Production of Purpose-Grown Biomass Resources and Collection of Wastes and Residues 18
FI.4. Improve Feedstock Supply Logistics 20
FI.5. Increase Reliability of Feedstock Handling Systems 23
FI.6. Improve Sustainability of Biomass and Waste Supply Systems 25
Conversion Technology Innovation 28
CT.1. Decarbonize, Diversify, and Scale Current Fermentation-Based Fuel Industry 29
CT.2. Develop Options To Increase Production and Reduce Carbon Intensity of Existing ASTM-Qualified Pathways 31
CT.3. Develop Biointermediates and Pathways for Compatibility With Existing Capital Assets 34
CT.4. Reduce Risk During Scale-Up and Operations 36
CT.5. Develop Innovative Unit Operations and Pathways 37
Building Supply Chains 39
SC.1. Build and Support Regional Stakeholder Coalitions Through Outreach, Extension, and Education 40

SC.2. Model SAF Supply Chains 43
SC.3. Demonstration of SAF Supply Chains 44
SC.4. Invest in SAF Production Infrastructure To Support Industry Deployment 47
Policy and Valuation Analysis 49
PA.1. Develop Improved Environmental Models and Data for SAF 49
PA.2. Conduct Techno-Economic and Production Potential Analysis 52
PA.3. Inform SAF Policy Development 54
Enabling End Use 57
EU.1. Support SAF Evaluation, Testing, Qualification, and Specification 58
EU.2. Enable Use of Drop-In Unblended SAF and SAF Blends up to 100% 59
EU.3. Investigate Synthetic Aviation Turbine Fuels Offering Performance or Producibility Advantages 61
EU.4. Integrate SAF Into Fuel Distribution Infrastructure 62
Communicating Progress and Building Support 64
CP.1. Stakeholder Outreach and Engagement on Feedstock Sustainability 65
CP.2. Conduct Benefits Assessment/Impact Analysis of SAF Grand Challenge 66
CP.3. Measure Progress of the SAF Grand Challenge 67
CP.4. Communicate Public Benefits of the SAF Grand Challenge 68
References 71
Appendix A: Detailed Roadmap Activities (Preliminary) 75
Appendix A.1: Feedstock Innovation Detailed Activities 75
Appendix A.2: Conversion Technology Innovation Activities 84
Appendix A.3: Building Supply Chains Detailed Activities 93
Appendix A.4: Policy and Valuation Analysis Detailed Activities 99
Appendix A.5: Enabling End Use Detailed Activities 104
Appendix A.6: Communicating Progress and Building Support Detailed Activities 109

List of Figures

Figure 1. Analysis of future U.S. domestic and international aviation CO_2 emissions 3
Figure 2. Graphic representation of the SAF Grand Challenge Roadmap 8
Figure 3. Feedstock supply and logistics overview. 13
Figure 4. Oilseed cover crop, *Brassica carinata*. 17
Figure 5. Example of advanced logistics depot system. 22
Figure 6. Conversion pathways to SAF 34
Figure 7. USDA supports several SAF-related regional public–private partnerships under the National Institute of Food and Agriculture Coordinated Agricultural Projects 42
Figure 8. Objectives and accomplishments through scale-up steps 45
Figure 9. World's first commercial flight using cellulosic-based SAF, produced by a Northwest Advanced Renewables Alliance project funded by USDA. 60
Figure 10. Public outreach through field days and listening sessions. 69

List of Tables

Table 1. SAF Grand Challenge Roadmap Action Areas and Workstream Summary 9
Table 2. Biomass Feedstock Potential 15
Table 3. ASTM Pathways 33

Introduction

The aviation sector is an important contributor to the American economy but a significant source of greenhouse gas (GHG) emissions. Aviation generates approximately 2% of U.S. human-made carbon dioxide (CO_2) emissions and contributes additional global warming impacts through high-altitude nitrogen oxide emissions and aviation-induced cloudiness. U.S. commercial aviation currently consumes approximately 10% of U.S. transportation energy. Aviation drives about 6% of the U.S. gross domestic product and just under 7% of national employment. The 2019 jet fuel uplift[5] in the United States was approximately 23 billion gallons and is expected to grow to about 34 billion gallons by 2050.[6]

Aviation is difficult to decarbonize because of the need for an energy-dense liquid fuel to power an aircraft that will carry several hundred passengers and cargo thousands of miles at high speeds in a vehicle that can weigh several hundred tons. To understand the energy needs of aviation, it helps to consider that at takeoff, the jet engines of a Boeing 777 wide-body jet are generating power levels comparable to a small nuclear reactor (e.g., 130 MW).[7] Energy sources other than liquid hydrocarbon jet fuels, such as battery technologies and hydrogen, will thus be limited in the near and medium term to small aircraft flying short ranges and are not expected to contribute to substantially reducing aviation emissions until after 2050. This makes widescale production and use of SAF the highest impact near-term strategy for significantly reducing aviation emissions and achieving the nation's net zero emissions goals for aviation by 2050.

In September 2021, the U.S. Department of Energy (DOE), U.S. Department of Transportation (DOT), and U.S. Department of Agriculture (USDA) launched a government-wide Sustainable Aviation Fuel (SAF) Grand Challenge[8] to meet growing demand for sustainable aviation fuels by working with stakeholders to reduce costs, enhance sustainability, and expand production and use of SAF. SAF is defined as drop-in fuel from wastes, renewable materials, and gaseous sources of carbon that achieves a minimum of 50% reduction in life cycle GHG emissions compared to conventional fuel. The SAF Grand Challenge adopted the goals of supplying at least 3 billion gallons of SAF per year by 2030 and sufficient SAF to meet 100% of aviation fuel demand by 2050, which is projected to be around 35 billion gal/yr. The SAF Grand Challenge affirmed to stakeholders that the U.S. government, across multiple agencies, is committed to SAF research, development, demonstration, and deployment (RDD&D).

[5] Refers to fuel loaded onto aircraft at U.S. airports for all domestic flights (including general aviation, cargo, and passenger operations) and all international departures (including U.S. and foreign operators).
[6] Federal Aviation Administration (FAA). 2021. *United States 2021 Aviation Climate Action Plan*. Washington, D.C.: FAA. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.
[7] Kellner, Thomas. 2017. "GE Just Turned the World's Most Powerful Jet Engine Into A 65-Megawatt Power Plant." *GE News*, Jan. 30, 2017. https://www.ge.com/news/reports/ge-oil-gas-just-turned-worlds-largest-jet-engine-65-megawatt-power-plant.
[8] DOE. 2021. "Memorandum of Understanding."

The SAF Grand Challenge Roadmap provides an outline of actions by U.S. government agencies to support stakeholders in realizing the goals set forth in the SAF Grand Challenge. Under the roadmap, federal government agencies will collaborate and coordinate with the aviation industry, fuel producers, agriculture, research, academia, state/local/tribal governments, and others to accelerate growth of a domestic SAF industry that utilizes U.S. manufacturing capacities and the U.S. workforce, contributes to U.S. energy security, aids economic growth in rural America, and supports a just transition to a low-carbon aviation future.

The roadmap will enable agencies to coordinate activities in RDD&D to catalyze technology innovation, public–private partnerships, policy frameworks, and investments needed to address barriers to realizing the SAF Grand Challenge goals.

It is important to note that realizing the goals of the SAF Grand Challenge will require actions outside of the roadmap scope. Namely, success will likely require legislative actions that invest in SAF RDD&D and create a policy environment where producers and end users choose to produce and use SAF, respectively. It will also require industry to build and purchase SAF supply. Furthermore, although the SAF Grand Challenge Roadmap will inform policy options, it is beyond the scope of the roadmap to suggest policy preferences, and no attempt is made to do so.

This roadmap has and will continue to incorporate input from key stakeholders to ensure alignment of government and industry actions and coordination of government policies. This roadmap is the beginning of an evolving, collaborative, and necessarily dynamic process. Regular updates will be informed by technological progress, market developments, and analysis activities.

Urgency of Action

SAF production and use are critical to the aviation sector. In line with the Biden administration's goal for net-zero GHG emissions by 2050,[9] the aviation industry has also committed to net-zero emissions by 2050.[10,11] In 2019, prior to the COVID-19 pandemic, commercial aviation produced 2.5% of domestic GHG emissions and 11% of transportation sector GHG emissions.[12] The aviation sector has and will continue to make significant improvements in fuel and operational efficiency improvements. However, this will only get the industry part of the way

[9] The White House. 2021. "Fact Sheet: Biden Administration Advances the Future of Sustainable Fuels in American Aviation." *Briefing Room*, Sept. 9, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/09/fact-sheet-biden-administration-advances-the-future-of-sustainable-fuels-in-american-aviation/.
[10] Airlines for America. 2021. "Major U.S. Airlines Commit to Net-Zero Carbon Emissions by 2050." *News Updates*, March 30, 2021. https://www.airlines.org/news/major-u-s-airlines-commit-to-net-zero-carbon-emissions-by-2050/.
[11] IATA. 2021. "Net-Zero Carbon Emissions by 2050." Press Release No: 66, Oct. 4, 2021. https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/. On October 4, 2021, the International Air Transport Association and its member airlines committed to achieve net-zero-carbon emissions by 2050.
[12] EPA. 2022. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020." Tables A-98 and ES-6, last updated July 13, 2022. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

toward net-zero emissions. Unlike the on-road transportation sector, energy alternatives (e.g., electricity and hydrogen) will not be viable for commercial aviation in the near term or midterm. The sector will remain reliant on high-energy-dense liquid fuels for years to come.[13] As indicated by Figure 1, SAF is the only viable means of meeting net-zero-emission targets.

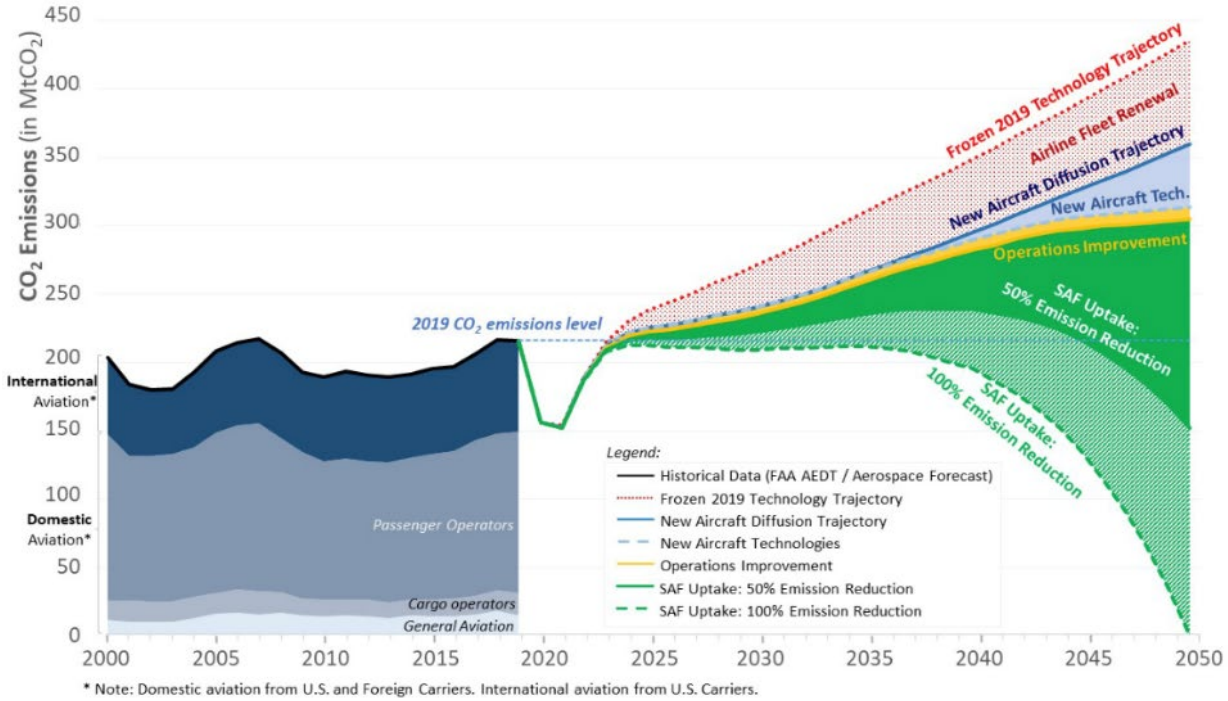


Figure 1. Analysis of future U.S. domestic and international aviation CO_2 emissions[14]

The SAF production goals set forth in the Grand Challenge are ambitious and necessary for the aviation sector to achieve net-zero emissions by 2050. In 2021, approximately five million gallons of SAF were produced domestically. Going from 5 million to 3 billion gal/yr by 2030 is a 600-fold increase that requires a 122% year-over-year growth in production to 2030. It is critical this growth start immediately. Robust federal support for commercially proven technology pathways is necessary to achieve this growth. The U.S. airline industry has committed to work with the federal government and other stakeholders to make 3 billion gal/yr of cost-effective SAF available to U.S. aircraft operators in 2030.[15]

At the same time and in parallel, the foundation must be set to achieve the longer-term 2050 goal. More than 400 biorefineries and 1 billion tons of biomass and/or gaseous carbon oxide feedstock will be needed to produce 35 billion gal/yr by 2050. This will require RDD&D on the

[13] As FAA notes, "there is no realistic option that could replace liquid fuels in the commercial aircraft fleet in the coming decades." FAA. 2021. *United States 2021 Aviation Climate Action Plan*.
[14] FAA. 2021. *United States 2021 Climate Action Plan*.
[15] Airlines for America. 2021. "U.S. Airlines Announce 3-Billion-Gallon Sustainable Aviation Fuel Production Goal." News Updates, Sept. 9, 2021. https://www.airlines.org/news/u-s-airlines-announce-3-billion-gallon-sustainable-aviation-fuel-production-goal/.

next generation of feedstocks and conversion technologies. It is crucial that demonstration projects prove technologies and supply chains in this decade if this level of industry buildout is to occur in the following two decades.

In addition to making a major contribution to the nation's overall climate goals, achieving the SAF Grand Challenge goals will drive economic development along the entire supply chain from farm to flight. The SAF Grand Challenge will support jobs in agriculture, forestry, infrastructure, construction, transportation, research and development, and other areas where America already excels at manufacturing and production. Much of the job creation will occur in rural America, where biomass is available and biorefineries will be located. Additional benefits include enhancing existing crop and forest productivity, providing opportunities for substantial engagement with and benefits to underserved communities and peoples, encouraging industry commitments, and enhancing public–private partnerships.

Roadmap Overview

The SAF Grand Challenge Roadmap provides an outline of actions by U.S. government agencies to support industry in achieving the goals set forth in the SAF Grand Challenge:

- Enable scale-up of the production and use of SAF to 3 billion gal/yr by 2030.
- Enable scale-up of the production and use of SAF to 35 billion gal/yr to meet 100% of domestic aviation fuel demand by 2050.[16]

The roadmap was developed with close collaboration between the sponsoring agencies—DOE, DOT/Federal Aviation Administration (FAA), and USDA—with inputs from other federal agencies including the U.S. Environmental Protection Agency (EPA), Department of Defense, National Aeronautics and Space Administration (NASA), and others. The roadmap development process also included engagement with key stakeholder groups representing the aviation industry (e.g., Commercial Aviation Alternative Fuels Initiative [CAAFI], Airlines for America, passenger and cargo airlines, manufacturers, and business aviation), fuel producers (e.g., Advanced Biofuels Association, Renewable Fuels Association, and energy majors), nongovernmental organizations (NGOs) (e.g., World Wildlife Fund and International Council on Clean Transportation), national laboratories, and academia. Five stakeholder input sessions were held with federal agencies, national labs and agency-funded researchers, and industry and NGO stakeholders. The roadmap contains input from all key stakeholders to ensure alignment of government and stakeholder actions and coordination of government policies.

Clearly, significant government and industry stakeholder support is crucial to achieve the goals and benefits of the SAF Grand Challenge. Federal government agencies intend to collaborate and coordinate with the aviation industry, fuel producers, agriculture, research, academia, state/local governments, and others to accelerate growth of a domestic SAF industry that utilizes U.S. manufacturing capacities and the U.S. workforce, contributes to U.S. energy security, and supports a just transition to a low-carbon aviation future. Going forward, the agencies will continue to seek and incorporate stakeholder input.

Roadmap Approach

Through this roadmap, the federal agencies will coordinate RDD&D activities to catalyze technology innovation, public–private partnerships, policy frameworks, and investments needed to address barriers to realizing the SAF Grand Challenge goals. These activities will span the entire supply chain from farm to flight.

The SAF Grand Challenge Roadmap outlines actions to address three key themes necessary to realize the emissions reductions expected from the Grand Challenge goals:

[16] The White House. 2021. “Fact Sheet.”

1. **Expanding SAF supply and end use** through support for regional feedstock and fuel production development; outreach, extension, and workforce development; new infrastructure and commercialization support through federal programs; implementation of supporting policies that may be enacted; enabling approvals of diverse SAF pathways; and continued outreach and coordination with military and industry end users.
2. **Reducing the cost of SAF** through critical activities that drive down cost of production across the supply chain, expand the feedstock and conversion technology portfolio, leverage and repurpose existing production infrastructure, reduce risk to industry, and provide incentives for production.
3. **Enhancing sustainability of SAF** by maximizing the environmental co-benefits of production, reducing the carbon intensity (CI) of SAF supply chains, ensuring robust standards that guarantee high environmental integrity, and enabling approvals of higher blend levels of SAF.

Roadmap Action Areas

The SAF Grand Challenge Roadmap lays out a plan of six action areas in which the federal government and stakeholders will collaborate to support achieving these SAF production levels.

Feedstock Innovation

The Feedstock Innovation Action Area lays out R&D workstreams facilitating sustainable feedstock supply system innovations across the range of SAF-relevant feedstocks, as well as enabling supply chain optimization to reduce cost, technology uncertainty, and risk; increase yield and sustainability; and optimize SAF precursors (e.g., ethanol and isobutanol). Using an evolving approach, feedstock supply systems will be developed to interface with existing or emerging conversion technologies to enable SAF production to meet near-term (2030) and longer-term (2050) U.S. SAF production targets. The Feedstock Innovation Action Area overlaps with other action areas in the roadmap, including Conversion Technology Innovation, Building Supply Chains, and Policy and Valuation Analysis.

Conversion Technology Innovation

The Conversion Technology Innovation Action Area covers R&D through pilot scale from the receipt of biomass at the refinery gate through finished fuel to achieve technology improvements and carbon intensity reductions. The effort includes processes that are already commercialized, such as the hydroprocessed esters and fatty acids (HEFA) pathway, or nearing commercialization (e.g., the alcohol-to-jet [ATJ] pathway), and addresses work on processes that will be ready for commercialization beyond 2030 but need to be developed now. Workstreams between the Conversion Technology Innovation and Feedstock Innovation action areas will need to collaborate to ensure the delivery of feedstock suitable for conversion and conversion processes that maximize retainment of emissions reductions achievable through feedstock. Technology that is developed through integrated piloting is handed off to the Building Supply Chains area workgroups for regional supply chain demonstration projects.

Building Supply Chains

The SAF supply chains area encompasses feedstock production, collection, and distribution to SAF production facilities; conversion of feedstock to fuel; and transport of finished fuel to the infrastructure required to fuel aircraft. Because current fuel certifications require SAF to be blended with conventional fuels, the SAF supply chain also requires coordination with conventional jet fuel industries. As SAF production is a nascent industry, SAF supply chains are immature, may be regionally unique, and will likely require significant resources and investment to establish. This action area will support SAF production expansion through R&D transitions from pilot to large scale, demonstration projects to validate supply chain logistics and business models, and public–private partnerships and collaboration with regional, state, and local stakeholders.

Policy and Valuation Analysis

The objective of this action area is to provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF. Workstreams in this action area will evaluate the impact of existing and new policies to address key barriers that prevent production and use of SAF. Data and analytical tools will be used to demonstrate where policy needs to be developed to address major production challenges and enhancements to emission reductions. Workstreams will develop improved environmental models and data for SAF, conduct techno-economic and production potential analysis, and inform SAF policy development. Key activities include engagement and collaboration with key stakeholder groups, including NGOs and international organizations such as the International Civil Aviation Organization (ICAO), on data and method development.

Enabling End Use

The Enabling End Use Action Area focuses on RDD&D activities to facilitate the end use of SAF by civilian and military users. The action area focuses on addressing critical barriers and requirements for safe and cost-effective use of SAF via standards development and critical R&D and analysis. The workstreams include SAF qualification, reaching 100% drop-in SAF, fuel performance evaluation, and SAF integration with existing fuel distribution infrastructure. Efforts spanning these key areas will address critical barriers to SAF deployment.

Communicating Progress and Building Support

Effective communication that transparently demonstrates the environmental, climate, and economic benefits of SAF is vital to building public trust and increasing support. For the SAF Grand Challenge to be successful, public awareness of SAF as one of the solutions to reduce net GHG emissions from aviation, while also simultaneously investing in the U.S. domestic economy, will be critical. This includes making transparent, science-based analysis and data on the impacts and benefits of SAF and progress toward SAF Grand Challenge goals available to the public. Communication activities will support workstreams across the other five action areas, including engagement with key stakeholder groups such as NGOs.

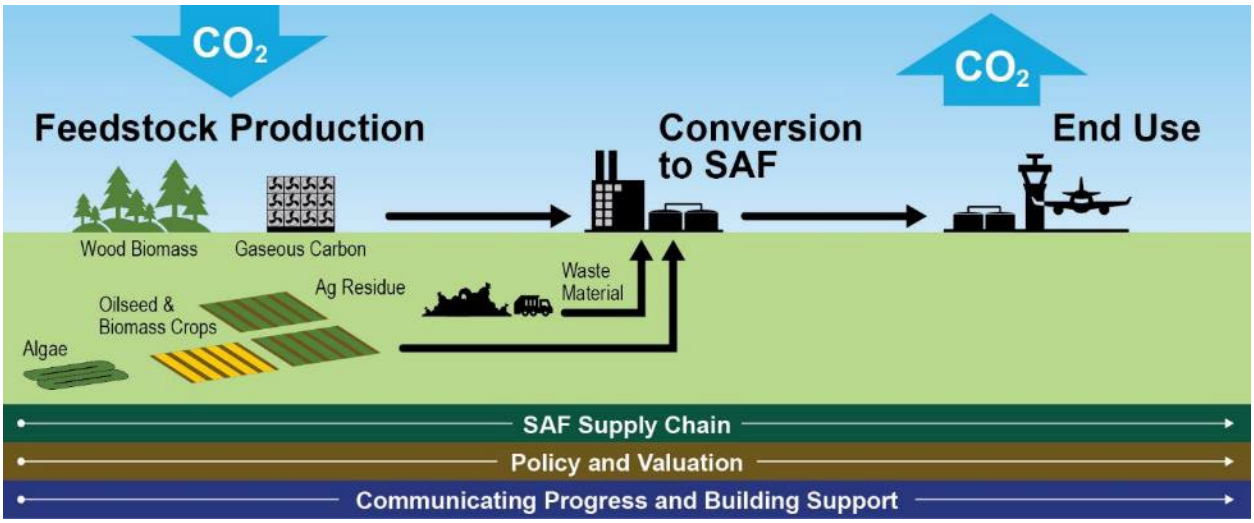


Figure 2. Graphic representation of the SAF Grand Challenge Roadmap

Each of the six action areas is further broken down into workstreams. These workstreams define critical high-level activities within each action area. Action areas and the related workstreams are summarized in Table 1. Appendix A provides a more granular description of the roadmap activities, including potential deliverables and possible timelines for action. The activities currently defined in Appendix A are a preliminary list of possible activities under each workstream. During fiscal year 2023, public–private implementation teams will be formed around these action areas and workstreams. These implementation teams will further develop and refine these lists of specific activities and timelines.

The roadmap is intended to be the beginning of an evolving, collaborative, and necessarily dynamic process. This will require regular updates at least every 2 years, informed by analysis activities. These periodic reviews will assess progress and redirect activities, as necessary and appropriate, to optimize adaptation to changing technology, markets, and political factors.

The next six sections provide a higher level of explanation for each of the action areas of the SAF Grand Challenge Roadmap and provide detail on the workstreams that have been identified for each action area.

Table 1. SAF Grand Challenge Roadmap Action Areas and Workstream Summary

1. Feedstock Innovation (FI)	
WORKSTREAM FI.1: Understand resource markets and availability. Develop databases and market analysis (including competitive uses) for commodity and commercially available feedstocks under increased demand for SAF and assess and analyze the factors affecting the availability of non-commodity/commercial feedstocks. **WORKSTREAM FI.2: Maximize sustainable lipid (fats, oils, and greases [FOG]) supply for 2030.** Given near-term relevance of SAF conversion of lipids to meeting 2030 goals, take a coordinated approach to lipid feedstock research, development, and demonstration (RD&D) to support expansion to meet 2030+ goal, development of a lipid multigenerational project plan, and coordination of U.S. government support for near-term lipid crop expansion (e.g., oilseed cover crops). **WORKSTREAM FI.3: Increase production of purpose-grown biomass resources and collection of wastes and residues.** Increase the production and collection of biomass resources (besides lipids) for 2030 and beyond by conducting/supporting R&D on crop genetic development, sustainable production and management, and crop harvest or residual/waste collection.	**WORKSTREAM FI.4: Improve feedstock supply logistics.** Support the development of supply chain systems, including transportation, storage, and preprocessing logistics, to increase efficiencies and decrease cost and carbon intensity of supply logistics from the producer's field to the conversion facility door. **WORKSTREAM FI.5: Increase reliability of feedstock handling systems.** Acquire a deep understanding of the behavior and characteristics of solid feedstocks and enable development of computational models that inform R&D to increase the reliability of feedstock handling operations. **WORKSTREAM FI.6: Improve sustainability of biomass and waste supply systems.** Develop an understanding of how biomass production and waste collection for use as a biofuel feedstock impact air, water, soil, biodiversity, and social/environmental justice.
2. Conversion Technology Innovation (CT)	
WORKSTREAM CT.1: Decarbonize, diversify, and scale current fermentation-based fuel industry. This workstream will reduce the carbon intensity of the existing starch ethanol industry while increasing its production capacity, without requiring the planting of additional corn. This workstream will also further improve the economics and CI of alcohol-to-jet processes and other pathways that utilize fermentation to make SAF molecules or precursor molecules.	**WORKSTREAM CT.3: Develop biointermediates and pathways for compatibility with existing capital assets.** The focus area of this workstream is on various biointermediate streams that are likely to be transferred between entities for processing from feedstock to finished fuel. This workstream will (1) investigate opportunities to integrate with industry both on the upstream and downstream ends by identifying priority intermediates, (2) determine value added due to industry integration and compelling business opportunities and business models, (3) determine critical material attributes at interfaces with industry partners, and (4) develop R&D plans to achieve intermediate conversion for industry engagement.

