Assessing the Readiness and Competitiveness of Virginia's Sustainable Aviation Fuel (SAF) Supply Chains

Produced for the Virginia Department of Aviation

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Executive Summary

This report summarizes SAF initiatives underway internationally and in the United States, with emphasis on documenting relevant activities in Virginia, its bordering states, and other states that are emerging as SAF leaders. It also summarizes SAF research and related activities initiated in Virginia at the behest of the Virginia Department of Aviation (DOAV) over the last decade. It concludes with a summary of Virginia's strengths, weaknesses, opportunities, and threats related to SAF commercialization and a list of recommendations compiled by the Virginia coalition that has been engaged in SAF research to date.

There has been significant investment in SAF initiatives internationally and within the United States over the last few years, including creation of a *SAF Grand Challenge Roadmap* by federal agencies such as the Department of Agriculture, the Department of Energy, the Department of Transportation, the Environmental Protection Agency, and others. Collaboration among these multiple agencies illustrates how SAF supply chains intersect multiple diverse interests and stakeholders. The completed roadmap (delivered in 2022) lays out ambitious goals for aviation emissions reductions and SAF production volume targets by 2030 and 2050. To help achieve these goals, the federal government has created new financial incentives (e.g., tax credits) for SAF production and committed significant funding for supply chain feasibility studies and construction of infrastructure to produce, transport, distribute, and store SAF. There are currently six SAF production facilities operating in the US. SAF is not currently being produced or consumed for commercial aviation use in Virginia.

Individual states are also taking action to commercialize SAF. California and Illinois have created state-level incentives for SAF production and lead the way in SAF consumption by volume. Other leaders include Minnesota and Pennsylvania, where state agencies are working with consortia of public and private partners to spearhead SAF and related low-carbon energy projects. Several states bordering Virginia are pursuing less significant SAF initiatives. For example, an airport in North Carolina is consuming SAF, and Kentucky has explored draft legislation related to creation of financial incentives for SAF consumers and producers. However, none of the states bordering Virginia have created any specific SAF-relevant legislation to date.

In Virginia, a coalition comprising representatives from the Virginia Department of Aviation (DOAV), the University of Virginia (UVA) School of Engineering and Applied Sciences, the Commonwealth Center for Advanced Logistic Systems (CCALS), the Commercial Aviation Fuels Initiative (CAAFI), and others has been researching regional SAF supply chains for more than a decade. DOAV-initiated work has progressed in three phases, focusing on feedstock availability and supply chain feasibility for selected SAF production processes. The coalition is funded by the Federal Aviation Administration's (FAA's) *Fueling Aviation's Sustainable Transitions (FAST-SAF)* program. The UVA-led team is receiving Tier 1 funding to refine existing SAF supply chain models and convene meetings of relevant stakeholders, with emphasis on fuel transportation, blending, distribution, and storage within the SAF life cycle. Virginia's FAST-SAF award is one of only seven Tier 1 projects awarded via this new program. Two of the other six recipients are in Pennsylvania, and one other is in North Carolina.

Results from the Virginia SAF coalition's completed and ongoing work highlight the Commonwealth's **strengths** related to SAF readiness, namely: a strategic location in the Mid-Atlantic, world-class port and transportation infrastructure (including a proposed inland port), possible pipeline access to facilitate low-cost distribution to East Coast airline hubs, strong demand for SAF co-products (e.g., sustainable marine fuels), good availability of non-crop biomass feedstocks, and superior systems analysis capabilities and stakeholder engagement via the existing Virginia SAF coalition. Additional work is required to build awareness of these strengths and forge partnerships among relevant stakeholders. **Weaknesses** include challenging topography, which could present difficulties for feedstock collection, uncertain viability of previously modeled conversion processes, higher pipeline injection costs relative to bordering states, and absence of existing oil refineries and related processing infrastructure. **Threats** include: market conditions whereby prices for competing biofuels tend to be higher than for SAF, and competing demands for relevant feedstocks. Overall, lack of existing supply, unknown demand, and unfavorable cost comparisons with other biofuels (most notably biodiesel) and conventional jet fuel represent the most significant challenges to SAF commercialization.

Key recommendations of this report include: leveraging systems analysis capabilities of the existing SAF coalition members to attract and engage relevant supply chain participants; partnering with the Virginia Department of Energy, Virginia Department of Forestry, the Virginia Economic Development Partnership, and other agencies to highlight common interests intersecting SAF and related biofuels; coordinating biomass capacity and bioeconomy planning at the state level; adopting SAF development and investment as a Virginia priority; working with relevant maritime and aviation stakeholders to conduct coordinated planning for SAF co-products and related infrastructure (e.g., processing and refining facilities, distribution networks including pipeline, rail, roadway, and port); and ensuring that relevant infrastructure is in place to support proposed SAF supply chains.

