U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Alternative Aviation Fuels: Overview of Challenges, Opportunities, and Next Steps

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Preface

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) invests in a diverse portfolio of energy technologies to create and sustain American leadership in the transition to a global clean energy economy. In addition to an overview of alternative aviation fuel trends, this report summarizes the results of a public workshop sponsored by EERE's Bioenergy Technologies Office in Macon, Georgia, from September 14–15, 2016. The views and opinions of the workshop attendees, as summarized in this document, do not necessarily reflect those of the U.S. government or any agency thereof, nor do their employees make any warranty, expressed or implied, or assume any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe upon 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. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. government or any agency thereof.

Contents

Executive Summary

The goal of this report is to provide bioenergy stakeholders with (1) an overview of the current state of alternative aviation fuels, as reported in findings by recent working groups, and (2) findings from the Alternative Aviation Fuel Workshop hosted by DOE's Bioenergy Technologies Office (BETO) in September 2016.

Due to projected growth of the aviation industry, there are many important drivers to the development of alternative jet fuels, including domestic energy security, diversity of fuel supplies, less fuel price volatility, and lower long-term fuel cost. Ancillary benefits of involve growth of the bioeconomy with associated job creation and employment opportunities as well as environmental and sustainability benefits. The aviation industry faces significant challenges in improving environmental sustainability and reducing its carbon footprint. Unlike other liquid fuels (e.g., diesel or gasoline) with developed alternatives (e.g., battery or electrical power), alternatives to currently used aviation jet fuels are at the early stages of development. In the near term, the most promising option is bio-derived aviation fuel, which has driven interest from industry (ranging from fuel producers to downstream consumers, including airlines and engine manufacturers) as well as governments and international agencies to initiate the development and production of aviation jet fuel.

Biofuels are key to mitigating the growth constraints of the aviation industry. Biobased jet fuels also present a tremendous opportunity to transition away from fossil fuels towards domestically produced aviation biofuel that would further reduce U.S. reliance on foreign oil and create jobs, particularly in rural areas, and to advance the mission of BETO for the development of sustainable alternative fuels.

While several conversion pathways have been approved for biobased aviation fuels, remaining technical, social, and regulatory barriers have limited both the production of bio-derived jet fuel and the growth of the industry. To better understand these barriers and to help develop a potential research, development, and demonstration (RD&D) strategy to further support the development of bio-derived jet fuel, BETO held a workshop to engage stakeholders and to gain further understanding about challenges and opportunities related to aviation biofuels, including the following:

- Advance progress needed to achieve affordable, scalable, and sustainable production of aviation biofuels
- Increase the economic and technical competitiveness of aviation biofuels from lignocellulosic biomass
- Enhance the environmental and sustainability benefits of aviation biofuels
- Ensure robust feedstock and product supply chains to support the development and deployment of aviation biofuels.

More than 100 bioenergy industry stakeholders participated in the Alternative Aviation Fuel Workshop led by BETO's Demonstration and Market Transformation (DMT) program on September 14–15, 2016, in Macon, Georgia. Participants represented public- and private-sector organizations, national laboratories, and academic institutions working to advance biorefinery technologies.

Industry leaders, including national laboratory representatives, presented during the workshop plenary session, and participants collaborated in four breakout sessions through a series of questions and exercises designed to provoke thoughts and gather information relevant to DOE's mission and the needs of industry.

Key findings from the plenary presentations include the identification of common characteristics of successful alternative aviation fuel production. Some of the common characteristics mentioned during the workshop include the need to make fuel of sufficient quality for desirable blending impacts, ensuring the execution of proper scale-up approaches and techniques, and forward-looking methods for achieving higher profitability and maintaining competitiveness of the bioenergy industry. The stakeholders' discussions also emphasized the importance of stable government policies necessary for the continued growth of the bioenergy industry.

Each breakout session was composed of 30–35 workshop attendees. Key findings from the participant breakout sessions covered topics of best practices, lessons learned, challenges, potential solutions, and resources needed to overcome current challenges. Brief summary points provided during those discussions are outlined below.

The session "Economic and Technical Competitiveness" discussed primary barriers to more comprehensive and comparable alternative jet fuel (AJF) techno-economic analyses (TEAs). These included the need to develop a consistent methodology (including the base set of financial and technology readiness assumptions) to develop TEAs, as well as DOE's role in supporting this development.

Outcomes included recommendations for BETO to continue to work collaboratively with existing organizations, such as the Commercial Aviation Alternative Fuels Initiative (CAAFI) and Federal Aviation Administration (FAA), as well as to organize a stakeholders' working group across the supply chain to inform the development of these analyses.

Further recommendations are that analyses should consider both forward-focused projections of these technologies, which have been scaled and de-risked (the N^{th} plant approach), and near-term, early-adopter economics. From the nearer-term considerations, the analyses can help identify the biggest scale-up risks and barriers for a technology, thereby informing further research and development (R&D) considerations for both DOE and industrial stakeholders.

The session "Fuel Conversion and Scale-Up" focused on challenges that hinder the scale-up and commercialization of emerging AJF pathways. These included technical barriers for AJF pathways, ranging from a lack of availability or access to equipment, low-cost feedstocks, capital, and experts for biofuel production scale-up to the expense and time required to move a process through the American Society for Testing and Materials (ASTM) certification process.

The lack of publicly available and/or reliable data for evaluation of these technologies was also identified as a limitation to the understanding of each of these pathways. Non-technical barriers were also discussed, including (1) the need for further public outreach and education on the benefits (e.g., societal and economic) and technical feasibility of AJFs, (2) the need for more consistent policies to further enable the development of a stable AJF market, and (3) the need to reduce uncertainties in regulations to move more AJFs to the market.

Outcomes included identification of more than 20 pathways for future consideration, recommendations for the roles DOE can play in aviation fuels RD&D, and scale-up of the production of biofuels and key co-products from bench to pilot and demonstration scales. Finally, participants deemed it essential that DOE support initial evaluations to obtain a set of baseline data for these emerging process strategies so that reliable and comparable evaluations could be developed.

The session "Environmental Sustainability and Life-Cycle Benefits" focused on identifying challenges and needs in developing a more comprehensive and comparable set of life-cycle analysis (LCA) studies. These challenges included inconsistencies in the estimated sustainability metrics (primarily greenhouse gas [GHG] estimates) in the literature. Outcomes included recommendations for BETO to develop a consistent approach to sustainability and economic analyses, as well as to publish the tools for these assessments to support the stakeholder community.

The session "Feedstock and Product Supply Chains" targeted barriers to developing a more comprehensive set of feedstock resources for AJF production. This included discussion of more than a dozen viable feedstock resources for producing AJFs, each of which has its own challenges. Critical barriers identified included the lack of sufficient feedstock supply availability and limited scaling, as well as the need for a better understanding of the best production and harvesting practices, particularly for new and emerging feedstocks.

Session attendees also discussed the opportunity for BETO to support stakeholders through public outreach, including technical experts and crop consultants supporting and engaging stakeholders for further development of new crops and best practices, as well as working with other organizations like the U.S. Department of Agriculture (USDA) to further enhance feedstock development (for example, improving yields and finding opportunities for double cropping to allow for efficient use of land and nutrients). Outcomes included recommendations for BETO to play a strong role in feedstock interface opportunities to help reduce risks of feed and handling at the biorefinery and improve performance of the conversion process through the integration of feedstock and fuels production.

It is essential for projects to perform robust data collection and ensure proper pilot- and demonstration-scale testing activities before scaling up to the commercial level. Such data are needed to successfully implement projects and to strengthen confidence in process operations, which is much needed to grow the industry and to attract outside investment.

BETO would like to express gratitude to all the participants for their time, efforts, and contributions. The discussions and information provided through the plenary presentations, open forums, and breakout sessions are extremely valuable to BETO's DMT program, EERE, and DOE, as this feedback is utilized to inform program strategies moving forward.

Introduction

BETO is one of ten technology development offices within DOE's EERE. BETO supports EERE's efforts to expand the adoption of sustainable, domestically produced transportation and aviation alternatives, and to stimulate the growth of a thriving, domestic clean energy manufacturing industry.

BETO's mission is to develop and demonstrate transformative and revolutionary sustainable bioenergy technologies for a prosperous nation. This mission is accomplished by transforming renewable, non-food biomass resources into commercially viable, high-performance biofuels, bioproducts, and biopower. Within BETO, the DMT program supports the targeted RD&D of technologies that will enable operational integrated biorefineries (IBRs) supported through public and private partnerships.

BETO's programmatic activities align with the EERE vision of a strong and prosperous America powered by clean, affordable, and secure energy. BETO works specifically on the following relevant strategic goals:

- Accelerate the development and adoption of sustainable transportation technologies
- Stimulate the growth of a thriving domestic clean energy manufacturing industry
- Lead efforts to improve federal sustainability and implementation of clean energy solutions.

The aviation industry faces significant challenges in improving environmental sustainability and reducing its carbon footprint. In addition, unlike other liquid fuels (such as diesel or gasoline) with developed alternatives (such as battery or electrical power), alternatives to currently used aviation jet fuels are at the earliest stages of development. In the near term, the most promising option is bio-derived aviation fuel, which has driven interest from industry (ranging from fuel producers to downstream consumers, including airlines and engine manufacturers) as well as governments and international agencies to initiate the development and production of AJF. Several conversion pathways have been approved for biobased aviation fuels, but significant technical, social, and regulatory barriers have been encountered by entrepreneurs and innovators alike and have limited the advancement of bio-derived AJF.

BETO technology program areas host regular workshops to identify technology barriers and gather stakeholder input about the potential roles for DOE in enabling biorefineries that can produce cost-competitive hydrocarbon biofuels, including aviation biofuels.

A previous workshop, hosted in November 2012, sought to benchmark the cost of producing sustainable biobased jet fuel processes. The event was held in advance of the 2012 CAAFI Research & Development Team Workshop and focused on sustainable alternative fuel costs, including new conversion pathways for biochemical and thermochemical processes, algae-derived aviation biofuels, feedstock handling, feedstock crop productivity, hydrotreated esters of fatty acids (HEFA) fuels, and Fischer-Tropsch (FT) jet fuel costs.

Significant challenges remain for the aviation industry in maintaining growth while enhancing environmental sustainability (CAAFI 2013). Biofuels currently offer the greatest opportunities for supporting the transition from fossil fuels to sustainably produced, biobased aviation fuels. But these biobased jet fuels face production cost and feedstock supply challenges. Alternative energy sources such as batteries, fuel cells, and natural gas, are not yet practical for aviation.

This report begins with an overview of the current state of alternative aviation fuels. Summarizing findings from recent working group studies—such as the National Science and Technology Council (NSTC) Aeronautics Science and Technology Subcommittee Alternative Jet Fuel Interagency Working Group—the "Challenges and Opportunities" section of this report describes important topics in alternative aviation fuels related to production, environmental benefits, policy considerations, and finance mechanisms. The "Future Growth" section describes the bioenergy industry's understanding of the competition between on-road diesel and jet fuels, new potential fuel production pathways, analysis needs, and collaborative efforts domestically and abroad.

BETO hosted the "Alternative Aviation Fuel Workshop" on September 14 and 15, 2016, in Macon, Georgia, with the objectives to further advance the understanding of current technical barriers and discuss the RD&D opportunities. The "Alternative Aviation Fuel Workshop Summary" section provides an overview of the workshop plenary presentations and breakout session discussions. This workshop content covers the event areas of focus, including economic and technical competitiveness, fuel conversion and scale-up, environmental sustainability and life-cycle benefits, feedstock and product supply chains, as well as opportunities for expanded stakeholder collaboration and continued industry support from DOE.

Part One: Alternative Aviation Fuel Trends

Challenges and Opportunities

Lignocellulosic-derived AJFs face multiple challenges associated with the near-term scale-up and deployment related to production economics, engineering processes, industry partnerships, certification, and financing.

Project developers who are able to successfully navigate this emerging business, technology, policy, and investment landscape have been rewarded with long-term offtake agreements from airlines who are eager to procure AJF. From an aviation industry perspective, the alternative fuels present an appealing opportunity to minimize harmful emissions, which are projected to increase given the forecasted industry growth.

There is a clear need to reduce the overall cost of production and develop pathways that are at cost parity with fossil-derived jet fuel. One of the key drivers associated with AJF production cost is the expense and availability of lignocellulosic feedstocks. Capital expenses for AJF facilities are largely affected by the cost for new facilities. Project developers have an opportunity to lower these expenses by utilization of bolt-on technologies or potentially by introduction of the bio-intermediates into the existing petroleum refinery and chemical industries.

Production Economics

Broader commercial production of AJF requires the production of the renewable fuels to be near or at cost parity with fossil-derived jet fuel. Jet fuel is the main operating cost for commercial airline operators. At the current price of oil (as of December 15, 2016), which ranges from $51/barrel for WTI and $55/barrel Brent crude oil, jet fuel accounts for roughly 27% of operating expenses for an airline (EIA 2016; IATA 2016). Increases in the price of jet fuel will significantly impact and increase operating costs for the aviation business.

Recent studies have suggested that a price increase of $1/barrel crude oil results in roughly $425 million of additional expenses for the airline industry (Davidson et al. 2016). By deploying greater volumes of AJF, the aviation industry has the opportunity to minimize this dependency on crude oil. For AJF to reach cost parity, the cost of production must decrease from current levels, which will require stable feedstock supply at lower prices.

Cost of Production

Numerous studies on the production of AJF from a range of feedstocks have estimated costs range anywhere from $2/gallon to well over $10/gallon (Wang 2016). These variations are highly dependent on assumptions around the AJF production process, plant scale, and performance. Despite efforts by analysts to be transparent about the basis of these economic evaluations, the lack of consistency and the range of assumptions in these studies limit the understanding of the current cost of AJF production.

There are, however, clear cost drivers in all AJF processes, including the following: feedstock cost and composition, capital cost of a proposed process, overall yield (conversion), quality and composition of the produced AJF, operating expenses, financial requirements, logistics, initial resources, and current production cost of the AJF pathways. Each of these drivers is described in Table 1.

Table 1. AJF Cost Drivers

Cost Driver	Description
Feedstock cost and composition	Feedstock costs can contribute 30% or more to the AJF price per gallon (Wang 2016).
Capital cost of a proposed process	While larger facilities' capital costs will be helped by economies of scale, near-term facilities are expected to be much smaller, and this is expected to drive up the cost on a per-gallon basis.
Overall yield (conversion)	Attaining the desired AJF product and blending ability of the fuel will be critical.
Quality and composition of the produced AJF	Given the stringent requirements of product specification for jet fuel, specific properties and molecular components are more desirable when blending into fossil-petroleum jet fuel.
Operating expenses	These can vary based on uncertainty in process performance, such as the need to replace and replenish raw materials like catalysts.
Financial requirements	Debt-to-equity ratios, potential loan rates and terms, and return on investments required to attract investors are all significant costs, particularly for first-of-a-kind facilities.
Logistics	Both handling and transport of feedstock to a biorefinery and transport of AJF to a blending facility and filling stations at the airport contribute to fuel cost.
Initial resources	Additional resources required and consumed for fuels certification and qualification contribute to the fuel cost. While these costs tend to be reduced upon approval, the approval process does not guarantee that these fuel production strategies will be scaled up.
Current production cost of the AJF pathways	Already approved by ASTM International, this cost has limited the market penetration of these pathways. Reported costs of the pathways can be greater than $10/gallon, which limits their marketability despite the operability and environmental benefits that AJFs offer.

Resource Availability

The availability of feedstocks is one of the main cost drivers and one of the most significant hurdles to be overcome in the scale-up of AJF production. The availability of lignocellulosic feedstocks, in particular, is needed to drive down production costs and increase market supply.

Currently, the bulk of AJF is produced from used cooking oil, animal fats, and vegetable oils (e.g., camelina and canola), via the HEFA pathway. These feedstocks have limited availability with a projected increase of only 8% by 2020 (from 3.8 to 4.1 million tons/year) (Milbrandt, Kinchin, and McCormick 2013). For perspective, in 2014, roughly 290 million tons of woody and agricultural biomass were consumed to produce fuel, heat and power, biobased chemicals, and wood pellets (DOE 2016). Many of these additional feedstocks will need to be developed for conversion to AJF.

The current market associated with lignocellulosic feedstocks supply has been limited due to uncertainties associated with demand for these feedstocks. Consistent policy measures are needed to provide investors with certainty about the future growth of feedstock production rates.

In order to bring plant-based feedstocks to market for aviation biofuels production, USDA, FAA, and the Research and Innovation Technology Administration developed the Feedstock Readiness Level tool. A feedstock would be graded from a Level 1 to a Level 9, with Level 9 indicating a mature level of commercialization. This communicates "the state of development of a feedstock concurrent with its readiness for use with a conversion process" (Steiner et al. 2012).

Technology Deployment

Another limiting barrier for AJF deployment is the technical risk associated with scaling up and operating production facilities. There are a number of ongoing efforts to scale up AJF process strategies and additional biofuel pathways to gain the technical expertise required for successful deployment of renewable fuels. Pilot plants and demonstration plants provide a valuable opportunity to validate technology developed on the laboratory scale.

Pilot- and Demonstration-Scale Processes

Since 2006, BETO's DMT program has supported more than 35 first-of-a-kind IBR projects. These investments in IBR projects, which facilitate the development of pilot- and demonstration-scale facilities, have allowed industry partners to utilize biomass resources as feedstocks for advanced biofuels and bioproducts. These initial projects have made important advances in integrating unit operations, validating TEAs, and proving a variety of technologies at scales, and enabling a path to commercialization; still, many challenges remain to be addressed.

These projects are located around the country and cover a wide range of technology pathways for the conversion of renewable feedstocks to biofuels at various technology development stages.

BETO uses the following definitions to identify IBR facility scales:

- **Pilot Plant**—Integrating unit operations and validating TEAs
- **Demonstration Plant**—Verifying performance at industrial scale and providing design specifications for a pioneer plant
- **Pioneer Plant**—Proving economic production of technology at commercial scales
- **Commercial Plant**—Operating full-scale production at commercial levels.

Federal support for first-of-a-kind IBRs could significantly reduce the technical and financial risks associated with new technology deployment, thus accelerating the growth of the U.S. bioeconomy.[1]

In July 2011, the Secretaries of Agriculture, Energy, and the Navy signed a memorandum of understanding to commit $510 million ($170 million from each agency) to produce hydrocarbon jet and diesel biofuels in the near term. This initiative sought to establish the following:

- Multiple, commercial-scale IBRs
- Cost-competitive biofuel with conventional petroleum (without subsidies)
- Domestically produced fuels from non-food feedstocks

[1] BETO refers to the "bioeconomy" as the industrial transition to sustainably using renewable aquatic and terrestrial biomass resources for producing fuel, biochemicals, and bioproducts. This extension of the U.S. bioenergy industry has the potential to create employment, bring opportunities to rural regions and communities, reduce costs of consumer goods, reduce transportation sector emissions, and improve energy security.

- Drop-in, fully compatible, military-standard fuels (referred to as MIL-SPEC and including F-76, JP-5, and JP8).

These accomplishments will

- Help meet the Navy's demand for 1.26 billion gallons of fuel per year (Haq, Kostova, and Brown 2016)
- Contribute to the Navy's goal of launching the "Great Green Fleet" in 2016
- Demonstrate the production and use of more than 100 million gallons of renewable fuel per year to dramatically reduce private-sector risk for drop-in biofuels production and adoption.

As part of this initiative, on September 19, 2014, three projects were selected for construction and commissioning: Fulcrum Sierra BioFuels, Emerald Biofuels, and Red Rock Biofuels. The location, feedstocks, and anticipated capacity for each of these projects are shown in Table 2, along with HEFA green diesel facilities (operational or planned) in the United States, as reported by the Energy Information Administration (Radich 2015).

Table 2. Operational or Planned U.S. Aviation Jet Fuel and Green Diesel Production Facilities; updated from Schwab 2016 (Fulcrum BioEnergy 2017; Emerald Biofuels 2017; Lane 2015; Lane 2016d; REG 2017; Diamond Green Diesel 2017)

Project	Location	Feedstock	Technology	Capacity* (million gallons/year)	Operation Year [anticipated]
Fulcrum Sierra BioFuels	Storey County, Nevada	Municipal solid waste (MSW)	Gasification, FT	10	[2019]
Emerald Biofuels	Gulf Coast	Fats, oils, and greases	HEFA	88	[2017]
Red Rock Biofuels	Lakeview, Oregon	Woody biomass	Gasification, micro-channel FT	16	[2017]
AltAir Fuels	Los Angeles, California	Fats, oils, and greases	HEFA	40	2016
REG Synthetic Fuels	Geismar, Louisiana	Fats, oils, and greases	HEFA	75	2014
Diamond Green Diesel	Norco, Louisiana	Fats, oils, and greases	HEFA	150	2013
SG Preston	South Point, Ohio	Fats, oils, and greases	HEFA	120	[2020]
SG Preston	Logansport, Indiana	Fats, oils, and greases	HEFA	120	[2020]

* All fuels are total gallons of production for combined jet and diesel.

In addition to the list in Table 2, LanzaTech is developing additional pilot-scale plants, including a facility for alcohol-to-jet (ATJ) in Soperton, Georgia. LanzaTech has partnered with Boeing, Virgin Atlantic, General Electric, and Pacific Northwest National Laboratory (PNNL), to develop and commercialize their ATJ processes. In recent efforts, LanzaTech produced 1,500 gallons of synthetic paraffinic kerosene (SPK) from non-fossil-based sources for testing (LanzaTech 2016).

Other developers committed to pilot- and demonstration-scale operations in the United States, such as Gevo, have included jet fuel products as part of their portfolio. Recently, Gevo signed an offtake agreement with Lufthansa to supply up to 40 million gallons of ATJ over a 5-year period (Lane 2016c).

Industry Partnerships

Collaboration within the bioenergy and aviation industries, as well as with traditional energy and chemical industries, can serve to assist companies working to develop and deploy AJF. Partnerships with petrochemical refineries introduce a valuable opportunity to reduce capital expenditures and production costs for project developers. Partnerships with airlines and aircraft manufacturers provide an opportunity to secure financing and policy support.

Petrochemical Refinery Integration

One potential opportunity for reducing the conversion cost for alternative aviation fuels is to develop partnerships with petroleum refinery owners and/or operators and develop strategies for co-processing or blending renewable-derived intermediates with crude oil fractions in existing infrastructure. Refinery and chemical plants insertion points, in the case of aviation biofuels, must be considered from a safety, reliability, predictability, and profitability perspective.

From this perspective, blending units are one potential insertion point. These are ideal for well-defined fuels with consistent quality, such as single molecules (e.g., farnesene). Intermediates requiring only minor treating (e.g., triglycerides, some direct liquefaction oils, and some catalytically derived sugar oils) may be inserted into hydrotreaters, provided their process performance is well understood. Intermediates requiring boiling range and/or composition changes to be acceptable for blending stocks (e.g., fast pyrolysis oils, some hydrothermal liquefaction [HTL] oils, and some catalytic fast pyrolysis oils) may require offsite or dedicated onsite hydrotreating, followed by catalytic- or hydro-cracking. BETO is investigating strategies for co-processing of the intermediates.