WORKSTREAM CT.2: Develop options to increase production and reduce carbon intensity of existing ASTM-qualified pathways. This workstream will investigate options to accelerate deployment of pathways that already have an approved specification under ASTM International. This workstream will also cover the conversion efforts needed to allow these pathways to accept additional feedstocks (e.g., sustainable oilseeds and brown grease) to increase volumes at existing facilities and to improve the CI of these technologies.	**WORKSTREAM CT.4: Reduce risk during scale-up and operations.** This workstream will proactively address resiliency in process and equipment design, in addition to conventional risk assessment methods such as bowtie. Note that this approach will be in addition to the project scale-up through integrated pilot and demo. Where possible, process performance and intermediate quality guarantees are needed to limit risk. **WORKSTREAM CT.5: Develop innovative unit operations and pathways.** Additional pathway development and deployment will be needed to broaden the availability of SAF. This workstream will explore next-generation or disruptive technologies that, when integrated in pathways, yield a CI of zero or less.
3. Building Supply Chains (SC)	
WORKSTREAM SC.1: Build and support regional stakeholder coalitions through outreach, extension, and education. Convene regionally specific stakeholder efforts to lead exploration of SAF production and provide outreach, extension, and education necessary to support the entire supply chain from feedstock producers to end users. **WORKSTREAM SC.2: Model SAF supply chains.** Develop and apply comprehensive and updated data, transparent analyses, and tools as a foundation for how best to build SAF supply chains for cost-effective, optimal GHG reduction and expedited deployment of feedstock and fuel technologies.	**WORKSTREAM SC.3: Demonstration of regional SAF supply chains**. Support feedstock-to-fueling demonstration projects to de-risk and mature key elements in the supply chain from feedstock through airport distribution. **WORKSTREAM SC.4: Invest in SAF production infrastructure to support industry deployment.** Invest in SAF production infrastructure and facility development with existing and new grant and support programs. Utilize loans and loan guarantees, production payments, assistance grants, government funding mechanisms, and other opportunities to enable rapid scaling of commercial technologies.
4. Policy and Valuation Analysis (PA)	
WORKSTREAM PA.1: Develop improved environmental models and data for SAF. Develop and utilize modeling capabilities, data, and analyses to quantify SAF greenhouse gas and other environmental impacts. This will ensure environmental integrity and appropriately account for SAF emission reduction benefits. **WORKSTREAM PA.2: Conduct techno-economic and production potential analysis.** Develop and utilize techno-economic analysis and resource	**WORKSTREAM PA.3: Inform SAF policy development.** Identify opportunities and strategies to improve existing policy and regulatory mechanisms that can increase availability of SAF. Identify gaps, needs, and impact of new policies on SAF availability and quality.

assessment models. Expand and refine modeling capabilities and generate analyses to inform RDD&D of SAF. Evaluate the opportunities and scenarios necessary to meet SAF Grand Challenge goals and provide direction to the effort to ensure optimum conditions for production expansion.	
5. Enabling End Use (EU)	
WORKSTREAM EU.1: Support SAF evaluation, testing, qualification, and specification. Lead a coordinated approach to support civil and military aircraft and engine fuel performance, safety testing, and specification approval; improve test methods; and enable coordination with aviation stakeholders. **WORKSTREAM EU.2: Enable use of drop-in unblended SAF and SAF blends up to 100%.** Lead a coordinated approach to enable drop-in SAF that can be used at up to 100%, beyond the current maximum blend limit of 50% by volume.	**WORKSTREAM EU.3: Investigate synthetic aviation turbine fuels offering performance or producibility advantages.** Analyze potential and challenges of new fuels with unique compositions for use in aviation that have enhanced performance benefits (e.g., emissions and energy density). **WORKSTREAM EU.4: Integrate SAF into fuel distribution infrastructure.** Conduct analysis on technical and capacity potential and challenges of the existing fuel distribution infrastructure for SAF integration.
6. Communicating Progress and Building Support (CP)	
WORKSTREAM CP.1: Stakeholder outreach and engagement on feedstock sustainability. Consultations will be held with NGOs and other stakeholder groups to exchange information about best practices to reduce life cycle GHG emissions from agricultural- and forest-derived feedstocks. **WORKSTREAM CP.2: Conduct benefits assessment/impact analysis of SAF Grand Challenge.** Develop analysis of SAF Grand Challenge impacts (e.g., jobs, fuel, and environment).	**WORKSTREAM CP.3: Measure progress of the SAF Grand Challenge.** Track progress against the SAF Grand Challenge goals and publish information on progress and outcomes on a regular basis. **WORKSTREAM CP.4: Communicate public benefits of the SAF Grand Challenge.** Maintain public support via a communication plan, including education on sustainability and jobs.

Feedstock Innovation

> Support and conduct R&D on sustainable feedstock supply that enables system innovations across the range of SAF-relevant feedstocks and identify optimization to reduce cost, technology uncertainty, and risk; increase yield and sustainability; and optimize SAF precursors (e.g., ethanol and isobutanol).

Using an evolving approach, feedstock supply systems will interface with extant or emerging conversion technologies to enable SAF production to meet near-term (2030) and longer-term (2050) SAF Grand Challenge production targets. The Feedstock Innovation Action Area interacts with other action areas in the roadmap, including Conversion Technology Innovation, Building Supply Chains, and Policy and Valuation Analysis.

Expanding feedstock supply to meet the 2030 and 2050 goals will take a coordinated effort to reduce feedstock cost, increase feedstock yield, improve sustainability, and provide profitable opportunities for feedstock producers. In the near term, policy support for SAF is needed to enable production and use of expanded lipid-based feedstocks. R&D is needed to improve the sustainability parameters (e.g., carbon intensity, water conservation, reduction of inputs, soil improvement, and biodiversity) of existing commodity feedstocks. Also, the full potential of double cropping with oilseeds needs to be reached.

Midterm and longer term, the trajectory is for growing expansion into feedstocks from waste streams, including agricultural and forest residuals, food waste, municipal solid waste (MSW), industrial waste gases, and dedicated herbaceous and woody crops. RD&D is needed to reduce feedstock production/collection, transportation, and preprocessing costs. In fact, feedstock supply chain logistics and the introduction of solid feedstocks into biorefinery processing systems remain key areas for continued RD&D.

Dedicated feedstock crop production on marginal and degraded lands (e.g., strip mines) will add to feedstock availability while potentially improving these lands by preventing erosion and increasing soil organic matter. The challenge here is to develop cost-effective systems and business models for the production, management, and harvesting of these challenging feedstock production sites.

To reach 2050 targets, an “all-of-the-above” approach is needed. This would necessarily include the collection and use of currently nonmarketable woody biomass. Enhanced use of this biomass would help solve current problems like catastrophic wildfires. In the western United States, there are 60 million acres of

2030 Feedstock Innovation Impact Highlights

Maximize sustainable lipid supply

Increasing the supply of sustainable lipid feedstocks to support near-term SAF production has been identified as a critical need. As an element of a coordinated approach to lipid feedstock RDD&D, USDA will work with U.S. farmers to develop and improve sustainable oilseed supply through expanded R&D and pilot trials for emerging oilseed cover crops. Expanding cover crops with low land-use-change impact will be vital to support the 2030 SAF production goal of 3 billion gal/yr (see Activity FI.2.4: Develop new sustainable oilseed cover crops).

insect-damaged conifers that contribute significantly to wildfires and ultimately biodegrade, releasing additional GHGs.[17] Work is ongoing to determine economic technology and business models to responsibly and sustainably remove these woody biomass assets for conversion to fuels and products.

Although the challenges for expanding feedstock supplies are many, so are the opportunities. Investing in RD&D to reduce cost and improve sustainability will be paramount to reach the stated SAF Grand Challenge goals, along with optimized policy and incentive support.

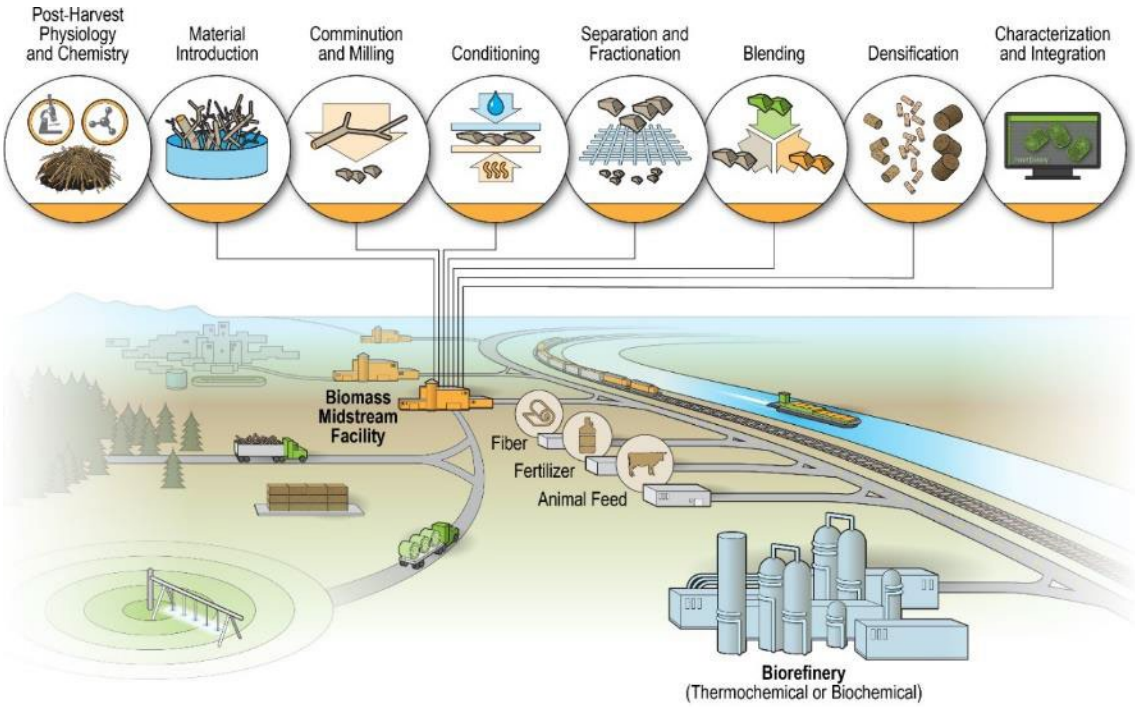


Figure 3. Feedstock supply and logistics overview.

Figure by Idaho National Laboratory

[17] BANR. 2022. "The Mountain Pine Beetle Epidemic." Accessed July 20, 2022. http://banr.nrel.colostate.edu/the-mountain-pine-beetle-epidemic/.

The key actions supporting SAF feedstock innovation are:

- **Understand resource markets and availability** to foster an understanding of supply and demand dynamics for feedstocks under the proposed production levels for SAF and develop common and accessible databases for SAF feedstock.
- **Maximize sustainable lipid supply for 2030** through a coordinated approach to lipid feedstock RDD&D.
- **Increase production of purpose-grown biomass resources and collection of wastes and residues** by enabling innovations that will lead to the development of technologies and strategies that will increase the availability of biomass and waste resources for use as biofuel feedstocks at reduced carbon intensity, inputs, and cost.
- **Improve feedstock supply logistics** with R&D to support the development of collection and harvesting systems, including transportation, storage, and preprocessing to increase efficiencies and decrease cost and carbon intensity.
- **Increase reliability of feedstock handling systems** through understanding how feedstock composition, structure, and behavior impact system performance.
- **Improve sustainability of biomass and waste supply systems** through understanding how biomass production and waste collection for use as a biofuel feedstock impacts air, water, soil, biodiversity, and social/environmental justice.

Detailed activities and suggested timelines are identified for each workstream in Appendix A.1.

FI.1. Understand Resource Markets and Availability

To reduce SAF cost and expand production, it is important to understand resource markets and availability. It is imperative to develop databases and implement market analysis for commodity and other commercially available feedstocks (e.g., crops, wood pellets, pulp chips, and algae) under increased demand for SAF and to assess and analyze the factors affecting the availability of non-commodity feedstocks (e.g., wood chips and landscape trimmings). Table 2 quantifies our current understanding of feedstock availability. These activities will foster an understanding of supply and demand dynamics for feedstocks under the proposed production levels for SAF, including evaluation of alternative and competing uses (e.g., biomass heat and power, biochemicals, bioproducts, and other biofuels), and develop common and accessible databases for SAF feedstocks. These activities will enhance identification of feedstock availability and limitations for SAF conversion technologies and supply/cost curves.

Feedstocks for 2030

Lipids are the feedstock to produce SAF through the HEFA pathway and will make up the vast majority of feedstock to meet the U.S. goal of 3 billion gal/yr by 2030 (~90% based on analysis of announced projects that could go into operation by 2030). However, starch- and sugar-based feedstocks are emerging as potential near-term feedstock for SAF through the ATJ pathway(s).

Utilizing lignocellulosic feedstock from MSW, woody biomass, forest operation residuals, mill waste, and agricultural residuals has the potential to add marginally to the 2030 feedstock pool through gasification and pyrolysis SAF conversion pathways.

Table 2. Biomass Feedstock Potential

Feedstock	Potential (million dry tons/year)
Biomass based on 2021 ethanol and biodiesel production capacity [a]	
Seed oils	9
Corn grain	148
Biomass based on *2016 Billion-Ton Report* [b]	
Forestry resources and woody wastes	133
Woody energy crops	71
MSW	55
Agricultural residues	176
Herbaceous energy crops	340
Algae input based on 2017 *Algae Harmonization Study* [c]	
Algae	235
Biomass based on 2017 *Biofuels and Bioproducts from Wet and Gaseous Wastes* [d]	
Fats, oils, and greases (FOG)	7
Wet wastes (animal waste, food waste, wastewater solids)	78
TOTAL	**1,252**

[a] Feedstock input based on existing production capacity divided by yield. 2019 biodiesel production capacity of 2.54 billion gal/yr[18] with assumed biodiesel yield of 281 gallons of gasoline equivalent per ton seed oil. Ethanol production capacity of 17.44 billion gal/yr[19] with yield of 118 gal ethanol/dry ton.

[b] Feedstock inputs are from the *2016 Billion-Ton Report*.[20] All pathways assume reference case 2040 projections at $60/ton.

[c] Algae feedstock is based on 2017 *Algae Harmonization Study*.[21] Total 235 million tons/yr based on the cumulative volume from the saline scenario, Table 11.

[d] Wet waste volume is from *Biofuels and Bioproducts from Wet and Gaseous Waste Streams*[22]; includes wastewater residuals, animal wastes, and food waste from Table 2-1. Total volume is scaled up by 9% for assumed population growth between 2017 and 2030.

[18] U.S. Energy Information Administration. 2021. "Monthly Biodiesel Production Report." Accessed Feb. 2021. https://www.eia.gov/biofuels/biodiesel/production/.
[19] Renewable Fuels Association. 2021. *Essential Energy: 2021 Ethanol Industry Outlook*. Ellisville, MO: RFA. https://ethanolrfa.org/file/1007/RFA_Outlook_2021_fin_low.pdf.
[20] DOE. 2016. *2016 Billion-Ton Report*.
[21] ANL, NREL, and PNNL. 2017. *Algae Harmonization Study: Evaluating the Potential for Future Algal Biofuel Costs, Sustainability, and Resource Assessment from Harmonized Modeling*. Golden, CO: National Renewable Energy Laboratory. NREL/ TP-5100-70715. https://www.nrel.gov/docs/fy18osti/70715.pdf.
[22] DOE. 2017. *Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Challenges and Opportunities*. Washington, D.C.: DOE. DOE/EE-1472. https://www.energy.gov/eere/bioenergy/downloads/biofuels-and-bioproducts-wet-and-gaseous-waste-streams-challenges-and.

Feedstocks for 2030 to 2050

To meet longer-term (2050) targets, the aforementioned feedstocks will be joined by dedicated herbaceous and woody biomass crops (e.g., switchgrass, miscanthus, and hybrid poplars), agricultural residuals (e.g., corn stover, cover crops, and livestock manure), invasive species (sourced though landscape restoration projects), micro- and macroalgae, wet wastes (e.g., food waste, municipal wastewater sludge, and animal manures), renewable natural gas and renewable hydrogen, and carbon-containing gases from waste and other sources (e.g., CO_2, carbon monoxide, and landfill methane), and direct air capture. Resource availability and market analyses need to be conducted and periodically updated (e.g., *Billion-Ton Report* and updates[23]). The Feedstock Readiness Level tool[24,25] can be used to provide insight into the readiness level of emerging feedstocks.

WORKSTREAM FI.1: Understand resource markets and availability	
Develop databases and market analysis (including competitive uses) for commodity and commercially available feedstocks under increased demand for SAF and assess and analyze the factors affecting the availability of non-commodity/commercial feedstocks.	
DELIVERABLE	**IMPACT**
A periodically updated understanding of the supply and demand dynamics for feedstocks under the proposed production levels for SAF and development of common databases for SAF feedstocks.	Identification of feedstock availability and limitations for SAF conversion technologies and supply/cost curves.
KEY THEMES: Reduce cost, expand production	

FI.2. Maximize Sustainable Lipid (FOG) Supply for 2030

Expanding SAF production to meet the 2030 goal requires a coordinated approach to lipid feedstock RD&D to increase sustainable lipid availability for the HEFA conversion pathways. Toward this end, a lipid multigenerational project plan will be developed, which will include evaluation of lipid feedstock using the Feedstock Readiness Level tool and coordination of U.S. government support for near-term lipid crop expansion (e.g., oilseed cover crops).

[23] DOE. 2016. *2016 Billion-Ton Report*.
[24] USDA. 2022. "Farm 2 Fly." Accessed July 20, 2022. https://data.nal.usda.gov/farm-2-fly.
[25] Steiner, Jeffrey J., Kristin C. Lewis, Harry S. Baumes, and Nathan L. Brown. 2012. "A Feedstock Readiness Tool to Complement the Aviation Industry Fuel Readiness Level Tool." *BioEnergy Research* 5: 492–503. https://doi.org/10.1007/s12155-012-9187-1.

Figure 4. Oilseed cover crop, *Brassica carinata*.

Photo courtesy of University of Florida

Expand the Lipid Supply for SAF Production

Understanding lipid aggregation potential through data collection and analysis of lipid types, characteristics, costs, quantities, and locations will allow optimization of diverse lipid aggregation for regional SAF production. A diverse array of lipids should be studied, including but not limited to oilseed crops (including soybean and canola), oilseed cover crops, food waste (e.g., used cooking oil/brown grease), distillers corn oil, and animal fat/tallow. Expanded use of commodity vegetable oils including soybean and canola could play a role in growing SAF volumes. An important near-term activity under the Feedstock Innovation Action Area will be to improve the CI scores through RD&D that improves cultivation practices, increases yield, and decreases inputs. Another important activity is gaining a better understanding of indirect land use change parameters and ramifications for expanded cultivation for soybean and canola—for example, understanding whether increasing lipid use will result in importation of palm oil for food applications in the United States. An important long-term activity will be expansion of oil feedstock resources beyond 2030, such as tree/bush oils, algae (microalgae and macroalgae), advanced microbial conversion of lignocellulosic wastes to lipids, and engineered oil excrescence in biomass itself.

WORKSTREAM FI.2: Maximize sustainable lipid (FOG) supply for 2030	
Given near-term relevance of SAF conversion of lipids to meeting 2030 goals, take a coordinated approach to lipid feedstock RDD&D to support expansion to meet 2030+ goal, develop a lipid project plan, and coordinate U.S. government support for near-term lipid crop expansion (e.g., oilseed cover crops).	
DELIVERABLE	**IMPACT**
More lipids available for qualified conversion pathways.	Increase the probability to produce 3 billion gal/yr of SAF by 2030 and beyond.
KEY THEMES: Expand production (for 2030 goal)	

FI.3. Increase Production of Purpose-Grown Biomass Resources and Collection of Wastes and Residues

SAF production needs to be expanded exponentially; therefore, means to reduce SAF cost to approach/reach parity with petroleum-based jet fuel are critical to achieve long-term (2050) success. The U.S. government needs to support R&D to increase the production and collection of biomass resources (beyond lipids). This means enabling innovations that will lead to the development of technologies and strategies that will increase the availability of biomass and waste resources for use as biofuel feedstocks at reduced CI, inputs (e.g., water, fertilizer, and pesticide), and cost. Policy (e.g., eligibility for low-carbon fuel incentives) and incentive programs for feedstock production support (e.g., Biomass Crop Assistance Program), as well as crop insurance and pesticide/herbicide labeling, should be studied in support of feedstock production systems.

Municipal Solid Waste

MSW is a potentially important SAF feedstock from the perspectives of abundance, low costs, and reduction of other environmental challenges associated with current disposal methods. In addition, MSW is a resource that does not require the use of arable land or land for food production. R&D is needed on collection, sorting, decontamination, and reduction of cost of disposal or recycling for non-biogenic waste. Strategies and technologies need to be optimized to increase the amount and purity of waste resources that can be collected at a reduced cost and CI for use as SAF feedstock.

Agricultural Residuals

Agricultural residuals such as corn stover have promise as feedstock that can be obtained at a scale to significantly support expansion of SAF production. Necessary R&D includes improved collection strategies, technologies, and demonstrations that reduce cost, improve or do not harm subsequent crop yield, improve soil and water quality, and optimize biodiversity.

Woody Biomass, Forest Operation Residuals, and Mill Waste

Woody biomass is a key feedstock available at scale where harvest, handling, and storage is well understood. However, R&D is needed on cost-effective forest management and collection paradigms enabling the use of greater quantities of sustainable forest health thinnings, forest operation residuals (e.g., slash and bark), and wildland fire mitigation material. Strategies, technologies, and demonstrations should be optimized that increase the amount of available woody biomass while improving forest health and reducing wildfire risk. Also, similar R&D is needed to reduce the cost and improve quality for wood-based feedstock from landscape, construction, and demolition wastes.

Dedicated Energy Crops

Significant funding and resources have gone into systems using dedicated energy crops (e.g., DOE Regional Feedstock Partnership,[26] Idaho National Lab Bioenergy Feedstock Library,[27] Biofuels Feedstock Development Program at Oak Ridge National Lab,[28] DOE Office of Science Center for Bioenergy Innovation,[29] and USDA National Institute of Food and Agriculture Coordinated Agricultural Projects[30]), but continued genetic enhancements, production, and management optimization, as well as improved logistics, are still needed. Long-term regional production trials/demonstrations are needed for dedicated energy crops (e.g., switchgrass, miscanthus, energy cane, hybrid poplars, and selected oilseed crops). Micro- and macroalgae production trials and cost-effective processing scenarios are needed for these aquatic feedstocks to reach their potential as dedicated biomass/oil feedstocks.

Wet Waste, Industrial and Waste Gases, Power-to-Liquid

Municipal wastewater sludge, livestock and poultry manure, and industrial wet processing and food wastes can be processed into renewable natural gas (methane) that can be used for energy, renewable hydrogen production, fertilizer production, and SAF production and coproducts. Although anaerobic digestion systems for animal manure are not uncommon, R&D is needed to enable the sustainable and economical digestion or co-digestion of other methanogenic feedstocks. Logistics paradigms need to be explored relative to integration and colocation with existing processing/collection facilities. Industrially generated CO_2 and carbon monoxide also have potential as SAF feedstocks near and beyond 2030. Further out, but under development by

[26] South Dakota State University. 2022. "DOE Regional Feedstock Partnership." Accessed July 20, 2022. https://www.sdstate.edu/north-central-regional-sun-grant-center/doe-regional-feedstock-partnership.
[27] Biomass Feedstock National User Facility. 2022. "Bioenergy Feedstock Library." Accessed July 20, 2022. https://bioenergylibrary.inl.gov/.
[28] Wright, L. L., J. H. Cushman, A. R. Ehrenshaft, S. B. McLaughlin, W. A. McNabb, J. W. Ranney, G. A. Tuskan, and A. F. Turhollow. 1992. *Biofuels Feedstock Development Program Annual Progress Report for 1991*. Oak Ridge, TN: Oak Ridge National Laboratory. ORNL-6742. https://doi.org/10.2172/6941410.
[29] DOE. 2022. "CBI: Center for Bioenergy Innovation." Accessed July 20, 2022. https://genomicscience.energy.gov/cbi/.
[30] USDA. 2022. "AFRI Regional Bioenergy System Coordinated Agricultural Products." Accessed July 20, 2022. https://www.nifa.usda.gov/afri-regional-bioenergy-system-coordinated-agricultural-projects.

industry, is direct air capture of atmospheric CO_2. Power-to-liquid (i.e., PtL, e-fuels) are also under development.

WORKSTREAM FI.3: Increase production of purpose-grown biomass resources and collection of wastes and residues	
Provide the R&D to increase the production and collection of biomass resources (besides lipids).	
DELIVERABLE	**IMPACT**
Development of technologies and strategies that will increase the availability of biomass and waste resources for use as biofuel feedstocks.	More biomass and waste resources are available at an acceptable carbon intensity and price for the production of SAF.
KEY THEMES: Reduce cost, expand production	

FI.4. Improve Feedstock Supply Logistics

Biomass supply chain logistics are critical to the economic, environmental, and social sustainability of SAF feedstocks. These logistics chains are diverse and often fine-tuned to a particular local set of biomass infrastructure, conversion technology, and distribution network. Some forms of biomass can be delivered directly to the biorefinery as fungible feedstocks (e.g., vegetable oils), while others may need significant preprocessing to reach feedstock status (e.g., lignocellulosics). R&D is needed to support the development of collection and harvesting systems, including transportation, storage, and preprocessing to increase efficiencies and decrease cost and carbon intensity. Localized densification related to energy derived from feedstocks is needed for all feedstocks. For oilseed, crushing or extraction needs to be done close to feedstock production. Lignocellulosic feedstocks require local methods of densification and moisture reduction (e.g., on-farm drying methods) to reduce transport costs.

Improve Conventional Supply Systems

The diverse feedstock resources required to meet the SAF supply goals have supply systems with vastly different levels of maturity and sophistication. Mature conventional supply systems for commodity crops such as corn (which supplies starch for ethanol production) and soybeans (which supply vegetable oil for hydrotreating into SAF) are well established. These established supply systems tend to improve efficiencies and reduce cost incrementally over time with improvements in the technologies that make up the supply chain. This is expected to remain true with these mature systems in the coming years with better materials of construction, electrification of some unit processes, improvements in artificial intelligence and sensor technology, advancements in cover crop use in soybean production systems, and other advancements that will reduce cost and carbon intensity.

Other feedstock resource supply systems are less mature and sophisticated. These conventional supply systems tend to be designed for collection of a biomass feedstock resource for purposes

that do not require large amounts of a commodity-quality feedstock. Such systems provide a basic background in the processes required to collect, field-process, handle bulk materials, store, and transport; however, the cost, carbon intensity, and quality of the feedstock resource typically is well below that required for conversion technologies. Examples of such systems are baled herbaceous materials, MSW, hog fuel, and wood chips. These less sophisticated conventional supply systems can provide feedstock resources to local plants with incremental improvements to lower cost and carbon intensity and meet feedstock specifications. All supply systems have exposure to supply risk due to local weather conditions, human and equipment resources, fire, and biomass resource competition. In addition, the conversion facility typically must manage biomass resource contracts, including verifying quality targets, and requires extensive storage and preprocessing facilities to ensure supply and that the biomass resource meets feedstock specifications.

The research and development that results in incremental change is being supported by both the public and private sector. In general, the private sector focuses on more applied science and engineering for well-established biomass feedstock resources where the return on investment will be quicker. The public sector, often in conjunction with the private sector, tends to focus on biomass feedstock resources that currently have minimal or no biofuel markets.

Develop Advanced Supply Systems

Innovative disruptive strategies and technologies rapidly improve the prospects for optimized supply chains. This can be true for established conventional biomass resource supply systems that produce a well-defined commodity, as well as supply systems that are not as mature. It is highly likely that a disruptive strategy will produce an advanced supply system that will redistribute the biomass resource supply risk within a newly formed supply chain. Examples of this are the depot system proposed by Idaho National Laboratory for herbaceous and woody feedstock (Figure 5). The depot approach moves feedstock supply risk to an intermediate facility, the depot, that will process biomass into a format that meets verifiable specifications and is more easily transported long distances. Another example is direct air capture, which will create an entirely new feedstock supply chain along with a new set of feedstock conversion interface issues that will depend on the production of any intermediate products and the conversion technology.

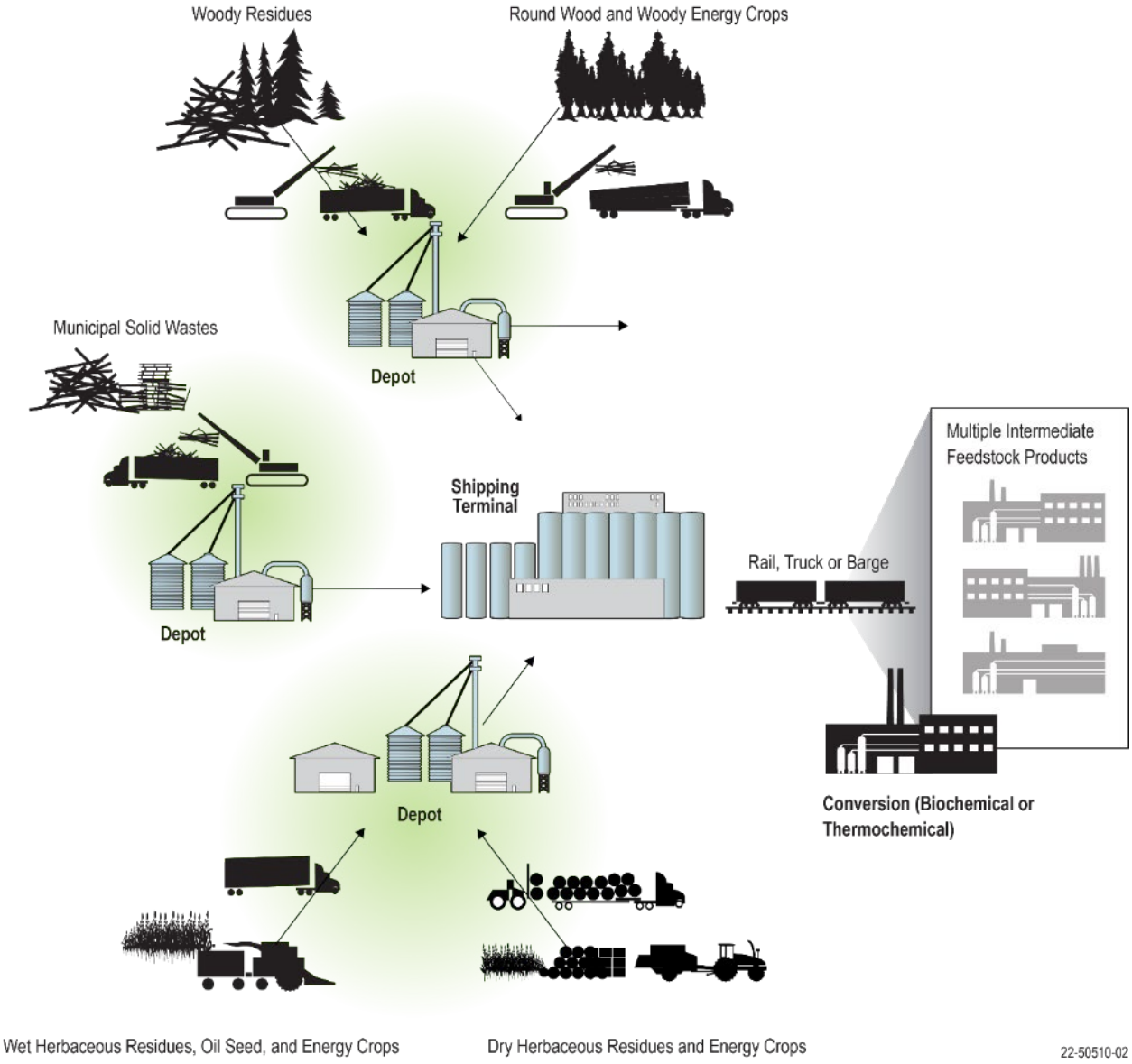


Figure 5. Example of advanced logistics depot system.