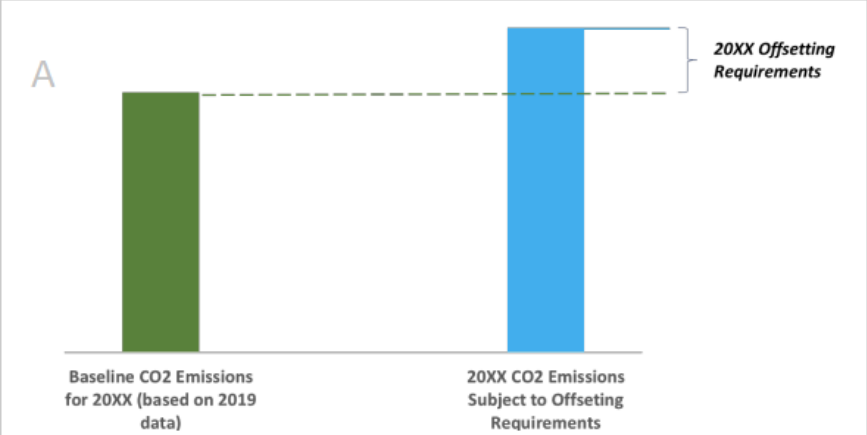
1.0 Introduction

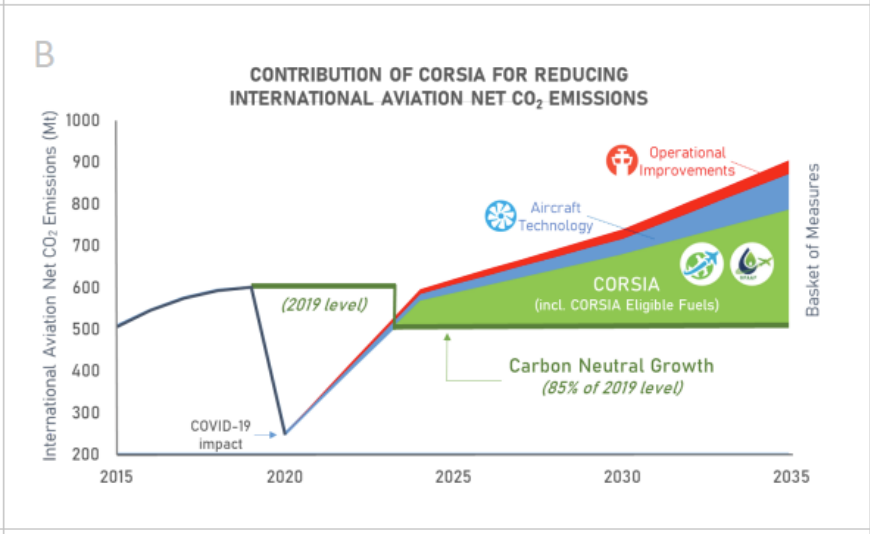
1.1 *What is Sustainable Aviation Fuel (SAF)?*

Sustainable aviation fuels (SAFs) are biofuels designed specifically for aviation that are produced from renewable resources, such as plant materials, agricultural residues, and waste fats or oils. The broad goal for SAF commercialization is to produce fuels that can be blended with conventional jet fuel and "dropped into" existing aircraft engines and fuel infrastructure, thereby reducing greenhouse gas emissions. SAFs are considered a critical component in the aviation industry's efforts to achieve carbon neutrality, as it is not anticipated that aviation (especially international travel) will be easily decarbonized via electrification.

1.2 What relevant frameworks govern SAF internationally?

The regulatory framework governing decarbonization of international aviation is administered by the International Civil Aviation Organization (ICAO), which is the United Nations agency responsible for oversight of global air mobility (ICAO, n.d.). In 2016, ICAO established the *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, which is a market-based framework for reducing the climate impacts of international aviation (IATA, 2024). Participating member states pledged to reduce the carbon intensity of international aviation with a goal of achieving carbon-neutral sector growth beyond 2020, at a level 15% below the 2019 emissions baseline. In other words, participating entities agreed to reduce emissions and/or purchase offsets to cover the difference between annual emissions and the target level, such that sector-wide emissions will remain constant even as aviation continues to grow (**Figure 1.A**) (IATA, 2024). The price of offsets relative to other emissions reductions measures influences the decision-making of aircraft operators and member states, as they search for the lowest cost means of meeting their individual emissions reductions requirements. Widespread use of SAF is expected to account for the most significant fraction of overall emissions reductions. Improvement in aircraft technology and systems operations are also being pursued (**Figure 1.B**) (IATA, 2024).