Several recent partnerships in this area of refinery and supply chain logistics have been announced, including the following:

- Ensyn has worked with Petrobras, in collaboration with the National Renewable Energy Laboratory (NREL) through support of BETO, to demonstrate production of drop-in hydrocarbon fuels through fluid catalytic cracking co-processing (Chum and Pinho 2015).
- Fulcrum BioEnergy and Air BP completed a 500-million-gallon jet fuel supply agreement in November 2016; Air BP will provide support for fuel supply and logistics services (Lane 2016a).
- Fulcrum BioEnergy and Tesoro have a strategic relationship in which Fulcrum plans to supply biocrude produced from sorted municipal solid waste (MSW) for upgrading in Tesoro's Martinez, California, refinery (Lane 2016b).
- Ensyn also plans to provide biocrude produced via pyrolysis from tree residues for upgrading in Tesoro's California refineries (Lane 2016b).

Environmental Benefits

The adoption of de-carbonization measures will be an important part of the aviation industry achieving its goal of carbon-neutral growth. The International Civil Aviation Organization (ICAO) describes environmental protection as one of their top priorities and has developed goals to limit or reduce the number of people affected by aircraft noise, the impact of aviation emissions on local air quality, and the global impact of aviation GHG emissions (United Nations ICAO 2017). The ICAO Committee on Environmental Protection, which was established in 1983, includes members from 24 nations, including the United States.

Domestically, industry partnerships have also developed to support the commercialization of AJF. For example, in 2008, the Sustainable Aviation Fuel Users Group was founded "in support of meeting the industry's goal of carbon-neutral growth beyond 2020" (SAFUG 2017). This group includes members, such as United, Virgin America, KLM, JetBlue, and other airlines, that have made significant progress in deploying AJF for commercial flights. These members are joined by affiliates, such as Boeing, Airbus, Embraer, and other aircraft manufacturers.

In 2013, the global jet fuel market was approximately 5.7 million barrels per day, with 1.4 million barrels per day in the United States (EIA 2013). Globally, aviation is projected to grow by approximately 4.3% per year (ATAG 2016). This expected increase in aviation demand could result in increases in both fossil fuel consumption and GHG emissions if AJF is not expanded further.

The bioenergy industry applies LCAs to quantify the GHG-emissions benefits of AJF. LCA methodologies have been used in studies that found the aviation industry emissions increase may be mitigated by the adoption of de-carbonization measures, such as AJF, reduction in the demand for all petroleum products, and development of low-carbon options for both electricity and hydrogen consumed in AJF production.

LCA studies have found that de-carbonization measures have the potential to reduce 2050 life-cycle GHG emissions by 2.4 grams of carbon dioxide (CO_2) equivalent per megajoule (MJ) below 2012 levels (Speth et al. 2016). This analysis illustrates that aviation emissions may remain steady despite industry growth if AJF is adopted along with minimization of petroleum use.

Certification

The fuel certification process can be very costly and time consuming, especially for small start-up companies, which can be a challenge for AJF development. This discussion reviews the steps required for the certification process as well as ongoing efforts by several organizations to reduce these costs and increase availability of resources to overcome this barrier.

Scale-Up and Technology Certification

One of the largest challenges for development of AJF is the expense and time required for certification. ASTM D4054, "Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives," was developed to ensure safe and reliable operation of aircraft on alternative aviation fuels for engine manufacturers, airplane builders, and owners (Radich 2015). This standard practice comprises a four-tiered process for testing new aviation fuels and fuel additives:

1. Specifying the new fuel (Tier 1)
2. Establishing "fitness for purpose" (Tier 2)
3. Testing components (Tier 3)
4. Testing engine and auxiliary power unit (Tier 4).

Upon completion of the D4054 tests, the D7566 "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" approval process begins. For this approval process, data developed under the D4054 testing protocols allow the ASTM subcommittee to compare the AJF properties and characteristics relative to conventional fossil-derived fuels. If the AJF is deemed to be equivalent to a conventional jet fuel, then it is referred to as a "drop-in fuel," and the pathway utilized to develop the fuel can be included under ASTM D7566. A provision under D7566 allows any fuel meeting the specifications to be reidentified as a conventional fuel. With this inclusion, any AJF can be seamlessly integrated into the infrastructure without the need for separate tracking or regulatory approval (Colket et al. 2016). The overall process for D7566 approval includes the following:

1. Drafting of research report by fuel producers based on Tier 1 and Tier 2 outcomes
2. Review of draft research report by aircraft engine manufacturers
3. Drafting of research report following Tier 3 and Tier 4 tests
4. Review of draft research report by aircraft engine manufacturers
5. Preparation of final research report incorporating manufacturers' feedback
6. Vote by ASTM on final research report
7. Vote by ASTM on specification to be added to D7566.

The D4054 is an iterative and rigorous evaluation process that requires candidate fuel producers to generate a range of fuel volumes to test properties, composition, and performance (Colket 2016). Volumes of fuel for the D4054 tests (shown in Table 3) are significant and are required early in the technology development stages.

While "Fuel Specification Properties" and "Fit for Purpose Properties" testing may be provided at no cost to the fuel producers, scaling up new technologies for producing the required volumes for Tier 3 and Tier 4 testing is a challenge. It can take several weeks or months to produce 5–10 gallons of fuel in a laboratory setting.

Table 3. Fuel Volumes Required for D4054 Testing (Rumizen 2013)

Tier	Fuel Volume in Gallons (Liters)
Tier 1 – Fuel Specification Properties	10 (38)
Tier 2 – Fit for Purpose Properties	10–100 (38–380)
Tier 3 – Component and Rig Tests	250–10,000 (950–38,000)
Tier 4 – Engine Tests	Up to 225,000 (852,000)

"Component and Rig Tests" and "Engine Tests" represent significant costs to the fuel producers. This is in addition to the capital and operating costs for pilot-scale production required to generate significant volume of AJF for the fuel certification process.

Typically, the certification process takes about 3 to 5 years and costs around $10 to 15 million (Csonka 2016; Colket et al. 2016). There is a clear need to drive down the certification and production costs and reduce the time required for certification. A multi-agency-led program, the National Jet Fuels Combustion Program, aims to streamline these costs and the fuels and resource requirements to secure ASTM approval of AJFs for commercial uses (Colket et al. 2017).

As of January 2017, only five AJF pathways have been certified by the ASTM D7566 process:

1. Synthesis gas (syngas) FT synthetic paraffinic kerosene (FT-SPK), which is certified at 50% maximum blend
2. Hydroprocessed lipids (HEFA-SPK), which is certified at 50% maximum blend
3. Biochemical sugars (hydroprocessed fermented sugars to synthetic isoparaffins [HFS-SIP]), where blending is certified at up to a maximum of 10%

4. Syngas FT synthetic paraffinic kerosene, plus the alkylation of light aromatics (primarily benzene) (FT-SPK/A), which is certified at 50% maximum blend

5. Isobutanol conversion (ATJ-SPK), where blending certification is set at 30% maximum.

Coordination of Certification and Qualification with Other Agencies

A number of domestic federal agencies and industrial stakeholders are working together closely under CAAFI to overcome the challenges associated with fuel certification and to expand the deployment of AJF.

CAAFI is a forum of domestic and international stakeholders that spans the entire development and deployment path of AJFs. CAAFI is co-sponsored by the Aerospace Industries Association, Airports Council International – North America, Airlines for America, and FAA. BETO has strong partnerships with FAA and other federal agencies, as well as with the aviation community, and is active in CAAFI. Similarly to the DOE-BETO workshops and alternative aviation activities, CAAFI held an alternative aviation fuels workshop in 2012—the CAAFI R&D Team Workshop.

Findings by the CAAFI R&D team for immediate and long-term needs included the following (CAAFI 2013):

- Critical enablers requiring immediate development
  - Flexible economic and engineering models capable of evaluating the wide variety of proposed approaches for alternative fuel facilities and supply chains
  - Detailed analyses of fuel chemistry effects on fuel properties to enhance specification development for alternative fuels with unusual chemical compositions (e.g., those composed of a single component or a mixture of components) and development of cost-effective tests for the suitability of alternative fuel
- R&D with near- and mid-term return on investment
  - Feedstocks and processes to reduce the cost of HEFA AJFs
  - Studies on relative economics due to competing uses of biomass resources
  - Development and streamlining of crosscutting technologies applicable to a variety of feedstocks and processes
  - Feedstock production systems that incorporate diversity to enhance resilience to environmental variability and stresses, such as drought
  - Technologies addressing barriers for the use of MSW and sewage sludge as feedstocks for alternative fuels
- Sustained R&D on high-benefit, low-readiness-level processes
  - Direct collection and conversion of atmospheric CO_2 to fuels (e.g., novel approaches to CO_2 capture and conversion)
  - Encouragement of innovation in high-impact areas by awarding prizes for the most promising ideas.

The outcomes of the CAAFI workshop—in addition to identification of short-, near-, and long-term R&D needs—included a position paper and follow-on breakout sessions during CAAFI General Meetings in 2014 and 2016 to review whitepapers and continue dialogues on opportunities for reducing fuel production costs and developing robust feedstock supply systems.

Existing Certification Facilities and Potential for Enhancement

CAAFI has identified additional resources to support industry through the ASTM processes, in order to further drive down the expense associated with fuels certification. Eleven universities and other research facilities worldwide have been identified by CAAFI as having the technical capabilities for performing aviation fuel property testing. Ten aircraft and engine original equipment manufacturers have also been identified that demonstrate the technical capabilities necessary to perform aviation fuel property testing, as required by D4054, and have expressed an interest in performing these tests. Contact information for each of these facilities is provided in the *ASTM D4054 Users' Guide* (Rumizen 2013).

Financing

As an emerging industry, bioenergy—and the aviation biofuels industry in particular—can involve high levels of risk as technology is advanced and commercialized. U.S. legislation has recognized the public benefit of biofuels since the Energy Policy Act of 1992 and provides for the allocation of public funding to the transformation of transportation fuel markets. Grants are a funding mechanism that tends to support early-stage technology development, while loan guarantees support technology transfer to the private sector, rather than research. Once a technology has been fully proven, project financing may become available through standard market vehicles, such as venture capital, private equity, or customer offtake agreements.

Grants, Loan Guarantees, and Other Finance Mechanisms

Several federal agencies, including, but not limited to, the National Science Foundation, USDA, DOE, U.S. Department of Defense (DOD), and FAA provide grants to support a growing bioeconomy. Grant programs, in conjunction with nongovernmental funding, facilitate the development of technologies from early research stage to validation at demonstration scales (technology readiness levels [TRLs] up to 7).

Pioneer-scale facilities (those involving higher TRLs designed to produce commercial-scale volumes of advanced biofuels at TRL 8) are generally supported through loan guarantee programs administered by DOE and USDA. Loan guarantee financing mechanisms are intended to encourage and support early commercial use of new or significantly improved technologies and spur the commercial deployment of advanced biofuels projects.

Other financing mechanisms include investments made by the private sector. A unique feature of the development of aviation biofuels is the strong participation and investments by airlines (e.g., Cathay Pacific, Southwest Airlines, United, and others), private corporations (e.g., FedEx), and oil companies (e.g., BP and Shell) in supply chain and technology development (Hammel 2016). A recent example of this outside investment is an offtake agreement between Fulcrum Energy and Air BP, which was announced in November 2016. With this $30-million agreement, Fulcrum Energy has the funds needed to accelerate the construction schedule for its next renewable jet fuel plant and provide Air BP with 50 million gallons per year of low-carbon, drop-in jet fuel (Biofuels International 2016).

Future Growth

While the "Challenges and Opportunities" section of this report focused on ways to further deploy AJF in the near term, this section reviews additional considerations for AJF that may impact long-term future growth. While existing AJF pathways are promising, many of the physical properties of AJFs are directly compatible with diesel and may be used as substitutes for on-road diesel.

Another significant factor in the future growth of AJF is the development of new fuel production pathways, including those currently undergoing the certification process and those that have a long-term potential. This section discusses those new fuel pathways as well as the analysis needed to understand their environmental and economic impact. Finally, this section reviews the collaborative efforts between domestic and foreign entities working towards further development of AJF and policy consideration to support additional growth.

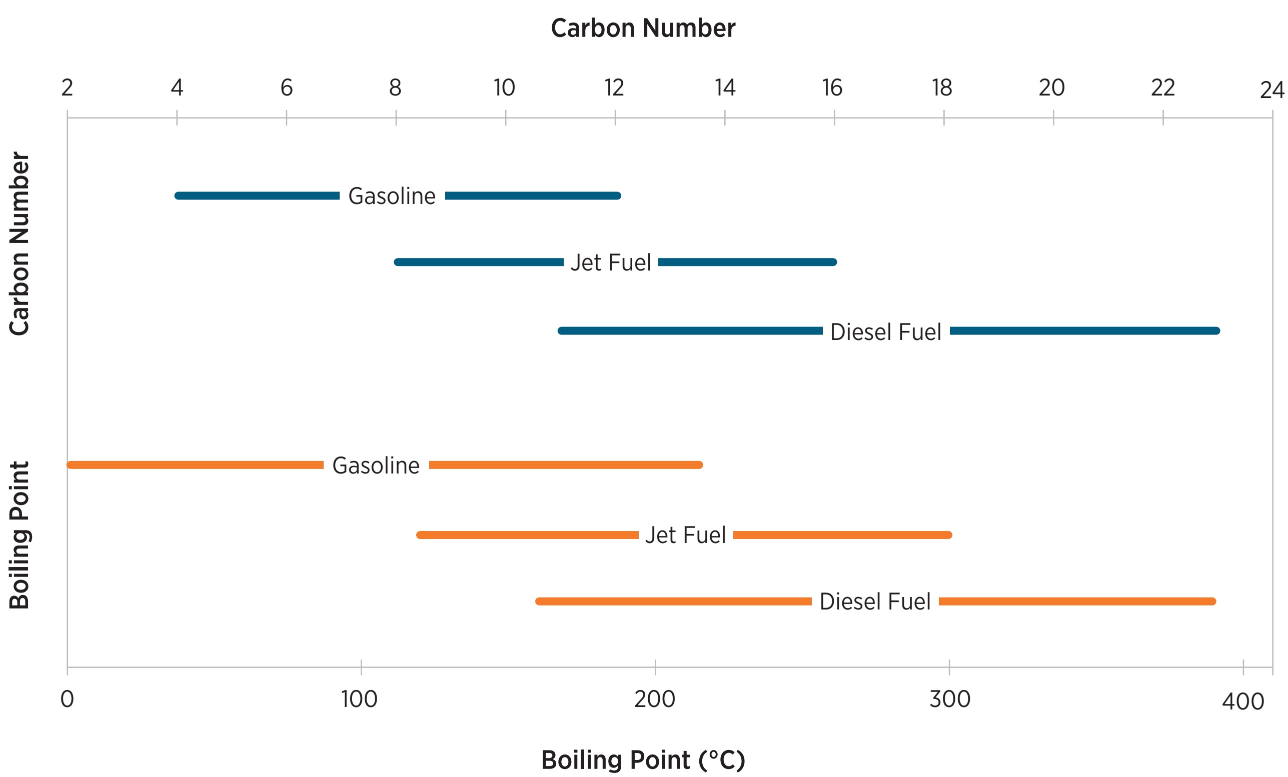
Competition between On-Road Diesel and Jet

Jet fuel is a suitable blendstock for the production of diesel fuel, and many of the physical property requirements for jet fuel meet or exceed the requirements for diesel. Figure 1 illustrates the common boiling point ranges and carbon numbers found in a range of transportation fuels. As highlighted, the jet fuel composition and boiling points fall within the light end of a typical diesel fuel. The one exception is the sulfur requirement in ultralow sulfur diesel, which limits sulfur to 15 parts per million (ppm), while jet fuel specifications are set at a maximum value of 3,000 ppm, which leads to 600 ppm as a global average value.

One of the clear advantages for renewable fuels over fossil crude is the absence of sulfur content, which makes them very attractive to meet ultralow sulfur diesel requirements in both the United States and in Europe. Given this clear synergy between diesel and jet fuel, there is a clear competition between utilization of these bio-derived fuels for each market. When considering current policy incentives for alternative on-road diesel fuel products in the United States (via Renewable Identification Numbers [RINs]) and the regulations in the European Union (EU), the cost benefits for renewable on-road diesel represent a very challenging competition for AJF. One approach to reduce the competition from on-road diesel would be implementing policy support and incentives for AJF similar to those for on-road fuels.

As suggested by the recent Massachusetts Institute of Technology (MIT) and RAND Corporation analysis, *Near-Term Feasibility of Alternative Jet Fuels*, "[t]he approach to addressing the issue of the competition between aviation and ground transportation for alternative-fuel usage is to consider a range of properties of the fuels under consideration to identify characteristics that might favor use in aviation over ground transportation" (Hileman et al. 2009). When considering sustainable air quality impacts, particularly near airports, the reduced sulfur content and reduced aromatic content of AJF translate to lower particulate emissions, particularly at elevations consistent with take-off and landing. When considering LCAs, it is critical to account for criteria air pollutants when calculating the additional benefits for AJFs compared to fossil fuels.

Figure 1. Common carbon number and distillation ranges for various transportation fuels (adopted from Holladay 2016)



Additionally, common fuel specifications are summarized in Table 4. As noted, specifications do vary depending on the jet fuel application and the organization setting these specifications.

Table 4. Summary of Common Jet Fuel Specifications (adopted from Wang et al. 2016)

Jet A-1					JP-8
	ASTM D1655-04a	International Air Transport Association	Def Stan 91-91	ASTM D7566	MIL-DTL-83133E Specs
Acidity, Total (mg KOH/g)	0.1, max	0.015, max	0.012, max	0.1, max	0.015, max
Aromatics (vol%)	25, max	25, max	25, max	25, max (8, min)	0.3, max
Sulphur, Total (wt%)	0.3, max	0.3, max	0.3, max	0.3, max	0.3, max
Distillation Temperature					
10% Recovery (°C)	205, max	205, max	205, max	205, max	205, max
20% Recovery (°C)	--	--	--	--	--
50% Recovery (°C)	--	--	--	-- (15, min)	--
90% Recovery (°C)	--	--	--	-- (40, min)	--
Final Boiling Point (°C)	300, max	300, max	300, max	300, max	300, max
Flash Point (°C)	38, min	38, min	38, min	38, min	38, min
Freeze Point (°C), max	-47	-47	-47	-40 Jet A; -47 Jet A-1	-47
Vicosity @ -20°C (cSt)	8, max	8, max	8, max	8, max	8, max
Net Heat of Combustion (MJ/kg)	42.8, min	42.8, min	42.8, min	42.8, min	42.8, min
Density @ 15°C (kg/m³)	775-840	775-840	775-840	775-840	775-840

Abbreviations: potassium hydroxide (KOH), centistokes (cSt).

New Potential Pathways

As highlighted previously, five AJF pathways have been certified by the ASTM D7566 process: FT-SPK, HEFA-SPK, HFS-SIP, FT-SPK/A, and ATJ-SPK. A maximum blending level has been identified for each of these certified routes, and the levels range from 10% up to 50% blending level. The variations in blending levels are primarily driven by the properties of each of these blending streams to meet the D7566 specification requirements.

There are seven additional pathways in the queue for the D7566 process:

1. Catalytic conversion of sugars by aqueous phase reforming (CCS-APR)
2. Catalytic hydrotreating of lipids (catalytic hydrothermolysis [CH])
3. Pyrolysis (hydrotreated depolymerized cellulosic jet [HDCJ])

4. Co-processing biocrude
5. Catalytic upgrading of alcohol intermediates (catalytic ATJ-synthetic kerosene with aromatics [CATJ-SKA])
6. Catalytic upgrading of ethanol (ATJ-SPK expansion)
7. HEFA expansion.

Additionally, over 15 different pathways have been identified as part of the pre-pipeline for production of AJF (Csonka 2016).

Proposed technologies include bolt-on designs, which could utilize existing infrastructure to drive down costs. Examples of such technologies include recent commercial-scale processes by AltAir that produce HEFA on a brownfield site and leveraging of existing infrastructure at the Paramount Petroleum refinery. With operational agreements in place between AltAir and Paramount Petroleum to provide operation and maintenance support, existing infrastructure was utilized to lower both operating and capital costs for these processes. Additionally, several other operations have been suggested for bolt-on opportunities, including upgrading a range of alcohol intermediates (i.e., ethanol, isobutanol, n-butanol, and mixed alcohols) to AJF.

Additionally, several catalytic conversion strategies are being pursued beyond the approved conversion of isobutanol to synthetic paraffinic kerosene (ATJ-SPK). These new catalytic conversion strategies are focused on making blends that include additional hydrocarbon products, such as aromatic content, to allow for greater blending volumes of the AJF product.

Further, technologies that could utilize waste streams for upgrading, such as CO_2 and waste sludge, are currently being investigated. HTL, for example, has the flexibility to process a range of feedstocks, from algal biomass, to waste sludge, to lignocellulosic feedstocks. Opportunities to biologically convert waste gas streams like CO_2 and methane are also being investigated to leverage low-cost feedstocks in carbon-efficient conversion options.

Finally, technologies under development with support from BETO are also being investigated for AJF production. A few examples include syngas fermentation, catalytic pyrolysis, fast pyrolysis with hydrotreating, and biological production of lipids with upgrading.

Analysis Needs

Given the number of AJF pathways that are either currently being developed or are projected for future development, it is critical to understand both the economic viability and the potential sustainability benefit for each of the pathways. Further, for a process to be viable, it is essential that it be cost competitive with fossil-derived jet fuel. Several analysis studies can help to address pathways' strategies or provide the initial estimate on the cost competitiveness and potential sustainability impacts of each pathway. The current existing analyses have many strengths and weaknesses.

TEA aims to understand the current economic status of a given conversion strategy and can also outline R&D directions and key conversion metrics required to develop pathways that would be cost competitive with fossil production routes. LCA works to develop AJF pathways with a higher energy efficiency and reduced impact on the environment (through lower GHG emissions and lower water footprints, for example). Additionally, the overall goal is to develop AJF pathways that have limited impact on the environment. While there have been several studies on the production of AJF that consider pathways that are either certified or are undergoing certification, there are a number of gaps remaining from an analysis perspective.

One of the biggest challenges for stakeholders to make sense of the results of economic and sustainability analyses is that the assumptions utilized in these studies are not based on a consistent analysis approach. For example, process designs typically employ key process metrics, such as conversion yields, based on the best information available, but the range of uncertainties of these values is typically unknown and can dramatically affect both cost and sustainability metrics.

For economic evaluations, a variety of financial assumptions are commonly used that greatly influence the minimum fuel selling price. These financial assumptions include a number of inputs, including internal rate of return and feedstock costs.

In sustainability analyses, the base life-cycle emissions (particularly for feedstocks) and the methodology consideration for co-products can dramatically shift the estimated sustainability results for a described pathway. Further basis for the LCA, including land-use change (LUC) considerations, sources of hydrogen, and co-product allocation versus displacement approaches, must be considered in each individual sustainability study.