Figure by Idaho National Laboratory

Like incremental improvements, disruptive advancements typically come from public and private sector R&D. In addition, disruptive advancements may come from the application of technology or strategy developed for other applications. No matter the source of the disruptive approach, it results in dramatic change and a redistribution of risk and rewards.

WORKSTREAM FI.4: Improve feedstock supply logistics	
Support the development of collection and harvesting systems, including transportation logistics, to increase efficiencies and decrease cost and carbon intensity of supply logistics from the producer's field to the conversion facility door.	
DELIVERABLE	**IMPACT**
Technologies and strategies that will increase the availability of low-cost and low-CI biomass and waste resources for use as a biofuel feedstock.	More biomass and waste resources are available at an acceptable carbon intensity, quality, and price.
KEY THEMES: Reduce cost, expand production	

FI.5. Increase Reliability of Feedstock Handling Systems

Many of the process bottlenecks and difficulties experienced in the nascent bioenergy industry are centered on feedstock handling and preprocessing operations, specifically where the feedstock supply system interfaces with the conversion process. Feedstock issues arise from the complexity and variability in feedstock dimensional, physical, chemical, and mechanical attributes that complicate feeding the material into the conversion process, as well as recalcitrance of feedstocks that prevents efficient conversion into fuels and products. Operational difficulties come from conversion equipment operation and reliability, process integration, and operational difficulties encountered with handling of solids, which can result in nonuniform conversion or heterogeneity of intermediates.

A key hypothesis of the roadmap framework is that poor quantification, understanding, and management of variability in biorefinery streams contributes significantly to the inability of biorefineries to operate continuously and profitably. Due to the increasing importance of these issues, there is a need to quantify, understand, and manage variability in biomass from field through downstream conversion and to understand how feedstock composition, structure, and behavior impact system performance.

Materials of Construction

The development of materials that resist wear and can tolerate the range of variability in feedstocks and operating parameters expected for biomass refineries is essential. Current biomass preprocessing/preconversion equipment was designed for different raw biomass materials and feedstock specifications (e.g., processing of agricultural products or paper pulp operations) but are not appropriate for biomass such as MSW, corn stover, forest residues, and dedicated energy crops. There is a lack of study of the materials of construction in this area, and equipment materials are often selected by trial and error. R&D is required to compare both the performance and cost trade-offs using techno-economic analysis to ensure improved performance on one surface is not at a potentially higher expense of the opposing surface.

Feedstock Variability

It is important to understand the level of variability in biomass materials and how it relates to the level of preprocessing required to meet feedstock quality and quantity specifications. The complexity of lignocellulosic biomass poses significant challenges to handling, preprocessing, and conversion operations. Industry lacks understanding of material and quality attributes; their magnitude, range, and distribution in available resources; tools for rapidly quantifying feedstock quality; and their impact to integrated feeding, preprocessing, and conversion. The multiscale approach will enable a fundamental understanding of how the structural and physicochemical attributes of cell wall composition and architecture underpin flow behavior, as well as mechanical, biochemical, and thermochemical deconstruction in preprocessing and conversion of biomass to product. It will also provide insight into how molecular and microscale attributes (compositional, structural, and physicochemical) manifest in macroscale biomass behavior in feeding, preprocessing, and conversion operations.

Material Handling

All currently accepted methods to quantitatively design bins and hoppers to feed particulate materials are based upon assumptions that the material behaves like a Mohr–Coulomb continuous material. This approach does not apply well for elastoplastic particulate materials like biomass, which has mechanical behavior far more complex than that of Mohr–Coulomb materials. There is a need to develop a set of modeling tools for gravity-driven bins and hoppers, mechanically assisted flow in atmospheric pressure augers, and mechanically assisted compression screw augers into pressurized reactors to enable consistent performance for a defined biomass material. These tools will be necessary to design a facility where general material heuristics are used, as well as to adapt enhanced process control and optimization across a defined specification of material quality.

Preprocessing

Preprocessing equipment, techniques, and strategies using science-based design and operation principles that result in predictable, reliable, and scalable performance of preprocessing unit operations are lacking, as is the understanding of their direct impact on primary biomass deconstruction. Through the development of first-principle models for select unit operations in relevant conversion pathways, equipment needs that relate feedstock specifications to biomass properties for preprocessing equipment can be determined. R&D should include process design, parameters, and control, which are multidisciplinary topics that include computational modeling, materials science, and mechanical, chemical, and control engineering.

WORKSTREAM FI.5: Increase reliability of feedstock handling systems	
Acquire a deep understanding of the behavior and characteristics of solid feedstocks and enable development of computational models that inform R&D to increase the reliability and performance of feedstock handling operations.	
DELIVERABLE	**IMPACT**
Development of technologies and strategies that will increase SAF plant efficiency and decrease downtime.	Reduction in feedstock uncertainty.
KEY THEMES: Reduce cost, expand production	

FI.6. Improve Sustainability of Biomass and Waste Supply Systems

Sustainability (economic, environmental, and social) is pivotal to the success of existing and emerging SAF supply chains, production systems, and value propositions. From the perspective of feedstock innovation, all three parameters play important roles that cannot be ignored. Economics drive the feedstock supply chain, whether for cultivated feedstocks or collected residuals and waste streams. Compensating feedstock producers for dedicated feedstocks resulting in environmental benefits will be important for widespread adoption. From an environmental perspective, there is a strong need to develop an understanding of how biomass production and waste collection for use as a biofuel feedstock impacts air, water, soil, and biodiversity. Social sustainability may be framed at the community and individual levels and includes both the social capital for communities and individuals to participate in facilitating designs for new agro-industrial footprints that may affect them, but also participating in and benefitting from SAF production and being protected from health, environmental, social (e.g., environmental justice), and fiscal risks that may emerge. R&D and analysis is needed to provide a better understanding of the environmental and social impacts of producing SAF feedstock from biomass and waste resources, leading to reduction in the uncertainty of environmental and social effects of SAF production systems.

Research and analysis of systems-level sustainability practices that lower CI scores will have to be conducted with a strategy to deploy best practices, which includes engagement with the NGO community and feedstock producers (see Workstream CP.1). For example, research to improve plant genetics and optimal agronomic practices will be necessary to continuously improve yields and sustainability. Current commodity crops with new oilseed or biomass crops grown over winter may provide environmental benefits (e.g., reduction in erosion and pollinator forage) that should be measured.

Environmental Data Collection and Analysis

Previous work on sustainability needs to be revisited and updated (e.g., *2016 Billion-Ton Report, Volume 2*[31]). A comprehensive regional and, as needed, subregional examination of environmental impacts of using agricultural and forest residues, agricultural and forest waste, MSW, dedicated energy crops, and algae to produce SAF feedstocks is needed. There is a large body of completed or ongoing work for perennial grasses,[32] oilseed cover crops,[33] energy cane,[34] short-rotation woody crops,[35] forest operation and mill residuals,[36] insect-damaged conifers,[37] and other feedstocks.[38]

Data are needed to enable defensible feedstock production decisions and inform policy based on an understanding of the environmental and social implications and trade-offs for the use of biomass and waste resources to produce SAF. Also, research is needed to provide insight into (1) targeting the appropriate places to produce or harvest biomass to deliver ecosystem services, and (2) measuring, verifying, and valuing those services. Providing this important valuation information for policymakers will enable additional income sources related to ecosystem services for feedstock producers.

Social Data Collection and Analysis

Studies need to assess the trade-offs of social implications from the use of biomass and waste resources to produce SAF feedstock. Understanding how SAF feedstock production can benefit equity and what environmental social barriers may exist would be highly desirable and facilitate a more equitable distribution of benefits and impacts from the production/collection of biomass and waste resources to produce SAF feedstock.

---

[31] DOE. 2017. *2016 Billion-Ton Report, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*. Jan. 13, 2017. https://www.energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-volume-2-environmental-sustainability-effects.

[32] Iowa State University. 2022. "CenUSA Bioenergy." Accessed July 20, 2022. https://cenusa.iastate.edu/; PennState Extension. 2013. "NEWBio Energy Crop Profile: Switchgrass." Last updated Aug. 22, 2013. https://extension.psu.edu/newbio-energy-crop-profile-switchgrass; West Virginia University. 2022. "MASBio at West Virginia University." Accessed July 20, 2022. https://masbio.wvu.edu/; Southeastern Partnership for Integrated Biomass Supply Systems. 2022. "Southeastern Partnership for Integrated Biomass Supply Systems." Accessed July 20, 2022. http://se-ibss.org/.

[33] IPREFER. 2022. "IPREFER – Integrated Pennycress Research Enabling Farm & Energy Resilience." Accessed July 20, 2022. https://www.iprefercap.org/; Southeastern Partnership for Advanced Renewables from Carinata. 2022. "SPARC." Accessed July 20, 2022. https://sparc-cap.org/.

[34] LSU AgCenter. 2022. "Sustainable Bioproducts Initiative." Accessed July 20, 2022. https://www.lsuagcenter.com/topics/crops/bioenergy/biofuels_bioprocessing/subi.

[35] Washington State University. 2020. "Advanced Hardwood Biofuels Northwest [Archived]." Last updated April 2020. https://hardwoodbiofuels.org/; PennState Extension. 2013. "NEWBio"; IBSS. 2022. "Southeastern Partnership"; West Virginia University. 2022. "MASBio."

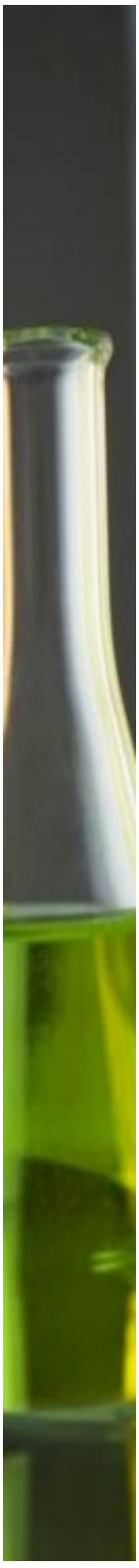
[36] Washington State University. 2022. "NARA." Accessed July 20, 2022. https://nararenewables.org/.

[37] BANR. 2022. "Bioenergy Alliance Network of the Rockies." Accessed July 20, 2022. http://banr.nrel.colostate.edu/.

[38] The University of Arizona. 2022. "Sustainable Bioeconomy for Arid Regions." Accessed July 20, 2022. https://sbar.arizona.edu/.

WORKSTREAM FI.6: Improve sustainability of biomass and waste supply systems	
Develop an understanding of how biomass production and waste collection for use as a biofuel feedstock impact air, water, soil, biodiversity, and social/environmental justice.	
DELIVERABLE	**IMPACT**
R&D and analysis that will provide a better understanding of the environmental and social impacts of producing SAF feedstock from biomass and waste resources.	A reduction in the uncertainty of environmental and social effects from the production/collection of biomass resources and waste for SAF feedstock.
KEY THEMES: Enhance sustainability	

Conversion Technology Innovation



> Support and conduct R&D, through pilot scale, on unit operations (and integration thereof) from the receipt of biomass at the refinery gate through to finished fuel for technology improvements/carbon intensity reductions. The effort includes processes that are already commercial, such as HEFA, or nearing commercialization (ATJ) and considers work on processes that will be ready for commercialization beyond 2030 but need to be developed now.

Conversion technologies and processes constitute the steps required to convert feedstocks into a fuel that meet required specifications as an aviation fuel. These conversion technologies include the pretreatment of feedstock, biological and/or catalytic processes for conversion, and separations or purification steps to recover intermediates or finished fuels, among others. The configuration of these operations varies significantly depending on the feedstock type or quality, scale of operations, access to other infrastructure, carbon intensity requirements, and many other factors.

Impacts to 2030 goals discussed herein are predominantly related to improvements to existing processes. Given the amounts of time required to properly de-risk and scale up new processes, it is anticipated that conversion technology innovations in the near term are most likely to be incremental yield and sustainability improvements in fermentation processes, technologies that can expand the feedstock pool for HEFA processes, and utilization of existing refining capacity to coprocess intermediates. Common to each of these technologies is the fact that they leverage existing capital investments, making these pathways to sustainable aviation fuel volumes more economically viable. These improvements are also anticipated to improve the carbon intensity of existing processes to enable compliance with greenhouse gas reduction goals for particular pathways.

Ultimately, there are limits to the amount of fuel that can be derived from fats, oils, greases, lipids, and starch sugars. Progress beyond 2030 volumes will require research, development, and scale-up of wholly new technologies and processes to realize the goal of 35 billion gallons of sustainable aviation fuel per year. These processes will enable the United States to mobilize other feedstock resources identified in the Feedstock Innovation Action Area, as well as other carbon sources such as waste gases.

A diversity of technologies and pathways will be needed, and no single process will be capable of realizing the goal of 35 billion gallons on its own. This is dictated by the need for a variety of end molecule types to achieve fuel properties for safe operation of airplanes. For example, feedstocks such as waste oils and lipids are well

2030 Conversion Technology Innovation Impact Highlights

Enable alcohol-to-jet and coprocessing pathways

The existing corn ethanol industry has tremendous near-term potential to increase SAF production volumes through the ATJ pathway. Reducing the carbon intensity and increasing the carbon efficiency of corn ethanol are key barriers to realizing this potential. Activities under Workstream CT.1 focus on improving the CI of existing corn ethanol facilities through carbon-smart technologies and agricultural practices (see Activity CT.1.1). Additionally, dramatic improvements in water balances and energy intensity of the ATJ process are possible through development of water-tolerant catalysts (see Activity CT.1.4) and advanced separation technologies (see Activity CT.1.5).

The utilization of bio-derived intermediates in existing capital assets may also contribute to the 2030 production goal. Developing processes to produce such intermediates that are "drop-in" substitutes for FOG or bio-oil in petroleum hydrotreaters (see Activity CT.3.3), identifying insertion and blending points (see Activity CT.3.4), and working with industry partners to determine critical material attributes of bio-derived intermediates (see Activity CT.3.5) are key examples of activities with potential impact on 2030 production goals.

suited to produce paraffinic hydrocarbons, whereas forest residues that contain lignin might be better suited to produce the cyclic compounds and aromatics required for fuel combustion and sealing properties. A multitude of technology pathways also enables fuel supply chain resilience by broadening the feedstock pool.

The key actions supporting the Conversion Technology Innovation Action Area are:

- **Improvements to fermentation fuel industry** to reduce the carbon intensity of the existing starch ethanol industry and increase its production capacity without requiring the planting of additional corn.
- **Improvements to existing ASTM-qualified pathways** to accelerate deployment of pathways that have already been qualified.
- **Development of biointermediates and pathways for compatibility with existing capital assets** to accelerate production and reduce cost of SAF.
- **Reduce scale-up and operational risk** by proactively addressing resiliency in process and equipment design.
- **Develop innovative unit operations and pathways** to broaden the availability of SAF.

Detailed activities and suggested timelines are identified for each of workstreams in Appendix A.2.

CT.1. Decarbonize, Diversify, and Scale Current Fermentation-Based Fuel Industry

There is significant potential for producing SAF volumes by leveraging existing starch ethanol capacity and other fermentative processes (e.g., isobutanol). Although the ethanol sector is

mature, there are improvements that can be made to improve the sustainability of these fuels and the conversion to SAF molecules or precursor molecules.

Near-term carbon intensity improvements in the alcohol production process can be realized in several ways, as identified by recent analyses using the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model.[39] These improvements are in addition to some of the agricultural practices identified in Workstream FI.6. These opportunities include integrating carbon capture and sequestration technologies with ethanol facilities, reducing the energy required for separations/concentration of alcohols following fermentation, and improving the tolerance of ATJ catalysts to impurities and water. Development and piloting of these process improvements is needed to validate CI reductions and plant-scale energy use before existing biorefineries are likely to implement them on a large scale. In addition to these process improvements to carbon intensity, there are opportunities to reduce GHG emissions via the agricultural practices of corn production; these are discussed in Workstream FI.6.

In the longer term, there are other steps that can be taken to further decarbonize the fermentation-based fuel industry without additional corn acreage. This can be accomplished through increased fuel yields from existing sugars. In addition, use of the agricultural residues remains a critical component of expanding the volumetric capacity of the fermentation fuel industry and yield of fuels from the existing acreage. 2050 SAF goals cannot be reached without the use of agricultural residues such as corn stover or energy crops (see Workstream FI.3). At this time, lignocellulosic feedstocks continue to have materials handling, pretreatment, and convertibility issues. Integrated process robustness on these steps has been elusive, and pilot systems that can operate reliably need to be demonstrated to enable confident design and operation of commercial-scale plants.

Moving beyond carbon capture and sequestration, there may be potential for the utilization of CO_2 waste. Such integrated use of CO_2 can reduce the carbon intensity of the fuel produced while also generating molecules that can be biologically or chemically upgraded to improve system-level yields. There is also potential to convert biomass-derived sugars to intermediates other than ethanol that can be more readily upgraded to SAF. These example technologies are in experimental development, and more investment is necessary before these can be piloted and ultimately demonstrated.

[39] Wang, Michael, Uisung Lee, Hoyoung Kwon, and Hui Xu. 2021. "Life-Cycle Greenhouse Gas Emission Reductions of Ethanol with the GREET Model." Presented at the 2021 National Ethanol Conference, Feb. 17, 2021. https://afdc.energy.gov/files/u/publication/ethanol-ghg-reduction-with-greet.pdf.

WORKSTREAM CT.1: Decarbonize, diversify, and scale current fermentation-based fuel industry	
Reduce the carbon intensity of the existing starch ethanol industry and increase its production capacity without requiring the planting of additional corn. This workstream will also further improve the economics and CI of ATJ processes and other pathways that utilize fermentation to make SAF molecules or precursor molecules.	
DELIVERABLE	**IMPACT**
Carbon intensity improvements to ethanol production and expanded buildout of ethanol or other ATJ facilities.	Improvements to the existing starch ethanol capacity can accelerate volumetric deployments of SAF, as the front-end processes (crop production, harvesting, and handling) have been de-risked. Creates additional volumes of SAF without introducing significant process complexity.
KEY THEMES: Expand production, enhance sustainability, reduce cost	

CT.2. Develop Options To Increase Production and Reduce Carbon Intensity of Existing ASTM-Qualified Pathways

As of October 2021, nine conversion process pathways for SAF production have been approved by ASTM International. To be used in commercial flights, SAF has to comply with ASTM D7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) and/or ASTM D1655 (Standard Specification for Aviation Turbine Fuels) standards. These pathways and the permitted blending levels are listed in Table 3.

There are opportunities to further reduce carbon intensity, enhance process efficiency, and yield improvements for these existing conversion pathways that have an approved specification under ASTM standards. These include such research, development, and scale-up efforts as:

- Increased efficiency and reliability of gasification, pyrolysis, and other thermal processing systems.
- Catalyst research and development to:
    - Increase selectivity and yield to desired products.
    - Increase tolerance to contaminants.
    - Increase time between catalyst regeneration.
- Improved reliability of cellulosic ethanol technologies and reducing the carbon intensity of starch and lignocellulosic processes through increased integration, waste handling, and CO_2 utilization.
- Process development to increase the variety and types of biomass-derived oils that can be processed to acceptable SAF intermediates.

- New and improved separation processes to remove impurities and catalyst poisons and enable nutrient recycle.
- Novel and improved reactor design to increase process intensity.

In addition to these and other RD&D efforts, a state of industry analysis of the existing ASTM pathways will be conducted to identify additional:

- R&D needs with current feedstocks.
- Opportunities to expand the acceptable feedstock base.
- Process improvements necessary to accept other feedstocks.

This analysis should be completed in conjunction with industrial partners to identify which unit operation(s) warrant R&D investment and to prioritize these investments.

In the near term, there is an opportunity to contribute significant volumes toward the 2030 goals by ensuring that the catalytic processes developed for HEFA can accept additional waste FOG and other sustainable oilseeds (see Activity FI.1.2). For example, a recent analysis found that there are approximately 500 million gallons of gasoline equivalent of brown grease available, but almost all of this is either landfilled or incinerated.[40] The oil compositions (e.g., carinata) and impurities (e.g., solids and free fatty acids) of these additional lipids can be different from incumbent oils, and additional processing/purification steps could be necessary or require the development of more robust catalysts. Ultimately, developing catalytic steps that can process all these oils in a commingled configuration is preferable from a capital cost perspective.

As this state of industry analysis is completed, it is expected that capital and operational expense improvements might be identified for key pathways such as Fischer-Tropsch synthesis and gas fermentation. Small or modular-scale systems might offer unique opportunities for SAF production in some cases as well but might present technical challenges where R&D for process intensification may be necessary for viability.

[40] DOE. 2017. *Biofuels and Bioproducts from Wet and Gaseous Waste Streams*.

Table 3. ASTM Pathways

ASTM Reference	Conversion Process (Abbreviation)	Possible Feedstocks	Blending Ratio by Volume	Year of ASTM Approval	Commercialization Proposals/Projects
ASTM D7566 Annex A1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT)	Coal, natural gas, biomass	50%	2009	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
ASTM D7566 Annex A2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA)	Bio-oils, animal fat, recycled oils	50%	2011	World Energy, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC
ASTM D7566 Annex A3	Synthesized iso-paraffins from hydroprocessed fermented sugars (SIP)	Biomass used for sugar production	10%	2014	Amyris, Total
ASTM D7566 Annex A4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (FT-SKA)	Coal, natural gas, biomass	50%	2015	Sasol
ASTM D7566 Annex A5	Alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK)	Biomass from ethanol or isobutanol production	50%	2016 (isobutanol); 2018 (ethanol)	Gevo, Cobalt, Honeywell UOP, LanzaTech, Swedish Biofuels, Byogy
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel (CHJ)	Triglycerides such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil	50%	2020	Applied Research Associates (ARA)
ASTM D7566 Annex A7	Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids (HC-HEFA-SPK)	Algae	10%	2020	IHI Corporation
ASTM D1655 Annex A1	Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery (Coprocessed HEFA)	FOG coprocessed with petroleum	5%	2018	
ASTM D1655 Annex A1	Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery (Coprocessed FT)	Fischer-Tropsch hydrocarbons coprocessed with petroleum	5%	2020	Fulcrum

WORKSTREAM CT.2: Develop options to increase production and reduce CI of existing ASTM-qualified pathways	
Investigate and develop options to accelerate deployment of pathways that have already been ASTM-qualified. This workstream will also cover the conversion efforts needed to allow these pathways to accept additional feedstocks (e.g., sustainable oilseeds and brown grease) to increase volumes at existing facilities and improve the CI of these technologies.	
DELIVERABLE	**IMPACT**
Yield, cost, and CI improvements to existing SAF pathways.	Accelerates deployment of SAF because pathways are already qualified. Expands capacity of existing facilities. Creates system resiliency and redundancy in feedstock and conversion options. Reduces risk for project development and financing. Creates opportunities to investigate options to increase blending rates in the future.
KEY THEMES: Expand production, enhance sustainability, reduce cost	

CT.3. Develop Biointermediates and Pathways for Compatibility With Existing Capital Assets

Due to risk, technical complexity, and capital expense, it is anticipated that many SAF supply chains will not be vertically integrated by a single organization or biorefinery. The technical expertise of feedstock preprocessing/pretreatment versus conversion versus fuel finishing and hydroprocessing are sufficiently unique that it is quite possible that these different technologies may not be collocated at a single plant site and operated by a single organization. Instead, there may be a variety of hub-and-spoke models.

In a segmented supply chain, it would therefore be anticipated that there will be priority "biointermediates" transferred between entities before finally being delivered to a blending and storage site or an airport as finished fuel. Such biointermediates could include cellulosic sugars, alcohols from fermentation or synthesis, stabilized bio-oils from pyrolysis, or biocrude from hydrothermal liquefaction. What is shared amongst these biointermediates is that they are sufficiently stable and can be stored and transported to another entity for further processing.

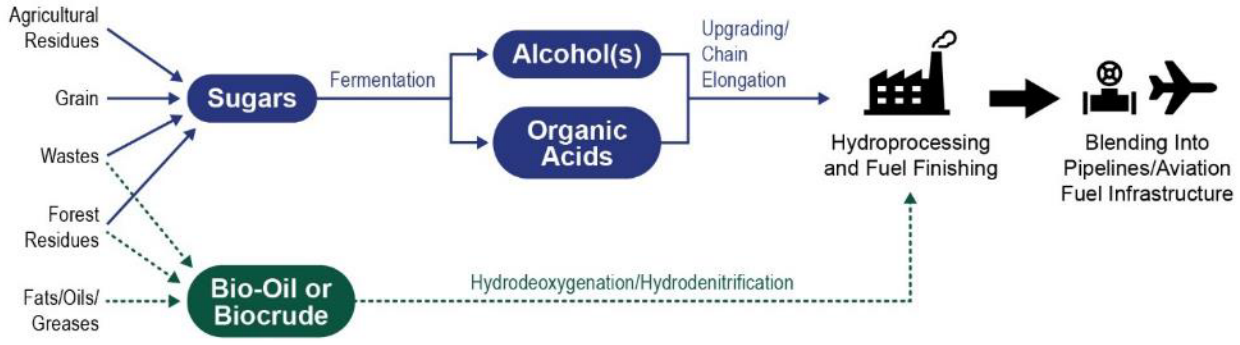


Figure 6. Conversion pathways to SAF

The acceptability of a biointermediate as an input to subsequent unit operations will be determined by various material attributes such as miscibility, stability, and the presence of impurities. Establishing and documenting quality specifications is critical to the development of supply chains to ensure that downstream conversion operations are not impacted negatively and that finished fuels meet the specifications to be reliable and safe in aircraft. This also relates to careful design of experiments at pilot scale (see Workstream CT.4), which can be used to inform these material attributes. These quality specifications can ultimately lead to performance guarantees on unit operations, which are critical for organizations to attract financing for future projects.

In later processing steps, notably hydroprocessing or other fuel-finishing steps, this framework can also leverage existing petroleum-refining assets such as hydrotreaters, hydrocrackers, and alkylation units to lessen the capital intensity of investments. The hydroprocessing steps are anticipated to have the highest capital costs, and by directing various streams to these existing industry assets, potential savings could be realized overall. To realize this, collaborations with petroleum refiners are necessary to define acceptable ranges for species such as oxygen, nitrogen, and sulfur and understand where in the refinery these biointermediates can be inserted.

This framework requires discussion and ideation with industry partners to identify priority biointermediates and understand the value propositions, downsides, and risks. It can also help to establish expectations on quality specifications and the associated price/value at these process or organizational interfaces. Lastly, it can help inform regulatory agencies such as EPA or the California Air Resources Board to ensure that biointermediate qualification for fuels can occur and that the appropriate energy and material balance data are being generated and collected through the value chain.