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Phase	Year	Countries Participating	Offsetting approach
Pilot Phase	2021–2023	Voluntary	100% sectoral
Phase 1	2024–2026	Voluntary	100% sectoral
Phase 2	2027–2029	All states whose market share exceeds 0.5% or is within 90% of the aggregate from largest to smallest. SIDS, LDCs, and LLDCs exempt.	100% sectoral
	2030–2032		At least 20% individual
	2033–2035		At least 70% individual

Figure 1. *(A) Illustration of carbon-neutral growth for aviation via offsetting of emissions above the selected baseline. (B) Anticipated emissions from international aviation, with illustration of approaches for achieving desired reductions ("basket of measures"). (C) Timeline of CORSIA implementation, with articulation of voluntary versus obligatory phases and offsetting requirements by phase (wherein offset amounts are computed based on sector-wide emissions and/or individual emissions for the preceding year). Panels A and B are reproduced from IATA (2024). Panel C is reproduced from ICCT (2017). All items used without permission.*

The CORSIA framework provides explicit guidance on how aircraft operators must calculate and report their "revenue tonne kilometers" (i.e., cargo and passenger capacity multiplied by distances flown on select flight routes) and calculate corresponding emissions (ICAO, 2024a). Monitoring and reporting requirements are applicable to all airplane operators producing at least 10,000 tonnes of CO2 emissions per year from aircraft with a maximum certificated take-off mass greater than 5,700 kg flying international routes. The requirement to monitor, report, and verify CO2 emissions from international flights is independent from offsetting requirements, i.e., even if an aircraft operator is not bound by CORSIA's offsetting requirement (by virtue of the CORSIA status of their home nation), they must still compute their relevant emissions and have them validated by a third-party entity (ICAO, 2024a). It is therefore significant that airplane operators (airlines) are bound by CORSIA, rather than the participating members states.

Regarding SAF, the CORSIA framework lays out a process by which carbon intensity (CI) is computed for various fuel production pathways. CI is defined as the life-cycle greenhouse gas emissions (GHG) arising from SAF production, in units of CO2-equivalent (CO2e) per gallon. To qualify as SAF under CORSIA, a production pathway must achieve at least 10% reduction in CI compared to fossil aviation fuel and it cannot consume feedstocks from "high carbon stock lands" (primary forest, wetlands, or peat lands) (Prussi, et al 2021).

The CORSIA framework is being implemented in several phases (**Figure 1.C**) (ICCT, 2017). The pilot phase was 2021-2023. The first phase is 2024-2026. The second phase will start in 2027. The pilot and first phases are voluntary. The second phase will mark the start of mandatory participation, with exceptions for Small Island Developing States (SIDS), Least Developing Countries (LDCs), and Landlocked Developing Countries (LLDCs). **Figure 2** summarizes participating member states as of March 2024 (ICAO, 2024b). Again, it is significant that airplane operators (airlines) are bound by CORSIA rather than participating members states. However, the governments of member states contribute to the achievement of CORSIA by administering the reporting systems and creating regulatory or economic incentives to help accelerate innovation.

Finally, under current ICAO regulations, commercial flights must use SAF blended with at least 50% fossil jet fuel to ensure compatibility with aircraft, engines and fueling systems. However, the industry is working towards commercial aircraft being permitted to fly on unblended (100%) SAF in the future (ATAG, 2023).