One of the gaps in the current TEA studies is their primary focus on future cost goals with very limited considerations of the current state of the technology or the wide range of conversion opportunities for AJF production. Without a focus on the near-term economics, understanding the current risks of the AJF pathways can be challenging. Such a focus should not only include processes that are being scaled up, but also emerging technologies under development (such as bolt-on approaches or considering waste-to-energy pathways). Without this focus, stakeholders may not know what is possible in tangible timeframes (2-, 5-, and 10-year considerations), resulting in uncertainty in investment.

The results of the TEAs, which should focus on processes that have been certified as well as new emerging pathways, could be utilized to support the need for policy intervention (e.g., Low Carbon Fuel Standard [LCFS] credit). In addition, TEAs could support outreach to policymakers and regulators to demonstrate that industry needs further policy support to meet the AJF goals set by a number of organizations. It will be critical for these discussions—and for generating interest from investors—to understand the current state of technology from a development standpoint. Stakeholders' engagement will be critical to support the further development of the industry.

Pioneer-scale plant estimates are available for the commercially relevant pathways, and information gleaned from the development of ethanol production via a post hoc analysis can be leveraged. These analyses can be applied to the assumptions in ongoing and future TEA studies to provide more confidence in the basis of these evaluations. A full supply chain consideration for near-term, pioneer-scale plants could enable more comprehensive investigation into feedstock drivers/solutions and infrastructure needs as more AJF pathways grow to commercial maturity.

U.S. and Worldwide Efforts

Numerous ongoing activities domestically and globally support the development of AJF. In 2015, more than 2,000 commercial flights were operated on AJF, enabled in part by offtake agreements (Csonka 2016). While not meant to be all-inclusive, Table 5 summarizes key AJF offtake agreements.

Table 5. Ongoing AJF Offtake Agreements (adopted from Csonka 2016)

Producer	Consumer	Agreement Terms
AltAir Fuels	United Airlines	5 million gallons/year from 2016
AltAir Fuels	World Fuel Services and Gulfstream Aerospace	3-year agreement, 30/70 blend
AltAir Fuels	SkyNRG and KLM	3-year agreement, enabling LAX flights
Fulcrum Sierra BioFuels	Cathay Pacific	375 million gallons per year
Fulcrum Sierra BioFuels	United Airlines	90–180 million gallons per year over 10 years
Red Rock Biofuels	Southwest Airlines and FedEx	3 million gallons per year
Total and Amyris	Cathay Pacific	48 A350 deliveries, 10% blend
Hawaii BioEnergy	Alaska Airlines	Supply from 2018
Gevo	Lufthansa	Up to 40 million gallons over 5 years (memorandum of understanding)
Neste	SkyNRG, Oslo Airport, KLM, Scandinavian Air-lines, and Lufthansa	Bioport on demand

Over the past decade, numerous multi-stakeholder initiatives have been created for the additional development of offtake agreements. The collaborative efforts have been critical for supporting the coordination and networking among stakeholders. Collaborations have included a wide range of economic and sustainability assessments, supply chain development, and R&D support. The partnerships are too numerous to list in this report; key internal groups are highlighted in Table 6.

Table 6. Multi-Stakeholder Organizations Focused on AJF (Wormslev et al. 2016; McGill University 2016; SAFUG 2016; NARA 2016; ATAG 2016; United Nations ICAO 2016)

Multi-Stakeholder Initiatives	Location	Partners
Commercial Aviation Alternative Fuels Initiative (CAAFI)	United States	FAA, Airlines for America, Airports Council International, Aerospace Industries Association
Midwest Aviation Sustainable Biofuels Initiative (MASBI)	United States	United Airlines, Boeing, Honeywell UOP, Chicago Department of Aviation, Clean Energy Trust, USDA, U.S. Department of the Navy
Sustainable Aviation	United Kingdom	Airport Operators Association, ADS, Airbus, Boeing, British Airways, NATS, Virgin Atlantic
Aviation Initiative for Renewable Energy in Germany (AIREG)	Germany	Air Berlin, Bauhaus Luftfahrt, Boeing, Deutsche Energie-Agentur, Lufthansa
Initiative towards Sustainable Kerosene for Aviation (ITAKA)	EU	EU Commission, Services and Studies for Air Navigation and Aeronautical Safety (SENASA), Airbus, École Politechnique Fédérale de Lausanne, Embraer, Manchester Metropolitan University, Neste, SkyNRG
European Advanced Biofuels Flightpath (EUABF)	EU	EU Commission, Airbus, Air France, KLM, Biomass Technology Group, British Airways, Lufthansa, Neste, Honeywell UOP
Nordic Initiative for Sustainable Aviation (NISA)	Nordic European Countries	Airlines: Scandinavian Airlines (SAS), Finnair, Norwegian Air Shuttle, Icelandair, Air Greenland, Malmo Aviation, Atlantic Airways Airports: Copenhagen Airport, Swedavia, Avinor, Finavia, Isavia Transport authorities of Denmark, Sweden, and Finland (as well as Airbus and Boeing) Organizations: Brancheforeningen Dansk Luftfart, Svenskt Flyg, Svenska Flygbranschen, NHO Luftfart, International Air Transport Association
Gardermoen Biohub	Norway	SkyNRG Nordic, Avinor, Statoil, Scandinavian Airlines (SAS), KLM, Lufthansa, Neste, Air BP
Bioport Holland	Holland	KLM, SkyNRG, Schiphol Airport, Neste Oil, Port of Rotterdam, Dutch State Secretary of Infrastructure and the Environment, Dutch Minister of Economic Affairs
Biojet Abu Dhabi (BAD)	United Arab Emirates	Etihad Airways, Boeing, Takreer, Total, Masdar Institute of Science and Technology
Initiatives for Next Generation Aviation Fuels (INAF)	Japan	International Airport, Japan Petroleum Exploration (JAPEX)

Table 6. Continued

Multi-Stakeholder Initiatives	Location	Partners
Brazilian Biojetfuel Platform (BBP)	Brazil	Brazilian Association of Airlines (ABEAR), Brazilian Biodiesel and Biojetfuel Union (UBRABIO), Boeing, GE, GOL Airlines, Curcas Diesel
Northwest Advanced Renewables Alliance (NARA)	United States	Washington State University, Alaska Airlines, Catchlight Energy, Compañía Logística de Hidrocarburos (CLH), Cosmo Specialty Fibers, Facing the Future, Gevo, Gevan Marrs LLC, Montana State University, Oregon State University, Pennsylvania State University, Salish Kootenai College, Steadfast Management, Thomas Spink Inc. (TSI), University of Idaho, University of Minnesota, University of Montana, University of Washington, University of Wisconsin, U.S. Forest Service – Forest Products Laboratory, U.S. Forest Service – Pacific Northwest Research Station, University of Utah, Western Washington University, Weyerhaeuser
Sustainable Aviation Fuel Users Group (SAFUG)	International	Supported through ICAO: Air China, AeroMexico, Air France, Air New Zealand, Alaska Airlines, ANA, AviancaTaca, British Airways, Cargolux, Cathay Pacific, Etihad, GOL, GulfAir, JAL, Jet Blue, KJM, Lufthansa, Qantas, Qatar Airways, SAS, Singapore Airlines, South African Airways, TAM, TUI Travel PLC, United, Virgin America, Virgin Atlantic, Virgin
BioFuelNet Canada (BFN)	Canada	Supported by the Government of Canada and hosted by McGill University; network includes over 150 partners
Sustainable Aviation Fuels Northwest (SAFN)	United States	Boeing, Alaska Airlines, Portland International Airport, Seattle-Tacoma International Airport, Spokane International Airport, Washington State University, Climate Solutions

The overarching goal for the use of AJF is to reduce emissions and reduce the environmental impact of the aviation section. The Air Transport Action Group is multi-stakeholder group that includes representatives from airlines, airports, pilot and traffic controller unions, chambers of commerce, industry associations, and other groups. The group set forth voluntary targets for the industry to reduce environmental impacts, including the following:

- Improving fuel efficiency an average of 1.5% per year (from 2009 to 2020)
- Placing a cap on CO_2 emissions from 2020
- Reducing GHG emissions by 50% by 2050 when compared to 2005.

Such voluntary targets have been adopted by the industry and have begun to be supported further by policy (ATAG 2016).

In 2012, aviation fuel was included in the EU Emission Trading System (EU ETS). The EU ETS, which is based on a cap-and-trade principle, covers the European Economic Area. The program has set a target for annual aviation emissions to be 5% below the 2004–2006 average. Under the program, airlines are allocated approximately 82% of free allowance for emissions while the remaining emissions must be offset with carbon certificates. One of the challenges associated with this approach, however, is the low credit associated with these carbon emissions (the highest value is €9 Euros/ton CO_2), which is much lower than the current cost of AJF. Beyond 2016, the aviation EU ETS will be tied directly to the global market-based mechanism (GMBM) being developed by the ICAO. The GMBM is part of a larger effort often referred to as a "basket of measures" working to establish consistent global certification approaches for CO_2 emissions (United Nations ICAO 2016; Kousoulidou and Lonza 2016).

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was established by the UN ICAO to address any increase in annual CO_2 emissions from international civil aviation above 2020 levels. The CORSIA is implemented in phases, with the pilot phase (2021–2023) and first phase (2023–2026) expecting voluntary members and the second phase (2027–2035) requiring participation from all countries that have an individual share in the international aviation activities. While this strategy is likely to achieve emissions reductions via offsets, it is expected that additional policies will be required to stimulate biofuels development (ICAO 2016; Kousoulidou and Lonza 2016).

In the United States, USDA, DOE, and the Navy executed a memorandum of understanding and invested $510 million in 2012 to begin developing partnerships with the private sector to produce advanced drop-in aviation and marine biofuels (Navy, DOE, and USDA 2011). In 2014, DOD, DOE, and USDA selected candidates (Emerald Biofuels, Fulcrum BioEnergy, and Red Rock Biofuels) for Phase 2 of the Defense Production Act (DPA) Title III for construction of biorefineries to produce advanced drop-in biofuels.

In 2012, the "Farm to Fly" program established a collaborative initiative between USDA, Airlines for America, and Boeing to promote the production of drop-in renewable jet fuels and establish a goal of producing 1 billion gallons of AJF by 2018 (USDA 2012). The program was extended until 2019 (and named "Farm to Fly 2.0") with the addition of DOE, the Department of Transportation (DOT), and FAA, along with private partners such as CAAFI (GreenAir Communications 2014; Male 2014).

DOD has included AJF in standard procurement practices since 2014, in an effort to further support the development of biofuel business opportunities (Wang et al. 2016). In 2016, the Office of the President released the *Federal Alternative Jet Fuels Research and Development Strategy* under the auspices of Aeronautical Science and Technology Subcommittee of the National Science and Technology Council. As described in the document, "the Strategy sets out prioritized Federal R&D goals and objectives to address key scientific and technical challenges that inhibit development, production, and use of economically viable AJFs that would provide energy security and environmental and social benefits relative to conventional fuels, while reducing duplication of effort, enhancing efficiency, and encouraging a coordinated R&D approach among Federal and non-Federal stakeholders. The Strategy complements department and agency R&D policy directives and should guide decisions about R&D program budgets and priorities" (NSTC 2016).

Additionally, Japan, Germany, the United Kingdom, the United Arab Emirates, Nordic countries (including Norway, Finland, Denmark, Sweden, and Iceland), and Brazil have developed roadmaps outlining initiatives and strategies for producing AJF.

While countries develop roadmaps and strategies, the cost of producing biojet is estimated to be 2–7 times more than fossil jet in the near term. Effective policy can provide a bridge for achieving price parity. One option is environmental levies (e.g., "green" levies and taxes paid on a per-passenger basis). The challenge associated with this approach is that it diverts money from the industry that might otherwise be invested in CO_2-reduction projects. Further, this strategy is expected to have only a limited effect on emissions. Finally, it requires airlines to increase their charges/taxes.

Still, policy support is essential and, given the global nature of the aviation industry, will likely have to be implemented in concert with regional, multi-stakeholder initiatives. One example of such a regional initiative is the concept of a bioport. A bioport may be positioned next to a major airport and be the center for implementation of local incentives schemes. One approach is “tendering,” a public contracting mechanism wherein scores are allocated and weighted based on the priorities of fuel price, CO_2 emissions, and local emissions. For example,

score = 0.6*price + 0.2* CO_2 emissions + 0.2*local emissions

The contractor with the lowest score wins the contract. This approach has been effective in Sweden, where it has been applied to marine shipping transport. Variations on this theme might also be effective in an aviation bioport concept, bolstering vertical integration across the supply chain to minimize the score of a given airline (see, for example, SkyNRG n.d.).

Conclusion

Domestic and global trends in energy security and corporate responsibility have encouraged many public and private sector organizations to commit to adopting alternative aviation fuels. Offtake agreements from biorefineries and airlines have demonstrated significant investment and the numerous stakeholder organizations that have formed around AJF illustrate the long-term growth potential.

There are more potential production pathways to be developed, as analysis capabilities are expanded. Many challenges remain in order to properly finance production facilities, effectively scale biorefining technologies, optimize production economics, and streamline certification processes. These challenges provide ample opportunity for developers, biomass growers, scientists, and industry partnerships to innovate and develop solutions that will provide readily available, affordable, and sustainable AJF to airlines around the world.

Part Two: Alternative Aviation Fuel Workshop Summary

On September 14–15, 2016, DOE-BETO hosted the Alternative Aviation Fuel Workshop in Macon, Georgia. The objective of this event was to collect input from lead experts in the biofuels industry to further advance the understanding of the current capabilities, barriers, and opportunities for production of alternative aviation fuels. After several years of alternative aviation development, it is clear that challenges remain.

Workshop Concept and Process

AJF production has increased over the last decade, with five conversion strategies now certified by ASTM International and dozens of pathways in the queue for certification. Policies and carbon-reduction goals from a range of countries continue to support the development and deployment of AJF. In the United States, initiatives by federal agencies—including DOD, USDA, DOE, DOT, and FAA—and private industry—such as fuels producers, airlines, and jet engine manufactures—have helped to further develop AJF routes. These entities' support ranges from direct funding for R&D to the development of offtake agreements to support market demand.

More than 100 workshop attendees represented public- and private-sector bioenergy stakeholder organizations working to advance biorefinery technologies. The workshop began with a half-day of presentations from experts providing an overview of recent research findings and case studies in each of the four areas. Following the plenary session, attendees were asked to provide insight about why alternative aviation fuels challenges persist and how DOE can assist the industry to implement solutions. DOE-BETO facilitated a total of four breakout sessions, which covered topics specific to each of the main workshop subject areas, including the following:

- Economic and technical competitiveness
- Fuel conversion and scale-up
- Environmental sustainability and life-cycle benefits
- Feedstock and product supply chains.

Participants in each session worked through a series of questions designed to generate discussion and gather information relevant to the needs of industry as well as the DOE mission. Each breakout group identified critical next steps to support the de-risking of the AJF technology pathways to further support the scale-up and commercialization of AJF. Opportunities, gaps, and data needs were identified for the near term, mid-term, and long term.

Summary of Presentations

The stakeholders and bioenergy expert presentations summarized in this section provide insights into workshop focus areas and include perspectives that are relevant to a wider adoption of the bioenergy industry. The presenters' perspectives are based on decades of industry experience, and they illustrate real-world considerations that bioenergy companies should take into account to succeed in this environment.

The first plenary session began with opening remarks by Jonathan Male, director of BETO. Zia Haq, lead analyst at BETO, provided an overview of the importance of aviation biofuels at DOE. Steven Csonka, executive director of CAAFI, summarized the demand for AJF; early offtake agreements; conversion pathways under consideration for approval/use; and issues for sustainability, economics, and supply/resource availability. This talk ended with a review of the key summary of needs outlined in the Federal Aviation Jet Fuel R&D strategy, which included the following:

- Feedstock development, production, and logistics
- Fuel conversion and scale-up

- Fuel testing and evaluation
- Integration challenges, including the need for modelling, TEA, and LCA, which could form a basis for informing the strategic approaches for a range of AJF potential pathways.

The plenary session "Overview of Alternative Jet Fuel (AJF) RD&D Efforts: Key Technical and Economic Challenges Identified for Different Processes" included speakers from industry and academia: Neville Fernandes from Neste Oil, Mark Staples from MIT, Kevin Weiss from Byogy Renewables, and Brice Dally from Virent Inc. The session speakers discussed efforts to successfully achieve project scale-up (pilot scale to commercialization) for production of biofuels and biochemicals, outlining ongoing industry efforts to successfully deploy both renewable jet and diesel blendstocks. While each of the speakers highlighted numerous advantages for renewable fuels, including GHG benefits, the presenters also highlighted the uncertainty associated with blending and downstream logistical costs, which are typically underestimated.

The next plenary session, "Greenhouse Gas (GHG) Life-Cycle Assessment (LCA) Results for AJF: Key Contributors to GHG Emissions and Emissions Uncertainty," included speakers from academia and government agencies: Jim Hileman from FAA, Ray Speth from MIT, Michael Wang from Argonne National Laboratory, Wallace Tyner from Purdue University, and Sharyn Lie from the U.S. Environmental Protection Agency (EPA). The session focused on sustainable aviation growth (e.g., carbon-neutral growth goals), the life-cycle GHG benefit of AJFs, an overview of current AJF GHG LCA methodologies, outcomes of analyses, and remaining challenges. As highlighted by the presenters, while a range of pathways have been evaluated by LCA, comparing these analyses is still a challenge because a variety of assumptions and boundary conditions were made in these studies. A more consistent approach to LCA was recommended to put these studies on a comparable basis. Additionally, the speakers highlighted that a number of critical LCA metrics should be considered in future studies, including a timeline for implementation of AJF pathways and an investigation of tradeoffs among energy, GHG, air emissions, and water-use attributes for different fuel systems.

In the "AJF Commercialization: Feedstock Systems Supply, Suitability, and Logistics" plenary session, speakers from the national laboratories and government agencies provided an overview of recent estimates of resource availability and potential conversion to jet fuel, as well as a discussion of unknown factors/methodology for estimating future resource availability. The participants included Harry Baumes from USDA, Laurence Eaton from Oak Ridge National Laboratory, David Archer from the USDA Agricultural Research Service, and Kent Swisher from the National Renderers Association.

Similar to both TEA and LCA conversion strategies evaluations, the feedstock speakers highlighted that each feedstock is unique and requires its own set of evaluations—ranging from the cost of production to sustainability implications to market drivers and supply chain expansion. A range of tools and approaches were highlighted for evaluating oil crop feedstocks that supply current diesel and AJF production pathways through emerging lignocellulosic feedstocks including herbaceous and woody biomass. A critical need for each of these tools was real-world data (including historical yield and required inputs for the production and transport of feedstocks) to support the analysis.

Economic and Technical Competitiveness

BETO invited five speakers to begin the discussion by reviewing their perspective on AJF-focused TEA: Mark Staples from MIT, Corinne Drennan from PNNL, Mary Biddy and Ling Tao from NREL, and Wallace Tyner from Purdue University.

Research Challenges for Assessing the Environmental and Economic Impacts of Alternative Jet Fuel Production Scale-Up

Mark Staples
Massachusetts Institute of Technology

Dr. Staples provided an overview of ongoing economic analysis in the MIT Laboratory for Aviation and the Environment. The discussion focused on harmonized stochastic TEAs of AJF pathways with an emphasis on a range of pathways, including the following:

- Advanced fermentation
- HEFA
- HTL of lignocellulosic feedstocks
- Aqueous phase processing
- Fast pyrolysis from agricultural residue.

Outcomes of this analysis showed that the major drivers vary depending on the production pathway. RINs and producer credits help to drive down costs of a number of AJF pathways, reduce risk in AJF production for investors, and strengthen market demand for fuel production.

Aviation Biofuels: Enhancing Technical & Economic Competitiveness

Corinne Drennan
Pacific Northwest National Laboratory

Dr. Drennan provided an overview of enhancing technical and economic competitiveness by considering the quality and value of the AJF both for property and molecular composition. For example, desired characteristics of the biofuels include the following:

- Miscible with petroleum-based fuels and transportable in current pipelines
- Performance and storability criteria meet jet engine standards
- Optimized hydrocarbon chain length/boiling point for aviation fuels (mid-distillates)
- Isoparaffins and n-paraffins with high energy content and chain length of C8–C16
- Aromatics only desired at low amounts (8%–12% required for seal swell).

Further, Dr. Drennan summarized ongoing public commitment by the aviation industry (primarily airlines) to purchase biofuels. The National Resources Defense Council 2016 Scorecard highlighted the leading airlines with broad involvement in creating sustainable fuel supply chains, as well as solid commitments to use and purchase biofuels:

- Air France/Royal Dutch Airlines (KLM)
- British Airways
- Cathay Pacific Airways
- Scandinavian Airlines (SAS)
- South African Airways
- United Airlines.

Additionally, there are a number of developing airlines engaged in advancing the fuel supply chain development, including the following:

- Air New Zealand
- Alaska Airlines
- Etihad Airways
- GOL Airlines
- Japan Airlines
- Qantas Airways
- Virgin Atlantic
- Virgin Australia Airlines.

The key summary of this presentation noted that AJF must be both technically and economically competitive. Developing the desired molecular intermediates that have the desired boiling range and good storage stability and energy density will help move products to market faster. Producing these fuels at cost-competitive prices by finding opportunities in lower-cost feedstocks or leveraging existing infrastructure could also support moving fuels to market faster.

Techno-Economic Approach towards Alternative Jet Fuel Conversion Pathways
Mary Biddy and Ling Tao
National Renewable Energy Laboratory

Dr. Biddy and Dr. Tao presented on the approach of TEA and the current data gaps and informational needs, as well as cost drivers for the production of AJF from lignocellulosic feedstocks, including the following:

- There is a broad range of publicly available data to utilize for TEA.
  - Large uncertainty is associated with yields and understanding current state of technology.
  - Good deal of data are intellectual property (IP) and protected; it is hard to understand how scaled processes are performing.
  - Yields greatly influence the economics and sustainability.
- Publicly available TEA financial assumptions are varied; no standard baseline
  - Comparisons are very difficult, particularly when not all parameters are explained or included in write-up.
  - Should be common practice to include all assumptions so studies are repeatable.
- There is uncertainty associated with feedstock assumptions.
  - Differences exist in both composition and costs.
  - Data are not always presented; best practice should be that analysis is reproducible.
- Most studies assume N^{th} plant economics; this approach does not include details associated with current scale-up risk and uncertainties.

- All feeding systems work at a fixed operating on-stream factor; this is a challenge in a first-of-a-kind plant
- Consider risks in doing TEA to make sure TEA highlights all challenges beyond specific parameters required to meet economic viability (i.e., rates).
- Identify gaps and challenges that would affect scale-up risk.