WORKSTREAM CT.3: Develop biointermediates and pathways for compatibility with existing capital assets	
This workstream focuses on various biointermediate streams that are likely to be transferred between entities for processing from feedstock to finished fuel. This workstream will (1) investigate opportunities to integrate with industry both on the upstream and downstream ends by identifying priority intermediates, (2) determine value added due to industry integration and compelling business opportunities and business models, (3) determine critical material attributes at interfaces with industry partners, and (4) develop R&D plans to achieve intermediate conversion for industry engagement.	
DELIVERABLE	**IMPACT**
Identification and development of new biointermediates and business models for SAF supply chains. Production opportunities utilizing depreciated or underutilized capital.	Accelerates SAF deployment by creating technologies compatible with existing infrastructure and supply chains. Significant capital expense savings. Maintains opportunities for existing workforce while retaining expertise.
KEY THEMES: Expand production, reduce cost	

CT.4. Reduce Risk During Scale-Up and Operations

Many documented biorefinery failures are a consequence of mistakes made during the scale-up process or skipping scale-up altogether. Retrospective analysis by DOE has found that these mistakes include improper quantification of risk; changing process configurations between pilot, demonstration, and commercial-scales; and inadequate time-on-stream data generated, among others. Although pilot plant and demonstration plant construction and operation investments are significant, the learnings from these plants can reduce commercial plant startup times, cost, and process upsets or failures. When there are process configuration changes needed at the commercial scale because of unanticipated issues, these costs accumulate very rapidly and quickly render an entire project uneconomical. Pilot-scale operations deliver return on investment to companies and investors by avoiding these unanticipated costs at the demonstration and commercial scale.

A critical need for the next generation of biorefineries is detailed process risk and process readiness assessments that can lead to appropriate operational envelopes for plant operators and performance guarantees from equipment manufacturers, technology vendors, and engineering/design firms. When failures do occur, these failures need to be understood at a fundamental level such that process changes address the root cause. As a bioenergy community, this also requires more openness and transparency about failures, lessons learned, best management practices, and the steps that can be taken to manage and prevent these failures in the future.

Funding and building pilot plants alone will not overcome the causes of these past failures. From the outset, these integrated pilot plants need to be designed to evaluate and understand problems when they occur and allow for contingencies when process configurations need to be evaluated. Once built, the pilot plants need to be operated strategically utilizing design-of-experiment practices to perform stress tests of the system. This includes running a unit operation at the margins of expected material input quality, evaluating long-term accumulations in recycle loops, and operating in non-steady-state conditions. To the extent practical, pilot investments should be highly instrumented to help operators diagnose causes of operational upsets, provide data to validate process models, and develop control systems. All of these can contribute to overall risk reduction in future scale-up and assist with securing financing and investor confidence.

Where possible, existing pilot plant infrastructure from public investments can be leveraged for some of these learnings. Other federally funded information such as reaction or process models, including supercomputing access, can also be employed to assist companies with scale-up on an as-needed basis. However, scale-up of single steps does not equate to scale-up of a process, and use of public pilot plant infrastructure is not a substitute for building a dedicated pilot plant representative of the actual process being scaled.

WORKSTREAM CT.4: Reduce risk during scale-up and operations	
This workstream will proactively address resiliency in process and equipment design, in addition to conventional risk assessment methods such as bowtie[41] and Bayesian risk analysis. Note that this approach will be in addition to the project scale-up through integrated pilot and demo. Where possible, process performance and intermediate quality guarantees are needed to limit risk.	
DELIVERABLE	**IMPACT**
Progress toward establishment of performance guarantees on conversion operations and systems. Generation of foundational data for agency acquisition guidelines such as DOE's 413.3 *Technology Readiness Assessment Guide*.[42]	Improved understanding and quantification of technology risks and uncertainties. Lower risk will reduce cost of financing capital. Can also reduce pioneer refinery capital costs because the biorefinery will not have to be overdesigned to reduce risk. Will accelerate pioneer biorefinery ramp-up to nameplate scale (avoiding startup failures).
KEY THEMES: Expand production, reduce cost	

CT.5. Develop Innovative Unit Operations and Pathways

To address aviation sector sustainability goals, significant reduction in pathway carbon intensity is necessary. This vision begins with analysis and development of conceptual designs for these types of biorefineries, including those that have zero or negative emissions. In addition to utilizing second-generation and waste feedstocks, deep decarbonization will require the capture and reuse of waste streams generated by the process such as CO_2 or liquid streams. They would also involve strategies for novel reductants such as renewable electrons, green hydrogen, or renewable natural gas. These design studies and R&D can help inform future development opportunities by funding agencies and create partnerships with industry to test these processes. Prior analysis has identified finding sources for renewable hydrogen and heat sources and maximizing the use of low-CI electricity sources as key ways to reduce the carbon intensity of the conversion unit operations of a biorefinery.

Workstreams CT.1–CT.4 have a larger emphasis on approaches that can contribute to SAF volumes on the near- to midterm basis. Ultimately, there are upper limits on the volumes of SAF that can be produced from existing feedstocks and conversion pathways. These upper limits are due to both the availability of sufficiently mature conversion pathways and the blending limits for the fuels from these pathways. To meet all the fuel property needs, conversion processes that

[41] Bowtie risk assessment is a means of assessing multiple scenarios that might contribute to a process/system failure or other unwanted event.
[42] DOE. 2011. *Technology Readiness Assessment Guide*. Washington, DC: DOE. DOE G 413.3-4A. https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a/@@images/file.

can sustainably produce each of the classes of molecules are necessary: n-paraffins, iso-paraffins, cycloalkanes, and aromatics.

The development and commercialization of cycloalkane- and aromatic-molecule-producing conversion pathways will be necessary to allow higher fuel penetration from pathways that do not produce these molecules. At present, aromatics are needed in limited amounts to ensure that seal-swelling properties are present so that these fuels can be compatible with existing aircraft. Work is ongoing to address engine and seal-swelling issues without the need for aromatics, which would help reduce aviation-induced cloudiness resulting from incomplete combustion of the aromatics in SAF.

Future fuel pathways can also improve sustainability in other ways such as the development of molecules or blends of molecules that avoid the formation of soot, aerosols, and other contributors to vapor trail emissions. Combustion modeling and fuel development that can propose alternative fuels could identify additive molecules or replacements to avoid these negative environmental impacts.

New pathways or molecules will require development of new conversion processes: biological, chemical, electrochemical, and combinations thereof. Research and development of these processes must start immediately if these technologies are to be adequately mature for piloting and scale-up and to contribute toward the 35-billion-gallon goal by 2050.

WORKSTREAM CT.5: Develop innovative unit operations and pathways	
Additional pathway development and deployment will be needed to broaden the availability of SAF. This workstream will explore next-generation or disruptive technologies that, when integrated in pathways, yield CIs of zero or less.	
DELIVERABLE	**IMPACT**
Novel pathways and processes that can deliver carbon-neutral or carbon-negative SAF molecules or blendstocks. Development of molecules/blendstocks that can meet future regulatory needs and objectives.	Increased sustainability of fuels toward zero- or negative-CI SAF. Opportunity to blend zero- or low-CI blendstock with higher-CI blendstock to still achieve >70% CI reduction. Allow for higher SAF penetration through the production of different molecule types. Develop redundancy for conversion options.
KEY THEMES: Expand production, enhance sustainability, reduce cost	

Building Supply Chains

> Support SAF production expansion through supply chains, ensuring R&D transitions from pilot to large scale and field validation and demonstration projects, validating supply chain logistics, enabling public–private partnerships, supporting development of bankable business models, and collaborating with regional, state, and local stakeholders.

A supply chain is a complete system that produces and delivers a product or service, from raw materials to final delivery to end users. SAF supply chains encompass feedstock production, collection, and distribution to SAF production facilities; conversion of feedstock to fuel; and transport of finished fuel to the infrastructure required to fuel aircraft. Because current fuel certifications require SAF to be blended with conventional fuels, the SAF supply chain also requires coordination with the conventional jet fuel industries. As a nascent industry, SAF supply chains are immature, may be regionally unique, and will require significant resources and investment to establish.

SAF supply chains will be complex and challenging to deploy. Feedstock of sufficient quality and quantity are required and must be matched to a cost-effective and proven process technology for conversion to a fuel meeting strict specifications for blending with conventional jet fuels. The logistics and methods to transport the SAF to be blended with conventional jet fuel and then sent to airport destinations must be in place. This will require the infrastructure for local storage, blending, and transport to airports to be developed. Equally important are adherence to local regulations, permitting requirements, and methods for fuel testing and quality assurance.

Demonstration and validation at scale will be key to the success of establishing SAF supply chains. Demonstrating process technologies to produce SAF is essential to de-risk and enable commercial development of SAF production facilities. Similarly, new biomass or waste feedstocks require the demonstration of ample supply availability, quality, handling systems, and processability at scales to support plants operating at throughputs of hundreds or thousands of tons per day.

Focus on developing effective supply chain logistics to meet the demand for fuel at major U.S. airports is also necessary. Feasibility studies will need to be conducted to identify sites to support SAF receipt, blending, storage, and delivery infrastructure to supply airports, both in the short and long term. Diverse stakeholder groups and coalitions will be required to evaluate SAF technology options, advance production, and develop distribution infrastructure to specific airports.

2030 Building Supply Chains Impact Highlights

Convene and support stakeholder coalitions

Standing up complex SAF supply chains will involve engagement with and contributions from a diverse group of stakeholders. Convening and incentivizing stakeholder coalitions will be vital to developing regional solutions to build a renewable fuels industry that improves environmental and economic performance while supporting job creation and social equity (see Activities SC.1.1 and SC.1.2). These coalitions will need to evaluate all elements of the supply chain and provide recommendations to advance deployment, attract investment, advocate for policy change, support workforce development, and identify solutions to deployment barriers and risks (see Activities SC.1.3 and SC.1.4).

Invest in SAF infrastructure

Utilize loans and loan guarantees, assistance grants, and other government funding mechanisms and opportunities to enable rapid scaling of commercial technologies. For 2030, these investments will leverage existing corn ethanol and agricultural industry and infrastructure to accelerate production (see Activity SC.4.3), as well as existing rail/heavy-duty/long-haul transport for airport SAF supply (see Activity SC.4.5). Near-term investments are expected to build on existing oil and gas refinery and other industrial brownfield industry and infrastructure to accelerate and ramp up to required volumes of production (see Activity SC.4.4).

Achieving the SAF Grand Challenge objectives for SAF production by 2030 and beyond will require rapid development of effective supply chains capable of meeting future airport SAF demand. The following key actions support the development of SAF supply chains in support of SAF supply expansion:

- **Convene regional stakeholder coalitions** to lead the exploration and development of SAF supply chains and provide outreach, extension, and education supporting SAF supply chain growth.
- **Develop and disseminate comprehensive data, analysis, and modeling tools** as a foundation for the development of low-GHG, cost-effective deployment of feedstock to fueling supply chains, SAF manufacturing, and logistics solutions.
- **Support feedstock-to-fueling demonstration projects** to de-risk and mature key elements in the supply chain from feedstock through airport distribution.
- **Invest in commercial-scale SAF production infrastructure and facility development** with existing and new public–private partnerships to expand domestic SAF supply.

Detailed activities and suggested timelines are identified for each workstream in Appendix A.3.

SC.1. Build and Support Regional Stakeholder Coalitions Through Outreach, Extension, and Education

Regional coalitions of stakeholders across the supply chain are vital to developing regional solutions to build a renewable fuels industry that improves environmental and economic performance while supporting job creation and social equity. For SAF to be successfully

delivered to an aircraft, there are many elements in the supply chain that must be considered. SAF may be produced from a variety of feedstocks and qualified conversion pathways.[43] Feedstock production and conversion to fuel may or may not be proximate to airports, making the logistics of fuel transport and distribution critical. Fuel delivery and storage differ from airport to airport, but excess capacity for introducing new fuel types is unlikely. This is addressed in further detail in Workstream EU.4. Innovative approaches and funding mechanisms will be needed to facilitate the growth of these emerging SAF supply chains.

An effective approach to tackling big challenges such as standing up new SAF supply chains is to assemble diverse groups of stakeholders with a mission to evaluate all elements of the supply chain and provide recommendations to advance deployment, attract investment, advocate for policy change, and identify solutions to deployment barriers and risks. Coalitions should determine how state clean energy policies, feedstock availability, and planned production facilities will dictate the regional deployment of SAF to supply medium and large airport hubs. Members of these coalitions should represent airports, airlines, state and federal agencies, academia, national laboratories, SAF producers, feedstock suppliers, environmental groups, and trade organizations. A representative model for regional coalition building is the Sustainable Aviation Biofuels Working Group established by the Washington State Legislature to further the development of the SAF industry in the state.[44] CAAFI has also developed publicly available SAF readiness tools along the fuel pathway that will aid regional coalitions in assessing their stage of development.[45]

The USDA Regional Bioenergy System Coordinated Agricultural Projects provide an excellent framework for regional stakeholder coalitions around emerging supply chains, and several of them have addressed SAF development. These projects integrate research, outreach, and education to support de-risking feedstock supply chains linked to emerging or existing conversion technologies. As illustrated in Figure 7, there is a large body of completed or ongoing work for supply chains for important feedstocks from these projects, including perennial

[43] CAAFI. 2022. "Fuel Qualification: Approved Fuels." Accessed Aug. 1, 2022. https://www.caafi.org/focus_areas/fuel_qualification.html#approved.
[44] Port of Seattle. 2022. "Sustainable Aviation Fuels." Accessed July 21, 2022. https://www.portseattle.org/page/sustainable-aviation-fuels.
[45] CAAFI. 2022. "Path to Alternative Jet Fuel Readiness." Accessed July 21, 2022. https://caafi.org/tools/Path_to_Alternative_Jet_Fuel_Readiness.html.

grasses,[46] oilseed cover crops,[47] energy cane,[48] short-rotation woody crops,[49] forest operation and mill residuals,[50] insect-damaged conifers,[51] and other feedstocks.[52]

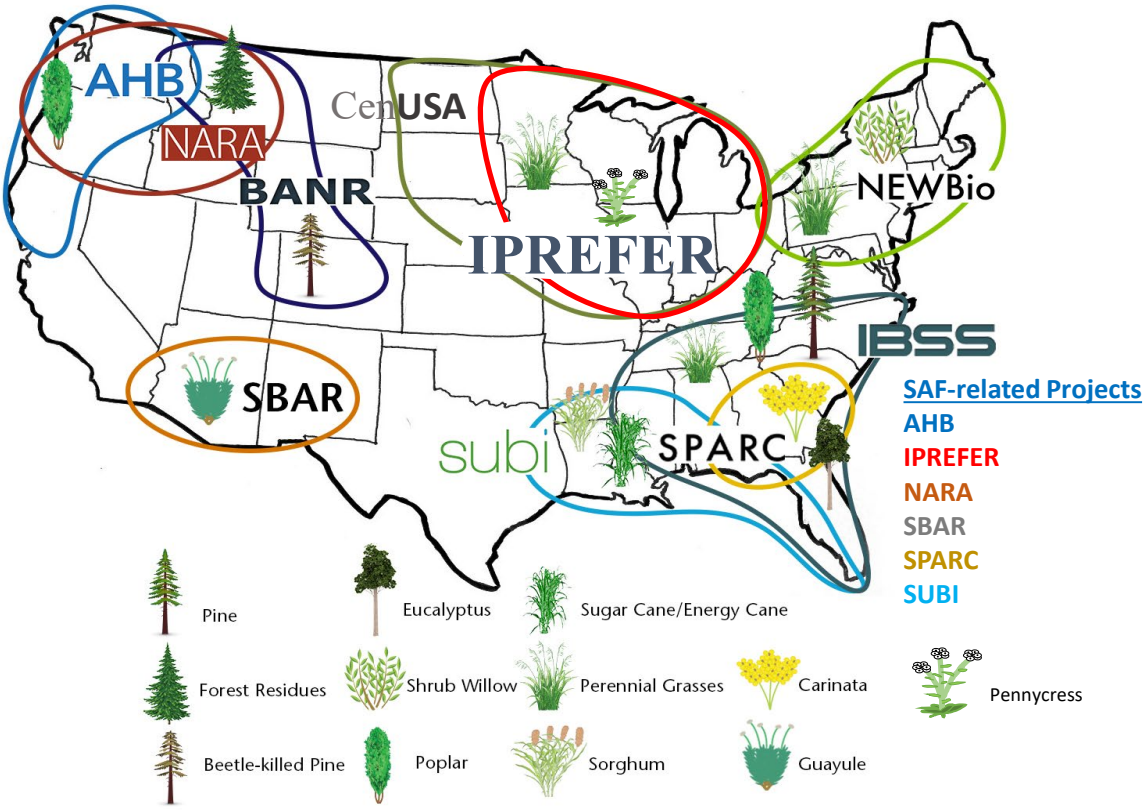


Figure 7. USDA supports several SAF-related regional public–private partnerships under the National Institute of Food and Agriculture Coordinated Agricultural Projects

[46] Iowa State University. 2022. "CenUSA Bioenergy"; PennState Extension. 2013. "NEWBio Energy Crop Profile"; West Virginia University. 2022. "MASBio at West Virginia University"; Southeastern Partnership for Integrated Biomass Supply Systems. 2022. "Southeastern Partnership for Integrated Biomass Supply Systems."
[47] IPREFER. 2022. "IPREFER"; Southeastern Partnership for Advanced Renewables from Carinata. 2022. "SPARC."
[48] LSU AgCenter. 2022. "Sustainable Bioproducts Initiative."
[49] Washington State University. 2020. "Advanced Hardwood Biofuels Northwest"; PennState Extension. 2013. "NEWBio"; IBSS. 2022. "Southeastern Partnership"; West Virginia University. 2022. "MASBio."
[50] Washington State University. 2022. "NARA."
[51] BANR of the Rockies. 2022. "Bioenergy Alliance Network of the Rockies."
[52] The University of Arizona. 2022. "Sustainable Bioeconomy for Arid Regions."

WORKSTREAM SC.1: Build and support regional stakeholder coalitions through outreach, extension, and education	
Facilitate regional stakeholder coalition formation to support the development of SAF supply chains from feedstock through fuel distribution logistics.	
DELIVERABLE	**IMPACT**
Established regional stakeholder coalitions developing SAF supply chains in targeted SAF markets.	Foundational step in the formation of effective supply chains for specific markets.
KEY THEMES: Expand production	

SC.2. Model SAF Supply Chains

Accurate and relevant data inform effective analysis and decision-making. Decision support tools provide essential insights and guidance when evaluating scenarios and options. Stakeholder coalitions that are striving to stand up SAF supply chains will require data and information including but not limited to feedstock availability, policy incentives, existing fuel infrastructure, fuel infrastructure siting, process economics, permitting requirements, and process technology. Stakeholder coalitions established in Workstream SC.1 will benefit from access to critical data and tools that empower rapid, informed decision-making when evaluating SAF supply chain options. Establishing a comprehensive inventory of data resources, modeling, and simulation tools, as well as continuing to develop and evolve these resources, will be critical to the success of emerging SAF supply chains.

Fortunately, there are plentiful resources available to coalitions engaged in SAF supply chain initiatives as a foundation of data and tools. The *2016 Billion-Ton Report*[53] provides estimates of potential biomass that could be available for SAF production. Lawrence Berkeley National Laboratory has developed a flexible model capable of quantifying production costs, life cycle emissions, water use, and other relevant metrics for a hypothetical facility with identified organic/biomass feedstocks.[54] Simulation tools such as the National Renewable Energy Laboratory's Biomass Scenario Model (BSM)[55] and the Freight and Fuel Transportation Optimization Tool (FTOT) developed by the U.S. Department of Transportation's Volpe Center[56] model flow allocation and report transportation costs, emissions, and other

[53] DOE. 2016. *2016 Billion-Ton Report.*
[54] BETO. 2021. "From the Lab to Jet Engines: New Software Tools will Speed Up Biojet Fuel Development." Oct. 20, 2021. https://www.energy.gov/eere/bioenergy/articles/lab-jet-engines-new-software-tools-will-speed-biojet-fuel-development.
[55] Lewis, Kristin C., Emily K. Newes, Steven O. Peterson, Matthew N. Pearlson, Emily A. Lawless, Kristin Brandt, Dane Camenzind, et al. 2019. "US alternative jet fuel deployment scenario analyses identifying key drivers and geospatial patterns for the first billion gallons." *Biofuels, Bioproducts and Biorefining* 13 (3): 471–485. https://doi.org/10.1002/bbb.1951.
[56] U.S. Department of Transportation Volpe Center. 2022. "FTOT-Public." GitHub, accessed July 21, 2022. https://github.com/VolpeUSDOT/FTOT-Public.

transportation-centric metrics. Argonne National Laboratory has developed and maintained the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model for determining life cycle emissions, which has been used as the foundation for many state, national, and international policy programs. The Bio-based circular carbon economy Environmentally-extended Input-Output Model (BEIOM) from the National Renewable Energy Laboratory provides environmental and socioeconomic impacts of biofuels from an economy-wide perspective.[57] BioTrans from Oak Ridge National Laboratory quantifies the economic and energy security benefits of biofuels and bioproducts.[58] FAA's Community Asset and Attribute Model (CAAM) helps identify potential social barriers or aptitude for developing a regional supply.[59]

Although there are many resources available to evaluate SAF supply chains, these models must be constantly updated. The SAF Grand Challenge will evaluate new strategies and platforms to make these models more easily updated and connected.

WORKSTREAM SC.2: Model SAF supply chains	
Develop and apply comprehensive and updated data, transparent analyses, and tools as a foundation for informed SAF supply chain development.	
DELIVERABLE	**IMPACT**
Provide stakeholder coalitions with data to facilitate development of SAF supply chains.	Empower supply chain coalitions with timely data, modeling, and simulation tools to enhance and accelerate analysis and decision-making.
KEY THEMES: Expand production	

SC.3. Demonstration of SAF Supply Chains

Demonstrating the performance and commercial viability of feedstock and fuel production systems, quantifying GHG reduction metrics, and validating process economics are essential activities for establishing SAF supply chains. Successful demonstration of SAF supply chain elements will need to address numerous technical and financial challenges, including the large funding gap as technologies mature and require significant capital investment.

Longtime industry experience, as well as analyses of some of DOE's previous projects, have indicated that it is crucial to properly scale up a new technology in applicable steps and appropriate scale-up ratios (as discussed in Section 2.4 related to pilot plant development). It is

[57] NREL. 2019. "Bio-based circular carbon economy Environmentally-extended Input-Output Model (BEIOM)." Last updated Sept. 17, 2019. https://bioenergymodels.nrel.gov/models/42/.
[58] NREL. 2019. "BioTrans." Last updated Sept. 17, 2019. https://bioenergymodels.nrel.gov/models/9/.
[59] ASCENT. 2022. "Alternative Jet Fuel Supply Chain Analysis." Accessed July 21, 2022. https://ascent.aero/project/alternative-jet-fuel-supply-chain-analysis/.

necessary, despite the significant cost, to scale up the integrated pilot-scale process to a demonstration scale to avoid having to learn the lessons at higher cost during the commercial stage. In most applications, demonstrations will span the entire supply chain from feedstock collection through delivery of SAF to airports for flight demonstrations. The objectives and possible technical accomplishments at each stage of scaling vary in a continuous learning and growing manner, as illustrated in Figure 8.

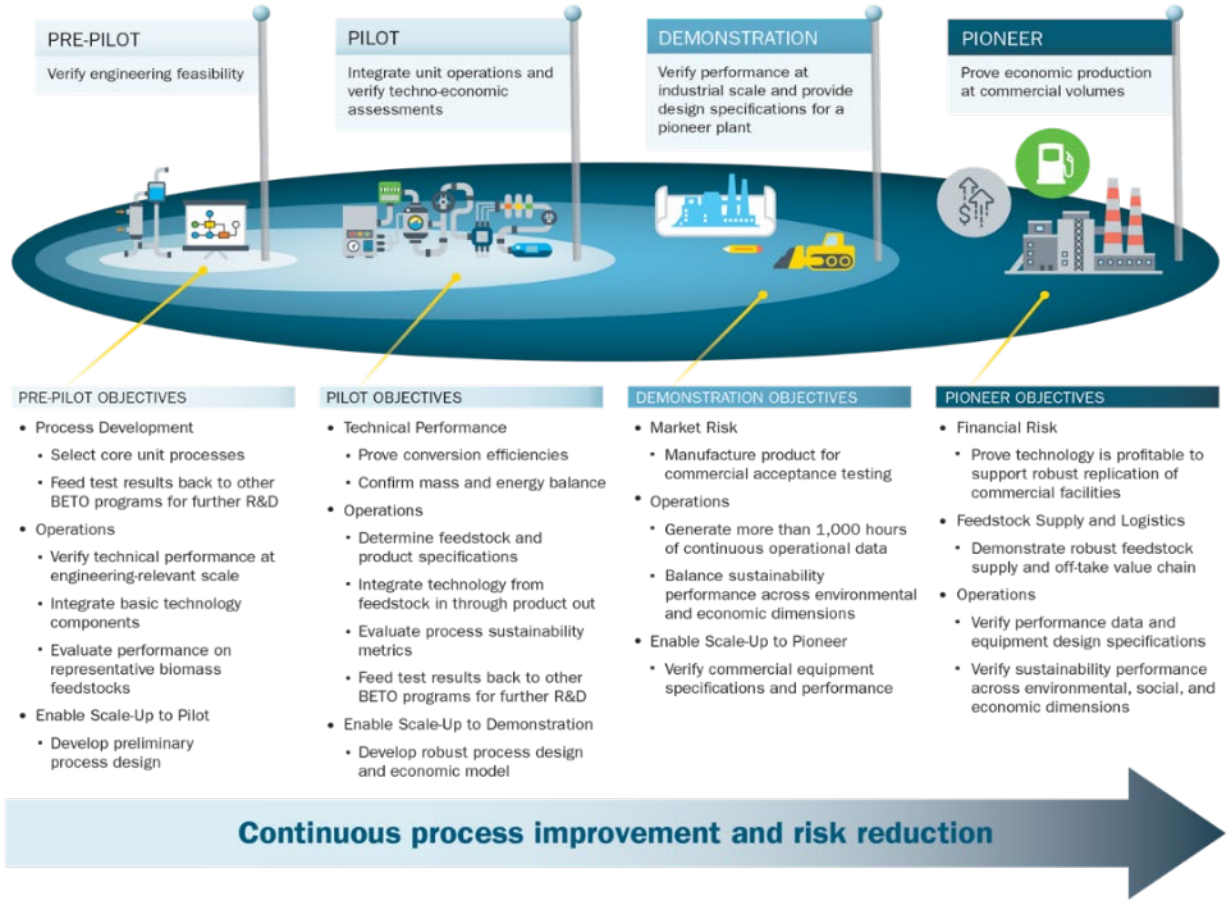


Figure 8. Objectives and accomplishments through scale-up steps

Studies have shown that the number and complexity of new process steps implemented in first-of-a-kind technology projects are a strong predictor of the challenges to be encountered with reliable performance and operations. Understanding relationships between and within process steps across the field to the flight supply chain is useful to inform R&D gaps and for further technology development. A demonstration-scale biorefinery and associated supply chain operating for adequate time on stream with all applicable feedstocks, enzymes, catalysts, etc., will provide further optimization and sufficient information for the commercial stage and will further reduce the risk of process upsets and failures.

A critical need for the next generation of biorefineries is detailed process risk and process readiness assessments that can lead to appropriate operational envelopes for plant operators and performance guarantees from equipment manufacturers, technology vendors, and

engineering/design firms. When failures do occur, the root causes need to be understood at a fundamental level such that process changes can address them.

As stated in Section 2.4, when there are process configuration changes needed at the commercial scale because of unanticipated issues, these costs accumulate very rapidly and quickly render an entire project uneconomical. Demonstration-scale operations deliver return on investment to companies and investors by avoiding these unanticipated costs at the commercial scale. In its technology scaling programs, DOE tracks and shares lessons learned in scale-up. A combined effort across the agencies may be undertaken to formalize this joint process and share these lessons through a systematic web-based portal.

DOE, USDA, and other federal agencies offer cooperative agreements and grants to fund energy innovations from R&D up through technology scale-up and demonstration. DOE has supported numerous integrated biorefinery demonstrations and recently released a funding opportunity announcement targeted at scale-up support for the SAF Grand Challenge.[60] Through the Agriculture and Food Research Initiative's Sustainable Agricultural Systems program, the USDA funds SAF supply chain projects.[61] Participants in SAF supply chains can leverage these and other federal grant opportunities to invest in process technologies to convert feedstock to fuel, reduce risk, and prove performance by maturing from the lab to pilot scale and on to demonstration scale. Demonstration validates process performance metrics and greatly reduces investor risk at higher scales.

In addition to federal assistance, demonstration projects will require a significant investment of private capital, which can come from various sources including owner equity, venture capital, corporate investors, green funds, institutional investors, and various philanthropic investments. Federal investment will be viewed as a key indicator of future performance. However, all investments, including at the demonstration scale, entail substantial risk and have no guarantee of a future commercial revenue stream.