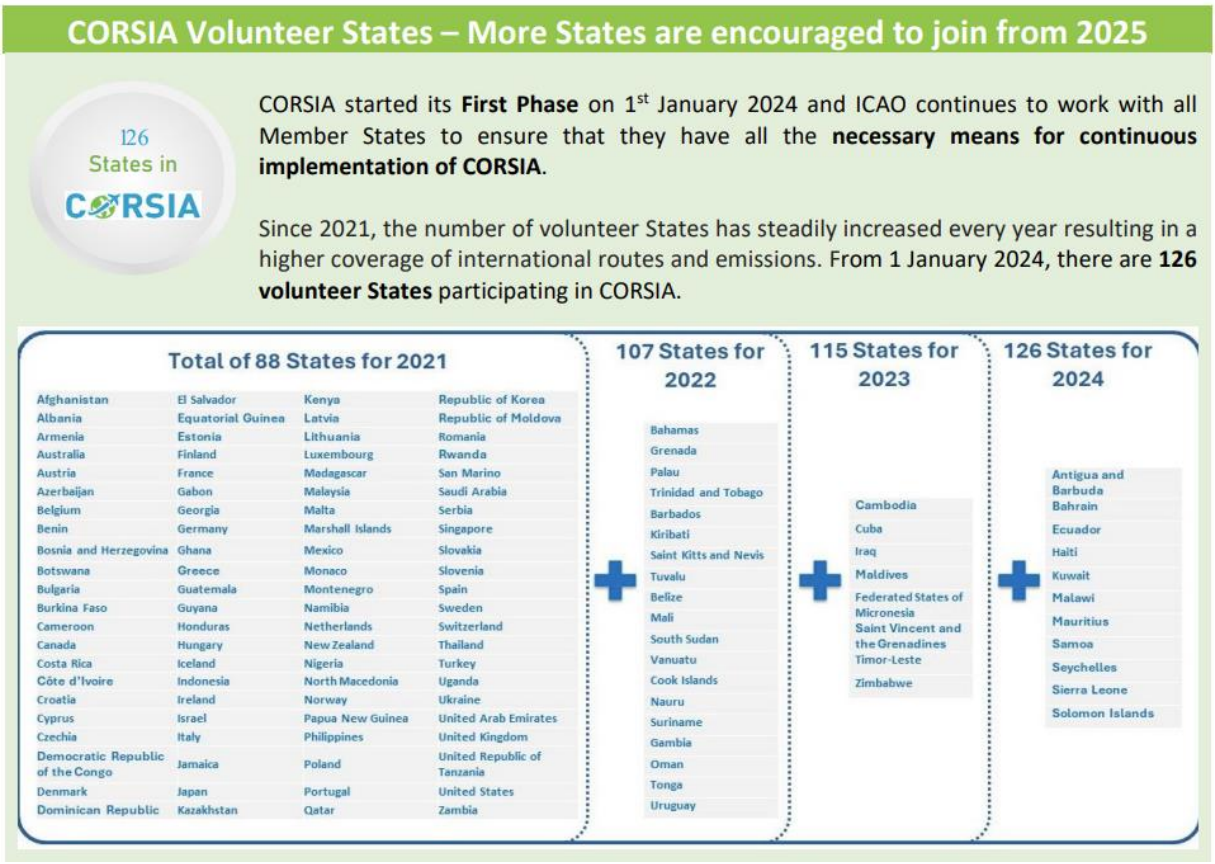

Figure 2. *CORSIA member states as of March 2024. Total number of member states is 126. All states are "voluntary" participants until 2027. Reproduced from ICAO, 2024b.*

1.3 What relevant frameworks govern SAF in the United States?

The Biden administration directed federal agencies to aggressively pursue aviation decarbonization as part of its *Build Back Better Agenda* (The White House, 2021). High-level goals of this directive were to reduce aviation emissions by 20% by 2030 and achieve fully zero-carbon aviation by 2050. SAF production volume targets are 3 billion gallons per year by 2030 and 35 billion gallons per year by 2050, with the goal of fully satisfying 100% of projected domestic demand by 2050. The *Inflation Reduction Act* of 2022 created federal incentives for SAF, including a blender's tax credit (BTC) of $1.25/gallon of fuel products achieving at least 50% reduction in life-cycle GHG emissions relative to fossil jet fuel. There is also a supplemental credit of one cent for each percent GHG reduction beyond 50%, up to $0.50 (IRS, 2024). The new incentives can be stacked with existing incentives under the Renewable Fuel Standard (Davis et al, 2024).

Various federal agencies, including the Department of Energy, Department of Transportation, Department of Agriculture, the Environmental Protection Agency, and others, are charged with implementation of the *SAF Grand Challenge Roadmap*. Collaboration among multiple agencies illustrates how SAF supply chains intersect many diverse interests and

stakeholders. The SAF roadmap summarizes anticipated activities for relevant agencies (US DOE, 2022). For example, the Federal Aviation Administration's (FAA's) *Fueling Aviation's Sustainable Transition* (FAST)-SAF program seeks to accelerate production and use of SAF by providing funds for supply chain feasibility studies and to support the build out of relevant infrastructure (FAA, 2024). The first round of competitive FAST-SAF investments were announced in August 2024. Approximately $245 million was awarded in Tier 1 and Tier 2 awards. Tier 1 awards focus on supply chain analysis and scoping studies. Tier 2 awards support build out of relevant SAF production, transportation, blending, and storage infrastructure (US DOT, 2024.)