Dr. Biddy concluded by noting that, while TEAs strive for consistency with financial assumptions, the underlying assumptions around cost of biomass and overall yields assumed in the design greatly influence the economic estimates. Further, there is a need to discuss what level of maturity is assumed in the technology for all economic analyses. Most analyses focus on N^{th} plant processes, but by focusing on such far-away targets, two questions are raised: (1) what might be missing from these types of analysis, and (2) are these efforts overlooking the technical challenges for newer technologies?

Quantifying Estimates of Induced Land-Use Change and Emissions from Sustainable Alternative Fuels

Wallace Tyner
Purdue University

Dr. Tyner provided an overview of ongoing analyses by his team on stochastic TEA for aviation and biofuels to review the key uncertainty drivers for the fuel production pathways. For the specific pyrolysis pathway analyzed, key uncertainties included yields, feedstock costs, hydrogen cost, and process capital cost. One of the key conclusions from this study is that a major driver in moving more fuels to market is to build the initial plants and reduce the risk associated with the first-of-a-kind technology and progress down the learning curve.

Fuel Conversion and Scale-Up

To begin the discussion, BETO invited three speakers who are technical experts in feedstocks: Glenn Johnston, executive vice president of regulatory affairs at Gevo; Ted Kniesche, vice president of business development at Fulcrum BioEnergy Inc.; and John Holladay from PNNL.

Fuels Conversion and Scale-Up

Glenn Johnston
Gevo

Mr. Johnston reviewed Gevo's work in the area of alcohols to hydrocarbon fuel conversion. Recently, the isobutanol-to-jet fuel pathway developed by Gevo was certified by ASTM, and the presentation reviewed details of both the conversion process and the process for fuel certification. As was outlined in the discussion, based on a recent article in the *New York Times*, aviation fuels account for roughly 2% of the global GHG emissions. Mr. Johnston also reviewed ongoing efforts by a range of consortiums to facilitate the scale-up of AJF. For example, the ICAO and its member states are working toward reduction of CO_2 emissions with a range of strategies, including green aircraft technologies, market-based measures (such as purchasing carbon credits), operational measures, and alternative fuels for aviation. In addition, ATJ was reviewed, and it was determined that a number of hurdles would need to be cleared. The challenge for AJF scale-up is that petroleum products cost less because (1) capital for fossil fuels is typically completely depreciated, whereas for AJF these are typically new facilities that require funding, and (2) the smaller companies producing AJF need to deploy new assets with high capital cost and funding is limited. One possible solution to overcome this challenge is current support from the DPA Title III funding, which has supported the establishment of domestic value chains for producing biofuels.

Converting MSW into Low-Cost, Renewable Jet & Diesel Fuels
Ted Kniesche
Fulcrum BioEnergy Inc.

Mr. Kniesche reviewed ongoing work involving the Fulcrum process to convert MSW to low-cost renewable jet and diesel fuels. The process was outlined as a steam reforming gasification system that converts MSW to syngas. The syngas is converted to syncrude, including jet and diesel fuels via FT upgrading. The process is in start-up operations with all construction completed on budget and schedule. Mr. Kniesche highlighted Fulcrum's business model, which includes several essential components:

- Strategic partnerships
- Proven technology with full engineering, procurement, construction wrap
- Lowest-cost producer
- Long-term, fixed-cost MSW feedstock agreements in place
- Long-term, fuel offtake agreements in place
- First project entering construction
- Large development program.

Alternative Aviation Fuels: Conversion and Scale-Up
John Holladay
Pacific Northwest National Laboratory

Dr. Holladay provided an overview of PNNL's experience in conversion and supporting scale-up. He highlighted the wide range of hydrocarbon components typically found in jet fuel, including 70%–86% paraffins with the various isomers and cyclic compounds needed to provide the energy content; 25% (or less) aromatics, which are required; roughly 7% for seal swell; a restriction of less than 1% of olefins to reduce gum formation; and sulfur-, nitrogen-, oxygen-containing compounds with limited allowance.

Conversion strategies to produce AJF from biomass should target components with the highest value. Even though many biofuel processes can easily make aromatics, these are not as desirable as the production of isoparaffins with a carbon range of C8–C16 due to their high energy content. PNNL, in partnership with LanzaTech, Boeing, GE, HSBC, Virgin Atlantic, and others, has been working to develop an ATJ pathway that takes ethanol and upgrades it to AJF via a four-step process.

PNNL has led catalyst development efforts to first create catalysts to support the conversion process, beginning at low TRL bench-scale test up through pilot scale. These technologies are currently being scaled, and the technology is being transferred to industry to further demonstration- and commercial-scale development. The ATJ process being developed by this team has completed engine/auxiliary power unit testing and is currently being tested by ASTM and FAA for final approvals. This ATJ pathway development highlights the working links between DOE, national labs, DOD, FAA, and industry to demonstrate a successful pathway for early TRL development through ongoing efforts to scale to commercial facilities.

Environmental Sustainability and Life-Cycle Benefits

BETO invited three speakers to begin the discussion, all of whom are technical experts in AJF sustainability analysis: Jeongwoo Han from Argonne National Laboratory, Robert Handler from Michigan Technological University, and Raymond Speth from MIT.

Well-to-Wake Analysis of Ethanol-to-Jet and Sugar-to-Jet Pathways
Jeongwoo Han
Argonne National Laboratory

Dr. Han discussed the well-to-wake analysis for ethanol-to-jet (ETJ) fuel and sugar-to-jet fuel pathways. While a number of studies are focused on hydroprocessed renewable jet and FT jet (FTJ), consideration of other pathways is limited, and the work developed by Argonne National Laboratory is focused on investigating other pathways for production. ETJ pathways considered in this analysis account for both corn ethanol and lignocellulosic ethanol production strategies followed by catalytic conversion to AJF.

The results showed that the lignocellulosic ETJ (via corn stover) had the potential to reduce GHGs by 73% relative to fossil feedstocks. Starch ethanol showed a lower impact on the GHG reduction relative to fossil feedstocks (around 10%). Further sustainability metrics, including water usage, were a major driver for ethanol production. For the STJ routes, which considered both biological and catalytic conversion to ATJ from lignocellulosic feedstocks, the source of hydrogen (either fossil-derived or biomass-derived) can impact the GHG estimates. While biomass-derived hydrogen significantly reduces the GHG emissions for the pathway, it comes at both a yield and economic cost. However, fossil-derived hydrogen may not help meet specific GHG targets for the pathway. Additionally, co-product handling influences the final results for the LCA, but the impact is much lower when the co-product is fuel rather than a commodity chemical.

LCA of Jet Pathways: Overview of Industry-University Cooperative Research
Robert Handler
Michigan Technological University

Dr. Handler discussed the LCA of jet pathways and provided an overview of industry-university cooperative research. While reviewing the results of pathways that have either been approved or are undergoing the approval process, a few key drivers were clear. Feedstock choice and cultivation /procurement decisions can have a large influence on the LCA. Factors like nitrogen utilization (nitrous oxide emissions) and an understanding of LUC can be very impactful. These variables may be site specific. It is critical to understand the tradeoffs of TEA and LCA. Opportunities for process intensification and minimizing heat/power and hydrogen demand can help the LCA, but there could be economic tradeoffs. Allocation methods for co-product sharing of burdens produce different results and therefore have different implications for decision making, with ongoing efforts at EPA and in the EU that consider different approaches for co-product impacts.

LCA of Current & Future GHG Emissions from Petroleum Jet Fuel
Raymond Speth
Massachusetts Institute of Technology

Dr. Speth discussed life-cycle GHG emissions for future jet fuels with a focus on opportunities for emission reductions. One of the key findings of the study was that many of the same reduction opportunities apply to both AJF and fossil feedstocks, including the following:

- Cleaner electricity generation can reduce emissions associated with fuel processing.
- Hydrogen used in fertilizer production and fuel conversion processing can substantially decrease GHGs when producing renewable fuels.
- The use of fossil fuels in feedstock production and transportation can also further reduce emissions, particularly if carbon-neutral transportation or reduced-combustion emission are employed.

Feedstock and Product Supply Chains

BETO invited three speakers to begin the discussion, all of whom are technical experts in feedstocks: Kevin Kenney from Idaho National Laboratory, Marty Schmer from the USDA Agricultural Research Service, and Ralph Cavalieri from Washington State University.

The Hidden Costs of Feedstocks: Lessons Learned from Cellulosic Ethanol Plants
Kevin Kenney
Idaho National Laboratory

Dr. Kenney discussed the lessons learned from the recent scale-up of a number of cellulosic ethanol facilities and the hidden costs of feedstocks. A study conducted by the RAND Corporation highlighted that when solids handling is critical for process operations (as is the case for biorefineries) facility operability is typically around 50% for the first year. As emphasized by a study by Bell et al. 2005, problems generally relate to an inadequate understanding of the behavior of particle systems. Additionally, feedstock variability and the current systems' limited ability to handle such changes to biomass properties have negatively impacted the industry. Industry feed handling problems highlighted include variabilities in the following areas:

- Moisture content affecting downstream processing:
  - Grinder throughput resulting in particle size variability
  - Inconsistent mass and heat transfer in conversion
- Particle size:
  - Large particles
    - Plugging problems in feeding systems, particularly in bins and augers
    - Downstream plugging adversely affecting conversion and contamination
  - Fine particles
    - Typically high in ash
    - Dust challenges with fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
- Foreign material (e.g., dirt and metal):
  - Causes plugging and equipment wear.

Dedicated Energy Feedstock Supplies in the Central U.S. for Alternative Energy Fuels
Marty Schmer
USDA Agricultural Research Service

Mr. Schmer reviewed ongoing efforts to develop dedicated energy feedstock supplies in the central United States for alternative energy fuels at the USDA Agricultural Research Service in Lincoln, Nebraska. The overall objective of this project is to develop systems to meet alternative energy fuel needs and increase economic returns while enhancing ecosystem services. The ongoing efforts have focused on intensifying cropping systems through land management practices; finding opportunities for integrated feedstock systems through both multi-feedstock and landscape approaches; and interfacing with the biorefinery. One example discussed was the management intensification with corn stover through the Resilient Economic Agricultural Practices project, which involves the government, universities, non-government agencies, and private industry, and integrates more than 250 site-years in the effort. As highlighted from the study, the advantage of corn stover is that more than 15 years of significant research and improvements can be leveraged on this feedstock, which is readily available and has a lower cost than many biomass feedstocks. Because farmers and producers are familiar with corn stover as a feedstock, growth of corn biomass has increased by 50% since the early 1980s, and there has been a trend toward increased conservation tillage in the United States. However, corn stover poses the following challenges:

- Corn stover has low harvestable yields and high producer participation.
- It lacks long-term, regional drought tolerance.
- It has a narrow harvest window to maintain desirable quality for biorefineries.
- It is challenging to maintain soil organic carbon, quality, and fertility.

One way to overcome many of these challenges is through landscape intensification with energy crops. USDA has been focused on a number of options, including switchgrass, prairie cordgrass, native mixtures, *miscanthus x giganteus*, and big bluestem. Because many of these feedstocks have seen agronomic improvements over the last 15 years, these types of feedstocks can boost yields with limited inputs and lower land requirements than corn stover. By applying feedstock management, the desired feedstock properties can be integrated with a specific conversion technology. Given these advantages, ongoing R&D is focused on the following:

- Reducing production costs, which are higher than current forest and agricultural residues like corn stover
- Understanding landscape management
- Helping farmers understand these new crops and their potential, as well as coordinating scale-up and logistics
- Improving designs for harvesting equipment
- Understanding long-term rotation.

Additional work supported by USDA also considers oil-seed/soybean rotation as another multi-feedstock system for integrating energy fuels, food, and feed.

Envisioning Alternative Aviation Fuel Supply Chains for the Northwest
Ralph Cavalieri
Washington State University

Dr. Cavalieri discussed the Northwest Advanced Renewables Alliance (NARA), which is led by Washington State University and supported by the Agriculture and Food Research Initiative Competitive Grant from the USDA National Institute for Food and Agriculture. NARA is a collaborative effort that brings in more than 20 different stakeholders across the supply chain, including government, private industry, and universities. NARA's goals are focused on sustainable biojet fuel, valuable lignin co-products, rural economic development, pilot supply chains, and energy literacy. With respect to supply chain elements, ongoing work focuses on feedstocks, transportation and infrastructure, pretreatment and conversion, product distribution, and understanding demand for products. These supply chain considerations also incorporate analysis to evaluate economics through TEA, sustainability through LCA, and community impacts to understand the benefits and tradeoffs for the resources found in the Northwest. From this set of studies, the team has seen that the existence of a strong, location-specific interaction between transportation infrastructure, feedstock density, topography, and location of conversion facilities demands detailed analysis for each supply chain feedstock source.

Summary of Stakeholder Input

Economic and Technical Competitiveness

This breakout session reviewed the challenges to developing a more comprehensive and comparable set of TEAs for a full family of AJF production concepts. Participants in this session discussed the bounds of the TEA topic area by working through a series of questions and exercises designed to provoke thought and gather information relevant to the DOE mission and needs of industry.

Summary of Discussion

While the group recognized that there have been studies in the public literature estimating the cost of AJF for a number of pathways, these studies have not used a consistent set of financial and technology readiness assumptions, resulting in a varied range of costs that are often conflicting. These variations in reported prices for AJF production are confusing for stakeholders, which limits the value of this information.

One of the suggestions from the stakeholders was for DOE to support the development of methodologies for the development of TEAs such that these studies are performed on a more consistent and comparable basis. To assist these studies, BETO was encouraged to work collaboratively with existing organizations, such as CAAFI and FAA, and to organize a stakeholder working group across the supply chain to inform the development of these analyses.

Additionally, the stakeholders recommended that these analyses not only focus on forward projections of these technologies, which have been scaled and de-risked (the Nth plant approach), but also to evaluate near-term, early-adopter economics. By examining these nearer-term considerations, the analyses could help identify the biggest scale-up risks and the barriers for a technology, thereby informing further R&D considerations for both DOE and industrial stakeholders. The participants recommended that this suite of analyses would be a helpful set of information for further discussions and engagement with stakeholders, policymakers, and equity investment groups, among others, and would further enable the development and deployment of AJF pathways.

Economic and Technical Competitiveness

The participants initially discussed their perspective on the current gaps of economic studies, which include developing a better understanding of the current technology and the state of development.

First, there is a need to consider designs and estimate at current scales (i.e., 500 tons/day or smaller).

Second, these analyses need to have a better linkage to real-world activities (in part due to lack of data), including accounting for process variability and upset data, feedstock variation and adopting extended process operations (thousands of hours) for critical process components (like catalyst stability).

Third, there are additional needs to understand feedstock impacts on AJF pathways, including the availability of resources, risk impact on catastrophic supply chain disruptions (droughts and floods), operability considerations for the impact of lack of feedstock heterogeneity, and flexibility of the conversion process to variability of feedstock quality.

Finally, there is a need to develop a new approach for AJF to account for uncertainty and risk associated with first-of-a-kind processes, including best practices and/or methodology to account for risk for new processes. Participants noted that understanding where each of these technologies will be in a near-term, defined timeframe, such as 5 years, would be beneficial to the stakeholder community.

The participants noted that, for these analyses to be impactful, they should consider and evaluate the fuel quality and blending constraints associated with aviation fuels, particularly given the stringent specifications on aviation fuels. These analyses need to link economic evaluations to life-cycle impacts. The analyses should also consider policy drivers and market impacts on the development of AJF pathways. More specifically, these analyses should work to understand the value of AJF to airlines for fuel hedging strategies through biofuel utilization, particularly in sustained low oil price scenarios. The analyses that consider the market competition between AJF and on-road (diesel) transportation would further investigate additional deployment scenarios. Finally, to lower the cost associated with the pathways and for near-term deployment, these analyses should consider opportunities to utilize existing infrastructure, either through retrofitting an existing process or co-processing at a petroleum refinery.

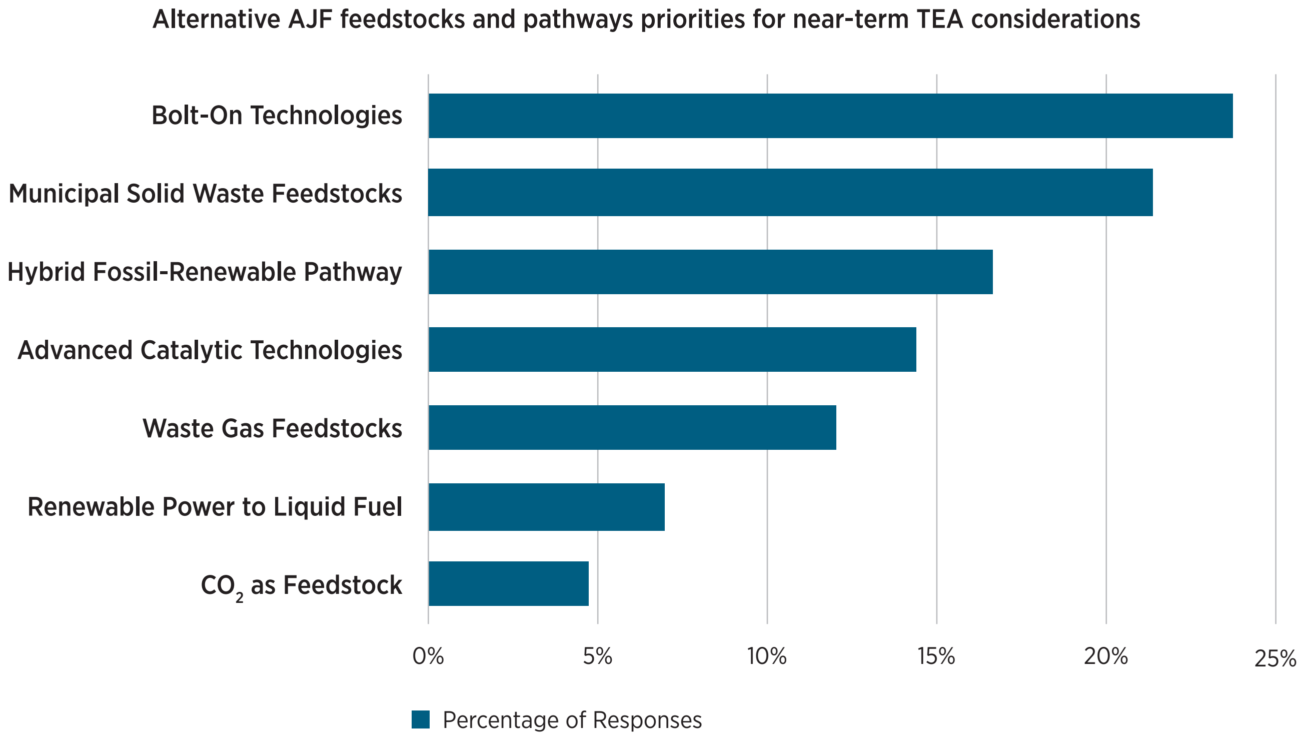
DOE was encouraged to further improve future TEAs by supporting development of evaluations, both new and ongoing, that (1) are harmonized and transparent in key assumptions (such as internal rate of return and financial assumptions) and (2) utilize reliable data (such as yields and on-stream considerations) for the analysis with a standard method for reporting yields that, at minimum, include mass balance and time on stream at reasonable operating rates.

One of critical gaps in TEAs is an understanding of the current cost of production for AJF. The group discussed studies that should be considered for current pioneer plant economics compared to N^{th} plant analysis. The participants suggested leveraging information gleaned from the development of pioneer plants for cellulosic and starch ethanol (and other industries) via a post hoc analysis. The group suggested that a full supply chain evaluation for near-term pioneer plants would enable more comprehensive investigation of feedstock drivers/solutions, infrastructure needs (including access to markets and roads, probability for feedstock or plant disruption due to weather, etc.), time-dependent considerations (such as competition for feedstocks due to multiple plant operations), and regional market considerations due to the location of the process facility.

One of the biggest challenges for moving AJF to deployment is bringing the fuel to the market; however, it can be challenging to assign a cost to the process. In future studies, fuels that could be utilized as examples of bringing new fuels to market could include E10, E85, biodiesel, methyl tert-butyl ether, and FT gasoline. Time scales can be built in (if they are not initially) to TEAs when considering plant construction and start-up time to better reflect the cost impacts associated with fuel certification. Additional market studies should discuss both who bears the substantial costs associated with the deployment process and the impact of policy drivers that could influence time to market, such as state-level incentives, dependent on the location of the process facility.

Given the very dynamic market and development associated AJF production routes, the group was asked to review potential near-term strategies for further TEA consideration of jet fuel production. The group identified the use of modular processes, such as microchannel reactor systems, and a range of potential feedstocks that could be employed for AJF production. As highlighted in Figure 2, the bolt-on technologies pathway and MSW feedstocks were identified as clear areas of interest for future consideration.

Figure 2. AJF feedstock and pathway priorities for near-term TEA considerations



The group discussed lessons learned from the ASTM pathway approval process, including the need to increase the speed and reduce the cost on the pathway fuel certification and approval process. The following points were noted:

- Interactions between the Renewable Fuel Standard (RFS) pathway approval process and ASTM approval process are unclear.
- Benefits to setting renewable volume obligations include outlining demand for fuel and supporting market and technology development. EPA could include anticipated volumes from companies that are expected to receive pathway approval and begin production during the compliance period.
- Challenges exist with the statutory terms (e.g., crop residue) and with getting pathways approved that were not contemplated at the time of enactment of the ASTM approval process. For example, it is unclear what is allowable as a feedstock, specifically regarding the definition of MSW.
- DOE needs to facilitate/support an effort to determine the required volumes of the fuel.

The group also reviewed potential policy vehicles or other mechanisms that could help move aviation biofuels to market faster. Specific incentives highlighted include investment tax credits, loan guarantees, an airport improvement tax, a global improvement tax, and tax credits to airlines that purchase bio-derived jet fuel.

Similar types of incentives have been either proposed or adopted in European airports, such as waivers for the EU emissions trading system, domestic CO_2 taxes, and reduction in landing fees for airlines that utilize a set amount of renewable jet fuel.

Additional suggested incentives include finding a way to valorize the impact of renewable fuels, including reducing criteria pollutants and improving water quality and biodiversity.

Discussion around policies and interagency collaborations identified the following points:

- Policies that drive the use of AJF are needed. Currently AJF does not qualify under the California LCFS; expanding the scope of the LCFS could help drive additional use.
- DOE is leading the effort with the California Air Resources Board to educate regulators on the impact that the current LCFS disincentive has on the aviation industry's ability to meet GHG-emission goals.
- AJF should be separated from diesel and marine fuels as defined by EPA. These fuels serve very different market sectors, and separating them would enable further development of AJF pathways.
- DOE could further develop interagency collaborations to help prioritize the purchase of aviation biofuels that meet a set GHG-reduction threshold for military and government aircraft, which would help move more technologies to industrial scale to meet demand.
- RINs should be considered for co-processing benefits in an existing petroleum refinery.
    - Current RFS regulations have a provision regarding RIN credits such that these credits are distributed only to the biogenic portion of the fuel based upon the biogenic portion's contribution to the fuel's heating value.
    - The group reviewed potential policy mechanisms to support the accurate estimation of RIN credits for co-processing of bio-derived intermediates. The need for more information by groups like EPA and the California Air Resources Board were highlighted as a potential area of support that BETO could provide.
    - There is a need for transparency of RIN valorization and a projection of future RIN estimates to support the growth of the AJF industry.