Rapid growth of SAF will require a diversity of feedstocks, many of which are not commercially available today. Identifying the barriers to the introduction of new feedstocks and reducing those barriers by demonstrating their performance in SAF supply chains will be essential.

[60] BETO. 2021. "U.S. Department of Energy Announces More Than $64 Million for Biofuels Research to Reduce Transportation Emissions." Sept. 9, 2021. https://www.energy.gov/eere/bioenergy/articles/us-department-energy-announces-more-64-million-biofuels-research-reduce.
[61] USDA. 2022. "AFRI Sustainable Agricultural Systems." Accessed July 21, 2022. https://www.nifa.usda.gov/grants/programs/afri-sustainable-agricultural-systems.

WORKSTREAM SC.3: Demonstration of regional SAF supply chains	
Support the demonstration of comprehensive regional SAF supply chains from feedstock collection to fuel blending and distribution.	
DELIVERABLE	**IMPACT**
Demonstrate key elements in the SAF supply chain to validate commercial readiness.	Reduce risk and accelerate commercial deployment and adoption of feedstocks, fuel production, fuel distribution, and logistics.
KEY THEMES: Expand production	

SC.4. Invest in SAF Production Infrastructure To Support Industry Deployment

SAF supply chains encompass an extremely complicated system of systems, including feedstock production, collection, and distribution to SAF production facilities; conversion of feedstock to fuel; and transport, storage, and delivery of the finished fuel to the infrastructure required to fuel aircraft. For these complex systems, access to capital will be a significant barrier to establishing SAF supply chains. Approximately $30 billion in capital expenditure could be required to build out the SAF production and delivery infrastructure needed to produce 3 billion gallons of SAF by 2030. Building enough capacity for the projected 35 billion gallons of SAF annually required by 2050 will mean hundreds of billions of dollars in capital investments.

SAF projects have significant challenges accessing debt financing to build out new capacity. Offtake agreements with a small number of sub-investment-grade offtakers and the volatility associated with California's Low Carbon Fuel Standard (LCFS) and EPA's Renewable Fuel Standard renewable identification number credits create revenue uncertainty that makes banks hesitant to write the billion-dollar loans that commercial-scale SAF plants can require. Securing debt financing can be especially challenging for first-of-a-kind commercial deployments of novel SAF feedstocks. Today, SAF project development is largely equity-financed, and when debt is involved, it comes with a high cost of capital that can strain project economics and push up prices for the end purchasers of SAF.

Commercial arrangements that provide more certainty around revenue for SAF projects can increase their financeability. These could include pooled offtake agreements that mitigate offtaker credit risk, book-and-claim systems that allow corporate buyers to enter into long-term offtake agreements with producers for the Scope 3 environmental attributes associated with SAF, or financial products that decrease the uncertainty associated with LCFS and renewable identification number credits.

Federal loan guarantee programs such as USDA's 9003 Loan Guarantee Program[62] and OneRD Guarantee,[63] as well as the DOE Loan Programs Office,[64] can provide some debt financing for SAF projects. Programs like these can be more receptive to financing first-of-a-kind commercial deployments of new technologies given USDA and DOE's familiarity with many of these new technologies.

In addition to federal loan assistance, these first-of-a-kind commercial projects will require a significant investment of private capital, which can come from various sources, including owner equity, venture capital, corporate investors, green funds, institutional investors, and various philanthropic investments.

The supporting federal agencies will need to implement a robust outreach program with these various types of investors to help develop interest and confidence to support early, mid-stage, and long-term industry growth. The federal outreach will need to be undertaken through a wide range of engagements, including social media, individual meetings, webinars/seminars, conferences, farmer field days, modified training and visitation extension services, and focused travel to meet face-to-face. Further, support and potential investment for U.S. SAF industry growth will be enabled by global SAF industry development, so the U.S. government's role must not be limited to U.S. borders.

WORKSTREAM SC.4: Invest in SAF production infrastructure to support industry deployment	
Invest in SAF production and distribution infrastructure with existing and new grant and support programs such as USDA and DOE loans and loan guarantees and other government funding mechanisms.	
DELIVERABLE	**IMPACT**
Support industry deployment of SAF feedstock development, fuel production facilities, and distribution infrastructure at commercial scale.	Accelerate SAF capacity growth through existing and new public–private partnerships.
KEY THEMES: Expand production	

[62] USDA. 2022. "Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program." Accessed July 21, 2022. https://www.rd.usda.gov/programs-services/energy-programs/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance-program.
[63] USDA. 2022. "OneRD Guarantee. Accessed July 21, 2022. https://www.rd.usda.gov/onerdguarantee.
[64] DOE. 2022. "Loan Programs Office." Accessed July 21, 2022. https://www.energy.gov/lpo/loan-programs-office.

Policy and Valuation Analysis

> Provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF, including evaluation of existing and new policies.

Sound data, analytical tools, and analyses are key to developing policies that maximize the social, economic, and environmental value of SAF. This action area will develop the data, tools, and analyses that will be used by decision makers to develop SAF policies. Although there are several existing policies that support SAF development, new policies will be needed to achieve the goals of the SAF Grand Challenge. This action area will not advocate for any policy position but will instead focus on ensuring that data, tools, and analyses are available to inform the decision-making process. Policy mechanisms remain a key tool to achieve the environmental and societal benefits of SAF in a cost-effective manner. The emphasis in this action area will be on developing and improving modeling tools, data, and expertise within federal government agencies, national laboratories, academic institutions, and industry. The focus will be on U.S. domestic federal and state policies, although it is recognized that these data would also aid international decision makers in their SAF development efforts.

Key objectives of this action area are addressed by the following workstreams:

- **Develop improved environmental and socioeconomic data and analytical tools for SAF.**
- **Conduct techno-economic and production potential analysis.**
- **Inform SAF policy development.**

Detailed activities and suggested timelines are identified for each workstream in Appendix A.4.

PA.1. Develop Improved Environmental Models and Data for SAF

Quality data are key to informing good policy decisions. The objective of this workstream is to gather and develop data and analytical modeling tools to quantify the life cycle GHG emissions and environmental impacts of SAF. In addition to life cycle GHG reduction activities that will be conducted under this workstream, activities will be undertaken to quantify the benefits of changing the composition of jet fuel, which is possible with the introduction of SAF. Activities will also investigate ecosystem service benefits of growing biomass on marginal soils and the subsequent impact on air and water emissions. Improved models and data will

2030 Policy and Valuation Analysis Impact Highlights

Convene life cycle analysis working group

A life cycle greenhouse gas emissions working group will be convened. As requested by the SAF Grand Challenge memorandum of understanding, this working group will define and agree on the appropriate science-based methodology for establishing life cycle emissions reductions under the SAF Grand Challenge, recognizing the need for credibility and taking note of consistency with international criteria, such as those developed by ICAO. The working group will focus on domestic needs for life cycle GHG emissions analysis (see Activity PA.1.1).

ensure environmental integrity and appropriately account for the benefits of SAF. Engagement and collaboration are essential with key stakeholder groups, including NGOs and international organizations such as ICAO, on data and method development. Workstream CP.1 describes related stakeholder engagement activities.

Life Cycle Greenhouse Gas Emissions Working Group

A key activity under this workstream is to convene a life cycle GHG emissions working group. As requested by the SAF Grand Challenge memorandum of understanding, this working group will define and agree on the appropriate science-based methodology for establishing life cycle emissions reductions, recognizing the need for credibility and taking note of consistency with international criteria, such as those developed by ICAO. The working group will focus on domestic needs for life cycle GHG emissions analysis. The work will start with a careful examination of different approaches being used for life cycle analysis, both domestically and internationally, including the methods used by ICAO for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The focus will be on identifying commonalities and areas of difference in the methodologies and tools being used. The working group will use these to identify best practices and to understand why different methods give different estimates of life cycle GHG emissions. This knowledge can then form the foundation for determining the appropriate methodology as requested by the memorandum of understanding. It will also provide transparency and certainty to markets with respect to which SAF production pathways would be eligible for the SAF Grand Challenge and other government programs. The working group will be formed immediately and continue to function as long as needed.

Development of SAF Data and Analytical Tools To Support Inclusion in Existing Policies

Data and analytical tools are needed to support the inclusion of novel SAF pathways within existing state, federal, and international policies. This activity will develop these data and tools to inform the process of including SAF pathways under the Renewable Fuel Standard, LCFS, Section 45Q tax credits, and other existing programs. These inclusionary policies for SAF are a necessary first step toward achieving desired production levels, but the aviation industry will be reliant on SAF in the near term to achieve meaningful emissions reductions, whereas other modes of transportation have multiple options to achieve carbon reductions. Therefore, the work

under Workstream PA.3 will explore policies that could prioritize SAF development and rapidly expand production for aviation use.

Book-and-Claim Crediting Mechanisms

This activity will examine how existing and new policies could utilize book-and-claim crediting mechanisms as a means of tracking SAF emission reduction benefits and ensuring those benefits are only claimed once by one party in emissions record systems. A SAF book-and-claim program would work similarly to mechanisms such as the supply of renewable electricity to the power grid and renewable natural gas into conventional natural gas pipelines. The advantage of a book-and-claim process is that physical transfer of renewable fuels is not necessary, but the contractual transaction of renewable fuels into the fuel distribution system will allow a consumer to pay for and get credit for those attributes. Electricity, natural gas, and fuels are fungible commodities that can be tracked and accounted for in a closed system from their introduction to final consumption. However, care must be taken to ensure that the emissions accounting is fully integrated into national GHG emissions inventory and accounting frameworks and is consistent with U.S. commitments under the United Nations Framework Convention on Climate Change, Paris Agreement, and CORSIA.

Non-CO_2 Environmental Impacts

Federal government agencies will continue their efforts to quantify the non-CO_2 environmental impacts of SAF use on air quality and climate change. SAF varies in its hydrocarbon composition relative to conventional jet fuel; further, SAF in general has zero fuel sulfur content. Measurements have consistently shown that SAF use reduces non-volatile particulate matter (i.e., soot or black carbon) and sulfur dioxide emissions. This activity will continue these measurements and will also quantify how changes in these emissions affect air quality and climate change. Of particular interest is the effect SAF combustion will have on contrails and aviation-induced cloudiness. Preliminary work shows that SAF use will change the properties of contrails and aviation-induced cloudiness, and these changes could result in a net climate benefit. However, additional work is needed before conclusions can be reached on this subject. The research needs to be done in coordination with engine manufacturers, academic institutions, national laboratories, and international organizations. This activity is very closely tied to activities in the Enabling End Use Action Area, as fuel composition changes associated with SAF (e.g., minimum aromatic content) must account for safety and operability considerations.

Evaluation of Co-Benefits of SAF

This activity covers varied efforts to evaluate co-benefits of SAF production. One area of interest is to better understand how soil organic carbon can be increased through the production of feedstocks for SAF. Feedstocks grown on marginal lands can have significant environmental benefits associated with crop diversity (e.g., soil organic carbon, nutrient management, and erosion) that are currently not accounted for in techno-economic analysis and risk assessments. DOE has begun research and analysis activities to better understand ecosystem service attributes through funded projects selected in the Bio-Restore program. In addition to understanding how

to enhance soil organic carbon benefits, this activity will examine how SAF production can be done in a manner that is sustainable with respect to both water quality and use. In addition to evaluating environmental sustainability, economic sustainability of SAF production will be evaluated. Biomass collection, harvesting, and conversion facilities will create employment opportunities along the entire supply chain. Analysis on job creation impacts is necessary to determine the true extent of the impacts and the additionality of these jobs compared to existing petroleum industry jobs.

WORKSTREAM PA.1: Develop improved environmental models and data for SAF	
Develop and utilize modeling capabilities, data, and analyses to quantify SAF GHG and other environmental impacts. This will ensure environmental integrity and appropriately account for SAF benefits. Stakeholder engagement will be done in collaboration with Workstream CP.1.	
DELIVERABLE	**IMPACT**
Enhanced environmental analysis and crediting capabilities.	Increased eligibility of new SAF pathways and crediting under existing and future incentive mechanisms.
KEY THEMES: Reduce cost, improve sustainability, expand production	

PA.2. Conduct Techno-Economic and Production Potential Analysis

This workstream will develop the data and analytical tools to conduct techno-economic analysis and resource assessments for SAF production. Considerable work is already underway at the DOE national laboratories, FAA Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), USDA Coordinated Agricultural Projects, and projects funded by the Agricultural Research Service. The goal is to coordinate, expand, and refine modeling capabilities and generate analysis to inform SAF RDD&D.

This workstream will focus on integrating modeling tools and datasets across multiple agencies to evaluate opportunities and scenarios necessary to meet the SAF Grand Challenge goals. Results from these activities will be available to guide decision makers on expanding SAF production in a manner that carefully considers GHG reductions, cost of production, and policy needs.

Techno-Economic Modeling Working Group

A techno-economic modeling working group will be established to harmonize approaches, support SAF policy evaluation, and inform RDD&D decisions across multiple agencies. An example of a current area of interest is the calculation of pioneer plant cost and correlation of those with n^{th} plant costs. The goal of the working group will be to establish common modeling assumptions to encourage collaborative analysis activities. This will lead to transparent and more accurate cost of production data for SAF pathways. The techno-economic modeling group

should also provide insights into the activities described in the following sections to assess domestic biomass resources and quantify SAF production potential.

Updated Biomass Resource Assessment

A key activity that has already begun is updating the *2016 Billion-Ton* resource assessment study. This report utilized the expertise of numerous experts from DOE, USDA, academia, and national laboratories. The update will rely on existing organizational expertise and expand scope to other areas as needed. There are several areas that need to be revised, such as incorporating the latest data on supply potential of waste FOG, future potential for oilseed crops (e.g., carinata, camelina, and pennycress), more accurate data of available biomass from forestry residues based on geographical information system-derived data sets, analysis of wet waste resources (e.g., sewage sludge, wastewater treatment facility effluents, and manure), and potential for waste gases including methane and CO_2 (e.g., industrial flue gases and direct air capture). The focus of this activity will be on domestic U.S. resources, with the acknowledgement that imports of feedstocks could occur depending on economics and the policy environments of the United States and exporting countries. Work on resource assessments will be done in collaboration with Workstream FI.6 activities and specifically Activity FI.1.6.

Domestic and International SAF Production Potential

This activity will continue efforts to quantify the amount of SAF that can be produced under a variety of economic and environmental conditions, both in the United States and globally. The analysis will consider both unconstrained potential for SAF production and constrained production that considers economic and environmental factors. The assessment could provide an indication of needs for feedstock imports to produce SAF domestically or for SAF exports from the United States to foreign markets.

WORKSTREAM PA.2: Conduct techno-economic and production potential analysis	
Develop and utilize techno-economic analysis and resource assessment models. Expand and refine modeling capabilities and generate analysis to inform SAF RDD&D. Evaluate the opportunities and scenarios necessary to meet SAF Grand Challenge goals and provide direction to the effort to ensure optimum conditions for production expansion.	
DELIVERABLE	**IMPACT**
Increased utilization of SAF due to transparent and more accurate quantification of cost of production and resource availability.	Increased transparency regarding SAF cost of production and feedstock requirements.
KEY THEMES: Reduce cost, expand production	

PA.3. Inform SAF Policy Development

This workstream will use the analytical tools and knowledge from Workstreams PA.1 and PA.2 to conduct analyses to inform decision makers on policy development. The work will not advocate for a specific policy option. Instead, it will define the conditions needed for successful development and deployment of SAF that can be verified to reduce GHG emissions and provide policymakers the desired end state without prescribing the means to achieve that state. The workstream will also identify gaps, needs, and impacts of new policies on SAF availability while also noting where policy gaps exist. The focus will be on U.S. federal, state, and local policies that can enable SAF production (e.g., new programs emerging from the 2022 Inflation Reduction Act, EPA's Renewable Fuel Standard, California's LCFS, and Oregon and Washington low-carbon fuel standards). Policies for SAF also need to be viewed in the context of support for competing fuels such as renewable diesel. Another dimension that needs to be considered are fuel import/export tariffs and how the countervailing nature of these policies affect market behavior. Finally, policies overseas also need to be considered. For example, the development of low-carbon fuel standards in Canada and the development of SAF mandates in Europe could have an impact on U.S. feedstocks and markets for SAF.

Inventory of Existing SAF-Relevant Policy Incentives

An activity that needs to begin immediately is an assessment of how existing and potential future policies and tax credits (including credits for carbon capture) could be combined to support SAF production. Selected SAF pathways are approved for incentivization under the Inflation Reduction Act, Renewable Fuel Standard, and California's LCFS. The 26 U.S. Code Section 45Q tax credit is also available for processes that can utilize waste CO_2. Further details on these existing incentives and regulatory mechanisms will be assessed under this activity. This activity will also examine whether modifications could be implemented under existing regulations to increase SAF production. An assessment of the status of available policy evaluation models and data is needed. For example, Washington State University, National Renewable Energy Laboratory, and Oak Ridge National Laboratory have a suite of relevant models that can be utilized for evaluating policy options. These tools can be improved, expanded, and updated to provide more accurate estimates of policy impacts.

Study the Impact of Inclusion of New Oilseed Crops

This activity seeks to develop data, analysis, and tools to support the inclusion of new oilseed crops (e.g., carinata, camelina, and pennycress) as secondary cover crops. In addition to expanding SAF supplies, these crops could provide environmental benefits (e.g., increased soil organic carbon sequestration and soil protection) while providing substantial economic benefits to famers. These feedstocks are being developed by USDA's Natural Resources Conservation Service in collaboration with academic institutions, farmers, and the private sector. This activity will conduct the analysis needed to support the development of crop insurance for these oilseed crops. This will reduce risk to the farmer for adoption of these crops as a feedstock for SAF production.

Study the Development of Government Procurement Mechanisms

This activity will explore the possibility of U.S. government purchases of SAF as a means of strengthening overall demand. Potential mechanisms that could be explored include purchase of SAF by the Defense Logistics Agency for the Department of Defense and the potential ability of General Services Administration allowances for the purchase of SAF in government travel. Government procurement restrictions related to cost competitiveness and regulated contract terms and conditions, as well as limited demand compared to the commercial sector, may play a significant role in the level of impact. This activity will explore how these and other mechanisms could be used for SAF purchases.

Assessment of Future Policy Options

This activity will leverage the knowledge gained in examining existing policy mechanisms to explore potential new national policies to support SAF production and greater emissions reductions such as a national low-carbon fuel standard. The data, analytical tools, and analyses being done in Workstreams PA.1–PA.3 form a strong foundation for the development of policy, and this activity will leverage all of that knowledge to examine the realm of what is possible. Such policies might be needed to reach 3 billion gallons in 2030. However, SAF production has to ramp up significantly beyond 3 billion gallons after 2030 to achieve the United States' goal for net-zero emissions by not later than 2050,[65] which necessitates the timely analysis of new policies. This activity will undertake analysis to understand the possible impact that these policies and consistency among them might have in terms of SAF production volume, GHG reductions, job creation, and other economic and environmental metrics. Consideration needs to be given to compensating feedstock producers, as dedicated feedstocks resulting in environmental benefits will be important for widespread adoption.

Conduct Assessment of Tax-Exempt Bonds, Green Bonds, and Private Equity-Based Financing

This activity will assess how biofuel projects can qualify for tax-exempt bonds, municipal bonds, green bonds, economic opportunity zones, equity guarantees, and other private equity-based financing mechanisms. The intent of this activity is to identify new options that could be used to provide financing for construction of SAF conversion facilities and other SAF-related supply chain infrastructure.

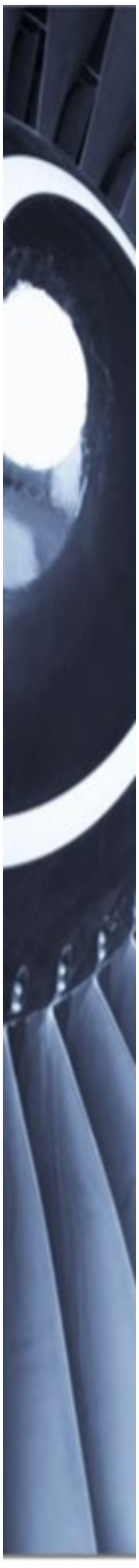
Analysis of Sharing of Risk Premiums by Airport Coalitions

This activity will involve an assessment of the sharing of risk premiums by airport coalitions. Airports in Europe have taken preliminary steps to form SAF purchase-oriented coalitions. It will be helpful to understand the lessons learned from those activities and recommend modifications as needed for U.S. market conditions. The concept of buying pools is being explored in the United States and can be one of the options explored under this activity.

[65] U.S. Department of State and U. S. Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050.* Washington D.C. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

WORKSTREAM PA.3: Inform SAF policy development	
Identify opportunities and strategies to improve existing policy and regulatory mechanisms that can increase availability of SAF. Identify gaps, needs, and impact of new policies on SAF availability.	
DELIVERABLE	**IMPACT**
Expansion of policy support to SAF via existing policies and authorities. Analysis and reports to inform future policy.	Increased utilization of SAF due to changes in existing policy and/or development of new policies.
KEY THEMES: Reduce cost, enhance sustainability, expand production	

Enabling End Use



Facilitate the end use of SAF by civil and military users by addressing critical barriers, including efficient evaluation of fuel engine and aircraft performance and safety, advancement of certification and qualification processes, expansion of existing blend limits, and integration of SAF into fuel distribution infrastructure.

This action area focuses on addressing critical barriers and requirements for safe and cost-effective use of SAF via standards development and critical R&D and analysis. The workstreams include SAF qualification, 100% drop-in SAF, fuel performance evaluation, and SAF integration with existing fuel distribution infrastructure. Efforts spanning these key areas will address critical barriers to SAF deployment. The key objectives for each of the workstreams are as follows:

- **SAF evaluation, testing, qualification, and specification:** Supporting fuel qualification via the ASTM D4054 (Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives) Clearinghouse can alleviate the testing burden on fuel producers.
- **Enable use of drop-in unblended SAF and SAF blends up to 100%:** Work to develop specifications for 100% SAF, both in neat form and blended with other SAF, enables additional opportunities for fuel producers and suppliers to simplify distribution logistics and reduce risk along the supply chain.
- **Investigate Jet A fuel derivatives offering performance or producibility advantages:** Understanding the advantages and challenges of novel jet fuels with unique performance differences, such as greater energy density, will help identify reasonable opportunities that may exist for such fuels.
- **Integrate SAF into fuel distribution infrastructure:** Although the focus of the SAF Grand Challenge is on drop-in SAF, fully fungible with existing supply and distribution infrastructure and aircraft, there are logistical questions related to fuel blending and efficient integration into existing fuel supply infrastructure that must be addressed for scaling up SAF delivery to airports.

Detailed activities and suggested timelines are identified for each workstream in Appendix A.5.

2030 End Use Impact Highlights

Enable SAF use up to 100%

Currently, SAF is required to be blended (at a maximum of 50% by volume) with petroleum, but FAA is working with federal partners and industry to define drop-in jet fuel requirements for alternative fuels that can be qualified at levels up to 100% without the need for blending with petroleum. As an element of a coordinated approach to enable drop-in SAF that can be used up to 100%, one specific area of investigation being pursued by FAA is the use of cycloparaffins to promote elastomeric seal swelling and their potential to replace aromatic compounds. Qualification of 100% SAF could enable SAF producers to reduce cost and simplify logistics of delivery, allow maximum flow of SAF through constrained supply infrastructure, and increase the emissions benefits of SAF use, all of which will contribute to the 2030 goal (see Activity EU.2.4).

Integrate SAF into fuel distribution infrastructure

Distribution and delivery infrastructure gaps, capacity challenges, and integration needs for SAF are anticipated but not fully understood. DOT/FAA will support analysis and feasibility studies to assess SAF integration potential and challenges for SAF into current infrastructure, including delivery to pipeline systems and airports/end users. An understanding of the technical and capacity challenges and how these can be addressed safely and efficiently will be critical to supporting the 2030 SAF production goal of 3 billion gal/yr (see Activity EU.4.3).

EU.1. Support SAF Evaluation, Testing, Qualification, and Specification

The focus of the first workstream under the Enabling End Use Action Area is on SAF evaluation, testing, qualification, and specification through ASTM International. Historically, these activities have presented a barrier to using SAF due to costly and time-consuming testing and approval requirements. To create a transparent and efficient process, the community has established ASTM D4054 as a multitiered evaluation process covering fuel specification and fit-for-purpose properties, followed by rig and full-scale engine testing, if needed. There are two phases of review wherein aircraft and engine original equipment manufacturers (OEMs) review and evaluate fuel test data as part of the iterative approval process. Fuels that successfully complete the process are added to the jet fuel specification, either ASTM D1655 or ASTM D7566. This ensures that novel jet fuels can be safely used in existing aircraft and fuel distribution infrastructure without adverse effects on safety and performance.

FAA leads fuel testing efforts for civil aircraft by supporting the ASTM D4054 Clearinghouse at the University of Dayton Research Institute. The Clearinghouse provides an entry point for candidate fuels to begin evaluation, and the University of Dayton Research Institute facilitates fuel testing and research report review, assisting fuel producers throughout the D4054 process. The U.S. Department of Defense leads fuel testing efforts for military aircraft working through offices within the military services. FAA, Department of Defense, and OEMs coordinate closely

and share data on testing and evaluation activities. There is a D4054 user guide available via CAAFI.[66]

FAA supports fuel prescreening activities via ASCENT. The prescreening tests rely on small volume testing, on the order of milliliters, with fuel modeling tools to predict key fuel properties. This early-stage testing enables fuel producers to address potential process issues prior to entering the formal D4054 fuel qualification process. For fuels that meet a stringent set of property requirements, the D4054 Fast Track Process provides a streamlined approval route, avoiding high-volume rig and engine testing. Fuel pathways qualified via the Fast Track Process are limited to a maximum blend of 10% by volume with conventional jet fuel. The goal of all these activities is to create a predictable, effective, and efficient safety evaluation process for novel fuels and enable a broad set of qualified SAF to be added to the jet fuel specification.

An ongoing goal of this workstream is to continue to explore and validate additional methods to make SAF evaluation, testing, qualification, and specification more agile and efficient.

WORKSTREAM EU.1: Support SAF evaluation, testing, qualification, and specification	
Lead coordinated approach to support civil and military aircraft and engine fuel performance and safety testing and specification approval, improve test methods and enable coordination with aviation stakeholders.	
DELIVERABLE	**IMPACT**
Timely specification of jet fuel pathways.	Accelerate fuel safety testing and approval, reduce cost and time for new approvals and expand the range of qualified fuels to enable expansion of SAF supply.
KEY THEMES: Reduce cost, expand production	

EU.2. Enable Use of Drop-In Unblended SAF and SAF Blends up to 100%

Under current specifications, D7566-qualified fuels must be blended with conventional jet prior to being certified as D1655 jet fuel. The level at which the fuel must be blended with conventional jet is specified for each D7566 annex; most can be blended up to 50% by volume, but some are limited to 10% by volume (Annex A3 and Annex A7, respectively). The second workstream of the Enabling End Use Action Area focuses efforts on enabling approvals of SAF that can be used at greater than 50% and up to 100%. This includes pathways that can be used (1) neat—i.e., without any blending with conventional jet fuel or other qualified fuel pathways; or (2) with blending of multiple ASTM D7566 pathways, again eliminating the need to blend with conventional jet fuel. Activities under this workstream will support ongoing efforts under the ASTM Committee D02 on Petroleum Products and Lubricants, Subcommittee D02.J0.06 on

[66] CAAFI. 2013. *ASTM D4054 Users' Guide*. https://www.caafi.org/information/pdf/d4054_users_guide_v6_2.pdf.

Synthetic Aviation Turbine Fuels. This includes the 100% SAF Task Force working to amend ASTM D7566.

Figure 9. World's first commercial flight using cellulosic-based SAF, produced by a Northwest Advanced Renewables Alliance project funded by USDA.

Photo courtesy of Washington State University and Alaska Airlines

Work to develop 100% specifications involves close coordination across aviation fuel stakeholders encompassing aircraft and engine OEMs, fuel producers, and regulatory bodies, including FAA and the U.S. Department of Defense. Specifications that define fuel property requirements for 100% SAF may enable SAF producers to simplify their process logistics by removing the need to blend SAF with conventional jet fuel. Use of 100% SAF will also allow increased displacement of conventional jet fuel and maximize the life cycle GHG/air quality benefits from use of SAF.

While current efforts focus on establishing specifications that closely match current conventional jet fuel composition, future efforts will seek to address remaining barriers that constrain current fuel property requirements. This includes understanding the impact of fuel composition on nonmetallic fuel system components such as O-ring seals. Whereas aromatic compounds in conventional jet fuel typically ensure sufficient seal swell, other fuel components such as cycloparaffins may be able to replace the aromatic content, providing seal swell with reduced sooting tendencies. Many synthetic aviation turbine fuels do not contain aromatic compounds due to the nature of fuel hydroprocessing, so these compounds would need to be added to satisfy current operational needs.