It is unknown whether the Trump administration will take action to change the US's involvement in CORSIA. They have not made any announcement of policy positions related to aviation sustainability. CORSIA is distinct from the Paris Climate Treaty. It is perhaps notable that all major US airlines publicly expressed their support for CORSIA in 2019, when President Trump was in office for his first term (McMahon, 2019).

1.4 How and where is SAF produced?

Figure 3 illustrates the life cycle stages for a generic fuel production pathway (ICAO, 2022). The systems boundaries shown in the figure are stipulated under the CORSIA framework for calculation of a fuel's carbon intensity (CI). To qualify as a CORSIA-eligible production pathway, the resulting fuel must achieve at least 10% reduction in life-cycle GHG emissions relative to the fossil fuel benchmark. This threshold corresponds to GHG emission of less than 80.1 gCO2e/MJ (Prussi et al, 2021).

Figure 3. *ICAO's representation of the SAF life cycle under CORSIA. (from ICAO, 2022)*

To date, approximately eight SAF production processes have been certified under the CORSIA framework (ICAO, 2022). The certified processes make use of various bio-based feedstocks, and portions of some processes can be re-combined, such that the number of CORSIA-eligible fuels (CEFs) is significantly greater than the number of certified processes (ICAO, 2022). **Table 1** summarizes information about selected CORSIA-certified pathways based on ICAO guidance documents (ICAO, 2022).

Table 1. *CORSIA-certified processes for SAF production, with relevant information by life-cycle stage. (Adapted from ICAO, n.d.)*

Pathway	Chemical Process	ASTM Standard(s) and Blend Ratio	Feedstock, Transport Mode	Airports & Producers[1]
Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene **(FT, SPK)**	Woody biomass is gasified to produce syngas, which is then transformed into fuel	ASTM D7566 Annex A4 Max Blend = 50%	Municipal solid waste, agricultural and forest wastes, energy crops Pipeline, Truck	LAX, Fulcrum SFO, World Energy SEA, Lanza Tech ORD and DFW, Neste DEN, Gevo
Hydroprocessing Esters and Fatty Acids **(HEFA)**	Triglyceride feedstocks are broken down into fatty acid chains which are then processed into fuel	HEFA-SPK, ASTM D7566 Annex A2 Max Blend = 50%	Vegetable oils, animal fats, and cooking oils Pipeline, Truck	LAX, Fulcrum SFO, World Energy SEA, Lanza Tech ORD, Fulcrum and Neste DFW and BOS, Neste DEN, Gevo EWR & PHX, World Energy
Synthesized iso-paraffins from hydro-processed fermented sugars **(SIP)**	Sugars are fermented into long-chain hydrocarbons which are upgraded to fuel	ASTM D7566 Annex A3 Max Blend = 10%	Sugars (corn, cane, beet, etc.) Truck	LAX, Fulcrum SFO, World Energy SEA, Lanza Tech ORD, Fulcrum and Neste
Alcohol to jet synthetic paraffinic kerosene **(ATJ-SPK)**	Bio-feedstocks are biologically fermented to produce alcohols, which are processed into fuel	ASTM D7566 Annex A5 Max Blend = 50%	Ethanol, isobutanol, and isobutene from biomass Truck	LAX & SFO, Gevo SEA, LanzaTech DEN, Gevo
Catalytic hydro-thermolysis jet fuel **(CHJ)**	Fats or oily feedstocks are thermally decomposed into hydrocarbons that are processed into fuel	ASTM D7566 Annex A6 Max Blend = 50%	Vegetable oils, animal fats, and cooking oils Truck	LAX & SFO, Gevo SEA, LanzaTech DEN, Gevo
Integrated hydro-pyrolysis and hydroconversion **(IH2)**[2]	Lignocellulosic feedstocks are thermally decomposed into hydrocarbons that are processed into fuel	TBD[2] Max Blend = 5%	Waste biomass such as seaweed, aquatic plants, algae, bagasse, corn stover, and municipal solid waste (“trash”)	Shell (R&D)

[1] *Airports are designed using IATA codes.* [2] *The pyrolysis pathway (IH2) has not yet been formally certified (Csonka et al., 2023)*