Recommended Next Steps

The close-out discussion for the first day focused on the future direction of tools and resources needed to support the development of aviation jet fuel. Opportunities, gaps, and data needs were identified for the near term, mid-term, and long term (see Table 7).

Table 7. Time Frame for Opportunities and Needs for AJF Development

Near Term (2020)	Owner
More process performance data are needed to develop a baseline for retrospective analyses in future.	
Additional data are needed to develop the current state of technology. Currently, the lack of data is attributed to the lack of operating facilities with advanced technologies: • Estimation of yields at larger scales • Process variability and upset data • Feedstock variation • Extended process operations and understanding stability of catalysts and other critical process components (thousands of hours) • Reliable capital costs, which are especially challenging when new technologies are being developed and process designs are uncertain • Catalyst lifetimes, on-stream factors, and regeneration protocols • Separations technologies required to meet fuel specifications • Flexibility of process to make other co-products (both fuels and chemicals) adapt to market conditions.	
Need a better understanding of indirect LUC. Specifically, there is a need for better land-use data and attribution of land use to different causes. This information may be available via U.S. federal agencies (such as USDA), the United Nations, and the Land Observatory that collects historical data. Modeling to help determine what is important and what is not for indirect LUC could be pursued using in-depth investigation into the Global Change Assessment Model and the Global Trade Analysis Project (and any global models).	
Need user awareness and education about models to connect the right model to the right questions.	
Need to understand the policy drivers of RIN prices so that they can be projected.	
DOE should take the lead on establishing criteria and methodology for developing analyses that utilize credible data with assumptions fully disclosed and that are presented using "harmonized" apples-to-apples comparisons. DOE should consider utilizing other approaches to estimating economics (such as including error bars).	DOE
DOE can also play a role in providing expertise and insights into technology and processes.	DOE
Adopt a common set of assumptions/criteria for defining sustainable sources of biomass feedstocks.	
There is a need for more publicly available and accessible (direct or otherwise) TEA and LCA tools, such as the process and economic design report studies and Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, for project-level development. DOE owns many process model designs and economic tools; currently they are not publicly available due to the complexity/limitations of software, although some models (e.g., GREET) are accessible. Need to enable the TEA models to be used indirectly via expert assistance, perhaps via the Small Business Assistance program (or similar vehicle). The program could also provide training to facilitate use of process design tools, if appropriate.	
In TEA development, there is a further need to reconcile top-down targets with bottom-up technology scenarios and to understand alignments and reconcile disparities.	

Table 7. Continued

Near Term (2020)	Owner
Use TEA to support the need for policy intervention (e.g., LCFS credit). Conduct outreach to policy-makers and regulators to demonstrate industry needs and further policy support to meet the FAA goal of 1 billion gallons of AJF. Further engagement of stakeholders could help to support the development of these efforts.	FAA
ICAO goals have to be populated by specific technology pathways; there are currently uncertainties in the mechanism to get these technologies to market.	ICAO
Mid-Term (2025)	**Owner**
Need global tax and/or cap-and-trade to help support the further development of AJFs.	
Support further public outreach and education for the development of AJF including benefits and drivers for these production strategies.	
Understand how markets have developed around the world to provide learnings for development in the United States.	
Long Term (2030)	**Owner**
Utilize carbon from all waste materials (e.g., biogas, industrial effluents, and flared natural gas) to produce fuels and chemicals.	
Need carbon removal from ambient sources (i.e., air and water).	

Fuel Conversion and Scale-Up

This session focused on the challenges that hinder the scale-up and commercialization of emerging pathways and the role DOE can play in aviation RD&D and scale-up of the production of biofuels and key co-products from bench scale to pilot and demonstration scales. Participants in this session worked through a series of questions and exercises designed to help identify the next steps that DOE should consider for initiating efforts in this topic space.

Summary of Discussion

The second breakout session focused on understanding the challenges that hinder the scale-up and commercialization of emerging pathways. Additionally, the participants discussed the role DOE can play in aviation fuels RD&D and scale-up of the production of biofuels and key co-products from bench scale to pilot and demonstration scales.

Although there are five current AJF pathways that have been certified and several other pathways in the queue for future certification, the participants of this breakout group identified more than 20 pathways for future consideration by DOE-BETO. These technologies ranged from direct conversion of biomass to AJF through traditional biochemical, thermochemical, and hybrid conversion strategies; bolt-on technologies for upgrading ethanol intermediates; and the use of established petroleum refinery infrastructure for fossil and renewable co-processing.

While the participants encouraged DOE to support the most promising of this broad range of strategies, the group recognized that given the lack of publicly available and/or reliable data for evaluation of these technologies, it is challenging to determine which of these technologies has the most promise. The participants encouraged DOE to support initial evaluations to obtain a set of baseline data for these emerging process strategies so that reliable and comparable evaluations can be developed.

The group also reviewed both the technical and non-technical barriers that have limited the scale-up of current AJF processes. The technical barriers ranged from (1) a lack of availability or access to equipment, low-cost feedstocks, capital, and experts for biofuel production scale-up to (2) the expense and time required to move a process through the ASTM certification process.

BETO was encouraged to continue to support the reduction of scale-up costs all the way from feedstock production through driving down the cost of conversion with R&D improvements. Furthermore, the stakeholders encouraged BETO to work with ASTM and other organizational groups to help streamline the certification process and reduce the burden for the approval requirements. For non-technical barriers, the participants highlighted the need for further public outreach and education on the benefits (e.g., societal and economic) and technical feasibility of AJF, the need for more consistent policies to further enable the development of a stable AJF market, and the necessity of reducing uncertainties in regulations to move more AJF fuels to the market.

Following the invited speakers, the initial discussion focused on the top technical and market barriers that hinder the scale-up or commercial production of lignocellulosic AJF highlights from the group are summarized in Table 8. These barriers were grouped in seven main categories: process equipment, process scale-up, ASTM certification, cost of production, feedstock demands at the biorefinery, moving fuels to market, and cost reduction drivers.

Table 8. Top Technical and Market Barriers for Scale-Up of AJF

Process Equipment

Challenges due to

- Inefficient equipment (reactors as appropriate scale and similar designs) with a need to reduce cost and improve overall efficiency and productivity
- Insufficient number (and cost) of integrated operations (such as reactor systems with appropriate recycles or linkages to separation strategies); more proven integrated processes would reduce risk and could improve investor confidence.

Process Scale-Up

Challenges require

- Ensuring the laboratory R&D is scalable and having technical knowledge on how to scale such processes
- Support for operational experience for these AJF strategies; improving experience would reduce risk associated with both scale-up and operations.
- Technical staff, particularly technicians, who are trained, experienced, and can support process scale-up
- Development of long-term operational data with real feedstocks to reduce the risk associated with scale-up and operability
- Early demonstration of integration of process steps prior to scale-up, as integration of these steps is where many significant technology challenges exist.

ASTM Certification

- For the fuels to be certified, a significant volume must be produced, and this is typically at a high cost. These costs and timelines are challenging for a business to meet the needed requirements for investors.
- There could be challenges associated with market acceptance of the new fuel.

Table 8. Continued

Cost of Operation

Limited economic viability of a process due to

- A need for the development of cost-effective catalysts with proven on-stream time
- A need to develop catalysts that can scale up from bench to commercial scales, as many catalysts proposed at the bench scale utilize expensive rare earth metal catalysts and are not scalable
- A need to improve equipment maintenance (such as recharging catalysts)
- A lack of availability of catalytic materials at intermediate scales. Lab samples are typically free or can be easily purchased and commercial samples can also be purchased. Anything in between is a challenge, particularly if it is a non-commercial material.
- A need for new and novel separation strategies, which are often one of the expensive requirements. Current strategies for separations are often adopted from the hydrocarbon/fossil industry and may not scale appropriately to the scale of a biorefinery.
- The high oxygen content of biomass, which means production and upgrading of oxygenated intermediates need to be cost effective
- Hydrogen management to produce AJF, which will be a key cost driver and impact the sustainability footprint of a biorefinery
- A need to develop feedstock agnostic-focused conversion processes. This approach could mitigate some of the risk associated with feedstock variability and market availability.

Feedstocks to Biorefinery

- Feedstocks currently available to the market are primarily farmed materials. Other materials, like MSW, have limited availability for scale-up.
- There are challenges associated with feedstock specification variability to meet biorefinery requirements, typically resulting in difficulty with the process handling as well as yield impact due to this variability.
- Logistical challenges also exist, ranging from handling, to storage, to variability, to prep, because the infrastructure for this supply system is very limited to niche markets. There is a need to expand these supply chains to support the development of the industry.
- Due to the lack of availability, feedstock prices are very high, which negatively impacts the conversion process economics.
- There is a clear need to support the building of these feedstock markets.
- There is a demand for clean, cheap sugars. There is a need to drive down the cost of cellulosic sugars to be more cost competitive with commodity starch-based sugars.

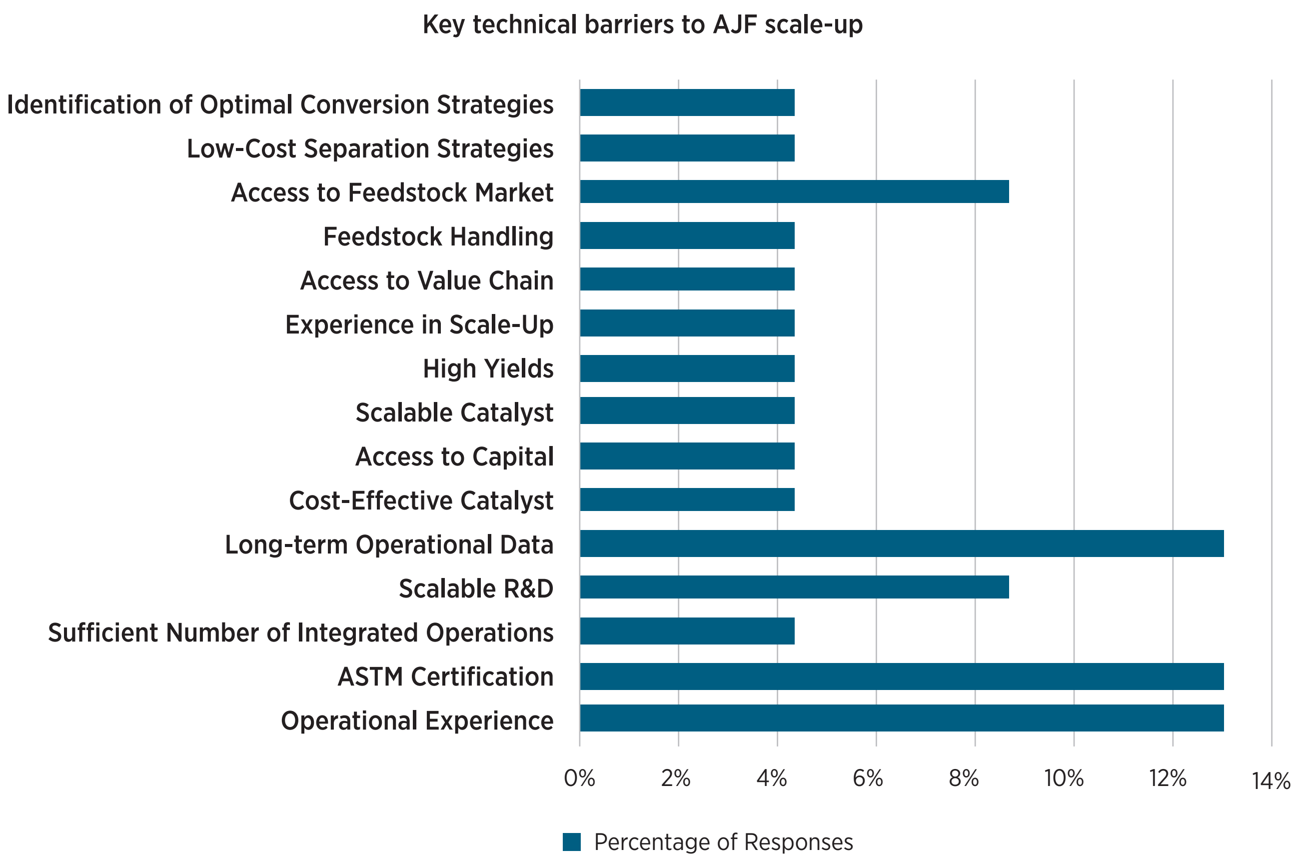
Moving Fuels to Market

- The industry is risk averse, and access to capital can be challenging without the appropriate data in hand at sufficient scales.
- There is a need to develop a better mechanism to access the fuel value chain. BETO and other government entities could help stakeholders (industry, government, and others) achieve common goals for AJF.
- There is a lack of understanding about molecules that can be used as drop-in replacements, specifically for jet fuel, given their very rigorous and detailed standards.
- There is a need to educate airlines and stakeholders on the technical feasibility and performance benefits of alternative aviation fuels to help stir investment and drive down risk.
- Competition with low-cost fossil fuels is an obstacle, as it will be hard to produce biofuels at prices that are comparable.

Table 8. Continued

Cost Reduction Drivers
• Markets should be developed for all product streams (no wasted carbon) to help improve carbon efficiency and better overall economics; the ability to respond to changes in the market is crucial. • For AJF to be successful, yields need to be high and need to maximize the amount of carbon that goes to product (which results in income). • Further studies are needed to understand the tradeoff amounts and the range of routes for production of AJF, including an understanding of economics, near-term potential, sustainability implications, and R&D needs. This could lead to easier standardization of transformational technology. • Alternative routes should be investigated, such as hybrid biological/chemical strategies and the enabling of the best, cheapest routes to final products. • Opportunities need to be developed to drive down cost through process intensification and integration.

Figure 3. Key technical barriers to AJF scale-up



As shown in Figure 3, the participants highlighted the key technical barriers that have limited the scale-up of AJF, including the cost and volumetric fuel requirements to meet with ASTM certification process, a lack of long-term operational data to help effectively scale up processes, and an uncertainty on how lab-scale data would scale to commercial-scale processes.

In additional to technical barriers, the group also discussed the non-technical barriers that have limited the scale-up of AJF pathways. These barriers were grouped into four main categories: education, policy, R&D, and financial investment for the growth of AJF pathways.

The key barriers as well as potential ways to overcome these barriers are reviewed in Table 9. Based on participants' feedback, the non-technical barriers were ranked (as shown in Figure 4) as key areas of near-term focus. These included developing more consistent policies to further enable the development of a stable market, improving the ASTM certification process to reduce time and expense for AJF approval, reducing the cost and improving availability of feedstocks for the biorefinery, and reducing uncertainties in regulations to move more AJF fuels to market.

Table 9. Non-Technical Barriers for Conversion and Scale-Up

Education

There is a need to gain further public acceptance on the technical feasibility of biofuels, particularly for AJF. This can be addressed by implementing the following potential solutions:

- Educate key stakeholders through existing opportunities.
- Enable development through strategic partnerships.
- Support the entire value chain to minimize risk associated with the development of AJF.
- Gain public acceptance on technical feasibility of biofuel.
- Risk aversion in the aviation industry has limited the development of fuels.

Policy

Uncertainty of policy associated with renewables has reduced confidence in investment.

- Uncertainty whether future carbon tax will further support the growth of the industry.

Regulatory uncertainty exists regarding whether and how an AJF will be certified.

GHG regulation/compliance is currently led by the government and could be improved if placed in the hands of independent certification (such as the EU's Renewable Energy Directive).

ASTM certification is a barrier for new fuels, particularly due to the amount of time and required fuel needed for testing.

- A possible solution would be to initially allow low blend levels and then increase the blending levels through a series of stage gate processes.

FAA approval process is focused on engines, not fuels.

- Adopt the Piston Aviation Fuels Initiative approach.

R&D

There is a lack of experienced operational personnel to commission and support the development of lignocellulosic facilities.

- Opportunities exist to increase learning through piloting and demonstration.

There is a need for operational features that are unique to biofuel facilities.

Lignocellulosic feedstock market is currently underdeveloped and current prices are too high.

- A need exists for acceptance by farmers to enter into new markets and new feedstock production strategies.

Competition exists for feedstock in other markets with other fuel production routes, such as diesel and wood pellets.

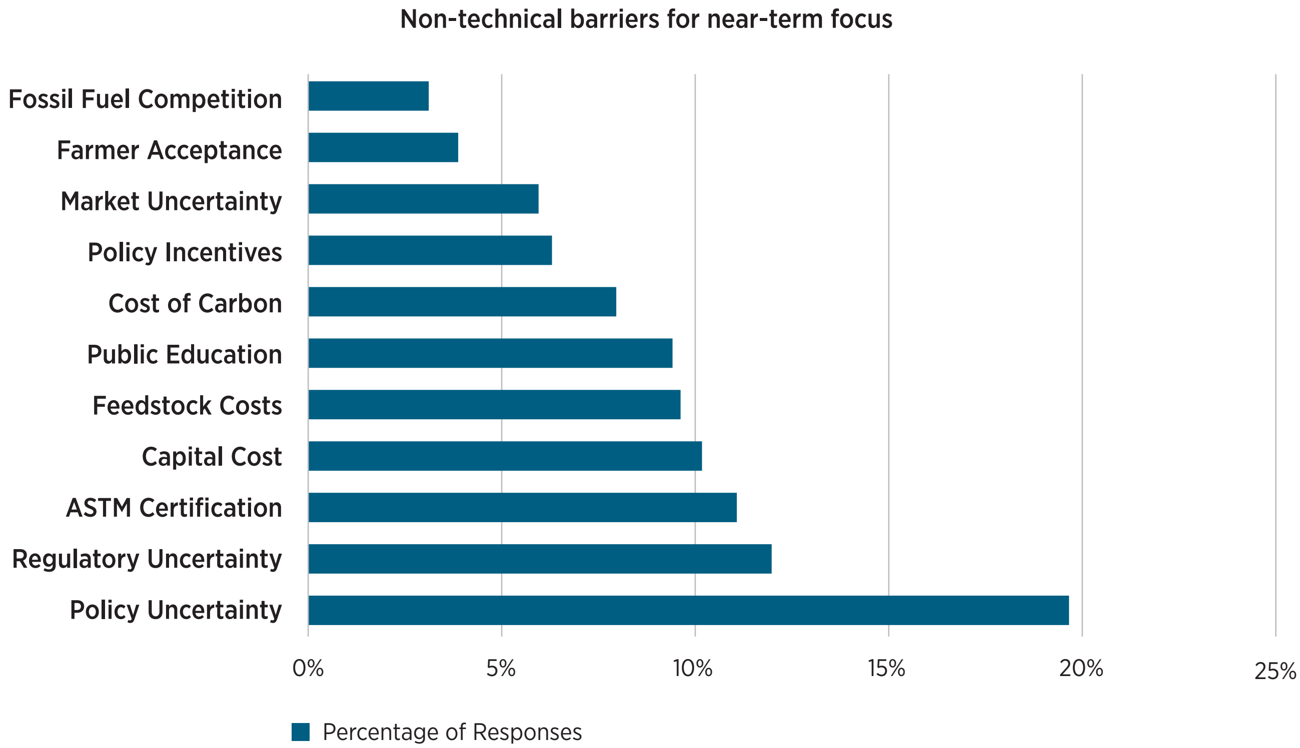
Financial Investment

There is a lack of financial support to develop truly disruptive technologies; these high-risk technologies reduce potential for investment.

High capital investment, required for many of these technologies, has limited investor interest.

- Develop technologies that are smaller scale and can be mass-produced (more like process skids).

Figure 4. Non-technical barriers for near-term focus

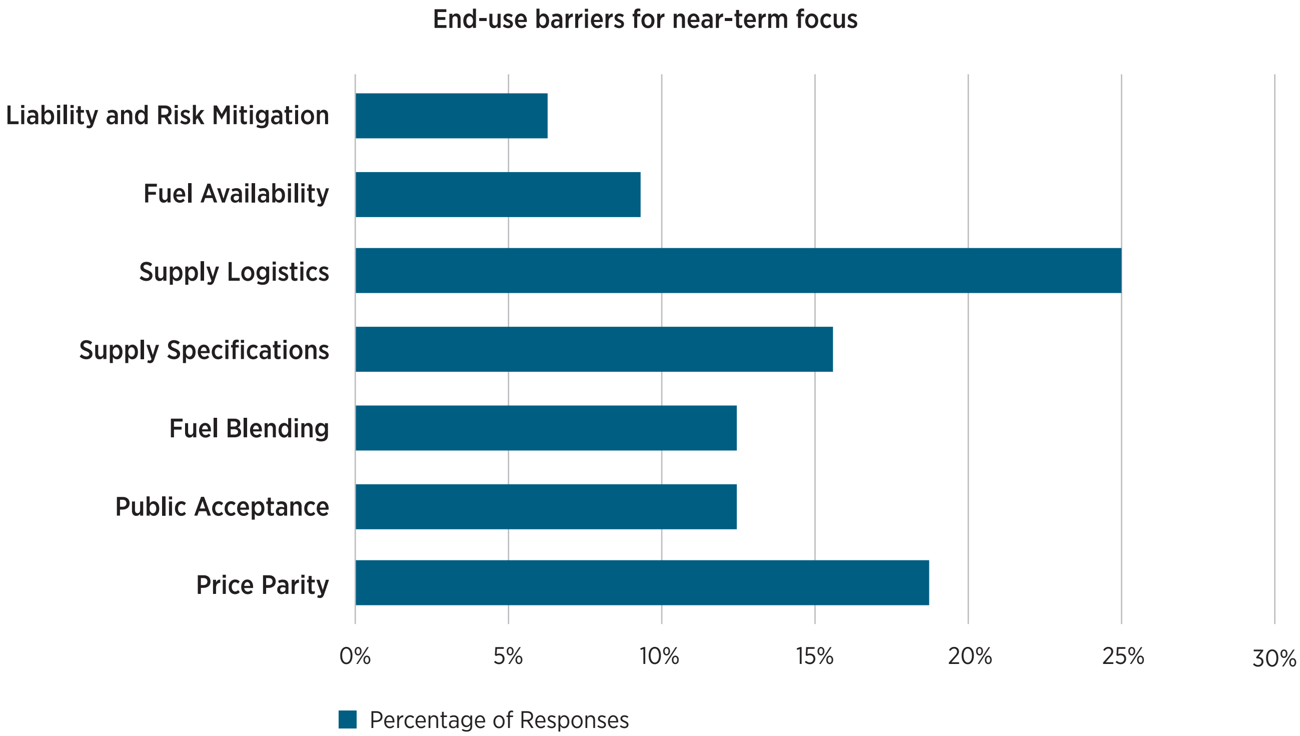


Based on the group discussions, the challenges related specifically to the end-user experience were highlighted as a key barrier. These barriers ranged from a need for cost parity to understanding blending and supply logistics to develop additional acceptance from end users. The participants reviewed these challenges in additional detail, as summarized in Table 10.