WORKSTREAM EU.2: Enable use of drop-in unblended SAF and SAF blends up to 100%	
Lead a coordinated approach to enable drop-in SAF that can be used up to 100%, beyond the current maximum blend limit of 50% by volume.	
DELIVERABLE	**IMPACT**
Define drop-in jet fuel requirements for alternative fuels that can be qualified unblended or blended with other alternative fuels.	Enable specification of higher blend levels of drop-in SAF beyond the current 50% limit for use in jet aircraft. This may reduce costs associated with fuel handling/logistics and allow for greater GHG and air quality benefits.
KEY THEMES: Reduce cost, enhance sustainability, expand production	

EU.3. Investigate Synthetic Aviation Turbine Fuels Offering Performance or Producibility Advantages

The third workstream for the Enabling End Use Action Area targets novel jet fuels that may provide unique performance or producibility advantages. These fuels, which fall under the broader category of synthetic aviation turbine fuels and can include SAF, may have fuel properties outside of the conventional jet fuel experience range. For example, these novel fuels may have higher energy density, on a volume or mass basis, than conventional jet fuel. Using this fuel in place of conventional jet fuel would enable longer-range operations for a given volume (or mass) of fuel. Enhanced thermal stability is another example of a synthetic aviation turbine fuel property that could fall outside of the conventional jet fuel property range. Enhanced fuel thermal stability could provide performance benefits by increasing the system heat that can be passed through to the fuel, thereby reducing the thermal load passed to supplemental aircraft system components. Reducing or eliminating supplemental aircraft thermal system components could provide system weight savings, thereby increasing overall fuel efficiency and reducing fuel costs, fuel burn, and associated emissions.

While these fuels may offer some performance or producibility advantages, the challenges of using these fuels will also be investigated as part of this workstream. Using a jet fuel with properties outside of the normal experience range for conventional fuels may require separate handling and storage infrastructure. Safety is paramount when evaluating and designing fuel certification and use standards. If the fuel provides significant performance benefits that then result in design changes to aircraft systems, the aircraft may have unique certification requirements specifying this fuel. Such a fuel would represent a non-drop-in fuel, meaning that it is not fully fungible with the fuel distribution infrastructure and cannot be used on all aircraft certified to use Jet A (ASTM D1655). The challenges associated with maintaining a segregated fuel supply system, including both logistical issues and safety risks, must be evaluated and documented.

WORKSTREAM EU.3: Investigate synthetic aviation turbine fuels offering performance or producibility advantages	
Analyze potential advantages and challenges of new fuels with unique compositions for use in aviation that have enhanced performance benefits (e.g., emissions, energy density, and reduced aviation-induced cloudiness).	
DELIVERABLE	**IMPACT**
Documentation, including qualification and quantification of benefits and barriers to the use of high-performance synthetic aviation turbine fuels.	Understand the potential of novel jet fuels with fuel properties outside of the conventional jet fuel experience range through a holistic approach that includes consideration of performance, safety, cost, and sustainability.
KEY THEMES: Reduce cost, enhance sustainability, expand production	

EU.4. Integrate SAF Into Fuel Distribution Infrastructure

The final workstream within the Enabling End Use Action Area focuses on addressing issues that prevent or limit SAF integration into existing infrastructure, as well as infrastructure barriers to widespread SAF deployment. Current blend limits require that producers blend SAF with conventional jet fuel according to a set level specified for each pathway annex in ASTM D7566. This creates logistical challenges, as SAF is not directly injected into pipeline infrastructure and generally is not transported in neat (unblended) form.

The Building Supply Chains Action Area noted the need to develop feasibility studies to identify sites to support SAF receipt, blending, storage, and delivery infrastructure to supply airports, in both the short and long term. The adequacy of existing aviation fuel storage facilities will need to be assessed, and investment in additional SAF storage capacity and blending capability will be required. New sites and infrastructure may be required to manage SAF inventories, and the time frame for SAF introduction to an airport must also be considered. In the short term, small amounts of SAF may be blended with conventional jet and delivered to airports by truck or rail. However, as SAF production volumes grow, storage and transportation capacity may need to increase to accommodate new SAF supply integration. New sites and increasing fuel capacity could require construction resources and face permitting hurdles. This workstream will investigate questions surrounding opportunities to reduce risk for SAF producers and minimize distribution costs while enhancing the overall sustainability of the delivery process through optimized supply chain logistics. This will include where SAF may best be blended with conventional jet and inserted into existing infrastructure.

A related task will be to investigate current fuel distribution infrastructure standards and identify existing concerns. Many domestic fuel pipeline systems are already at capacity, meaning they will be unable to supply additional volumes of fuel to meet growing demand across the liquid fuel markets, for both ground transportation and aviation. As jet fuel is a small fraction of the

liquid fuel product currently transported within domestic pipelines, additional jet fuel demand at major airports may not be accommodated with increased pipeline supply and may need to be railed or trucked into airport fuel facilities. Pipelines used to transport fuels for the military may present restrictions on SAF shipments if civil and military fuel specifications are not aligned. Some airports and airline fuel users have noted airport specific challenges to integration of SAF, which will also be examined. These and other issues will be explored.

This workstream will also characterize current conventional jet fuel properties, updating key jet fuel property data that are currently lacking. With jet fuel data updated across the supply system, fuel producers and suppliers will have a better understanding of the range of current, in-use jet fuel.

WORKSTREAM EU.4: Integrate SAF into fuel distribution infrastructure	
Conduct analysis on technical and capacity challenges of the existing fuel distribution infrastructure for SAF integration.	
DELIVERABLE	**IMPACT**
Documentation and standards to guide integration of SAF into existing fuel distribution infrastructure throughout the supply chain.	Efficient and safe integration of SAF into current fuel delivery systems.
KEY THEMES: Reduce cost, enhance sustainability, expand production	

Communicating Progress and Building Support

Engage stakeholder organizations, monitor and measure progress against SAF Grand Challenge goals, provide public information resources, and communicate benefits of the SAF Grand Challenge.

Effective communication that transparently demonstrates the environmental, climate, and economic benefits of SAF is vital to building public trust and increasing support. For the SAF Grand Challenge to be successful, public awareness of SAF as one of the solutions to reduce net GHG emissions from aviation, while also simultaneously investing in the U.S. domestic economy, will be important. Without increased awareness and positive public perception—from farmers needed to grow feedstocks to airline passengers flying on SAF—increasing production may remain a challenge. Building and maintaining support for SAF may be particularly challenging due to the complexity of the supply chains and modeling with multiple feedstocks and conversion pathways. SAF supply chains and impacts are not simple and will be prone to incorrect or misleading information that could rapidly sway public perception. Developments in modeling and production, including feedstock sustainability, need to be regularly and effectively communicated to avoid criticisms and broad generalizations based on outdated information or narrow data—especially given the tendency to affect policy. Therefore, coordination and transparent, accurate, and objective resources will be essential for public engagement and dialogue to build and maintain support. Most importantly, benefit and impact assessments that are made publicly available will be necessary to demonstrate that benefits are real, supported by data, and can be clearly understood. Communication activities will support workstreams across the other five action areas.

The following are key actions to communicate progress and build public support:

- **Stakeholder outreach and engagement on sustainability** to exchange information about best practices to reduce life cycle GHG emissions from agricultural- and forest-derived feedstocks.
- **Conduct benefits assessment/impact analysis of SAF Grand Challenge** to inform decisions, demonstrate benefits, and mitigate negative impacts.
- **Measure progress of the SAF Grand Challenge** to provide updates, measure success, and show where progress needs to be made.
- **Communicate public benefits of the SAF Grand Challenge** to address common concerns/misconceptions and further build public support.

2030 Communicating Progress and Building Support Impact Highlights

Stakeholder outreach and engagement on sustainability

Outreach and engagement with stakeholder groups will continue to be critical for building support and exchanging knowledge to achieve the 2030 goals. DOE, USDA, and FAA will hold consultations and listening sessions with the NGO, agricultural, and forestry communities to understand needs and best practices to reduce life cycle GHG emissions from feedstock production and improve sustainability (see Activities CP.1.1 and CP.1.2).

Detailed activities and suggested timelines are identified for each workstream in Appendix A.6.

CP.1. Stakeholder Outreach and Engagement on Feedstock Sustainability

The overall objective of the SAF Grand Challenge is to address the sustainability of aviation, a hard-to-decarbonize transportation sector. Achieving the SAF Grand Challenge volumetric targets should not result in unintended consequences that jeopardize overarching U.S. economy-wide GHG reduction goals. Feedstock and conversion pathways need to meet a minimum 50% GHG reduction threshold (including induced or indirect land use change effects) on a life cycle basis to qualify as a contributing pathway under the SAF Grand Challenge. Some feedstock and conversion technology pathways (e.g., fuels derived from waste and residue-based feedstocks) can meet this threshold with currently available practices and technologies. However, some pathways (e.g., fuels derived from corn starch and soybean oil) may require improvements in agricultural practice and technologies, relative to what is in use today, to meet this threshold. A series of consultations will be held with NGOs, feedstock producers (particularly agricultural and forestry communities), and other stakeholder groups to exchange information about data and best practices around the world to determine what has worked to reduce life cycle GHG emissions from agricultural- and forest-derived feedstocks. These discussions will also explore the environmental and social impacts of a buildout of sustainable aviation fuel, including key issues such as expanding the use of sustainable oilseeds (see Workstream FI.2) and the impacts of retrofitting existing refining infrastructure on local communities (see Workstream CT.3). Outcomes of these consultations will help inform the on-the-ground R&D and data gathering conducted under Workstream FI.6, the Conversion Technology Innovation Action Area, the life cycle analysis data and methods developed under Workstream PA.1, and the following workstreams to build public support.

WORKSTREAM CP.1: Stakeholder outreach and engagement on feedstock sustainability	
Hold a series of consultations with NGOs, feedstock producers (particularly agricultural and forestry communities), and other stakeholder groups to exchange data and information about best practices to reduce life cycle GHG emissions from agricultural- and forest-derived feedstocks and minimize other environmental and social impacts.	
DELIVERABLE	**IMPACT**
Reports and other publications with data and on lessons learned and potential for reducing carbon intensities. Disseminate best practices for key activities necessary for building the SAF industry.	Continued and expanded support and access to information. Ensure approaches are environmentally and socially sustainable.
KEY THEMES: Enhance sustainability	

CP.2. Conduct Benefits Assessment/Impact Analysis of SAF Grand Challenge

Decision makers and the public will require information on economic, social, and environmental cost/benefits to make informed decisions. This will include tools that evaluate the national and regional impacts of SAF production. Accurate, objective, and accessible information and analysis will aid in decisions on feedstock production, biorefinery siting/permitting, and supply chain networks, as well as state and local policies that facilitate SAF production (see Workstream FI.6). Information must be accessible to local and regional stakeholders, including local officials, energy development authorities, and advocacy groups. These publicly available analyses will support the outreach and regional supply chain activities in the Building Supply Chains Action Area.

Analysis of environmental and socioeconomic impacts will be required to have the information needed to limit negative effects on communities and ensure equitable distribution of resources. This transparency is important to build public trust. The goal is to make SAF production appealing from economic, social, and environmental aspects so that communities support elements of SAF production (e.g., siting of a new biorefinery). SAF has potential to offer environmental benefits over petroleum-based jet fuel (e.g., soot reduction), which must be supported by research and communicated. Benefits to communities will have to be continuously demonstrated, including the creation of new jobs and income for feedstock producers, to build community buy-in. Such benefits help allay concerns about regional impacts, whether environmental, social, or economic (see Workstreams PA.1 and PA.2). For example, there will be shifts in the workforce and available jobs within regions as the industry grows—knowing where there is an available workforce will be necessary for refinery siting. Importantly, identifying and communicating socioeconomic and environmental challenges early in

development can be used to anticipate potential negative impacts on communities that may have to be mitigated with additional, directed support (see Workstream SC.1).

WORKSTREAM CP.2: Conduct benefits assessment/impact analysis of SAF Grand Challenge	
Develop analysis of SAF Grand Challenge impacts (jobs, fuel, and environment).	
DELIVERABLE	**IMPACT**
Coordinated analysis of economic, social, and environmental costs and benefits of SAF production and use.	Support analyses for development of SAF feedstock production and conversion facilities.
KEY THEMES: Expand production, enhance sustainability, reduce cost	

CP.3. Measure Progress of the SAF Grand Challenge

A coordinated interagency approach to monitoring progress toward the SAF Grand Challenge goals will demonstrate success and indicate where progress needs to be made. This involves tracking feedstock to SAF production and use and making this information public—for example, through the creation of a common database on biorefineries, production, and end use. Methodology to estimate total SAF production, life cycle CO_2 reductions, and other sustainability characteristics with tracking to end use will be developed. This system should have the ability to cross-check end use with the CORSIA Central Registry. Furthermore, accounting for feedstock production and sustainability to mitigate concerns over environmental, social, or economic impacts (e.g., food costs) in an accessible manner would serve as a resource to build support among some environmental organizations. The information-sharing system will prioritize ease of use for public accessibility.

The SAF roadmap will be updated approximately every 2 years to account for progress, lessons learned, and new information to guide activities. This will require a dedicated interagency process and resources to collect information and integrate updates. Importantly, the roadmap appendix will include examples of regional supply chain successes to serve as models for future development (see Workstream SC.3). Beyond 2030, robust examples of functional regional supply chains should be included and shared as case studies. This will be a critical starting point for remaining small and mid-sized airports without SAF supply chains to start feasibility analyses. Updates should include analysis of where projects faced challenges so that others may learn from failures. Broad stakeholder engagement will continue to be crucial to assess and address technical, economic, and policy challenges.

WORKSTREAM CP.3: Measure progress of the SAF Grand Challenge	
Track progress against the SAF Grand Challenge goals and publish information on progress and outcomes on a regular basis.	
DELIVERABLE	**IMPACT**
Coordinated approach to tracking SAF and feedstock production and use and monitoring progress toward SAF Grand Challenge goals. Review progress and update SAF Grand Challenge Roadmap.	Continued and expanded public support.
KEY THEMES: Communication	

CP.4. Communicate Public Benefits of the SAF Grand Challenge

Public benefits of the SAF Grand Challenge must be widely communicated, with common concerns and misconceptions consistently addressed. Connecting sustainability criteria for SAF with positive impacts achieved should be a key point in public messaging. A coordinated interagency communications strategy that enables consistent messaging across agencies reinforces that this is a government-wide endeavor and builds confidence in the whole-government approach to SAF. Interagency communication products may consist of reports, blogs, joint public announcements, shared talking points, and educational materials. Communication materials should contain reciprocal linkages to related material released across agencies. For example, a USDA press release on a new feedstock development could be linked to related releases by DOE and FAA's SAF research website for a wider audience. Agency leadership will need accurate, objective talking points to discuss SAF as a climate-smart solution with significant advantages for U.S. domestic economic development and with reference to what each agency may contribute. As a publicly recognized entity, the Biomass Research and Development Board will continue to be used to leverage interagency coordination on communication efforts.[67]

[67] Biomass Research & Development. 2022. "Biomass Research & Development Board."

Figure 10. Public outreach through field days and listening sessions.

Photo courtesy of the Washington State University Extension

Communication products put SAF costs, benefits, and impacts in the right context for policymakers, stakeholders, and the public. Consistent, trusted communication will support advocacy groups, media, and NGOs to educate local and state officials. In coordination with industry and advocacy groups, specific communication campaigns could be created to address common criticisms and emphasize the premium benefits of SAF over petroleum-based fuels. The network of agricultural extension units and land-grant universities should be leveraged to disseminate information and technical experience (see Workstream SC.1). These channels of communication will be particularly important in supporting feedstock producers as new biomass and oilseed feedstocks are adopted. Farmers, forestry workers, solid waste managers, and other feedstock producers will need a trusted source of information and *clear examples of successes* to mitigate concerns over real and perceived risks (see Workstreams FI.1 and FI.3). Schools may also serve as a point to increase public awareness, such as through the incorporation of SAF as case studies for life cycle analysis, economic modeling, and agriculture in educational materials for high school or university courses (see Workstream SC.1). Grants for SAF-related research should support education and outreach; for example, many USDA competitive grants must include extension or outreach components for broader research impacts.

Reports and outreach activities mentioned previously (see Workstreams FI.1, SC.2, PA.1, PA.2) will be consolidated and made accessible in a central online repository for widespread public awareness. The SAF Grand Challenge website will also house a comprehensive list of resources (e.g., the Feedstock Readiness Level tool and publicly available and relevant research) and links to funding programs across the agencies. These resources should be leveraged to improve private sector awareness to help drive uptake and investment in SAF. CAAFI will continue to play a strong role in communication and coordination activities with industry.

WORKSTREAM CP.4: Communicate public benefits of the SAF Grand Challenge	
Maintain public support via communication plan, including education on sustainability and jobs.	
DELIVERABLE	**IMPACT**
Coordinated communications that include environmental, social, and economic benefits; address common concerns/misconceptions (e.g., food vs. fuel and land use change); and provide access to resources targeted at the general public and stakeholders.	Continued and expanded public support and access to information.
KEY THEMES: Communication	

References

Airlines for America. 2021. "Major U.S. Airlines Commit to Net-Zero Carbon Emissions by 2050." News Updates, March 30, 2021. https://www.airlines.org/news/major-u-s-airlines-commit-to-net-zero-carbon-emissions-by-2050/.

———. 2021. "U.S. Airlines Announce 3-Billion-Gallon Sustainable Aviation Fuel Production Goal." News Updates, Sept. 9, 2021. https://www.airlines.org/news/u-s-airlines-announce-3-billion-gallon-sustainable-aviation-fuel-production-goal/.

ANL, NREL, and PNNL. 2017 *Algae Harmonization Study: Evaluating the Potential for Future Algal Biofuel Costs, Sustainability, and Resource Assessment from Harmonized Modeling*. Golden, CO: National Renewable Energy Laboratory. NREL/ TP-5100-70715. https://www.nrel.gov/docs/fy18osti/70715.pdf.

ASCENT. 2022. "Alternative Jet Fuel Supply Chain Analysis." Accessed July 21, 2022. https://ascent.aero/project/alternative-jet-fuel-supply-chain-analysis/.

Bioenergy Alliance Network of the Rockies (BANR). 2022a. "Bioenergy Alliance Network of the Rockies." Accessed July 20, 2022. http://banr.nrel.colostate.edu/.

———. 2022b. "The Mountain Pine Beetle Epidemic." Accessed July 20, 2022. http://banr.nrel.colostate.edu/the-mountain-pine-beetle-epidemic/.

Biomass Feedstock National User Facility. 2022. "Bioenergy Feedstock Library." Accessed July 20, 2022. https://bioenergylibrary.inl.gov/.

Biomass Research & Development. 2022. "Biomass Research & Development Board." https://biomassboard.gov/.

Commercial Aviation Alternative Fuels Initiative (CAAFI). 2013. *ASTM D4054 Users' Guide*. https://www.caafi.org/information/pdf/d4054_users_guide_v6_2.pdf.

———. 2022a. "Fuel Qualification: Approved Fuels." Accessed Aug. 1, 2022. https://www.caafi.org/focus_areas/fuel_qualification.html#approved.

———. 2022b. "Path to Alternative Jet Fuel Readiness." Accessed July 21, 2022. https://caafi.org/tools/Path_to_Alternative_Jet_Fuel_Readiness.html

Federal Aviation Administration (FAA). 2021. *United States 2021 Aviation Climate Action Plan*. Washington, D.C.: FAA. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.

International Air Transport Association (IATA). 2021. "Net-Zero Carbon Emissions by 2050." Press Release No: 66, Oct. 4, 2021. https://www.iata.org/en/pressroom/2021-releases/2021-10-04-03/.

Iowa State University. 2022. “CenUSA Bioenergy.” Accessed July 20, 2022. https://cenusa.iastate.edu/.

IPREFER. 2022. “IPREFER – Integrated Pennycress Research Enabling Farm & Energy Resilience.” Accessed July 20, 2022. https://www.iprefercap.org/.

Kellner, Thomas. 2017. “GE Just Turned the World’s Most Powerful Jet Engine Into A 65-Megawatt Power Plant.” GE News, Jan. 30, 2017. https://www.ge.com/news/reports/ge-oil-gas-just-turned-worlds-largest-jet-engine-65-megawatt-power-plant.

Lewis, Kristin C., Emily K. Newes, Steven O. Peterson, Matthew N. Pearlson, Emily A. Lawless, Kristin Brandt, Dane Camenzind, et al. 2019. “US alternative jet fuel deployment scenario analyses identifying key drivers and geospatial patterns for the first billion gallons.” *Biofuels, Bioproducts and Biorefining* 13 (3): 471–485. https://doi.org/10.1002/bbb.1951.

LSU AgCenter. 2022. “Sustainable Bioproducts Initiative.” Accessed July 20, 2022. https://www.lsuagcenter.com/topics/crops/bioenergy/biofuels_bioprocessing/subi.

National Renewable Energy Laboratory (NREL). 2019. “Bio-based circular carbon economy Environmentally-extended Input-Output Model (BEIOM).” Last updated Sept. 17, 2019. https://bioenergymodels.nrel.gov/models/42/.

———. 2019. “BioTrans.” Last updated Sept. 17, 2019. https://bioenergymodels.nrel.gov/models/9/.

PennState Extension. 2013. “NEWBio Energy Crop Profile: Switchgrass.” Last updated Aug. 22, 2013. https://extension.psu.edu/newbio-energy-crop-profile-switchgrass.

Port of Seattle. 2022. “Sustainable Aviation Fuels.” Accessed July 21, 2022. https://www.portseattle.org/page/sustainable-aviation-fuels.

Renewable Fuels Association. 2021. *Essential Energy: 2021 Ethanol Industry Outlook*. Ellisville, MO: RFA. https://ethanolrfa.org/file/1007/RFA_Outlook_2021_fin_low.pdf.

South Dakota State University. 2022. “DOE Regional Feedstock Partnership.” Accessed July 20, 2022. https://www.sdstate.edu/north-central-regional-sun-grant-center/doe-regional-feedstock-partnership.

Southeastern Partnership for Advanced Renewables from Carinata. 2022. “SPARC.” Accessed July 20, 2022. https://sparc-cap.org/.

Southeastern Partnership for Integrated Biomass Supply Systems (IBSS). 2022. “Southeastern Partnership for Integrated Biomass Supply Systems.” Accessed July 20, 2022. http://se-ibss.org/.

Steiner, Jeffrey J., Kristin C. Lewis, Harry S. Baumes, and Nathan L. Brown. 2012. “A Feedstock Readiness Tool to Complement the Aviation Industry Fuel Readiness Level Tool.” *BioEnergy Research* 5: 492–503. https://doi.org/10.1007/s12155-012-9187-1.

The University of Arizona. 2022. "Sustainable Bioeconomy for Arid Regions." Accessed July 20, 2022. https://sbar.arizona.edu/.

U.S. Department of Agriculture (USDA). 2022a. "AFRI Regional Bioenergy System Coordinated Agricultural Products." Accessed July 20, 2022. https://www.nifa.usda.gov/afri-regional-bioenergy-system-coordinated-agricultural-projects.

———. 2022b. "AFRI Sustainable Agricultural Systems." Accessed July 21, 2022. https://www.nifa.usda.gov/grants/programs/afri-sustainable-agricultural-systems.

———. 2022c. "Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program." Accessed July 21, 2022. https://www.rd.usda.gov/programs-services/energy-programs/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance-program.

———. 2022d. "Farm 2 Fly." Accessed July 20, 2022. https://data.nal.usda.gov/farm-2-fly.

———. 2022e. "OneRD Guarantee. Accessed July 21, 2022. https://www.rd.usda.gov/onerdguarantee.

U.S. Department of Energy (DOE). 2011. *Technology Readiness Assessment Guide*. Washington, DC: DOE. DOE G 413.3-4A. https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a/@@images/file.

———. 2016. *2016 Billion-Ton Report*. https://www.energy.gov/eere/bioenergy/2016-billion-ton-report.

———. 2017a. *2016 Billion-Ton Report, Volume 2: Environmental Sustainability Effects of Select Scenarios from Volume 1*. Jan. 13, 2017. https://www.energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-volume-2-environmental-sustainability-effects.

———. 2017b. *Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Challenges and Opportunities*. Washington, D.C.: DOE. DOE/EE-1472. https://www.energy.gov/eere/bioenergy/downloads/biofuels-and-bioproducts-wet-and-gaseous-waste-streams-challenges-and.

———. 2021. "Memorandum of Understanding: Sustainable Aviation Fuel Grand Challenge." Sept. 8, 2021. https://www.energy.gov/sites/default/files/2021-09/S1-Signed-SAF-MOU-9-08-21_0.pdf.

———. 2022a. "CBI: Center for Bioenergy Innovation." Accessed July 20, 2022. https://genomicscience.energy.gov/cbi/.

———. 2022b. "Loan Programs Office." Accessed July 21, 2022. https://www.energy.gov/lpo/loan-programs-office.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office (BETO). 2021. "From the Lab to Jet Engines: New Software Tools will

Speed Up Biojet Fuel Development." Oct. 20, 2021. https://www.energy.gov/eere/bioenergy/articles/lab-jet-engines-new-software-tools-will-speed-biojet-fuel-development.

———. 2021. "U.S. Department of Energy Announces More Than $64 Million for Biofuels Research to Reduce Transportation Emissions." Sept. 9, 2021. https://www.energy.gov/eere/bioenergy/articles/us-department-energy-announces-more-64-million-biofuels-research-reduce.

U.S. Department of State and U.S. Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. Washington, D.C. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

U.S. Department of Transportation Volpe Center. 2022. "FTOT-Public." GitHub, accessed July 21, 2022. https://github.com/VolpeUSDOT/FTOT-Public.

U.S. Energy Information Administration. 2021. "Monthly Biodiesel Production Report." Accessed Feb. 2021. https://www.eia.gov/biofuels/biodiesel/production/.

U.S. Environmental Protection Agency (EPA). 2022. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020." Tables A-98 and ES-6, last updated July 13, 2022. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

Wang, Michael, Uisung Lee, Hoyoung Kwon, and Hui Xu. 2021. "Life-Cycle Greenhouse Gas Emission Reductions of Ethanol with the GREET Model." Presented at the 2021 National Ethanol Conference, Feb. 17, 2021. https://afdc.energy.gov/files/u/publication/ethanol-ghg-reduction-with-greet.pdf.

Washington State University. 2020. "Advanced Hardwood Biofuels Northwest [Archived]." Last updated April 2020. https://hardwoodbiofuels.org/.

———. 2022. "NARA." Accessed July 20, 2022. https://nararenewables.org/.

West Virginia University. 2022. "MASBio at West Virginia University." Accessed July 20, 2022. https://masbio.wvu.edu/.

The White House. 2021. "Fact Sheet: Biden Administration Advances the Future of Sustainable Fuels in American Aviation." Briefing Room, Sept. 9, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/09/fact-sheet-biden-administration-advances-the-future-of-sustainable-fuels-in-american-aviation/.

Wright, L. L., J. H. Cushman, A. R. Ehrenshaft, S. B. McLaughlin, W. A. McNabb, J. W. Ranney, G. A. Tuskan, and A. F. Turhollow. 1992. *Biofuels Feedstock Development Program Annual Progress Report for 1991*. Oak Ridge, TN: Oak Ridge National Laboratory. ORNL-6742. https://doi.org/10.2172/6941410.

Appendix A: Detailed Roadmap Activities (Preliminary)

The following tables provide a more granular description of the roadmap activities, including potential deliverables and timelines for action. The activities currently defined here represent a preliminary list of possible detailed activities under each workstream. During fiscal year 2023, public–private implementation teams will be formed around these action areas and workstreams. These implementation teams will further develop and refine these lists of specific activities and timelines.

Appendix A.1: Feedstock Innovation Detailed Activities

Description: R&D on sustainable feedstock supply system innovations across the range of SAF-relevant feedstocks and identify optimization to reduce cost, technology uncertainty, and risk; increase yield and sustainability; and optimize SAF precursors.