Table 1 highlights the wide variety of SAF production processes that are of interest for commercialization in the near future. The table also provides information about each SAF life-cycle stage (**Figure 3)**. Regarding **FEEDSTOCK**, there is wide variability in what biological materials can be consumed to produce SAF. Various **CONVERSION** processes consume different feedstocks. The resulting fuels are compatible with different **TRANSPORTATION and DISTRIBUTION** modes, based on features of the fuel itself and/or existing networks in the specific geographic regions where particular feedstocks are accessible. It should be emphasized that several of the processes in **Table 1** produce multiple fuel co-products. For example, the Fischer-Tropsch (FT, SPK) and pyrolysis (IH2) pathways each produce varying ratios of bio-based diesel, gasoline, and kerosene (including SAF). The ratios of the output fuels can be adjusted over time, allowing a production facility to respond to changes in demand, price, etc. Finally, regarding **USE** phase, more than eighteen US airports are already consuming SAF in appreciable quantities (*Alliance for Aviation Across America*, n.d.). These airports are primarily located on the East and West Coasts, which makes sense given that CORSIA governs SAF use for international flights. Additionally, western states have been especially aggressive in pursuing SAF use, which is reflected in the higher number of West Coast airports consuming SAF (LAX, SFO, SEA, PHX, DEN) relative to Midwestern and East Coast airports (ORD, EWR, BOS), as noted in **Table 1**.

Figure 4 illustrates the geographic locations of SAF production facilities in the US (ICAO, 2024). Green dots denote six currently operational facilities. These entities are using a variety of production processes and producing SAF at different scales. There are also SAF production facilities in operation outside of the US. Yellow dots denote two failed SAF production sites, Fulcrum Bioenergy (Nevada) and Red Rock Biofuels (Oregon). Both facilities were designed to make use of the Fischer-Tropsch conversion process, consuming either municipal solid waste (Fulcrum) or wood waste (Red Rock) as feedstock. The Fulcrum facility shut down in May 2024, due to "poor management" leading to regulatory challenges (e.g., failing to secure permanent operation permits) and technical problems (e.g., undersized equipment and unexpected clogging) (Bettenhausen, 2024). The parent company filed for bankruptcy in September 2024 (Hussain, 2024). It is unknown whether the facility will be sold and reopened (Bettenhausen, 2024). The Red Rock facility experienced significant delays and multifaceted challenges, including technical difficulties with the gasification process and financial shortfalls caused by cost overruns. The facility was never able to achieve its SAF production volume targets. The original owners defaulted in 2022 (SAF Path, 2024). In early 2023, the facility was acquired by a new owner, Next Renewable Fuels, who plan to operate only the gasification portion of the plant, producing renewable natural gas (RNG) (methane) instead of liquid SAF (Sickinger, 2024).

Finally, the remaining yellow dots in **Figure 4** represent two special cases. The first corresponds to BWI airport (Maryland), which collects and sends used grease/oil from airport restaurants to a refinery facility operated by Neste Corporation. The second of the special cases corresponds to the PIT Hydrogen and SAF Hub (Pennsylvania), which is not yet operational, but it is in advanced planning stages. Excess storage capacity at the old US Airways hub will be leveraged for SAF production via the ATJ and/or FT pathways. This location also offers good access to existing transportation networks via railway and the Ohio River, which will facilitate

efficient SAF distribution. Once it is complete, the PIT hub is likely to be the closest SAF production facility to major airports in Virginia.

NAME	PATHWAY	FEEDSTOCKS	CAPACITY (MILLION LITERS/YEAR)
Phillips 66	HEFA	cooking oil, fats, greases, soybean oil	3028.33
Lanzajet	ATJ	ethanol from agricultural waste, municipal waste, energy crops	37.9
WorldEnergy	HEFA	oil-based feedstocks	1158.30
AirCompany	GFA	Carbon	n/a
Gevo	ATJ	isobutanol	0.378541
Calumet Speciality Partners	HEFA	beef tallow, soy bean oil, canola oil, and camelina oil	232.1
PIT Hydrogen and SAF HUB	FT	hydrogen, carbon monoxide	264.979
BWI Airport	HEFA	cooking oil	5.5 tons
Red Rock Biofuels	FT	woody waste	75.7082
Fulcrum Bioenergy	FT	landfill waste	1514.16

Figure 4. *Locations of SAF production facilities currently in operation (green), or in planning or failed (yellow). Data were generated using ICAO's open-access tracker (ICAO, 2024c).*

To summarize, **Table 1** highlights the wide flexibility that exists in designing each component of the SAF supply chain. **Figure 4** reveals that different SAF processes have been explored with varying degrees of success to date. An overarching conclusion based on **Table 1 and Figure 4** together is that successful SAF production requires careful tailoring of supply chain components to the geographic region in which it will operate.