Table 10. End-User Barriers

Price Parity
Lack of current price parity for AJF when compared to fossil-derived products: • Could be supported by policy incentives • Not clear customer willing to pay premium for AJF.
Understanding the value proposition critical to garner acceptance from fossil refiners, including understanding the impact of blending AJF.
Supply Logistics
Need for tracking and potential database for all blendstock products
Potential cost for biofuel infrastructure at airports
Acceptance of alternative fuel in airport pipelines and hydrant systems
Port authorities allowing alternative fuel into their system
Supply Specifications
Stringent specification requirements for military applications; potential need to remove access; additional need for more producers to have access to submit to the Defense Logistics Agency procurement process
Fuel Blending
Blending logistics (including handling, blending, transport, and accounting for RINs): • Work with fuel producers and airports on proper handling and blending methodology • Work to ensure proper fuel handling processes followed.
Public Acceptance
Uncertainty of public acceptance of a new fuel while flying
Need education and improved awareness to support the private jet owners for adoption of AJF
Fuel Availability
Limited experience with producing fuels and a need to develop trust that supply and specifications are consistent
Liability and Risk Mitigation
From the aircraft manufacturers' perspective, demonstrating technical feasibility will be key: • Unwilling to accept liability for impacts that AJF might have on engines • Need to develop a risk mitigation strategy for AJF acceptance.
Need for airline end users to further support adoption of biofuels: • Overcoming negative public impression of biofuels will be critical for acceptance. • Global consistency in requirements and incentives will help to further expand the demand for AJF. • Cost competitiveness with fossil-derived jet fuel will be key; airlines do not want to pay more for fuel nor does the industry want to pass the cost on to customers.   - There is a need for continuation of policy incentives. • As more AJF becomes available, there is uncertainty in the supply chain and airport logistics.

Figure 5. End-use barriers for near-term focus



When asked to rank the various identified end-user barriers (as illustrated in Figure 5), the group noted these challenges to address in the near term:

- Build and make available a consistent supply of AJF. Focus has been directed more toward fuel certification; now that there are five approved pathways, there is a need to build up the production of these AJF pathways.
- Reduce the cost and move biofuels toward price parity of fossil-derived jet fuels. Customers will not be willing to pay a premium for fuels. Policies can help to drive down cost, particularly in the early market development stage, to help to establish cost-competitive production strategies.
- Support the education of both the public and stakeholders to further garner acceptance for AJF. This includes demonstration of technical feasibility of these fuels.
- Gain acceptance by customers, primarily the airlines, to build the market and demand to enable further development and private investment in AJF.

While five pathways have already been certified, the group was polled on what they felt were the next emerging pathways; a summary is listed in Table 11. These pathways range from co-processing in existing petroleum refineries to developing bolt-on technologies to expand the production of AJF from starch-based and lignocellulosic alcohols to a range of hydrocarbon production pathways.

Table 11. Potential AJF Conversion Pathways

Co-Processing and Co-Production
Co-processing in conventional petroleum refineries by upgrading bio-derived intermediates: • Developing opportunities to utilize existing infrastructure could drive down cost of biofuels. • Current pathways are under development by a number of refiners. • Mixed methane and biomass processing could provide opportunities to maximize hydrogen utilization for jet production while still meeting GHG target reductions for advanced biofuels.
Explore the co-production of aviation fuel with other transportation fuels (diversify portfolio in biorefinery).
Expand the concept to IBRs (feedstock agnostic).
ATJ
ETJ: • Assist scale-up of bench- and pilot-scale facilities that have demonstrated techno-economic viability and ability to meet technical specifications of ASTM (short-term timeframe) • Need ASTM testing approval • There is potential for DOE support by leveraging existing assets to support testing needs. • Potential bolt-on technology could result in near-term delivery to marketplace and more straightforward/ lower-cost scalable entry to renewable jet fuel. • Need funding for fully integrated demo to de-risk for at least 2 years of operation before scaling up.
ATJ with additional upgrading to SPK: • Modify ATJ route that could produce a blendstock that can be incorporated at a higher volume percentage • Explore new DPA Title III funding • Need more funding for the National Jet Fuels Combustion Program through FAA and others • Help EPA to move pathway approvals faster through the system for AJF (resources).
ATJ with additional upgrading to SPK/A: • Explore ATJ/synthetic kerosene with aromatics (ATJ-SKA), an expansion of ATK-SPK iso-butanol • Expand testing on ATJ-SKA from the FAA Continuous Lower Energy, Emissions, and Noise program • Provide aromatic content missing in ATJ-SPK pathway and allow for a higher blending opportunity • Secure ATJ-SKA funding.
ATJ (mixed alcohols): • Extend ETJ catalysts to thermochemical mixed alcohol synthesis; 5- to 7-year timeframe with sufficient funding • Focus on ranges of alcohols to produce odd and even chain lengths; may produce a fuel that can be blended at a higher level • Develop catalysts to improve branching; could also increase blending potential by improving cold flow properties that limit most straight chain hydrocarbons.
Pyrolysis/Hydrotreating
Pyrolysis and hydrotreating: • Process has the potential for high-carbon-yield pathways. • Process aligns with the BETO support pyrolysis hydrocarbon pathway (per the Multi-Year Program Plan [MYPP]) as well as routes towards refining integration. • Selective hydrodeoxygation is critical for meeting fuel requirements to limit oxygenated species in fuels.

Table 11. Continued

Pyrolysis/Hydrotreating
Catalytic fast pyrolysis: • Expected timeline is 5–10 years. • Process aligns with DOE-BETO hydrocarbon pathways (per the DOE-BETO supported design reports as outlined in the MYPP). • There is potential for easier product separations with production of low oxygenated fuels. • There is a need for new catalyst development. • Process scale-up considerations need to include variations for traditional fluid catalytic cracking processing due to higher solids throughput, higher catalyst loading, and coke considerations: - How to maintain heat balance - How to deal with excess char, particularly in start-up.
HEFA-plus (Green Diesel): • Additional support to produce volumetric fuel required for testing will be required. • Process will provide positive support for ASTM efforts.
HTL and hydrotreating: • Pathway is appropriate for wet biomass feedstocks, such as wastes. • Longer-term development needs DOE support as a research opportunity. • Algae application for high yield from whole algal biomass should be explored. • Process is similar to pyrolysis; selective and robust hydrodeoxygenation is critical for meeting fuel requirements to limit oxygenated species in fuels.
Microbial Production
Explore potential of direct microbial production of hydrocarbons from sugar (beyond currently certified hydroprocessed fermented sugars/synthesized isoparaffins).
Microbial production of lipids with subsequent upgrading of lipids to jet fuel: • Process aligns with ongoing BETO-supported hydrocarbon pathways work (specifically the biological conversion of sugar pathway outlined in the MYPP). • Additional work is being investigated by USDA.
Direct microbial production of long-chain hydrocarbons from methane: • Process is a potential waste-to-energy pathway. • Process requires additional development of both organisms (methanogens) and reactor/process design to enable high yields. • Primary focus of methanogens has been the focus of chemicals rather than fuels (polyhydroxyalkanoates).
Biological Production/Conversion
Biological production of small bio-derived molecular building blocks, followed by chemical catalytic condensation: • Explore early TRL to utilize known and viable small molecule production products via anaerobic fermentation (e.g., acetone, lactic acid, etc.) • Focus on catalytic upgrading of intermediates to build branched hydrocarbons • Need to understand completion of bio-derived intermediates relative to chemicals market.
Biological CO_2-to-fuel conversions: • Process provides an opportunity to utilize waste stream for production of fuel. • Explore optimization and development of known organisms (e.g., CO_2 to isobutanol) • Syngas fermentation is another potential route.

Table 11. Continued

Fischer-Tropsch
Jet-selective FT may not fit in existing pathways: • Hybrid FT/zeolite catalysts do not make long-chain waxes that need hydrocracking and hydroisomerization. • It is unclear at this time if pathway fits into ASTM D7566 - 16b (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons), which assumes FT then hydrocracking/isomerization. • Pilot-scale studies are necessary to produce sufficient product for evaluation as SPK. • Process has the same issues as other SPK or SKA: extensive and expensive characterization needed to confirm product meets ASTM specifications.
Catalytic Conversion of Sugars
• Process passed the Tier 1 and 2 approval process and is pending volume production for further testing. • BETO could help support the production volumes for Tier 3 and 4. • Biobuilding blocks developed from robust biological pathways can be used to make highly branched hydrocarbons. • Process can encompass a range of catalyst development work (better, faster, more robust, etc.). • Process could fund 10,000 gallons of production.
Microalgae Feedstock
• Red seaweed has a high carbohydrate content and should be sustainable and easy to harvest. • This could also be included in HTL development, wherein all the biomass structures are converted, not just carbohydrates.
Homologation and Oligomerization
Low-temperature dimethyl ether homologation and oligomerization: • Process roughly 5 years away • Explore catalyst development, scale-up, and volume production • Promising new pathway but needs DOE support.
CO_2 Utilization/Solar Fuels
Process has the potential for cross-agency collaboration, such as with the Office of Fossil Energy ($20 million).

Based on this large number of pathways, the participants responded to questions about scale-up challenges specific to the conversion strategy. These challenges were grouped into five key areas: further finance and investment to help scale-up more AJF processes, better defined metrics and data required to support the scale-up, knowledge and expertise of scale-up itself, additional analysis to understand near-term and future potential economics and sustainability, and the need for further training for personnel to be qualified to scale-up AJF processes. The challenges and needs that were identified for all of the pathways are summarized in Table 12.

Table 12. AJF Pathway Challenges

Finance and Investment

Support for scale-up and developing opportunities for affordable capital via both grants and low-interest, high-risk loans:

- There is an opportunity for interagency support/collaboration to support scale-up.
- Grants and loans could be provided to build pilots and demos.
- Loans for commercial plants are needed.
- Cap-and-trade programs could use the funding to capitalize on projects.

Funding to support running processes to develop needed information to obtain support from investors:

- A minimum of 1,000 hours is suggested (USDA requires 500 hours of operation).
- Fund fully integrated processes to collect data required for scale-up.
- Fund fully instrumented reconfigurable pilot units for process and catalyst testing.

Patient capital:

- DOE could support cost share to reduce risk and moderate industrial tendency toward too-quick transitions.

First plant should be brownfield/bolt-on to reduce capital expenditure:

- Subsequent plants should be designed from the ground up to get the best efficiency for the lowest long-term production cost.

Lack of availability of low-cost feedstocks:

- Need feedstock with low impurities
- Support runs to understand how feedstock impurities/off-spec material affects processes.

Determine the technology risk insurance for first units.

Develop a technical framework for risk assessments.

Data and Metrics

Clearly defined metrics as stage gates for each step in the scale-up process:

- Scale up a specific technology that meets performance metrics (do not modify catalyst/process while undergoing scale-up)
- Set stage gates that are flexible to allow for process to evolve

Support for process operation optimization tools:

- Need data before tools can be effectively developed
- There is a potential to integrate development of tools with data developed from fully integrated process.

Scale-Up

Collective scale-up knowledge/scaling relationships could be established via consortium development.

Scale-up varies from very small scales (1 gal/day) to large systems (1 million gal/day).

Biorefining industry lacks large-scale expertise.

Table 12. Continued

Techno-Economic and Life-Cycle Analyses
Preliminary initial economic analysis is needed to give a feasible/non-feasible process prior to full TEA/LCA.
Need to have more developed TEAs and LCAs to understand the current state of the art as well as the potential of these technologies
BETO support is needed for the development of standard guidelines for preparing TEA/LCA on a consistent basis.
BETO support is needed for the development of baseline data required for TEA/LCA for comparison.
Plant Personnel
Need experienced operators/engineers from other industries such as petrochemicals, power, and liquefied natural gas to support scale-up: • A DOE program is needed that allows biorefining industry to pull in this specialized expertise more effectively. • DOE could provide/develop a much more detailed database of lessons learned from failed ventures.

When considering specific technologies to further enable the industry, the group highlighted a few key topics in each type of conversion pathway. Since many biochemical processes have been scaled and are operating on lignocellulosic feedstocks, the group suggested sharing lessons learned from scaling these technologies. For thermochemical conversion technologies, the participants highlighted the need for further development of these processes. Additional details are summarized in Table 13.

Table 13. Summary of AJF Conversion Technologies Challenges

Biochemical Processes
Because many of the lignocellulosic ethanol facilities are primarily focused on biochemical conversions strategies, there are opportunities to learn from the scale-up of these facilities: • Support industrial stakeholders by sharing lessons learned from these scale-up efforts • Develop improved and thorough risk mitigation programs and lessons learned from other industries.
There is a need to consider co-product opportunities (as either fuels or chemicals) to help drive down costs.
Build a plug-and-play demonstration-scale unit that can scale up the technologies, such as the one built by the Air Force Research Laboratory: • There is flexibility to plug and play with different reactor systems to run different technologies. • Consider different front-end systems at a 200–500 gal/month scale.
Thermochemical Processes
There is a need to develop more adequate small-scale operational facilities to develop required data for further investment: • Need to fully fund at required levels of scale-up • Don’t skip steps (approximately 10 times scale-up per step).
Fully integrated pilot data needs to be developed: • Support funding for extended tests • Support funding for pilot plant construction • Support fuel characterization for ASTM standards.

Table 13. Continued

Thermochemical Processes
Similar to the biochemical process, co-products could help drive down the economics of the integrated process.
Bolt-On Strategies
There is potential to reduce capital by leveraging/tying into infrastructure that is already developed (utilities, wastewater treatment, etc., for a process).
Need to understand integration potential
Need to develop positive LCAs and TEAs for the entire integrated process
Support needs aggressive funding to help support investment.
Suggest to government agency to support grants and low-interest, high-risk debt and equity to support initial demonstration until market can be developed for technology
Hybrid Processes
Both biochemical and thermochemical factors can be applied.
Catalyst performance over extended time: • Need to prove and demonstrate regeneration and catalyst robustness.

Recommended Next Steps

The close-out discussion for the first day focused on future directions to support de-risking the technology to further support the commercialization of aviation jet fuel. Opportunities, gaps, and data needs were identified for the near term, mid-term, and long term (see Table 14). For near-term opportunities to support additional deployment of AJF, a focus towards increasing funding for R&D, developing stabilizing policy, and increasing availability to jet fuel offtake agreements were all expected to potentially attract additional investment. In the mid-term, participants suggested that focusing on additional stabilizing policies and support for the development of high-quality data on fully integrated processes at small scales (for new technologies) would grow the industry. For long-term consideration, participants suggested that developing programs that allow the co-optimization of fuels and aviation engines and providing further support for developing long-term contracts would also support growth and development.

Table 14. Resources Needed to Support De-Risking AJF Technology and Commercialization

Near Term (2020)
Investigate the value of co-products: • Improve economic viability of a process with low-volume/high-value products • Choose funding processes that are economically viable rather than solely focused on the production of AJF • Consider both economics and sustainability when evaluating co-product impacts.
Support stable policy environment with incentives: • Continued support of Renewable Fuel Standard 2 (RFS2), blender's tax credit, and LCFS • Consistent policy to stabilize investor uncertainty by building out viable market pull for AJF.
Support streamlining of the ASTM standardization process: • Determine a baseline property-based profile that new pathways must fit; allow for greater approval of fuels • Even the playing field for analysis of fossil and biofuels.
Focus research dollars on economically viable pathways: • Begin early technology development to avoid costs of nonessentials • Consider diversification of pathways that utilize a range of feedstocks • Prioritize funding based on strength of TEA and LCA at bench and pilot scales • Avoid pathways that do not have a strong business case and/or a strong sustainability profile • Embrace risk by quantifying probabilities for scaling each pathway based on evidence and expert judgement.
Develop analytical techniques for AJF that are applicable to feedstocks production: • Replacing outdated techniques and/or modifying techniques specific for fossil feedstocks • Models to more accurately make predictions.
Continue to support access to capital and funding: • Support the appropriate approach of scale-up without skipping steps in the process (from pilot to demo to commercial) • Prove out steps from bench scale through to pilot and commercial scales. Necessary steps cannot be skipped, even if pressured to do so, or the consequences (as has been demonstrated many times) could result in the failure of a process to work appropriately.
Stimulate development of risk insurance mechanisms
Support the logistics and infrastructure readiness for biofuel at scale: • Includes the development of more feedstock supply availability and potential agreements.
Develop mechanisms to enable further offtake agreements: • Airlines make real investment to encourage the progress of the industry • Equity from airlines helps to de-risk investment for lenders and capital markets.
Continue to improve interagency cooperation: • Interagency funding of shared assets to both develop and test fuels. • Relevant agencies include USDA, DOD, DOE, and EPA.

Table 14. Continued

Near Term (2020)
Require both a qualitative and quantitative understanding of uncertainties to address when de-risking: • Create a portfolio of quantifiable risk elements to clarify actions to be taken • Conduct workshops that provide participants with the guidance needed to apply the process and tools of the decision sciences. • The goal is to quantify the amount of uncertainty (risk) for each technology pathway based on key decision criteria. • Fully integrated pathways consist of sub-elements that are common across each pathway. There will be elements that are unique and mutually exclusive. The total sum of all identifiable uncertainties across each pathway presents its risk profile. • Develop risk profiles (identified by workshop participants) that are measured in terms of cost, time, and other utility values • Workshops should be facilitated by experienced decision consultants in a high-feedback environment. Participants can work to create a hierarchy of elements to address. These elements should be ranked based on near-, mid-, and long-term decision needs. • A critically important skill in risk analysis is assessing information that is both meaningful and reliable. • Conduct interviews with subject matter experts who have the content knowledge needed for each technology pathway to obtain probabilities and ranges as appropriate. • The output of this process can be used to prioritize actions from least to most risky.
Mid-Term (2025)
Support policy adaptations: • Government must take steps to enable manufacturers to keep moving forward. This could be supported from funding as well as policy, which brings more fuels to market. • Develop performance-based incentives • Create government incentives for industries (not just companies) that reduce GHG emissions • Support the development of more approved processes.
Develop initiatives and mechanisms that enable end users and fuel manufacturers to collaborate more frequently
Support a more streamlined ASTM process to reduce cost and fuel requirements and speed up certification timeline
Enable access to feedstocks that meet quality specifications
Support the development of high-quality data on fully integrated processes at small scale (for new technologies)
Develop models relating jet fuel composition to performance on currently required tests
Long Term (2030)
Develop programs that allow the co-optimization of fuels and aviation engines: • Co-Optimization of Fuels and Engines (Co-Optima) for aviation • Opportunities and mechanisms for greater interaction between AJF producers and aviation engine manufacturers.
Develop a balanced portfolio between transformational technology development and incremental technology improvements
Support the development of long-term agreements

Environmental and Sustainability and Life-Cycle Benefits

This session focused on the challenges of developing a more comprehensive and comparable set of GHG LCAs for a full family of AJF production concepts. Participants worked through a series of questions and exercises designed to better understand LCA challenges and the roles of DOE and industry in this effort.

Summary of Discussion

Participants in the third breakout session discussed the challenges of and the need to develop a more comprehensive and comparable set of LCA studies. Despite the many studies in the public domain and the peer-reviewed literature for a range of AJF strategies, estimated sustainability metrics (primarily GHG estimates) are not consistent due to wide variations in the assumptions that are utilized in these analyses.

Similar to the feedback in the "Enhancing the Economic and Technical Competitiveness of Aviation Biofuels from Lignocellulosic Biomass" breakout session, the third breakout group outlined the need for further support from BETO to develop a consistent approach to analysis. Furthermore, participants identified a need to evaluate the implications of assumptions around "upstream" elements of the life cycle (e.g., fugitive methane emissions for natural gas production that impact the overall electricity and hydrogen production GHG profile) and outline the appropriate time scale for assessing impacts of GHG emissions (100 years, 20 years, etc.).

The impacts of co-products and LUC (both direct and indirect) are areas that affect LCA estimates and were recommended for additional consideration for more consistent studies. The participants encouraged not only the development of both these sustainability and economic analyses, but also the publication of the tools for these assessments to support the stakeholder community.

Following the invited speakers, the initial discussion focused on uncertainties of LCA evaluations for AJF production via FT and HEFA, which are both commercially available production strategies (see Table 15). Specific gaps ranged from additional analysis needs and data required to support these analyses to a need to consider LUC issues.

Table 15. Gaps and Uncertainties Sustainability for HEFA and FTJ Pathways

Land-Use Issues

Direct and indirect LUC both were highlighted, particularly when considering the range of HEFA feedstocks:

- Additionally, when considering HEFA production strategies, participants questioned which specific oil seed crops and scales would be available for these feedstocks.
- Indirect LUC uncertainties were ranked as the number-one concern among the participants.

Analysis

For FTJ, the participants highlighted uncertainties in scales and the LCA for forest feedstocks.

Consistency is key for comparable LCAs:

- Overarching themes about the importance and implications of assumptions around "upstream" elements of the life cycle (e.g., fugitive methane emissions for natural gas production that impact the overall electricity GHG profile) were reviewed.
  - Both pathways will require hydrogen in upgrading. The viability of non-carbon-based hydrogen sources, considering logistics of production capacity and time, were noted.
  - The participants suggested a potential coordination with DOE's Hydrogen and Fuel Cells Office to understand synergies and consistent assumptions between the biorefinery and hydrogen production systems.
- Developing consistent methodologies will be necessary.
- Defining boundary conditions will be necessary.
- It will be necessary to outline the appropriate time scale for assessing impacts of GHG emissions (100 years, 20 years, etc.).

There is a need for independent or third-party experts to conduct analysis:

- Producers who conduct their own LCA could potentially be biased.
- Request supporting details on the data availability and tests on the quality of fuel from producers.

Data

There is a need for methodologies to handle differences in data quality for results that are generated for lab-scale, pilot-scale, and mature industries.

- Understanding of residue removal practices by landowners.

Many of the underlying uncertainties and gaps outlined for FTJ and HEFA conversion strategies were also identified for emerging pathways, including LUC considerations, consistency of methodology, and impacts of assumptions, particularly for upstream production. Additionally, given the early maturity of these technologies, participants highlighted the lack of data, ability to compare data on a range of scales, and concerns about data quality (particularly for yield considerations). Further, for these new pathways that have not undergone certification, understanding the amount of AJF that can be blended with petroleum to meet fuel specifications could also influence LCA considerations.

Finally, for the new technologies, identifying the tipping point where a "waste product" with no embodied environmental impact is identified as a co-product will be critical for IBRs.

Like the uncertainties outlined above, the identified data gaps were between established pathways (HEFA and FT) and new emerging pathways. As highlighted previously, the need for methodologies to handle differences in data quality for results that are generated for lab-scale, pilot-scale, and mature industries is both critical and potentially more uncertain for these emerging technologies. Additionally, depending on the stage of development, there will be uncertainties in yields of both the conversion process and feedstock production, as well as uncertainty of the overall design, including energy usage and fossil demand that will influence the LCA.