WORKSTREAM FI.1: Understand resource markets and availability. Develop databases and market analysis (including competitive uses) for commodity and commercially available feedstocks under increased demand for SAF, and assess and analyze the factors affecting the availability of non-commodity/commercial feedstocks.				
DELIVERABLE: An updated understanding of the supply and demand dynamics for feedstocks under the proposed production levels for SAF and development of common databases for SAF feedstocks. IMPACT: Identification of feedstock availability and limitations for SAF conversion technologies and supply/cost curves. KEY THEMES: Reduce cost, expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY FI.1.1: Market analysis of lipid feedstocks.	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for FOG and virgin vegetable oils.	An understanding of the potential availability for lipid feedstocks to produce SAF, as well as R&D and policy needs.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.1.2: Market analysis of starch-based ethanol.	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for starch-based ethanol.	An understanding of the potential availability for starch-based ethanol feedstocks to produce SAF, as well as R&D and policy needs.	2023	2030
ACTIVITY FI.1.3: Market analysis of U.S.-produced wood pellets.	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for U.S.-produced wood pellets.	An understanding of the potential availability for U.S.-produced wood pellet feedstocks to produce SAF, as well as R&D and policy needs.	2023	2030
ACTIVITY FI.1.4: Market analysis of forest residuals and mill wastes.	A report containing a market analysis, including policy implications, on the supply/demand impact of increased SAF demand for forest product waste.	An understanding of the potential availability for forest product waste to produce SAF feedstock, as well as R&D and policy needs.	2023	2030
ACTIVITY FI.1.5: Market analysis/inventory of wet wastes.	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for wet wastes. These should include but not be limited to agricultural, food processing, MSW, and wastewater sources.	An understanding of the potential availability for wet wastes to produce SAF feedstock, as well as R&D and policy needs.	2023	2030
ACTIVITY FI.1.6: Revision of 2016 Billion-Ton Report with greater detail on MSW and alga resources.	A report that is an update of the original *2016 Billion-Ton Report* with updated data and greater detail on MSW and alga resources.	An understanding of the potential availability of agriculture and forestry resources, dedicated energy crops, MSW, and alga resources for the production of biofuels.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.1.7: Market analysis on existing micro- and macroalgae.	A report containing a market analysis, including policy implications and relevant data, on the supply/demand impact of increased SAF demand for micro- and macroalgae on the existing industry.	An understanding of the potential availability of micro- and macroalgae to produce SAF feedstock, as well as R&D and policy needs.	2023	2030
ACTIVITY FI.1.8: Market analysis to explore the potential for renewable hydrogen and/or renewable natural gas.	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for renewable hydrogen and renewable natural gas on the existing industry.	Quantifying the degree to which renewable hydrogen can be made available from the existing >2,000 anaerobic digesters and alignment with potential demand by the SAF industry. Under what scenarios/scales should certain feedstocks be converted to biogas/renewable natural gas, and under what scenarios should the wastes be converted to liquid transportation fuels?	TBD	TBD
ACTIVITY FI.1.9: Market analysis to explore the potential for gaseous sources of carbon (carbon monoxide, CO_2).	A report containing a market analysis and relevant data, including policy implications, on the supply/demand impact of increased SAF demand for gaseous sources of carbon on the existing industry.	An understanding of the potential availability of carbon from point source and direct air capture for the production of biofuels.	TBD	TBD

WORKSTREAM FI.2: Maximize sustainable lipid (FOG) supply for 2030. Given near-term relevance of SAF conversion of lipids to meeting 2030 goals, take a coordinated approach to lipid feedstock RDD&D to support expansion to meet 2030+ goal, development of a lipid project plan, and coordination of U.S. government support for near-term lipid crop expansion (e.g., oilseed cover crops).				
DELIVERABLE: More lipids available for qualified conversion pathways. IMPACT: Increase the probability for the production of 3 billion gal/yr SAF by 2030 and beyond. KEY THEMES: Expand production (for 2030 goal).				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY FI.2.1: Understanding sustainable waste lipid aggregation potential.	Deliver data and analysis of costs, quantities, and location for optimization of diverse lipid aggregation for regional SAF production.	Increased lipid feedstock to meet 2030 SAF production goals.	2023	2030
ACTIVITY FI.2.2: Identifying sustainable lipid feedstock potential from industrial effluents and byproducts.	A report outlining the identity, quality, quantity, and cost of lipid feedstock from industrial effluents and byproducts.	Increased lipid feedstock to meet 2030 SAF production goals.	TBD	TBD
ACTIVITY FI.2.3: Expanding potential for existing sustainable oilseed/row crop production.	A report outlining the identity, quality, quantity, and cost of lipid feedstock from expanded oilseed crop production. Strategies on the use of oilseed cover crops and crop rotations that allow for the increase in vegetable oil production without requiring additional land in agriculture.	Increased lipid feedstock to meet 2030 SAF production goals.	TBD	TBD
ACTIVITY FI.2.4: Develop new sustainable oilseed cover crops.	Expanded R&D and pilot trials for emerging oilseed cover crops.	Increased lipid feedstock to meet 2030 SAF production goals.	TBD	TBD

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.2.5: Expansion of sustainable oil feedstock resources beyond 2030: tree/bush oils, algae (micro- and macroalgae), advanced microbial conversion of lignocellulosic wastes to precursor molecules, and engineered oil excrescence in biomass itself.	Expanded R&D and pilot trials for emerging oilseed feedstock crops.	Increased lipid feedstock to meet 2030 SAF production goals and beyond.	2030	2050
WORKSTREAM FI.3: Increase production of purpose-grown biomass resources and collection of wastes and residues. Provide the R&D to increase the production and collection of biomass resources (besides lipids).				
DELIVERABLE: Development of technologies and strategies that will increase the availability of biomass and waste resources for use as biofuel feedstocks. IMPACT: More biomass and waste resources are available at an acceptable carbon intensity and price. KEY THEMES: Reduce cost, expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY FI.3.1: MSW collection, sorting, and decontamination R&D.	Strategies and technologies that increase the amount and purity of waste resources that can be collected at a reduced cost and CI for use as an SAF feedstock.	The production of more waste-derived SAF feedstock resources.	2023	2030
ACTIVITY FI.3.2: Agricultural residue collection R&D (carbon:nitrogen ratio).	Strategies, technologies, and demonstrations to sustainably collect agricultural residue that will optimize nitrogen availability and reduce nitrous oxide emissions from agronomic soils.	The ability to produce low-CI agricultural residues for use to produce SAF feedstock.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.3.3: Forest management for increase of sustainable thinning, residue collection, and wildland fire mitigation operation material.	Strategies, technologies, and demonstrations that increase the amount of available forest residues and thinning material, and the sustainable management of forests to reduce the incident and intensity of wildland fire.	Expanded woody resources for use as an SAF feedstock.	2023	2030
ACTIVITY FI.3.4: Dedicated energy crop production trials.	Demonstrations on the production of dedicated energy crops (switchgrass, miscanthus, hybrid poplars, and selected oilseed crops).	Proof of concept for the commercial production of energy crops.	2023	2040
ACTIVITY FI.3.5: Micro- and macroalgae production trials.	Demonstration of the production of micro- and macroalgae.	Proof of concept for the commercial production of micro- and macroalgae.	2030	2040
ACTIVITY FI.3.6: Utilize sludge, manure, and industrial waste.	Strategies, technologies, and demonstrations that increase the amount of available sludges, manures, and industrial wastes.	Expand the commercial collection and use of sludges, manures, and industrial waste.	TBD	TBD
ACTIVITY FI.3.7: Develop gaseous carbon feedstocks.	Strategies to support utilization of gaseous carbon sources.	Proof of concept for the commercial collection of gaseous carbon.	TBD	TBD
ACTIVITY FI.3.8: Develop and support renewable natural gas/hydrogen resources.	Strategies, technologies, and demonstrations that increase the amount of available renewable natural gas and hydrogen.	Expand the commercial collection and use of renewable natural gas and hydrogen.		

WORKSTREAM FI.4: Improve feedstock supply logistics.

Support the development of collection and harvesting systems, including transportation logistics, to increase efficiencies and decrease cost and carbon intensity of supply logistics from the producer's field to the conversion facility door.

DELIVERABLE: Technologies and strategies that will increase the availability of low-cost and low-CI biomass and waste resources for use as a biofuel feedstock.

IMPACT: More biomass and waste resources are available at an acceptable carbon intensity, quality, and price.

KEY THEMES: Reduce cost, expand production.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.4.1: Improve conventional supply systems.	Strategies and technologies that provide incremental improvement in biomass resource logistics and handling systems.	Near-term improvement in current biomass and waste resource logistics and handling systems (including storage).	2023	2030
ACTIVITY FI.4.2: Develop advanced supply systems.	Innovative disruptive strategies and technologies to collect, handle, move, process, and store biomass and waste resources (e.g., depot concept).	Development of resource supply systems that remove or reduce supply risk to the SAF conversion facility.	2030	2040

WORKSTREAM FI.5: Increase reliability of feedstock handling systems.

Acquire a deep understanding of the behavior and characteristics of solid feedstocks, and enable development of computational models that inform R&D to increase the reliability of feedstock handling operations.

DELIVERABLE: Development of technologies and strategies that will increase SAF plant efficiency and decrease downtime.

IMPACT: Reduction in feedstock uncertainty.

KEY THEMES: Reduce cost, expand production.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.5.1: Improve the understanding of the basic science behind the flowability and processing of solid biomass and waste materials necessary to produce feedstocks.	Pilot strategies, model and engineering tools, and technologies to cost-effectively preprocess biomass and waste resources into SAF feedstock.	Increase the success of conversion facilities through the production of on-specification feedstocks that reduce downtime, increase efficiency, and reduce cost and CI.	2023	2030
WORKSTREAM FI.6: Improve sustainability of biomass and waste supply systems. **Develop an understanding of how biomass production and waste collection for use as a biofuel feedstock impacts air, water, soil, biodiversity, and social/environmental justice.**				
DELIVERABLE: R&D and analysis that will provide a better understanding of the environmental and social impacts of producing SAF feedstock from biomass and waste resources. IMPACT: A reduction in the uncertainty of environmental and social effects from the production/collection of biomass resources and waste for SAF feedstock. KEY THEMES: Improve sustainability.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY FI.6.1: Revision of the *2016 Billion-Ton Report, Volume 2* (sustainability) based on a revised Volume 1.	A report on the environmental impacts of using agricultural and forest residues, agricultural and forest waste, MSW, dedicated energy crops, and algae to produce SAF feedstocks.	Data to enable defensible feedstock production decisions and policy based on an understanding of the environmental implications and trade-offs for the use of biomass and waste resources to produce SAF.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY FI.6.2: Expanding environmental services research to cover additional locations, environments, biomass, and waste resources.	A report that provides insight into (1) targeting the appropriate places to produce or harvest biomass to deliver ecosystem services; (2) measuring, verifying, and valuing those ecosystem services in a scientifically rigorous manner; and (3) reducing uncertainty in modeled estimates of ecosystem services (to respond to and inform policy).	Provide important valuation information for policymakers to enable additional income sources related to ecosystem services for feedstock producers.	TBD	TBD
ACTIVITY FI.6.3: Assessing the pros and cons on environmental justice from the use of biomass and waste resources to produce SAF feedstock.	A report that highlights how SAF feedstock production can benefit environmental justice and what environmental justice barriers may exist.	Enable more equitable distribution of impacts from the production/collection of biomass and waste resources for the production of SAF feedstock.	TBD	TBD
ACTIVITY FI.6.4: Assessing the increases in carbon capture, reductions in GHG emissions, and reductions in exogenous nitrogen and herbicide inputs required to grow dedicated energy feedstocks compared to annual row crops.	A report on the current state of the art for growing dedicated energy crops, including best estimates of current climate mitigation potential.	Improved CI, sustainability, and yield for dedicated energy crops.	TBD	TBD
ACTIVITY FI.6.5: Improving plant genetics and agronomic practices to continuously improve crop yields and sustainability.	Developing technologies, strategies, and demonstrations that support climate-smart agriculture and forestry practices, which includes advanced genetics, reduced inputs, and increased yield per unit land.	Optimized yields and increased sustainability.	TBD	TBD

Appendix A.2: Conversion Technology Innovation Activities

Description: This action area covers R&D, through pilot scale, on unit operations (and integration thereof) from the receipt of biomass at the refinery gate through to finished fuel for technology improvements/carbon intensity reductions. The effort includes processes that are already commercial (e.g., HEFA) or nearing commercialization (e.g., ATJ) and considers work on processes that will be ready for commercialization beyond 2030 but need to be developed now.

WORKSTREAM CT.1: Decarbonize, diversify, and scale current fermentation-based fuel industry. **Reduce the carbon intensity of the existing starch ethanol industry and increase its production capacity without requiring the planting of additional corn. This workstream will also further improve the economics and CI of ATJ processes and other pathways that utilize fermentation to make SAF molecules or precursor molecules.**				
DELIVERABLE: Carbon intensity improvements to ethanol production and expanded buildout of ethanol or other alcohol-to-jet facilities. Anticipated benefits by 2030. IMPACTS: Improve sustainability of the U.S. 17-billion-gallon/year (9.4-billion-gallon/year SAF) starch ethanol industry. Improved minimum fuel selling price of resulting fuels. Expands markets for ethanol as light-duty market contracts. Creates additional volumes of SAF without introducing significant process complexity. KEY THEMES: Expand SAF production, improve sustainability, reduce cost.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CT.1.1: Improve CI in existing corn ethanol facilities with the addition of carbon-smart technologies and agricultural practices.	Pilot technologies that can improve GHG emissions from 40% to as much as 70% lower than petroleum.	Enable existing corn ethanol market to transition to SAF by lowering carbon intensity.	2023	2026
ACTIVITY CT.1.2: Utilization of second-generation feedstock (such as corn stover) in existing starch ethanol refineries to increase production without increasing land use.	Complete the R&D necessary so that fiber-derived and cellulosic sugars can utilize existing fermentation capacity.	Increase ethanol production volumes with minimal capital expense and lower carbon intensity with no additional land use.	2023	Late 2020s

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.1.3: Investigation and production of new fermentation products (alcohols other than ethanol, butanol, or acids) that can be directly upgraded to finished fuels.	Identification of novel fermentation products that are compatible with existing hydroprocessing infrastructure and catalysts. Production of sufficient fuel quantities to enable alpha and beta property testing toward ASTM compliance.	Increase near-term volumes of HEFA-derived SAF.	2023	2028
ACTIVITY CT.1.4: Investigate options for residual lignin (e.g., torrefaction for solid fuel, addition to dried distiller's grains, and liquefaction).	Complete the R&D necessary for at least one lignin technology that exceeds economic and sustainability performance relative to boiler combustion. Coordinate with industrial partner to demonstrate technology at scale.	Lignin valorization is critical to mobilizing second-generation (cellulosic) sugars and can incentivize production of additional second-generation feedstocks and improve system-level economics and sustainability.	2023	2035
ACTIVITY CT.1.5: Development of water-tolerant catalysts and reactors for alcohol-to-jet processes.	Complete development of catalysts tolerant of water at levels of up to 80%. Coordinate with catalyst manufacturers to manufacture engineered forms for testing.	Dramatic improvement to water balance and energy intensity of ATJ processes.	2023	2030–2035
ACTIVITY CT.1.6: Development of advanced separations for fermentation products.	Demonstrate high alcohol/fermentation product recovery with reduced energy intensity compared to stripping or other incumbent approaches.	Thermal separations result in significant operational and environmental costs to fermentation processes. Integrated or advanced separations approaches can dramatically lower operational costs, water consumption, and GHG footprint.	2023	2028–2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.1.7: Validate next-generation carbon capture and sequestration/utilization technologies on biorefinery carbon streams.	Through analysis and real-world demonstration, confirm GHG reduction potential and assess the cost of incorporating such technologies at existing biorefineries.	Such technologies would provide a way to lower the carbon intensity and/or increase the carbon efficiency of the existing biorefinery fleet.	CCS: now CCU: 2030	CCS: 2030 CCU: 2040
ACTIVITY CT.1.8: Organism tolerance to feedstock inhibitors and/or product.	Robust organisms that can tolerate lignocellulosic inhibitors as well as novel fermentation products over an extended period of time at relevant titer/rate/yield	Provides flexibility of feedstock of varying quality, increases system uptime, and lowers separation energy consumption.	2023	2030
WORKSTREAM CT.2: Develop options to increase production and reduce CI of existing ASTM-qualified pathways. **Investigate and develop options to accelerate deployment of pathways that have already been qualified. This workstream will also cover the conversion efforts needed to allow these pathways to accept additional feedstocks (e.g., sustainable oilseeds and brown grease) to increase volumes at existing facilities and to improve the carbon intensity of these technologies.**				
DELIVERABLE: Yield, cost, and carbon intensity improvements to existing pathways. Anticipated benefits by 2030. IMPACT: Accelerates deployment of SAF because pathways are already qualified. Expands capacity of existing facilities. Creates system resiliency and redundancy in feedstock and conversion options. Reduces risk for project development and financing. Creates opportunities to investigate options to increase blending rates in the future. KEY THEMES: Expand SAF production, improve sustainability, reduce cost.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CT.2.1: Identify and quantify potential opportunities to reduce capital and operating expenses in existing pathways.	A complete state-of-industry analysis, developed in consultation with industry/independent engineers, for each of the qualified ASTM pathways to identify remaining R&D needs.	Analysis can support development of priority R&D opportunities, focus areas, and technical objectives. Confirm reasons certain pathways are not being pursued at commercial scale. Accelerate technologies to pilot readiness.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.2.2: Conduct R&D to further reduce fuel selling price and CI/sustainability of existing pathways.	Strategies and technologies to improve economics and sustainability of existing qualified pathways.	Lower CI scores can increase incentives and support financing facilities.	2023	2030
ACTIVITY CT.2.3: Conduct R&D to broaden feedstocks for qualified pathways (e.g., brown grease and sustainable oilseed crops).	A federal R&D plan that provides actionable information on the feasibility of using alternative feedstocks in existing ASTM pathways.	More available feedstocks to support existing pathways, thus increasing the potential volume of SAF produced by 2030.	2023	Before 2030
ACTIVITY CT.2.4: Pursue process intensification technologies.	Issue funding opportunity based on state-of-industry analysis focused on process intensification.	Process intensification can lower capital and operating costs and enable smaller or modular solutions.	2025	Before 2030
WORKSTREAM CT.3: Develop biointermediates and pathways for compatibility with existing capital assets. **The focus area of this workstream is on various biointermediate streams that are likely to be transferred between entities for processing from feedstock to finished fuel. This workstream will (1) investigate opportunities to integrate with industry both on the upstream and downstream ends by identifying priority intermediates, (2) determine value added due to industry integration and compelling business opportunities and business models, (3) determine critical material attributes at interfaces with industry partners, and (4) develop R&D plans to achieve intermediate conversion for industry engagement.**				
DELIVERABLE: Identification and development of new business models for SAF supply chains. Production opportunities utilizing depreciated or underutilized capital. IMPACT: Accelerates SAF deployment by creating technologies compatible with existing infrastructure and supply chains. Significant capital expense savings. Maintains opportunities for existing workforce while retaining expertise. Safer operations at industrial scale. Brand-name benefits. KEY THEMES: Expand SAF production, reduce cost.				

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.3.1: Identify and conduct preliminary techno-economic/life cycle analysis priority intermediates from biomass/waste feedstocks; develop R&D plans to achieve intermediate conversion processes.	In collaboration with industry, develop a report or database of potential biointermediates and the characteristic need to make business decisions. Quantification of market clearing price.	Identification of priority intermediates can inform future funding opportunities and focus areas for government R&D investment.	2024	2025
ACTIVITY CT.3.2: Stakeholder engagement to understand value propositions of intermediates and their respective markets.	Understanding of priority biointermediates for industrial applications.	Direct research to priority intermediates for early adoption into market.	2024	2025
ACTIVITY CT.3.3: Develop processes to produce intermediates that are “drop-in” substitutes for FOG into petroleum hydrotreaters.	Strategies and technologies that will enable use of renewable feedstocks in petroleum hydrotreaters. Collaborate with industry to get pilot-scale testing and deliver performance guarantee.	Further utilization of HEFA or HEFA-like processes and infrastructure to expand capacity. Diversification of feedstocks for these processes.	2023	Varies
ACTIVITY CT.3.4: Identify insertion and blending points at existing refinery and hydroprocessing facilities for priority intermediates.	A report/list describing the most promising points at which biointermediates can be inserted or blended into existing refinery/hydroprocessing infrastructure.	Increase likelihood of using existing infrastructure and reducing capital expenses for production of SAF.	2023	2030
ACTIVITY CT.3.5: Determine critical material attributes and associated price/value at interfaces with industry partners, especially for priority intermediates.	An understanding of what intermediate attributes are influential in determining whether they can be inserted into existing infrastructure.	Establishment of these intermediate specifications for key intermediates (e.g., cellulosic sugars, pyrolysis oil, and hydrothermal liquefaction oil) can reduce risk and set expectations for downstream unit operations. Reduces risk for scale-up operations.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.3.6: Generate the data and analytical procedures to support EPA and state LCFS biointermediate qualification and tracking for incentives.	Develop cross-agency programmatic efforts to establish the appropriate analytical quantification methodology needed for tracking/attributing the use of intermediates.	Provides data to the appropriate agencies to support biointermediate pathway certification and analysis using the Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model for Renewable Fuel Standard and LCFS programs.	2023	2030
WORKSTREAM CT.4: Reduce risk during scale-up and operations. **This workstream will proactively address resiliency in process and equipment design, in addition to conventional risk assessment methods such as bowtie and Bayesian risk analysis. These approaches will be in addition to the project scale-up through integrated pilot and demonstration. Where possible, process performance and intermediate quality guarantees are needed to limit risk.**				
DELIVERABLE: Progress toward establishment of performance guarantees on conversion operations and systems. Generation of foundational data for agency acquisition guidelines such as DOE's 413.3 *Technology Readiness Assessment Guide*. IMPACT: Improved understanding and quantification of technology risks and uncertainties. Lower risk will reduce cost of financing capital. Can also reduce pioneer refinery capital costs because the biorefinery will not have to be overdesigned to reduce risk. Will accelerate pioneer biorefinery ramp-up to nameplate scale (avoiding startup failures). Reduce risk of future government investments, especially in pilot- and demonstration-scale biorefineries. KEY THEMES: Expand production, reduce cost.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CT.4.1: Development of resilient and highly instrumented pilot systems.	Pilot plants built need to have sufficient automation and allow for integrated/ unattended operations.	Ensuring systems are resilient and/or redundant, where necessary, without overengineering (which is cost-prohibitive). Development of systems that can identify "unknown unknowns."	2023	2040

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.4.2: Ad hoc technical support of unanticipated problems that may show up during technology development and scale-up.	Leverage existing pilot plant infrastructure from public investments as well as other federally funded tools, such as process models and/or supercomputing access.	Provides assistance to companies with scale-up on an as-needed basis.	2023	2040
ACTIVITY CT.4.3: Long-duration (~8,000 hours) pilot-scale time-on-stream runs of integrated systems to test durability.	Perform and provide data on long-duration time-on-stream runs.	Reduced risk of failure of future pilot and demonstration plants.	2023	2040
ACTIVITY CT.4.4: Develop fundamental understanding of operational failures in conversion operations for emerging pathways.	Produce studies that explore and define the common points of failure in conversion unit operations.	Allows for development of mitigation approaches (e.g., more robust organisms and catalysts).	2023	2040
ACTIVITY CT.4.5: Conduct risk assessment for conversion operations and systems.	Develop an industry-vetted process hazard or failure mode and effects analysis for each pathway at pilot or lower readiness levels.	Provides a uniform approach to assess the risk of novel operating systems.	2023	2040
ACTIVITY CT.4.6: Utilizing risk assessment information and utilizing design of experiment, determine the operational envelope for priority SAF pathways.	Define acceptable feedstock quality attributes and operational regimes for at least three novel pathways at pilot or lower readiness levels.	Progress toward development of performance guarantees for conversion unit operations and systems; reduced risk and improved likelihood for access to financing for scale-up.	2023	2040
ACTIVITY CT.4.7: Process integration risk.	Integrated process configurations need to be substantially explored at the pilot scale to elucidate unanticipated issues.	Non-product accumulations and blow-down considerations are critical and can only be studied in pilot systems.	2023	2040

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.4.8: Process stability.	Pilot investments should be highly instrumented to help operators diagnose causes of operational upsets, provide data to validate process models, and develop control systems.	Understanding of stable systems and being able to trace back failures and system drifts. Development of process control systems that can prevent out-of-control processes.	2023	2040
WORKSTREAM CT.5: Develop innovative unit operations and pathways. **Additional pathway development and deployment will be needed to broaden the availability of SAF. This workstream will also explore next-generation or disruptive technologies that, when integrated in pathways, yield CIs of zero or less.**				
DELIVERABLE: Novel pathways and processes that can deliver carbon-neutral or carbon-negative SAF molecules or blendstocks. Development of molecules/blendstocks that can meet future regulatory needs and objectives. Anticipated benefits by 2040–2050. IMPACT: Increased sustainability of fuels. Zero- or negative-CI SAF. These could have higher value in the future when there are carbon taxes. Opportunity to blend zero- or low-CI blendstock with higher-CI blendstock to still achieve >70% CI reduction. Allow for higher SAF penetration. Potential for 100% SAF blendstock options. Develop redundancy for conversion options. KEY THEMES: Expand SAF production, improve sustainability, reduce cost.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CT.5.1: R&D and industrial engagement on incorporating novel reductants such as renewable electrons and photons.	Strategies and technologies that enable use of waste CO_2 to improve system yields.	Improve CI of process to net-zero or net-negative system-level emissions.	2023	2040
ACTIVITY CT.5.2: Complete conceptual designs for zero- or negative-emission biorefineries.	Analyses that explore the technical and economic feasibility of biorefineries designed to produce net-zero fuels.	An understanding of what it would realistically take for industry to achieve carbon-neutral liquid fuels.	2023	2040
ACTIVITY CT.5.3: Develop aromatic and cycloparaffin production pathways to balance the components of SAF to 100% blends.	Strategies and technologies to produce additional components of SAF.	Enable a fully renewable 100% SAF blend that meets ASTM standards.	2023	2040

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CT.5.4: Identify and research novel catalysts for hydrodeoxygenation and hydrodenitrification processes on bio-derived intermediates.	Demonstrate long-duration catalyst performance that can reduce nitrogen and oxygen levels that are required by ASTM International/OEMs.	Enabling an SAF that meets ASTM standards.	2023	2040
ACTIVITY CT.5.5: Develop, produce, and test fuels/blends to avoid sooting, aerosols, and other contributors to vapor trail emissions.	Analyses and experimental data that propose alternative fuels that reduce sooting.	Reduce contrails, which are a persistent source of global warming potential, even if the fuel is 0 gCO_2/MJ SAF.	2023	2040
ACTIVITY CT.5.6: Develop, produce, and test molecules that can achieve seal swell properties of aromatics.	Adequate R&D to establish a solid list of renewable molecules that meet the aromatic needs of jet fuel.	An option for 100% renewable jet fuel that meets seal swelling needs.	2023	2040
ACTIVITY CT.5.7: Develop capability to hydrotreat and finish blended streams that require different process intensity (e.g., hydrogen pressure and catalyst functionality).	Create research area on multifunctional catalysts and/or multifunctional reactor beds to process blended streams without losing yield to off-spec fractions (e.g., lights).	Provides a pathway from existing capital and operations at the fossil refinery scale to renewable fuel scales (critical for 35-billion-gallon goal).	2023	2040
ACTIVITY CT.5.8: Develop pathways that can process/convert multiple feedstocks.	Demonstrate bench-scale processes that can accept multiple feedstocks or switch feedstocks and produce sufficient-quality fuels or intermediates.	Processes that can accommodate feedstock switching can increase system resilience.	2023	2040

Appendix A.3: Building Supply Chains Detailed Activities

Description: Support SAF production expansion through regional supply chains, ensuring R&D transitions from pilot to large scale, field validation and demonstration projects, validating supply chain logistics, enabling public–private partnerships, and developing bankable business models and collaboration with regional, state, and local stakeholders.