2.0 Benchmarking Relative to Other States

This section summarizes SAF activity in Virginia's bordering states and others that are perceived to be SAF leaders. Content in each sub-section summarizes notable facilities producing or consuming SAF and provides information about feedstocks of interest and/or special SAF incentives within each state.

2.1 Bordering and Nearby States

Kentucky. Kentucky has proposed several kinds of incentives for production, consumption (use), transport, and research related to various biofuels, including biodiesel, hydrogen, and SAF, (KRS 154.31, KRS 154.32-020). SB 313 calls for the creation of a tax credit for SAF consumers ($2.50/gallon) and producers, the latter capped at $1 million per taxpayer and $5 million total annually. The draft legislation allocated $25 million for forgivable loans aimed at SAF projects with a minimum investment of $100 million (SB 313, 2024). The legislation was sent to committee in early 2024 but has not yet been enacted.

Maryland. Maryland created the *Maryland Aviation Association Green Promotion and Reporting Program* in 2022 (Maryland Clean Energy Center, 2024). The Baltimore/Washington International Thurgood Marshall Airport (BWI) collects approximately 60-70 tons of used cooking oil per year from airport restaurants that is sent out for processing into SAF at Neste refineries, as part of the "Solution ZERO" initiative. It is unknown whether the SAF produced from BWI feedstocks is consumed at BWI or if it is sent elsewhere in Neste's distribution network. The sustainability content on the BWI website does not mention that SAF is consumed there (BWI, n.d.). Maryland is also interested in use of corn and soybeans to produce SAF. Maryland does not currently have any specific SAF-related legislation or incentives.

North Carolina. North Carolina's Piedmont Triad Airport (Greensboro) is using SAF produced by Neste. The fuel is transported to the airport via pipeline or truck and blended with fossil-derived Jet A fuel. The Piedmont Triad Airport Authority is receiving approximately $285,000 from the FAST-SAF Tier 1 program, to conduct a study that will identify new or converted infrastructure required to facilitate greater SAF utilization at the airport. In 2022, Boom Supersonic announced plans to open a $500 million manufacturing facility in Greensboro, NC. This site will produce a new commercial airliner, Overture, which will be capable of flying on 100% SAF at twice the speed of today's fastest passenger jets. Overture has garnered significant commercial interest, including orders from United Airlines, American Airlines, the United States Air Force, and others. North Carolina's top feedstock crops include soybeans and corn. The state has numerous biofuel incentives but no specific incentives for SAF.

Tennessee. The University of Tennessee has been engaged in visible SAF-related research. Tennessee's top feedstock crops for SAF production are soybeans and corn. Tennessee's Farm Bureau provides information about available federal incentives, but Tennessee does not currently have any specific SAF-related legislation or incentives.

West Virginia. West Virginia has a state-wide prohibition on subsidies for producing alternative fuels. Therefore, they do not have any specific SAF incentives.

2.2 Other Visible Leaders in SAF

California. California is well-known as a leader in SAF. They have an ambitious goal of consuming 5% SAF by 2025, which would dramatically reduce GHG emissions (e.g., a savings equivalent to removing 432,000 passenger vehicles per year). Under the state's *Low Carbon Fuel Standard* (LCFS), SAF credits are worth approximately $1.00-1.50/gallon, which can be stacked with federal incentives. Moreover, California entities have been selected to receive more than $120 million in federal grants under the FAA's new FAST-SAF program for six projects. These initiatives will focus on various components of the SAF supply chain, with two pertaining to additional SAF production facilities, and the other four focusing on distribution, blending, and storage infrastructure (FAA, 2024). San Francisco International Airport (SFO) currently consumes the most SAF of any airport in the world. Its SAF is produced by World Energy and Neste via the HEFA and ETJ pathways (Table 1). Finished fuel is transported to SFO via pipeline, with distribution managed by Shell and purchases made by SkyNRG. Despite California's strong incentives for SAF, it is still more profitable to produce biodiesel than SAF.

Illinois. United Airlines recently started using SAF for some flights at Chicago O'Hare (ORD). Projected consumption is 1 million gallons per year, which will account for approximately 3% of the airport's annual fuel consumption. The fuel is produced by Neste. As of 2023, Illinois offers a $1.50/gallon tax credit to purchasers and users of SAF for the period 2023-2032. This credit can be stacked with federal incentives. As of April 2024, no companies had applied for the credit. Two Illinois entities are receiving grants from FAA's FAST-SAF Tier 2 awards. The combined awards are worth more than $42 million, and they will be spent on upgrading SAF distribution, unloading, blending, and storage infrastructure, including the Chicago Fuel Terminal.