Participants discusses various estimates on the potential amount of AJF that would be needed in the near term, with the overall benefits for the expansion of AJF production. Competition for resources could also potentially impact the range of products that can be produced from biomass.

Table 16. AJF Expansion Benefits and Consequences

Potential Benefits	Potential Consequences
Stimulation of rural economic development	Increased feedstock cost, which would also be a way to increase supply of feedstock
Emissions reductions in aviation	Potential to increase feedstock production through direct or indirect LUC (extensification)
Energy security and GHG benefits	Stimulation of production intensification
Low sulfur emissions and lower particulate emissions	Potential increase in end-product pricing and price variability and potential impact to continuity of supply if inadequate feedstock is available
Multiple pathway opportunities to build infrastructure for biorefinery and high-value co-product development	Change from a contract product to a commodity
Increase of crop rotation diversity and associated ecosystem services	Risk reduction for producers by creating more flexibility in the market and opening up more opportunities for sale
Potential for regional production and consumption	Increase in demand, which incentivizes increase in supply and growth of the market
Contribution to public (and global) exposure of alternative, more-sustainable fuels	Development of more efficient production systems
Better understanding, valuation, and more in-depth understanding of bioresource production	Possibility that the most economically competitive pathways may not be the ones with the best GHG benefits (dependent on policy incentives)
	A premium and scaling based on quality and/or source
	Import of resources versus export
	Resource consumption, such as water consumption

LCA can capture some of these competition considerations by

- Incorporating social and economic parameters and impacts
- Evaluating the tradeoff between GHG reductions and economics to consider the different competitive aspects for each technology route
- Using energy allocation instead of displacement to allocate energy among co-products
  - AJF facilities produce a range of fuel products (e.g., jet, diesel, chemicals, gasoline, and power), so each facility has a choice of competition (e.g., facilities making HEFA will vary the amount of diesel that is produced relative to jet fuel).

When considering the range of conversion options and feedstock options, the group was polled to see if the right mix was available for optimal GHG-reduction impact. The group noted that one of the challenges of LCA is defining the boundaries and area of focus. The definition of "right" will vary by the region being considered and the resources that are in that region. Further, there is a need to consider all three pillars of sustainability—economic profitability, environmental sustainability, and social acceptance. The optimal choice will not be based on GHG benefits alone. Participants in the group also noted that GHG emissions are not the current barrier for AJF. Rather, the key barrier is economic viability of many of the pathways.

Given that most of industry utilizes a different method for sustainability analysis than EPA and the national laboratories, the results from LCAs can be drastically different and are dependent on the methodology used. The participants suggested that if the goal is to understand the relative ranking of technologies, then these differences are acceptable when applying a consistent method within a policy.

The group did note that one of the biggest challenges is that software tools are often expensive and complex, and it is unclear which methodologies are utilized for aspects of co-product allocation. Further, each software package has its own different database, and thus there is a clear need for data exchange and reconciliation among models and software.

Finally, to overcome inconsistencies, the participants suggested that BETO support the creation of a very detailed traceability protocol for each component within the biochemical/bioproducts production. For these protocols, BETO could support the development of more pathway examples that focus on making the same product. These studies could provide details on a consistent methodology for LCA development.

The group reviewed the modeling methods that have been developed and used to measure indirect impacts on the production of biofuels in general and AJF in particular (e.g., competition between feedstocks, food, market, land use, and land change). Table 17 provides a summary.

Table 17. LCA Modeling Methods and Key Assumptions to Consider

Gaps in Current Models
Data and underlining relationships in computable general equilibrium models need further improvements and enhancements.
Macro-level models can capture the general dynamic but may not be representative of micro-level dynamics.
Global Trade Analysis Project, Forest and Agricultural Sector Optimization, and Food and Agricultural Policy Research Institute models can benefit from each other's advancements in the past 8 years.
Efforts are needed to combine LCA and macro-level economic/ecological models.
Indirect effects should be addressed equally for baseline jet fuels and AJFs.
Land-Use Issues
The data required for indirect LUC calculations for emerging feedstocks are poor; this needs to be improved.
Additionally, knowledge of LUC should be used to carefully examine feedstock production practices that will not lead to LUC (including yield increases, multi-cropping).
Roundtable on Sustainable Biomaterials, a voluntary certification scheme, in collaboration with stakeholders, has developed a method by which to measure indirect LUC. • It is important to understand feedstock production that will not lead to indirect LUC; the Roundtable on Sustainable Biomaterials has a method for this, too.

The group further discussed methods to distinguish co-relationships and causal relationships between biofuel demand and LUC. Responses included the following:

- Develop regional hypotheses and ways to test correlations to determine causation
- Initially determine correlation using statistical analyses; take into consideration that all other factors causing LUC would have to be proven false
- Utilize stakeholder inputs and surveys to determine the credibility of data for analysis
    - LUC affects biofuel demand by steering industries away from certain feedstocks (e.g., palm oil because of its impact on wildlife).

While participants expressed uncertainty about whether LCA tools could investigate the causal relationships between biofuel demand and LUC or whether an analysis for computable general equilibrium models was more appropriate, participants noted that these relationships will vary by region and that LUC and biofuel consumption relationships will be non-linear.

During the production of AJF using a combination of renewables and fossil inputs, it is necessary to consider the minimum GHG performance criteria. The LCA results will be dependent on methodology, audience, and the goal of the analysis. If the overall goal of LCA is to understand GHG reduction relative to fossil-derived jet fuel, the feedstock source consideration should have minimum impact when included in the analysis.

Additional metrics for sustainability beyond GHG were considered, as well as how these values would be evaluated and quantified, including the following:

- **Noise** and the frequency of flights' overall impact density needs to be considered.

- **De-icing impacts** can be investigated via the composition of de-icing and its impact on stormwater runoff and use of industrial oil-water separators.
- **Exhaust emissions** that affect air quality (NO_x, SO_x, black carbon, hydrocarbons, and CO) and climate change (CO_2, H_2O, NO_x, SO_x, black carbon, and aviation-induced cloudiness):
  - The relationships between aircraft exhaust emissions and air quality and climate impacts are very complicated and prone to uncertainty.
  - The level of scientific understanding associated with the climate impact of aviation-induced cloudiness is low to very low.
  - Models for impacts of contrail and aviation-induced cloudiness need to be developed and validated.
- **Fossil energy demand** can be quantified by standard GHG methodologies.
- **Materials** that the plane and its interior are made of (e.g., plane body of recycled materials and seats made of recycled textiles) should be considered.
- **All packaging** materials for in-flight food, food sources, plastic cups, "emergency" brochures, and other in-flight support items must be evaluated.
  - A checklist for the various attributes of a plane and its operation could be developed for use by third-party auditors.

Participants reviewed the most promising pathways and highlighted the following:

- Co-production with petroleum, which is beneficial for leveraging existing infrastructure and capital
- FT routes, particularly with purpose-grown feedstocks
- HEFA with waste oil feedstocks
- Numerous emerging technologies and feedstocks that have not been certified by ASTM.

The group discussed the following critical factors that influence life-cycle energy consumption of aviation fuels:

- Regional differences and available resources
- Feedstock production
  - Sustainable management practices
  - Feedstock production logistics (gathering and preprocessing and transport)
  - Nitrogen fertilization that is detrimental to net energy balance
  - Minimal nitrogen fertilizer, soil maintenance, and rotation health are critical to long-term sustainability.
- Conversion process understanding
  - Requires good mass balance
  - Needs to use minimal fossil fuel resources (e.g., reuse process propane, close loops, and recover heat efficiently)
  - Hydrogen used for upgrading source.

Feedstock and Product Supply Chains

This session focused on challenges to developing a more comprehensive and comparable set of resource assessments for a full family of AJF production concepts. Participants in this session discussed the bounds of this topic space and worked through a series of questions and exercises designed to provoke thought and gather information relevant to the DOE mission and needs of industry.

Summary of Discussion

The fourth breakout session discussed the barriers to developing a more comprehensive set of feedstock resources for AJF production concepts. The participants identified more than a dozen viable feedstock resources for producing AJF; however, each of these feedstocks has their own associated challenges. Many of the feedstocks lack sufficient supply availability and—with limited demand for feedstocks due in part to policy uncertainty—scaling of these feedstocks has been limited. As these feedstocks are scaled up, a better understanding will be needed of the best production and harvesting practices, particularly for new and emerging feedstocks.

Following the overview of the speakers, the group discussion focused on feedstock challenges and needs. The initial discussion focused on the question, what are the viable feedstocks to produce AJF? The participants agreed that there would not be sufficient volume of oil extracted from oil seeds to meet out-year goals for AJF. This is primarily due to low yields of oil seeds from feedstock production, conversion, and limited market expansion. In addition, the oil seeds directly compete with food. There is a clear need to enable additional feedstocks, including renewable lignocellulosic feedstocks, to meet long-term demands for biofuels, particularly AJF.

There is an opportunity for BETO to support the development of best practices for feedstock production and to further support stakeholders through public outreach. These opportunities include having technical experts and crop consultants support and engage stakeholders for further development of new crops and best practices, as well as working with other organizations like USDA to further enhance feedstock development (e.g., improving yields and finding opportunities for double cropping to allow for efficient use of land and nutrients). The participants also encouraged BETO to share success stories of those who developed and implemented best practices to convince stakeholders to adopt such approaches rather than continuing in a business-as-usual approach.

As these feedstocks are produced, each conversion facility will require a better understanding of feedstock properties and how well a conversion process can handle feedstock variations. In addition, there is a need to demonstrate the storage stability of a broad range of feedstocks.

The group outlined the feedstocks shown in Table 18, with a focus on a range of feedstocks and potential conversion technologies where they were best suited. Production strategies that favor carbohydrate production via agricultural residues, perennial grasses, sugar beets, or herbaceous feedstocks in general were aligned with biochemical and most starch-based ethanol strategies, while woody feedstocks and waste streams were more closely aligned with thermochemical conversion strategies.

Table 18. Potential AJF Feedstocks and Conversion Strategies for Utilization

Feedstock	Potential Conversion Process for Utilization
Agricultural residues	• Both biochemical and thermochemical pathways • Bolt-on technologies for starch-based ethanol facilities
Perennial grasses and dedicated energy crops	• Both biochemical and thermochemical processes
Woody biomass (including forest residues)	• Thermochemical gasification and pyrolysis • Biochemical fermentation (with the appropriate pretreatment) • Hydrothermal processes
MSW	• Thermochemical gasification (including FT) and pyrolysis
High biomass sorghum	• Thermochemical gasification and fast pyrolysis • Biochemical fermentation routes
Sugar beets and sugarcane	• Ethanol fermentation • Biochemical fermentation pathways
Oil seeds	• HEFA and hydrotreated renewable jet pathways
Fats, oils, and greases	• HEFA and hydrotreated renewable jet pathways
Algae (high lipid-producing)	• HEFA and hydrotreated renewable diesel
Algae (all types)	• HTL
Sewage and manure	• Biogas-to-jet fuel pathway • HTL pathway
CO_2	• Catalytic conversion to small molecular synthesis • Heterotrophic algae production (to biochemical conversion)
Industrial flue gases	• Microbial conversion to platform molecules (such as syngas fermentation)

Based on the discussion, the feedstock barriers were grouped into five categories: production, distribution, scaling, conversion, and technology (see Table 19).

From the standpoint of production, there is a need to increase overall crop yields and develop sustainability practices to enable reduced nutrient and water usage. Additionally, the workshop participants noted a need for developing risk analysis tools for producers to support conversations with processors and biorefineries to help develop contracting options. There is a need to understand the distribution impact that pre-processing beyond physical modifications will have on the cost of the feedstock and the effect on the sustainability footprint. Storage of the feedstock adds expense, as the footprint required for facilities can be large and there is a fire safety risk associated with large storage. During the discussions of the challenges for feedstock properties and compositional variability, it was suggested that there is a clear need for DOE-BETO to outline the limits of heterogeneity that each conversion process can handle and methodologies for modification of biomass characteristics that are economically and sustainability viable. The storage and biomass handling strategies impact biomass characteristics. As such, establishing best practices will be the key to meet the conversion process metrics.

The participants outlined potential solutions to overcome the outlined barriers and challenges, including (1) create a centralized method for data management and knowledge sharing to support stakeholders; (2) understand and implement a sustainability strategy for each crop; (3) support long-term agroecological research; (4) develop a timeline/program schedule; (5) support agricultural extension education and tools to farmers; (6) develop a national agricultural extension resource availability database; (7) support field offices with additional training on energy crops (various agencies); and (8) have technical experts and crop consultants support and engage stakeholders for further development of new crops and best practices.

Table 19. Feedstock Barriers

Production
There is a lack of feedstock availability in sufficient amounts.
Risk management tools for producers are needed: • USDA's Risk Management Agency crop insurance products • Contracting options with processors/biorefiners.
There is quality degradation over time in storage.
Policy uncertainty exists, such as how EPA/RFS qualifications impact markets and demand and result in low production.
There is a current lack of high-yield varieties; need to invest in breeding programs.
Lack of uniformity in biomass properties specifications exists, as this is set by the producer. There is an opportunity to develop specifications at a higher level.
Lack of knowledge of production practices, particularly for new feedstocks, creates an opportunity for BETO to support demonstration/extension/education efforts.
There is a competition for land and resources with other, more profitable crops.
Soil contamination is possible, particularly with higher amounts of biomass production. This provides an opportunity to develop improved harvest methods/equipment.
New oil seed crops lack approved pesticides, fungicides, etc.: • Registration of new pesticides • Development of herbicide resistant oil seed varieties.
Need multiple/redundant markets for feedstock to ensure a demand for feedstocks if a farmer grows it.
Need longer-term offtake agreements from DOD and others to enable operational commercial production.
Distribution
Lignocellulosic feedstock is very low density and can be costly to transport on a $/ton basis.
Requirements for the storage facilities to hold a single harvest feedstock can require a large footprint: • There is an inherent fire risk at these storage facilities.

Table 19. Continued

Distribution
Pre-processing beyond physical modifications will add expense to the price of the feedstock, and an understanding of how these process steps affect the sustainability footprint is critical: • Further, this is RFS related. Feedstock cannot be partially processed offsite and then finished at another site for RIN generation (pending the biointermediates proposal). • It is unclear where preprocessing will end and where it will be located. Will there be some equipment at the biorefinery to support preprocessing, or is this solely at a depot?
The lack of feedstock uniformity can be challenging for utilization of a biorefinery, which requires specific properties: • One potential solution is preprocessing and blending. • Additionally, establishing a quality assurance of feedstock and material is needed at each step of the supply chain.
Given the requirement for an individual biorefinery, transportation options may be limited to trucking, and transportation of the amount of biomass required to meet the Billion-Ton goals must include consideration of the logistics of moving around this amount of feedstock.
There is a need for standardization/commoditization of feedstock to a standard for specific conversion technologies (i.e., for ASTM).
Scaling
Scaling up the processes will require a better understanding of solids handling.
There is a failure to pilot the entire integrated preprocessing systems.
Unexpected wear and tear on equipment occurs due to biomass abrasion.
There is a lack of understanding around the tradeoffs between the economies of scale and cost of transportation of feedstocks.
Transportation and logistical challenges exist, as biomass is currently transported by truck when it could be moved by rail or barge.
Biomass composition varies from different production scales.
There is a lack of investment funding for process demonstration and pioneer facilities.
Due to challenges in the current demand, there is limited feedstock availability.
Big oil is interested in entering the market.
Financial risk from government is shared for construction of pioneer facilities (e.g., loan guarantees).
There are challenges to build the market/scale up feedstocks, particularly energy biomass, due to lack of contractual agreements.
There are additional environmental pressures (increased crop disease and pests) when scaling up, including pest management and quality assurance.
Conversion at the Biorefinery
There are insufficient feedstock specifications or quality needs.

Table 19. Continued

Conversion at the Biorefinery
There is a lack of understanding about how conversion process can handle the heterogeneity or modification of characteristics of the biomass: • Need road-mapping by BETO • Need to effectively match feedstocks to conversion technologies per end use • Conversion processes that rely heavily on conventional feedstock logistics and limit the type of biomass that is acceptable result in reduced operational reliability.
Material handling challenges exist.
There is a lack of reliable feedstock supply.
Current feedstocks prices are too high to enable the industry; drivers for reduction are both capital and operating costs: • Opportunities exist to reduce cost via depot systems. • Technology and markets for valuable co-products could improve costs.
There is a lack of quality assurance/preprocessing standards for feedstocks.
There is a lack of investment funding for demonstration and pioneer facilities.
"Tune-ability" of product slate of conversion process could ensure responsiveness to market conditions (ability to make more/less jet fuel).
Lack of consistent (and beneficial) policy to enable market development results in investors being uncertain about future growth of AJF conversion processes: • This includes uncertainty of RINs for the various pathways. • Biomass Research and Development Initiative board should address policy impacts.
Technology
Inertia exists regarding the adoption of new practices; need to insert innovative technologies into the supply chain.
Economics and the cost of whole technology are obstacles: • Opportunity to use prediction models and simulations • Realize the value of feedstocks • Uncertainty of policy and pathway approval process.
Not all information is publicly available; many companies protect innovation due to IP limitations.
Most processes show an improvement due to increased scale; however, the lack of investment in capital and/or capital requirements that are too high to draw investors impede growth.

Additionally, as discussed in the challenges, developing markets and driving down costs could further grow the demand for biomass. The following are potential routes to support this development:

- Expand land available for additional feedstock crops
- Increase the yield for each feedstock crop
- Minimize the risk for new crop development
  - Develop tools and studies associated with LUC considerations
  - Improve understanding of biodiversity and micro ecosystem changes with new feedstocks
  - Develop the understanding of invasive species potential
- Double crop feedstocks to allow for efficient use of land and nutrients
  - Benefits from producer participation
  - Initial incentives to make it economical
  - Conservation agriculture benefits (from a sustainability/land footprint standpoint)
- Intensify feedstocks to improve on per-acre yields
  - There is an opportunity for further development through breeding.
  - Need to understand sustainability and economics associated with intensification if fertilizer increases
  - Cover crop is also a possible approach toward land intensification that would help support increased ecosystem services and potential biodiversity habitat.

With respect to the primary feedstocks for near-, mid-, and long-term development projections, the group outlined the following list of resources needed (as shown in Table 20) on the first day of discussions. Near-term feedstocks range from agricultural to forest residues, while long-term feedstocks focus on algal biomass and waste streams.

Table 20. Resources Needed for Feedstock Development

Near Term (2020)
Waste streams
Agricultural residues
Forest residues
Animal waste
Conservation crops (dual purpose crops)
Fats, oils, and greases
Mid-Term (2025)
Fatty acids
Terpenes
Long Term (2030)
MSW
Dedicated crops
Wood
Lignocellulose
Algae
Waste gases
CO_2 to hydrocarbons (direct pathway)

Summary of Proposed Solutions

Discussions on the second day of the workshop focused on how the diverse AJF stakeholder community could work together to resolve some of the challenges outlined on day 1, specifically when considering a funding opportunity announcement (FOA). The proposed suggestions are listed in Table 21. These proposed solutions highlight a number of areas that BETO could support, ranging from (1) developing consistent methodologies for application in all analysis studies and developing publicly available analyses to support industry and policymaker decisions, to (2) supporting further collaborations between industrial stakeholders and federal agencies to expand the development of AJF pathways, to (3) specifically highlighting AJF pathways in key BETO publications, such as the Multi-Year Program Plan (MYPP).

Table 21. Proposed AJF Solutions

TEA
The participants suggested that while projects should confine their analyses to "business" issues, there is a real need to quantify externalities and use this analysis to drive policy discussions. The latter should be a concerted effort between all relevant government agencies and stakeholders across the value chain.
If the primary objective is to achieve commercialization at a large scale and affordable price point, then the decision to place funding should be informed by TEA evaluations. One of the challenges in conducting TEAs is the focus on target aspects and loss of granularity needed to look at individual pinch points/key drivers in the current state of technology. For example, one current challenge being faced by industry today is getting the feedstock into a reactor (not included in TEA for an Nth plant, but sometimes for a pioneer plant).
Additional TEAs, which consider the risk at current operating conditions, current scales, and current process variability, would better inform key R&D needs to move the technology to larger scales and into the marketplace. A central authority on TEAs of AJF is needed to help guide alignment among stakeholders and further the discussions. In addition, the national AJF R&D strategy white paper emphasized that further discussion of advanced techno-economic and regional development path analyses of AJF would be helpful.
The group reviewed possible ways that BETO could structure an FOA to best address the challenges identified. The group suggested that the use of TEA and other data sets would determine what technical challenges must be resolved to make AJF meet economic goals. The FOA would then be explicit to solving technical gaps (e.g., biomass feed into a reactor) rather than cover overall solutions for an entire integrated process. However, some of the participants noted that being too focused on basic science for these specific gaps could make the FOA too prescriptive.
The participants also noted that protecting IP and proprietary data is a big challenge for industry in providing a broad set of TEAs for public use. The group felt that, overall, the FOA should be structured based on BETO's goals. Specifically, if the goal is commercialization, then the TEA goal should be to understand pathways and how they can become more cost competitive. However, if the goal is policy assessment, the TEA could be done with the goal to understand the economic impacts under different policy considerations.
Sustainability Data Library
Develop a library of process models to provide key inputs needed for the conversion process of LCA parameters (including mass and energy consumption)
Develop a repository for data used for LCA that is maintained in the Bioenergy Knowledge Discovery Framework (KDF) or at one of the DOE labs that could be linked to the GREET and other models
Ensure that fuel producers provide detailed information on fuel composition over the course of their production runs to assist the ASTM certification qualification process and the analysis of the fuel-use impacts on jets
Encourage the use of LCA data by TEA practitioners and vise-versa. This information can form a useful basis for fuel production assessments and consequential LCA efforts.