WORKSTREAM SC.1: Build and support regional stakeholder coalitions through outreach, extension, and education. **Convene regionally specific stakeholder efforts to lead exploration of SAF production and provide outreach, extension, and education necessary to support the entire supply chain from feedstock producers to end users.**				
DELIVERABLE: Set of established regional stakeholder coalitions in targeted markets across the United States to build SAF supply chains. IMPACT: Foundational first step in creating regional supply with identified end users. Include regional outreach to feedstock growers, conversion facilities, storage, and distribution facilities—essentially all elements of the fuel supply system. KEY THEMES: Expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY SC.1.1: Convene and incentivize regionally specific stakeholder efforts to lead exploration of SAF production.	Regional consortia that identify end points (airports/airlines), stakeholders, prior work on feedstock (existing data for a region), and NGOs and can build business cases for SAF deployment to benefit the state or region.	Increased efforts to deploy technologies by engaged stakeholders.	2023	2030
ACTIVITY SC.1.2: Conduct outreach, education, and extension work in SAF-producing regions and across the fuel supply chain.	Dissemination of technical and economic information and improved access to outcomes of federally funded SAF R&D activities.	Region-specific knowledge and a system of trusted distribution is necessary for growers to produce new feedstocks and fuel producers to invest in SAF production capacity.	2023	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY SC.1.3: Assess state clean fuels policy, regional feedstock, and airport hubs to determine high-priority opportunities for deployment of stakeholder coalitions.	Delineate target regions with high potential for stakeholder developments and preliminary assessment of regional needs.	Increase probability that selected regions will be successful at deploying effective stakeholder consortia.	2023	2024
ACTIVITY SC.1.4: Develop and support regional workforce and education programs to create the technical expertise necessary for all levels of the supply chain.	Funding for technical programs at community colleges and universities.	Regional supply and production can only be built if the workforce capacity exists in the region (create jobs).	2023	2030
ACTIVITY SC.1.5: Develop diversity, equity, and environmental justice plans for all elements of the supply chain to ensure wide distribution of resources and benefits.	Regional plans.	Build community support and improve equity associated with supply chain solutions.	2023	2025
ACTIVITY SC.1.6: Develop regional environmental health and safety plans.	Regional plans.	Maintain community support and ensure environmental benefits.	2023	2030
ACTIVITY SC.1.7: Engage in international outreach and shared development of supply chains.	Outreach plans.	Expanded and stable supply chain systems.	2023	2030
WORKSTREAM SC.2: Model SAF supply chains. **Develop and apply comprehensive and updated data, transparent analyses, and tools as a foundation for how best to build SAF supply chains for cost-effective, optimal GHG reduction and expedited deployment of feedstock and fuel technologies.**				
DELIVERABLE: Comprehensive and updated models of SAF supply chains and opportunities. IMPACT: Provide tools and timely data for stakeholder coalitions in Workstream SC.1. KEY THEMES: Expand production, reduce cost, improve sustainability.				

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY SC.2.1: Assess and leverage existing models for feedstock, supply, infrastructure, logistics, and social capital and policy.	Create an integrated view of regional SAF supply chain opportunity and potential.	Empower supply chain coalition stakeholders with data for decision-making.	2023	2025
ACTIVITY SC.2.2: Conduct model gap analysis of planned vs. potential SAF supply chain development potential.	Inventory and align modeling activities to develop common vision and harmonized tool suite for use in building SAF supply chains.	Empower supply chain coalition stakeholders with data for decision-making.	2024	2025
ACTIVITY SC.2.3: Develop geospatial data on existing feedstock sources, infrastructure, brownfield sites, hydrogen sources, etc.	Database and maps of critical infrastructure.	Empower supply chain coalition stakeholders with data for decision-making.	2023	2025
ACTIVITY SC.2.4: Develop and use logistics tools related to transportation optimization (e.g., Freight and Fuel Transportation Optimization Tool and BioTrans).	Create an integrated view of regional SAF supply chain opportunity and potential.	Empower supply chain coalition stakeholders with data for decision-making.	2023	2030
ACTIVITY SC.2.5: Invest in new modeling capabilities for feedstock, supply, infrastructure, logistics, and social capital (and policy) to create an integrated view of regional fuel supply chain opportunity/potential.	Open-source modeling tool sets and capabilities to enable supply chain development activities.	Provide comprehensive supply chain modeling and simulation capability for stakeholder coalitions.	2025	2030
WORKSTREAM SC.3: Demonstration of regional SAF supply chains. **Support regional feedstock/fuel supply chain demonstrations for risk reduction and commercial deployment. Mature key elements in the supply chain from feedstock to airport distribution at demonstration scale.**				
DELIVERABLE: Support structure to establish regional *feedstock and fuel technology* supply chains through demonstration. IMPACT: Accelerate SAF supply chain demonstration through public–private partnerships. KEY THEMES: Expand production, reduce cost.				

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY SC.3.1: Fund comprehensive regional supply chain demonstrations using analysis, modeling, data, outreach, and policy analysis to complete groundwork to enable effective deployment of regional feedstock and fuel technologies.	Fund a comprehensive SAF supply chain demonstration project in every U.S. region.	De-risk and expand domestic SAF feedstock supply.	2023	2030
ACTIVITY SC.3.2: Incentivize development of low-carbon-intensity feedstock production, harvesting, transport, storage, and overall logistics through full demonstration stage.	Fund public–private partnerships to demonstrate commercial-scale feasibility of SAF feedstock supply.	De-risk and expand domestic SAF feedstock supply.	2023	2030
ACTIVITY SC.3.3: Identify and prioritize the development of key technical SAF production pathways.	Validate the most promising SAF pathways for 2030 and future supply goals.	De-risk and expand domestic SAF feedstock supply.	2023	2040
ACTIVITY SC.3.4: Scale-up and demonstration of cost-effective, low-GHG renewable fuel technology pathways that can use a variety of feedstocks to produce jet fuel at a demonstration scale.	Demonstration-scale SAF production facilities validating feasibility of cost-effective production at commercial scale.	De-risk and expand domestic SAF feedstock supply.	2023	2040
ACTIVITY SC.3.5: Leveraging and outreach to existing rail/heavy-duty/long-haul transport renewable fuel development efforts (renewable/sustainable fuel production yields a distribution of distillation cuts).	Identify, leverage, and collaborate with producers to source SAF cuts from other production infrastructure.	De-risk and expand domestic SAF feedstock supply.	2023	2040
ACTIVITY SC.3.6: Leverage other government funding programs such as H2Hubs and other Bipartisan Infrastructure Law activities.	Identify, leverage, and collaborate with other federal agencies to accelerate investment in demonstration projects.	De-risk and expand domestic SAF feedstock supply.	2023	2040
ACTIVITY SC.3.7: Aggregate and share critical lessons learned from demonstration-scale projects.	Compile and share lessons learned from demonstration-scale projects across federal agencies.	De-risk and expand domestic SAF feedstock supply.	2023	2050

WORKSTREAM SC.4: Invest in SAF production infrastructure to support industry deployment. Invest in SAF production infrastructure and facility development with existing and new grant and support programs. Utilize loans and loan guarantees, assistance grants, and other government funding mechanisms and opportunities to enable rapid scaling of commercial technologies.				
DELIVERABLE: Support industry deployment of SAF *feedstock and fuel technologies* in commercial production. IMPACT: Partnerships with the federal government to enable project financing and production expansion. KEY THEMES: Expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY SC.4.1: Grow SAF supply by increasing SAF production capacity of multiple commercial-scale, cost-effective, low-GHG renewable fuel technology pathways.	Loans and loan guarantees and/or other federal assistance programs to finance commercial-scale project development.	Accelerate commercial-scale production of SAF.	2025	2030
ACTIVITY SC.4.2: Increase sustainable feedstock availability via buildout of commercial-scale, low-carbon-intensity feedstock production, harvesting, transport, storage, and overall logistics.	Loans and loan guarantees and/or other federal assistance programs to finance commercial-scale project development.	Accelerate commercial-scale production/availability of feedstocks for SAF production.	2025	2030
ACTIVITY SC.4.3: Leverage existing corn ethanol and agricultural industry and infrastructure to accelerate production.	Actions to accelerate conversion of first-generation ethanol to low-GHG aviation fuel.	Accelerate commercial-scale production of SAF.	2023	2030
ACTIVITY SC.4.4: Build on existing oil and gas refinery and other industrial brownfield industry and infrastructure to accelerate and ramp up to required volumes of production.	Provide incentives to leverage existing commercial efforts to produce sustainable fuels for diesel and marine markets.	Accelerate commercial-scale production of SAF.	2023	2030
ACTIVITY SC.4.5: Leverage existing rail/heavy-duty/long-haul transport for airport SAF supply.	Provide incentives to leverage existing commercial efforts to produce sustainable fuels for diesel and marine markets.	Accelerate commercial-scale production of SAF.	2023	2040

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY SC.4.6: Convene stakeholders to accelerate SAF supply chain investment.	Development of multiple sources of global finance to be incorporated into investing in this critical supply chain.	Accelerate commercial-scale production of SAF.	2025	2030

Appendix A.4: Policy and Valuation Analysis Detailed Activities

Description: Provide data, tools, and analysis to support policy decisions and maximize social, economic, and environmental value of SAF, including evaluation of existing and new policies.

WORKSTREAM PA.1: Develop improved environmental models and data for SAF. **Develop and utilize modeling capabilities, data, and analyses to quantify SAF GHG and other environmental impacts. This will ensure environmental integrity and appropriately account for SAF benefits. Stakeholder engagement will be done in collaboration with Workstream CP.1.**				
DELIVERABLE: Enhanced environmental analysis and crediting capabilities. IMPACT: Increased eligibility of new SAF pathways and crediting under existing and future incentive mechanisms. KEY THEMES: Reduce cost, improve sustainability, expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY PA.1.1: Convene life cycle GHG modeling working group to support needs of the SAF Grand Challenge, in line with the SAF Grand Challenge memorandum of understanding.	Working group to support ongoing development of methods and tools to estimate life cycle GHG emissions for use in SAF Grand Challenge activities that require GHG evaluation.	Facilitate life cycle GHG emissions inventory evaluations for the SAF Grand Challenge and potentially other areas, as appropriate. Provide transparency and certainty to markets with respect to which SAF pathways would be eligible under the SAF Grand Challenge.	2022	2030
ACTIVITY PA.1.2: Develop data, analyses, and methods to support inclusion of SAF pathways within existing state, national, and international policies.	Information to support the potential inclusion of SAF pathways under existing policies.	Expanded production of SAF due to policy support.	2022	2030
ACTIVITY PA.1.3: Engage community on needs to create market pull by enabling book-and-claim crediting mechanism.	Research and data to inform policy.	Increase eligibility of SAF pathways to receive credits under existing and new incentive mechanisms.	2022	2030

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY PA.1.4: Conduct coordinated research on non-CO_2 environmental impacts on air quality and climate change.	Research and data to understand how SAF use changes emissions that affect air quality and climate change through changes in contrails and aviation-induced cloudiness.	Increased awareness of potential additional environmental benefits of SAF use.	2022	2030
ACTIVITY PA.1.5: Conduct coordinated research on environmental co-benefits of SAF as compared to fossil-based jet fuel.	Research and data to understand how SAF use could impact economics and environment.	Increased awareness of potential additional economic and environmental impacts of SAF use.	2022	2030
ACTIVITY PA.1.6: Communicate environmental analysis progress with stakeholders (coordinate with Workstream CP.1 activities).	Conference/workshop that supports SAF environmental analysis learning opportunities.	Increased awareness and coordination of advances in SAF environmental analysis methodologies.	2023	2030

WORKSTREAM PA.2: Conduct techno-economic and production potential analysis.

Develop and utilize techno-economic analysis and resource assessment models. Expand and refine modeling capabilities and generate analysis to inform SAF RDD&D. Evaluate the opportunities and scenarios necessary to meet SAF Grand Challenge goals and provide direction to the effort to ensure optimum conditions for production expansion.

DELIVERABLE: Increased utilization of SAF due to transparent and more accurate quantification of cost of production and resource availability.

IMPACT: Increased transparency regarding SAF cost of production and feedstock requirements.

KEY THEMES: Reduce cost, expand supply.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY PA.2.1: Establish techno-economic modeling working group to harmonize approaches, support SAF policy evaluation, and inform RDD&D decisions.	Common modeling assumptions and collaborative analysis.	Transparency and more accurate cost of production data for SAF pathways.	2022	2025

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY PA.2.2: Conduct coordinated analysis to understand SAF production potential and inform RDD&D approaches.	White papers and reports, as appropriate.	Improved assessments of SAF production potential.	2022	2025
ACTIVITY PA.2.3: Update the *Billion-Ton Report* to include latest data on waste oils, oilseed crops, forest biomass, wet wastes, and CO_2 availability	Publish peer-reviewed and updated study.	Quantification of domestically available feedstock resources.	2022	2025
ACTIVITY PA.2.4: Conduct analysis to determine global SAF potential using biomass, wastes, industrial waste gases, and atmospheric CO_2 use in power-to-liquid fuels.	Publish peer-reviewed study.	Quantification of globally available feedstock resources, SAF production potential, and life cycle GHG reduction impacts.	2022	2025
ACTIVITY PA.2.5: Communicate techno-economic analysis progress with stakeholders (coordinate with Workstream P.2 activities).	Conference/workshop that supports SAF techno-economic analysis learning opportunities.	Increased awareness and coordination of advances in SAF economic analysis methodologies.	2023	2026
WORKSTREAM PA.3: Inform SAF policy development. **Identify opportunities and strategies to improve existing policy and regulatory mechanisms that can increase availability of SAF. Identify gaps, needs, and impact of new policies on SAF availability.**				
DELIVERABLE: Expansion of policy support to SAF via existing policies and authorities. Analysis and reports to inform future policy. IMPACT: Increased utilization of SAF due to changes in existing policy and/or development of new policies. KEY THEMES: Reduce cost, improve sustainability, expand production.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY PA.3.1: Conduct inventory of SAF-relevant policy incentives at federal, state, and local levels.	Publication of white paper and report summarizing findings.	Identify lessons learned from existing federal, state, and local incentive programs.	2022	2023

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY PA3.2: Assess status of available policy evaluation models, data, and approaches, and improve as needed (Biomass Scenario Model, Washington State University, Oak Ridge National Laboratory).	Publication of white paper summarizing findings.	Improve existing policy evaluation models to expand capabilities and provide a suite of tools that can be used to evaluate proposed incentives (e.g., tax credits and national LCFS).	2022	2025
ACTIVITY PA.3.3: Develop data, analyses, and methods to support the inclusion of new oilseed crops (e.g., carinata, camelina, and pennycress) as secondary, cover crops by the Natural Resources Conservation Service, and to support the development of crop insurance for these oilseed crops.	Reduce farmer risk from oilseed cover crops that can support SAF production.	Expanded production of SAF from oilseed crops due to cover crop designation by the Natural Resources Conservation Service.	2022	2025
ACTIVITY PA.3.4: Support the development of government procurement mechanisms to reduce aviation GHG emissions through SAF use.	Increased demand for SAF use in government as a means to reduce GHG emissions.	Expanded production of SAF due to demand.	2023	2030
ACTIVITY PA.3.5: Assess how existing and potential future policies and tax credits (including credits for carbon capture) could be combined to support SAF production.	Publication of report summarizing findings.	Expanded production of SAF due to tax incentives.	2023	2025
ACTIVITY PA.3.6: Conduct assessment of biofuel projects to qualify for tax-exempt bonds, municipal bonds, green bonds, economic opportunity zones, and private equity-based financing.	Publication of white paper and report summarizing findings.	Expanded production of SAF due to innovative private sector financing mechanisms.	2023	2025

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY PA.3.7: Conduct study of impacts of new national policies to support SAF production (e.g., a potential national low-carbon fuel standard and potential tax credits).	Publication of report summarizing findings.	Evaluate potential for new national policies to result in faster growth of SAF by incentivizing lower-carbon-intensity pathways at the national level.	2023	2025
ACTIVITY PA.3.8: Conduct analysis of sharing of risk premiums by airport coalitions.	Publication of white paper and peer-reviewed study.	Increase demand for SAF by replicating airport consortia in the United States and globally.	2022	2030

Appendix A.5: Enabling End Use Detailed Activities

Description: Facilitate the end use of SAF by civil and military users by addressing critical barriers, including efficient evaluation of fuel engine performance and safety, advancement of certification and qualification processes, expansion of existing blend limits, and integration of SAF into fuel distribution infrastructure.

WORKSTREAM EU.1: Support SAF evaluation, testing, qualification, and specification.
Lead coordinated approach to support civil and military aircraft and engine fuel performance and safety testing and approval, improve test methods, and enable coordination with aviation stakeholders.

DELIVERABLE: Timely approval of SAF pathways.

IMPACT: Accelerate fuel safety testing and approval, reduce cost and time for new approvals, and expand the range of qualified fuels to enable expansion of SAF supply.

KEY THEMES: Reduce cost, expand production.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.1.1: Continue funding of D4054 Clearinghouse to coordinate new fuel approvals (see also Workstreams CT.2 and CT.5).	Approvals of additional SAF pathways under the drop-in SAF specification (ASTM D7566).	Expedite SAF testing, evaluation, and qualification to expand the portfolio of qualified SAF pathways available to meet SAF Grand Challenge goals.	Current	N/A
ACTIVITY EU.1.2: Global coordination of SAF evaluation activities (other Clearinghouses).	Ongoing outreach with international efforts to leverage resources.	Coordinated evaluation activities to reduce cost and time of new approvals.	Current	N/A
ACTIVITY EU.1.3: Formalize CAAFI prescreening capabilities with new test methods and modeling to focus screening on viable candidates prior to entering ASTM D4054 process.	Structured prescreening function.	Reduce cost and time for SAF testing.	2022	2024
ACTIVITY EU.1.4: Develop new SAF test methods to provide better production compositional control.	ASTM test methods.	Reduce cost and time for SAF testing and expand the range of qualified fuels to enable expansion of SAF supply.	2022	2027

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.1.5: Expand jet fuel acceptable compositional and property scope via investigation of other (qualified) foreign jet fuels (e.g., Russian and Chinese) to broaden population of acceptable SAF.	Updated specification tables in ASTM D1655 and D7566.	Expand the range of qualified fuels to enable expansion of SAF supply.	2022	2026
ACTIVITY EU.1.6: Institutionalize concept of D4054 Fast Track process with OEM community to improve OEM understanding and acceptance.	Fast-track approvals for candidate SAF to enable earlier commercialization.	Accelerate SAF commercial availability, reduce cost and time for SAF testing, and expand the range of qualified fuels to enable expansion of SAF supply.	Current	N/A
ACTIVITY EU.1.7: Develop and validate methods to expedite new pathway certification processes (e.g., models, supercomputing, and artificial intelligence).	New validated models.	Facilitate ASTM approval process to keep up with demand.	2022	2026

WORKSTREAM EU.2: Enable use of drop-in unblended SAF and SAF blends up to 100%.

Lead a coordinated approach to enable drop-in SAF that can be used at up to 100%, beyond the current maximum blend limit of 50% by volume.

DELIVERABLE: Define drop-in jet fuel requirements for alternative fuels that can be qualified either unblended or blended with other alternative fuels.

IMPACT: Enable approval of higher blend levels of drop-in SAF beyond the current 50% limit for use in jet aircraft. This may reduce costs associated with fuel handling/logistics and allow for greater GHG and air quality emissions benefits.

KEY THEMES: Reduce cost, improve sustainability, expand production.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.2.1: Incorporate 100% drop-in SAF provision in D7566.	D7566 revision to incorporate 100% drop-in SAF.	Enable greater environmental benefit through higher SAF blend level, reduce SAF logistics, and expand the range of qualified fuels to enable expansion of SAF supply.	Current	2024

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.2.2: Support issuance of synthetic aromatic kerosene annex for blending with synthetic paraffinic kerosene fuels.	Synthetic aromatic kerosene annex.	Enable greater environmental benefit through higher SAF blend level, reduce SAF logistics, and expand the range of qualified fuels to enable expansion of SAF supply.	Current	2024
ACTIVITY EU.2.3: Support ASTM International issuance of permittivity test method and incorporate in D7566.	D7566 ASTM permittivity test method.	Expand the range of qualified fuels to enable expansion of SAF supply.	2022	2025
ACTIVITY EU.2.4: Investigate use of cycloparaffins to promote elastomeric seal swelling (see also Workstream CT.4).	Research report with testing data and analysis.	Enable greater environmental benefit through higher SAF blend level and expand the range of qualified fuels to enable expansion of SAF supply.	Current	2026
ACTIVITY EU.2.5: Develop means to ensure adequate lubricity of 100% drop-in SAF in supply infrastructure.	ASTM D1655 revision or other industry standard revision.	Enable greater environmental benefit through higher SAF blend level and reduce SAF logistics.	2023	2027
ACTIVITY EU.2.6: Support demonstration flight tests of 100% drop-in SAF.	Complete demonstration flight using 100% drop-in SAF.	Enable greater environmental benefit through higher SAF blend level.	Current	N/A

WORKSTREAM EU.3: Investigate synthetic aviation turbine fuels offering performance or producibility advantages.

Analyze potential and challenges of new fuels with unique chemistries for use in aviation that have enhanced performance benefits (e.g., emissions, energy density, and reduced aviation-induced cloudiness).

DELIVERABLE: Documentation including qualification and quantification of merits and barriers to use of high-performance components of jet fuel.

IMPACT: Understand the potential of novel jet fuels with fuel properties outside of the conventional jet fuel experience range through a holistic approach that includes consideration of performance, safety, cost, and sustainability.

KEY THEMES: Reduce cost, enhance sustainability, expand production.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.3.1: Investigate high-energy-dense fuels.	ASCENT report and/or white paper.	Understanding the potential benefits, trade-offs, and challenges of new fuels.	2022	2025
ACTIVITY EU.3.2: Investigate high-thermal-stability fuels.	ASCENT 31/66/73 reports and/or white paper.	Understanding the potential benefits, trade-offs, and challenges of new fuels.	Current	2025
ACTIVITY EU.3.3: Investigate combustor operability of high-cycloparaffinic fuels.	CLEEN[68] III final report – General Electric.	Understanding the potential benefits, trade-offs, and challenges of new fuels.	Current	2026
ACTIVITY EU.3.4: Investigate limited carbon number distribution and flatter distillation curve.	D7566 specification revisions.	Understanding the potential benefits, trade-offs, and challenges of new fuels.	2023	2026
WORKSTREAM EU.4: Integrate SAF into fuel distribution infrastructure. Conduct analysis on technical and capacity potential and challenges of the existing fuel distribution infrastructure for SAF integration.				
DELIVERABLE: Documentation and standards to guide integration of SAF into existing fuel distribution infrastructure throughout supply chain; identification of SAF integration issues and infrastructure needs. IMPACT: Efficient and safe integration of SAF into current fuel delivery systems to enable expanded availability to diverse users. KEY THEMES: Reduce cost, expand production, improve sustainability.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY EU.4.1: Characterize existing conventional jet fuel property distribution.	Updated conventional fuel property data via publication on ASCENT jet fuel database.	Understand baseline fuel supply and impacts of introduction of new fuels.	Current	2025

[68] The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is the FAA's principal environmental effort to accelerate the development of new aircraft and engine technologies; https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen.

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY EU.4.2: Investigate current fuel distribution infrastructure standards and concerns.	Analysis report characterizing current distribution infrastructure status.	Baseline understanding of current infrastructure.	2022	2025
ACTIVITY EU.4.3: Assess integration potential and challenges for SAF pathways into current infrastructure, including delivery to pipeline systems and airports/end users (see also Workstream SC.3).	Analysis report(s) and/or feasibility study (or studies) identifying potential actions.	Understand integration issues and infrastructure needs.	2023	2026
ACTIVITY EU.4.4: Develop accommodating provisions for shipping SAF blend components through pipelines (e.g., maintaining thermal stability via use of metal deactivator additive).	TBD industry standard revision.	Reduce SAF logistics and costs.	2022	2025

Appendix A.6: Communicating Progress and Building Support Detailed Activities

Description: Engage stakeholder organizations, monitor and measure progress against SAF Grand Challenge goals, provide public information resources, and communicate the public benefits of the SAF Grand Challenge to critical stakeholders and the public.

WORKSTREAM CP.1: Stakeholder outreach and engagement on feedstock sustainability. **Hold a series of consultations with NGOs and other stakeholder groups to exchange information about best practices to reduce life cycle GHG emissions from agricultural- and forest-derived feedstocks and minimize other environmental and social impacts.**				
DELIVERABLE: Reports and other publications on lessons learned and potential for reducing carbon intensities. Disseminate best practices for key activities necessary for building the sustainable aviation fuel industry. IMPACT: Continued and expanded support and access to information. Ensure approaches are environmentally and socially sustainable. KEY THEMES: Enhance sustainability.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CP.1.1: Hold consultations and listening sessions with NGO community about best practices to reduce life cycle GHG emissions from agriculture- and forest-derived feedstocks.	Reports and other publications on lessons learned and potential for reducing carbon intensities.	Improved coordination and support with NGO community; better-informed decision-making.	2023	2025
ACTIVITY CP.1.2: Hold consultations and listening sessions with agricultural and forestry communities to understand needs to improve sustainability.	Reports and other publications on lessons learned and potential for reducing carbon intensities.	Improved support with feedstock producers and on-the-ground knowledge of feedstock producer needs to improve sustainability.	2023	2030
ACTIVITY CP.1.3: Hold consultations and listening sessions as identified by NGOs and other stakeholder groups (e.g., impacts of retrofitting or repurposing existing refining infrastructure).	Development of best practices and identification of key pollutants and other sustainability indicators of concern.	Dissemination of best practices to ensure social and environmentally sustainable buildout of the SAF industry.	2023	2030

WORKSTREAM CP.2: Conduct benefits assessment/impact analysis of SAF Grand Challenge. Develop analysis of SAF Grand Challenge impacts (jobs, fuel, and environment).				
DELIVERABLE: Coordinated analysis of economic, social, and environmental costs and benefits of SAF production and use. IMPACT: Support analyses for development of SAF feedstock production and conversion facilities. KEY THEMES: Enhance sustainability, expand production, reduce cost.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CP.2.1: Quantify SAF economic and environmental benefits and costs.	Public tools that evaluate regional economic and environmental impacts of SAF production (supports Building Supply Chains Action Area outreach activities).	Better-informed decision-making for state/local feedstock production and SAF-related projects.	2023	2024
ACTIVITY CP.2.2: Identify and address social challenges related to SAF production.	Socioeconomic analysis of impacts of SAF production to identify where additional efforts are required to limit negative effects and promote equitable distribution of resources across communities.	Mitigates potential negative impacts on communities and ensures equitable distribution of resources to maintain wide public support.	2023	2030
WORKSTREAM CP.3: Measure progress of the SAF Grand Challenge. Track progress against the SAF Grand Challenge goals and publish information on progress and outcomes on a regular basis.				
DELIVERABLE: Coordinated approach to tracking SAF and feedstock production and use and monitoring progress toward SAF Grand Challenge goals. Review progress and update SAF Grand Challenge Roadmap. IMPACT: Continued and expanded public support. KEY THEMES: Enhance sustainability.				

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CP.3.1: Create a coordinated interagency approach to tracking SAF production and use data and make this public (common database on biorefineries, production, and end use).	Information-sharing system and tracker through a common database on SAF biorefineries, production, and end-use (with ability to cross-check end use with the CORSIA Central Registry).	Demonstrates success to build support and/or indicates where progress needs to be made.	2022	2024
ACTIVITY CP.3.2: Update SAF roadmap every 2 years with what has been accomplished and new information.	Process for updating SAF roadmap on a regular basis (e.g., every 2 years) and updated versions.	Demonstrates success and lessons learned and provides access to this information for stakeholder use.	2024	N/A
WORKSTREAM CP.4: Communicate public benefits of the SAF Grand Challenge. Maintain public support via communication plan, including education on sustainability and jobs.				
DELIVERABLE: Coordinated communications that include environmental, social, and economic benefits; address common concerns/misconceptions (e.g., food vs. fuel and land use change); and provide access to resources targeted at the general public and stakeholders. IMPACT: Continued and expanded public support and access to information. KEY THEMES: Enhance sustainability.				
ACTIVITY	**DELIVERABLE**	**IMPACT**	**BEGIN**	**END**
ACTIVITY CP.4.1: Develop coordinated communications strategy.	Interagency communications strategy that enables cross-agency promotion of communications products (e.g., reports, blogs, and public announcements; documentary of feedstock from farm to refinery, airport, and jet).	Improved awareness of each agency's public communications builds confidence in the whole-government approach to SAF.	2022	2023

ACTIVITY	DELIVERABLE	IMPACT	BEGIN	END
ACTIVITY CP.4.2: Develop communications products and engage stakeholders to improve awareness of SAF benefits.	Communications products and stakeholder engagement that puts SAF costs, benefits, and impacts in the right context for policymakers, stakeholders, and the general public; ensure agency leadership has accurate, objective talking points to SAF as a climate-smart solution.	Widespread public awareness and confidence in SAF benefits and success.	2022	2030
ACTIVITY CP.4.3: Develop website to consolidate all reports and outreach activities.	Website that contains all agency reports (deliverables from other action areas) and other relevant information.	Increase public access to information.	2022	2023
ACTIVITY CP.4.4: Collect and consolidate information and resources with regular updates (e.g., funding opportunities and technology information).	SAF guide web resource that contains a comprehensive list of resources and programs across the U.S. government.	Improve stakeholder access to information and where to find support.	2022	2030

U.S. DEPARTMENT OF ENERGY

DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

USDA

EPA

For more information, visit: biomassboard.gov

September 2022

Cover photos from iStock 658796966, 868922846, 1205260350, and 1309788966.