Table 21. Continued

Policy
With regard to potential FOAs, the group highlighted that stakeholders need a better understanding of DOE's goals in this area and potentially less prescriptive FOAs. The question was raised about what TRLs are the focus of FOAs. To date, the only DOE solicitation that the public has seen is for an IBR, and the lower TRL research was not included. Funding at an earlier-stage TRL would give clearer signals of what DOE wishes to accomplish in aviation fuels and would potentially move new technologies forward. Additionally, there was discussion around reconsidering the 25% contingency requirement in recent IBR FOAs, which makes it harder to raise money to complete a project. However, additional feedback noted that by including this in the FOA, DOE is getting a good handle on risk and limiting the pool of developers to those with a high degree of success. This approach makes the funding more like a loan guarantee than an FOA.
Finally, several participants believed that a collaborative FOA between agencies might be helpful as it could be more effective to have incremental resources applied to an existing framework than to start something from scratch. Potentially, federal collaboration would address the need for involvement from the private sector and engage additional stakeholders.
Large-Scale Collaborative Efforts
Continue direct coordination with CAAFI: • They can coordinate and identify problems and take the overall view of a comprehensive program. • Having DOE and CAAFI working together could result in appropriate partnerships, such as direct links between academia, industry, and national labs.
Continue close coordination with DOE, DOD, USDA, and FAA on jet fuel topics (potentially using Office of Science and Technology Policy framework)
Provide means for national labs to partner and build relationships with FAA Aviation Sustainability Center (ASCENT), universities, and industrial partners
Create a consortium similar to the Energy Materials Network consortium, through which decreased FOA cost share or additional funds are available by working with consortium members: • Five-year periods with a possibility to renew using stage-gated funding at the three-year point for the remaining two years.
Set up a center like the Board of Scientific Counselors to keep a sustained interest in a specific topic area: • Sustain relationships and projects beyond 3 years • Ensure funding throughout the lifetime of the project with this sustainable platform (not just end after 3 years) • Board of Scientific Counselors program under the Office of Science is a good example of a long-term project.
Use Co-Optima as a model for aviation (not re-designing engines but bringing in all stakeholders in a concerted effort to adopt jet fuel): • Look for the properties and how the fuels perform, without picking a fuel • Build consortia like Co-Optima that help define and generate the basic data, e.g., fuel properties and how they translate into engine performance (not pathway specific).
Explicitly request partnerships with aircraft/airframe manufacturers, engine manufacturers, airlines, technology, and feedstock providers.
Define the early-stage/pre-commercial R&D needs that can be addressed in consortia like the National Alliance for Advanced Biofuels and Bioproducts, rather than at a late stage (e.g., the National Advanced Biofuels Consortium).

Table 21. Continued

Large-Scale Collaborative Efforts
Fund pathway review through ASCENT and have pathway reviews as part of the bi-yearly meetings
Develop a Piston Aviation Fuels Initiative–type FAA program partnered with the DOE/BETO conversion program (from conversion and fuel production through certification)
Provide sufficient time for these teams to navigate legal (and other) partnership agreements. To help to build these partnerships, a number of mechanisms were discussed: • Adopt an approach like DOE's Advanced Research Projects Agency–Energy, which actively engages partnership development with a partnering tool on their website and actively directs the partnerships • Create a networking clearinghouse for potential project partners; structure workshops to enable discovery of potential partners • Leverage existing or prior DOE-funded regional partnerships • Work with an umbrella organization that could pull together regional partnerships and bring a national policy perspective (in a way, CAAFI is doing this) • Collaborate with other EERE-supported tech-to-market programs, like Lab-Corps, which may also be a helpful and established resource • Build on regional initiatives (such as NARA and Farm to Fly), which have developed around the full value chain. This should also encompass a national perspective. This type of partnership could cover areas not typically funded by DOE, such as oil seeds. Such initiatives could involve policy more than general partnerships do. For example, the FAA currently supports ASCENT, a collaborative effort between a number of universities (including Washington State University and MIT) with a structure that involves steering and governing by stakeholders with industry and national labs. There is potential that DOE could further support such existing efforts.
Support future FOA considerations: • Simplify processes for IP between institutions with different priorities: - Normalize the agreements between the several national labs in order to minimize the micromanagement from individual lab IP offices - Because the federal contract seems to be a limiting factor, an effort should be made to eliminate the additional interpretation provided by individual lab IP offices. • Establish a sustainable process to fund original equipment manufacturer reviews and continue progress on a regularly scheduled basis • Develop a publicly available teaming list like the Advanced Research Projects Agency–Energy model • Reconsider the cost-share requirements for the design phase of projects, which requires proposals for subsequent phases that, in turn, reduce the incentive and the risk for participating in the first phase • Guarantee offtake agreements if specific fuel specs are met within a FOA project.
Support AJF via programmatic efforts; ensure that jet fuel is fully called out and highlighted in MYPPs, Annual Operating Plans, etc.: • Jet fuel has not received its due place in the hydrocarbon pathways as there is not enough targeted effort around jet fuel. • For a long time, the emphasis was on diesel and ethanol; now it is on electric vehicles. • Industry pull is for jet fuel; we need to support industry's demand for AJF. • Inclusion of a wide range of potential biomass sources would also be helpful, i.e., exclude only food. • Get DOE to host quarterly meetings for pathway reviews • Have a networking system dedicated to AJF • Create listening days at aviation events to engage industry face to face • Develop a nonprofit DOE user facility that might be run by the national lab system (e.g., NREL and PNNL) or a university.

Table 21. Continued

Large-Scale Collaborative Efforts
Focus on topic areas as well as stages of development based on the TRL of pathway/technology: • A differing opinion suggested to move away from "one size fits all" TRL focus.
Capitalize on FOAs to lower cost share or allow in-kind contributions: • Smaller companies cannot provide the cash necessary for cost share.
Expand FOA guidance to include pathways that have not yet been approved by ASTM.
Ask fuel producers to provide data such that others can compute the values using a variety of LCA methods.
Allow suitable time to find industry cost share: • Implement during full proposal time so concept paper can be submitted in advance of finding to give more time if a partner is not lined up beforehand • Narrow the pool of applicants at the preproposal stage.
Develop more focused incubator FOAs.
Ensure that FOAs are not overly prescriptive, e.g., the DPA FOA allowed only ASTM-approved pathways: • FOAs are so specific that they appear to be written directly to companies even if they are not. • Need to better define the end goal as opposed to defining the process to get to the end goal; this will promote more innovative proposals.
Opportunity for a face-to-face discussion on reviewer concerns instead of the one-way email exchange: • The current process only allows for one response to the reviewer comments.
Make FOAs more open and less prescriptive and do not limit feedstock selection but instead base on LCA reduction.
Simplify the TEA requirement: • Need to refine applicant TEA requirements for early stage TRL; okay to require applicant to have thought through the potential upside, but not at the level of detail currently required • The current TEA requirements for low-level TRLs are burdensome.
Structure FOAs with opportunity for follow-on funding for successful projects, using a phased approach: • BETO currently does not guarantee that successful projects have the opportunity for future funding; this relies on whether BETO puts out another relevant FOA. • Develop FOAs similar to the approach used by other offices, such as the Office of Fossil Energy.

Day 2 wrapped up by considering the most important challenges identified during the break-out discussions. The primary highlights are summarized in Table 22 and include barriers associated with economics, policy, collaboration, data needs, and outreach. The participants specifically highlighted areas where BETO could take the lead to support stakeholder needs, including developing analysis and understanding policy impacts to help make a viable baseline business case for the development of AJF. Additionally, BETO was encouraged to develop a working group that considered the barriers for AJF development across the supply chain and to work closely with other groups (such as CAAFI, FAA, and USDA, among others) to further develop AJF pathways. Finally, when considering conversion strategies, the participants suggested that BETO encourage fuel producers to investigate a range of feedstock options and to consider developing feedstock agnostic conversion strategies. Additionally, participants encouraged BETO to support processes that focused on low aromatic jet fuel production strategies to improve the air emission impacts of AJF blendstocks.

Table 22. Summary of Critical AJF Challenges

TEA Barriers
The current TEAs represent a future, target state and are missing or are not capturing all of the current state of technology and feedstocks. Future TEAs should consider feasibility within defined timelines.
There is a need to develop best practices on how to account for risk associated with scale-up in TEAs.
There are gaps for new technologies being developed, and the lack of information on accurate equipment designs and scaling factors can be a challenge for the TEA evaluations.
There are technologies that are not yet captured in current TEA studies.
Current TEAs may face challenges in being comprehensive in terms of pathways, as not all information is publicly available due to IP considerations and the proprietary nature of these emerging fuel production strategies.
Policy Barriers
There is a need to establish guidelines for elements of a business case that people can use as a starting reference point (separate guidance for different regions that accounts for specific advantages and challenges).
Collaboration Barriers
It would be beneficial to consolidate the knowledge bases from TEA, conversion/scale-up, feedstocks, offtake opportunities, transportation, access to market, power, pipelines, and refineries. Develop a working group of people from across the supply chain to review these details in depth and aggregate the findings.
There is an opportunity to utilize previous experience with regional partnerships to enable federal partnerships to explore these linkages further.
Data
BETO-funded projects must require data sharing while being mindful of company PI: • If needed, a non-disclosure agreement can be put in place so companies can share data with DOE and labs. • Need to require the use of and input into the KDF • Have to show value to the people providing the data so that they are willing to accept the risk.
Develop a data requirement spreadsheet to help companies understand the type of data to be reported to BETO.
Funding and Grants
Spread more funding around to more initial teams on a short time horizon to work with DOE to prove their R&D claims during the Task 1 validation period; BETO should then make additional funding decisions after that: • MEGA-BIO: Bioproducts to Enable Biofuels call requires a very detailed initial spreadsheet of data, but spreadsheet was really difficult to fill out and explain during the proposal submission.
Ensure transparency about why particular projects are awarded grants: • Award more grants to smaller-scale companies, and perhaps amend the requirement to match funding. • It would also be very helpful if BETO could connect these smaller companies with investors.
Consider running the FOA like the old enzyme hydrolysis FOAs, in which the FOA efforts leveraged and relied on the past/current national lab investments/DOE designs and the FOA products were integrated into and contributed to DOE designs in an approach coordinated with the national labs.

Table 22. Continued

Outreach and Education
Develop information on the benefits that will accrue from the learning-by-doing process: • Could leverage the large base of information on ethanol, biodiesel, and advanced biofuel facilities • Information from other energy sectors could also prove useful. • These data would be invaluable to the LCA and TEA communities.
R&D
Encourage fuel production using a range of fuel feedstocks as opposed to a single feedstock. Feedstock variations would ensure the facility is robust to variations in supply and would allow for more sustainable agricultural practices, as opposed to monoculture.
Encourage the production of paraffinic fuels (normal, iso, and cyclo) with a minimum of monoaromatic compounds and no polyaromatic compounds. This would encourage fuels that have low black carbon emissions from jet fuel combustion while maintaining the desire that the fuels be drop-in and able to use current infrastructure.

Conclusion

Breakout session participants encouraged BETO to play a strong role in feedstock interface opportunities not only to help de-risk feed and handling at the biorefinery, but also to improve performance of the conversion process through the integration of feedstock and fuels production. The summary of these critical next steps is briefly summarized in Table 23.

Table 23. Opportunities to Support De-Risking AJF Technology and Commercialization

Near Term (2020)
R&D
Investigate the value of co-products: • Improve economic viability of a process with low-volume/high-value products • Choose funding processes that are economically viable rather than solely focused on the production of AJF • Consider both economics and sustainability when evaluating co-product impacts • Develop a flexible process to make other co-products (both fuels and chemicals) that adapt to market conditions.
Focus research dollars on economically viable pathways: • Begin early on in technology development to not spend money on things that are non-starters • Consider diversification of pathways that utilize a range of feedstocks • Prioritize funding based on strength of TEA and LCA at bench and pilot scales • Do not fund pathways that do not have a strong business case and/or a strong sustainability profile • Embrace risk by quantifying probabilities for scaling each pathway based on evidence and expert judgement.
Develop analytical techniques for AJF that are applicable to feedstocks being produced: • Replace outdated techniques and/or modify techniques specific for fossil feedstock • Develop models to make predictions that are more accurate.

Table 23. Continued

Near Term (2020)
R&D
Require both a qualitative and quantifiable understanding of uncertainties to address when de-risking: • Create a portfolio of quantifiable risk elements to achieve clarity on what actions to take • Conduct workshops that provide participants with the guidance needed to apply the process and tools of TEA and LCA and other economic evaluation tools • Quantify the amount of uncertainty (risk) for each technology pathway based on key decision criteria • Explore the sub-elements that are common across the multiple, fully integrated pathways. There will be elements that are unique and mutually exclusive. The total sum of all identifiable uncertainties across each pathway presents its risk profile. • Develop risk profiles (identified by workshop participants) that are measured in terms of cost, time, and other utility values • Conduct interviews with subject matter experts who have the content knowledge needed for each technology pathway to obtain probabilities and ranges as appropriate • Prioritize actions based on least risky to most risky.
Develop additional data to evaluate the current state of technology of the conversion strategies (currently the lack of the data is attributed to the lack of operating facilities with advanced technologies): • Estimate yields at larger scales • Assess process variability and upset data • Determine feedstock variation • Gain understanding of catalyst stability, extended process operations, and other critical process components (thousands of hours) • Calculate reliable capital costs, which are especially challenging when new technologies are being developed and process designs are uncertain • Determine catalyst lifetimes, on-stream factors, and regeneration protocols • Incorporate separations technologies required to meet fuel specifications • Establish criteria and methodology for developing analyses that utilize credible data with assumptions fully disclosed and that are presented using “harmonized” apples-to-apples comparisons • Develop methodologies for comparing technologies at different TRLs and different data quality for both TEA and LCA • Define time frame studies: for TEA, scale-up considerations on when new processes expected to come online; for LCA, appropriate time scale for assessing impacts of GHG emissions.
Policy
Support stable policy environment with incentives: • Continue support for RFS2, blender’s tax credit, and LCFS • Develop consistent policy to stabilize investor uncertainty by building out viable market pull for AJF • Use TEA and LCA to support need for policy intervention (e.g., LCFS credit). • Engage stakeholders further to help support the development of AJF.
Stimulate development of risk insurance mechanisms
Support streamlining of the ASTM standardization process: • Determine baseline property-based profile that new pathways must fit; allow for greater approval of fuels.

Table 23. Continued

Near Term (2020)
Government and Industry Collaboration
Continue to support access to capital and funding: • Support the appropriate approach of scale-up without skipping steps in the process (from pilot to demo to commercial) • Prove out steps from bench scale all the way through to pilot and commercial. Cannot skip steps, even if pressured, or the consequences (as demonstrated several times) could result in the failure of a process to work appropriately.
Support the logistics and infrastructure readiness for biofuel at scale: • Include the development of more feedstock supply availability and potential agreements • Consider a range of feedstocks, from forest and agricultural residues to waste streams (including animal waste and fats, oils, and greases).
Develop mechanisms to enable further offtake agreements: • Encourage industry progress when airlines make a real investment • De-risk investment for lenders and capital markets by increasing airline equity.
Continue to improve interagency cooperation: • Develop and test fuels via interagency funding of shared assets.
Increase access to publicly available TEA and LCA tools for project-level development: • Enable the TEA models to be used indirectly via expert assistance, perhaps via the Small Business Assistance program (or similar vehicle) • Provide training to facilitate the use of process design tools, if appropriate.
Continue to develop a better understanding of indirect LUC: • Develop better land-use data, including attribution of land use to different causes • Determine whether information is available via U.S. federal agencies (such as USDA), the United Nations, and the Land Observatory that collects historical data • Perform modeling to help determine what is important and what is not for indirect LUC. This data could be pursued using in-depth investigation into the Global Change Assessment Model and the Global Trade Analysis Project (and any global models).
Support stakeholder community by developing a working group from across the supply chain to review the consolidated details in depth and aggregate the findings considering linkages from • TEA • Conversion/scale-up • Feedstock • Offtake opportunities • Transportation • Logistical access to markets.
Mid-Term (2025)
R&D
Develop models relating to jet fuel composition to performance on currently required tests
Understand how markets have developed around the world to provide learnings for development in the United States

Table 23. Continued

Mid-Term (2025)
Policy
Support policy adaptations: • Take steps to enable manufacturers to keep moving forward. This could be supported from funding as well as policy, which brings more fuels to market. • Develop performance-based incentives • Create government incentives for industries (not just companies) that reduce GHG emissions • Support the development of more approved processes.
Support a more streamlined ASTM process to reduce cost and fuel requirements and speed up timeline for certification
Government and Industry Collaboration
Develop initiatives and mechanisms that enable end users and fuel manufacturers to collaborate more frequently
Enable access to feedstocks that meet quality specifications (such as ash or moisture content) required by the biorefinery
Support the development of high-quality data (such as high mass and carbon closure, and extended time on stream) on fully integrated processes at small scale (for new technologies)
Develop a global tax and/or cap-and-trade to help support the further development of AJFs
Support further public outreach and education for the development of AJF, including benefits and drivers for these production strategies
Long Term (2030)
R&D
Develop a balanced portfolio between transformational technology development and incremental technology improvements
Utilize carbon from all waste materials (e.g., biogas, industrial effluents, and flared natural gas) to produce fuels and chemicals
Government and Industry Collaboration
Develop programs that allow the co-optimization of fuels and aviation engines: • Create a Co-Optima for aviation • Develop opportunities and mechanisms for greater interaction between AJF producers and aviation engine manufacturers.
Support the development of long-term agreements: • Help grantees maintain continuous growth and uptake in the market • Connect grantees with parties who may be interested in obtaining offtake agreements.

Appendix A: Acronyms and Abbreviations

AJF	alternative jet fuel
ASCENT	Aviation Sustainability Center
ASTM	American Society for Testing and Materials (ASTM) International
ATJ	alcohol-to-jet
BETO	Bioenergy Technologies Office
CAAFI	Commercial Aviation Alternative Fuels Initiative
CATJ-SKA	catalytic alternative jet fuels–synthetic kerosene with aromatics
CCS-APR	catalytic conversion of sugars by aqueous-phase reforming
CH	catalytic hydrothermolysis
CO_2	carbon dioxide
Co-Optima	Co-Optimization of Fuels & Engines
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DMT	Demonstration and Market Transformation
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPA	Defense Production Act
EERE	Office of Energy Efficiency and Renewable Energy
EPA	U.S. Environmental Protection Agency
ETJ	ethanol-to-jet
EU	European Union
EU ETS	EU Emission Trading System
FAA	Federal Aviation Administration
FOA	funding opportunity announcement
FT	Fischer-Tropsch
FTJ	Fischer-Tropsch jet
GHG	greenhouse gas
GMBM	global market-based mechanism
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HDCJ	hydrotreated depolymerized cellulosic jet

HEFA	hydrotreated esters of fatty acids
HFS-SIP	hydroprocessed fermented sugars to synthetic isoparaffins
HTL	hydrothermal liquefaction
IBR	integrated biorefinery
ICAO	International Civil Aviation Organization
IP	intellectual property
KDF	Knowledge Discovery Framework
LCA	life-cycle analysis
LCFS	Low Carbon Fuel Standard
LUC	land-use change
MIT	Massachusetts Institute of Technology
MJ	megajoule
MSW	municipal solid waste
MYPP	Multi-Year Program Plan
NARA	Northwest Advanced Renewables Alliance
NREL	National Renewable Energy Laboratory
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
R&D	research and development
RD&D	research, development, and demonstration
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
SIP	synthetic isoparaffins
SKA	synthetic kerosene with aromatics
SPK	synthetic paraffinic kerosene
SPK/A	synthetic paraffinic kerosene, plus the alkylation of light aromatics (primarily benzene)
syngas	synthesis gas
TEA	techno-economic analysis
TRL	technology readiness level
USDA	U.S. Department of Agriculture

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Appendix C: Workshop Agenda

Wednesday, September 14, 2016

Time	Agenda Item (orange = auditorium; blue = breakout rooms)
7:30 a.m.–8:00 a.m.	**Registration**
8:00 a.m.–8:20 a.m.	**Welcome and Opening Remarks, Bioenergy Technologies Office (BETO)** • Jonathan Male, Director: BETO Overview • Zia Haq: Importance of Aviation Biofuels at U.S. Department of Energy (DOE)
8:20 a.m.–8:45 a.m.	**Sustainable Jet Fuel Development: Demand, Feedstocks, Pathways, Efforts, and Needs** • Steve Csonka, Executive Director, Commercial Aviation Alternative Fuels Initiative
8:45 a.m.–9:45 a.m.	**Overview of Alternative Jet Fuel (AJF) Research, Development, and Deployment Efforts: Key Technical and Economic Challenges Identified for Different Processes** Moderator: Kristen Lewis, Department of Transportation (DOT) • Neville Fernandes, Neste Oil • Mark Staples, Massachusetts Institute of Technology • Kevin Weiss, Byogy Renewables • Brice Dally, Virent Inc.
9:45 a.m.–10:00 a.m.	**Networking Break**
10:00 a.m.–11:00 a.m.	**Greenhouse Gas (GHG) Life-Cycle Assessment Results for AJF: Key Contributors to GHG Emissions and Emissions Uncertainty** Moderator: Jim Hileman, Federal Aviation Administration • Ray Speth, Massachusetts Institute of Technology • Michael Wang, Argonne National Laboratory • Wallace Tyner, Purdue University • Sharyn Lie, U.S. Environmental Protection Agency
11:00 a.m.–12:00 p.m.	**AJF Commercialization: Feedstock Systems Supply, Suitability, and Logistics** Moderator: Kristin Lewis, DOT, Volpe National Transportation Center • Harry Baumes, U.S. Department of Agriculture (USDA) • Laurence Eaton, Oak Ridge National Laboratory • David Archer, USDA Agricultural Research Service • Kent Swisher, National Renderers Association
12:00 p.m.–12:45 p.m.	**Lunch**
12:45 p.m.–5:00 p.m.	**Breakout Session IA: Enhancing the Economic and Technical Competitiveness of Aviation Biofuels from Lignocellulosic Biomass** Moderator: Zia Haq, DOE • Mark Staples, Massachusetts Institute of Technology • Corinne Drennan, Pacific Northwest National Laboratory • Mary Biddy, National Renewable Energy Laboratory • Wallace Tyner, Purdue University

Wednesday, September 14, 2016

Time	Agenda Item (orange = auditorium; blue = breakout rooms)
12:45 p.m.–5:00 p.m.	**Breakout Session IB: Fuels Conversion and Scale-Up** Moderator: Borka Kostova, DOE • Glenn Johnston, Gevo Inc. • Ted Kniesche, Fulcrum BioEnergy Inc. • John Holladay, Pacific Northwest National Laboratory
12:45 p.m.–5:00 p.m.	**Breakout Session II: Environmental and Sustainability Considerations and Opportunities to Improve the Life-Cycle Benefits of Aviation Biofuels** Moderator: Siva Subramanian, DOE • Jeongwoo Han, Argonne National Laboratory • Robert Handler, Michigan Technological University • Ray Speth, Massachusetts Institute of Technology
12:45 p.m.–5:00 p.m.	**Supply Chains to Support Aviation Biofuels** Moderator: Harry Baumes, USDA • Kevin Kenney, Idaho National Laboratory • Marty Schmer, USDA Agricultural Research Service • Ralph Cavalieri, Washington State University
5:00 p.m.–5:30 p.m.	Day 1 Breakout Session Reports
5:30 p.m.	Adjourn Day 1

Thursday, September 15, 2016

Time	Agenda Item
7:15 a.m.–8:15 a.m.	Networking
8:15 a.m.–8:30 a.m.	Welcome Back Remarks
8:30 a.m.–10:30 a.m.	Breakout Sessions I–III: Advancement Activity Action Plans
10:30 a.m.–11:30 a.m.	Breakout Session Day 2 Reports, Action Plans, and Q&A
11:30 a.m.–11:45 a.m.	Closing Comments and Next Steps
11:45 a.m.	Lunch and Site Visit
11:45 a.m.–3:15 p.m.	Optional Site Visit (Group 1): LanzaTech Freedom Pines Biorefinery
1:00 p.m.–4:45 p.m.	Optional Site Visit (Group 2): LanzaTech Freedom Pines Biorefinery
5:00 p.m.	Adjourn Workshop

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