Pennsylvania. The PIT Hydrogen and SAF Hub is in advanced planning to open an SAF production facility at the Pittsburgh International Airport. This project received a FAST-SAF Tier 1 grant ($105,000) to gather insights about transportation of SAF from Pittsburgh to other regional airports. Notably, the goal of their effort is to distribute SAF to *other* airports. It is not known what the cost comparison would be between importing SAF from this location vs. producing it in Virginia for use at Virginia airports. The City of Philadelphia also received a FAST-SAF Tier 1 grant ($300,000) to study and then make recommendations about infrastructure improvements to increase SAF uptake in the region. Although Pennsylvania does not directly border Virginia, it is relatively close by, which makes it potentially significant that Pennsylvania entities won two of seven FAST-SAF Tier 1 awards in the program's first year (2024). Tier 1 awards focus on SAF supply chain studies (FAA, 2024).

Minnesota. As of 2024, Minnesota offers a tax credit of $1.50 per gallon of SAF produced or blended in Minnesota or sold to a purchaser who consumes it in an aircraft departing from a Minnesota airport (MN Department of Revenue, 2024). The credits are stackable with relevant federal incentives. Additionally, the Minnesota SAF Hub is an initiative of the GREATER MSP Partnership, which works in collaboration with major partners like Delta Air Lines, Ecolab, and Xcel Energy to produce SAF at scale (Greater MSP, n.d.). In November 2024, it was announced that the production facility will be located in Moorhead, MN. It is expected to cost approximately

$5 billion and will be constructed over a four-year period. It will produce 193 million gallons of SAF per year starting in 2030 (Business Facilities, 2024).

3.0 SAF Activity in Virginia

3.1 Previous Activity

The Virginia Department of Aviation (DOAV) has been exploring SAF supply chains in Virginia for over a decade. This work has been undertaken by a coalition comprising the University of Virginia (UVA), the Commonwealth Center for Advanced Logistic Systems (CCALS), the Commercial Aviation Alternative Fuels Initiative (CAAFI), and others. The coalition's work has focused on assessing the feasibility of SAF production in Virginia, primarily for use at Washington Dulles International Airport. This work has progressed in multiple phases and is still ongoing.

Phase I (completed in 2014) focused on characterizing and quantifying SAF feedstock availability in Virginia. In 2018-2019, the Virginia Center for Innovative Technology funded an aviation biofuels commercialization effort that extended the work initially undertaken by DOAV and the Virginia SAF coalition. The follow-on work focused on advancing specific biofuels commercialization plans, with emphasis on the Appalachian region, particularly within the Cumberland Plateau in the former coal fields regions. In the same interval, the ATIP Foundation received parallel funding from USDA and others to assess the availability of SAF-relevant feedstocks in the region of interest. Key outputs from early work conducted in Phase I and related studies included a *Charter for Implementation of Sustainable Aviation Fuels in Virginia 2022-2030* and an *Update on Sustainable Aviation Fuels for Virginia* for the Governor's office, both in 2022. The SAF coalition hosted staff from Senator Mark Warner's office in late 2022, to update them on the progress of SAF-related research in Virginia.

Phase II (completed in 2023) comprised detailed analysis of SAF supply chains, focusing on several specific combinations of feedstocks and CORSIA-relevant conversion pathways. Key questions of interest for the Phase II study included: *WHAT* combinations of feedstocks and conversion pathways are most appealing in Virginia; *WHERE* should production facilities be located; *HOW MUCH* SAF could be produced; *HOW MUCH* life-cycle CO2 emissions would be created by each pathway of interest; and *HOW MUCH* financial incentive would be needed to make SAF cost competitive with fossil jet fuel?

To answer these questions, the UVA team created supply chain models for two SAF production platforms (gasification with Fischer-Tropsch [GFT] and pyrolysis) and two regionally abundant feedstocks (woody wastes and municipal solid wastes [MSW]). The modeling estimated SAF production costs, volumes, GHG emissions, and other metrics. **Figure 5.A** summarizes the set of hypothetical SAF production pathways for both near-term ("pilot") and longer time horizons ("mature"). **Figure 5.B** summarizes the results of the location (county) suitability analysis. High-level results from the location analysis were consistent with previous USDA-funded research conducted by the University of Tennessee that identified the Tazewell region as a good location for siting of a biorefinery consuming hardwood residues to produce bioenergy (UT Institute, n.d.). **Figure 5.C** depicts projected SAF production costs, with and without currently available federal incentives. These data are shown alongside the historical price per gallon for fossil jet fuel, to show the cost-competitiveness of the evaluated SAF supply chains in Virginia.

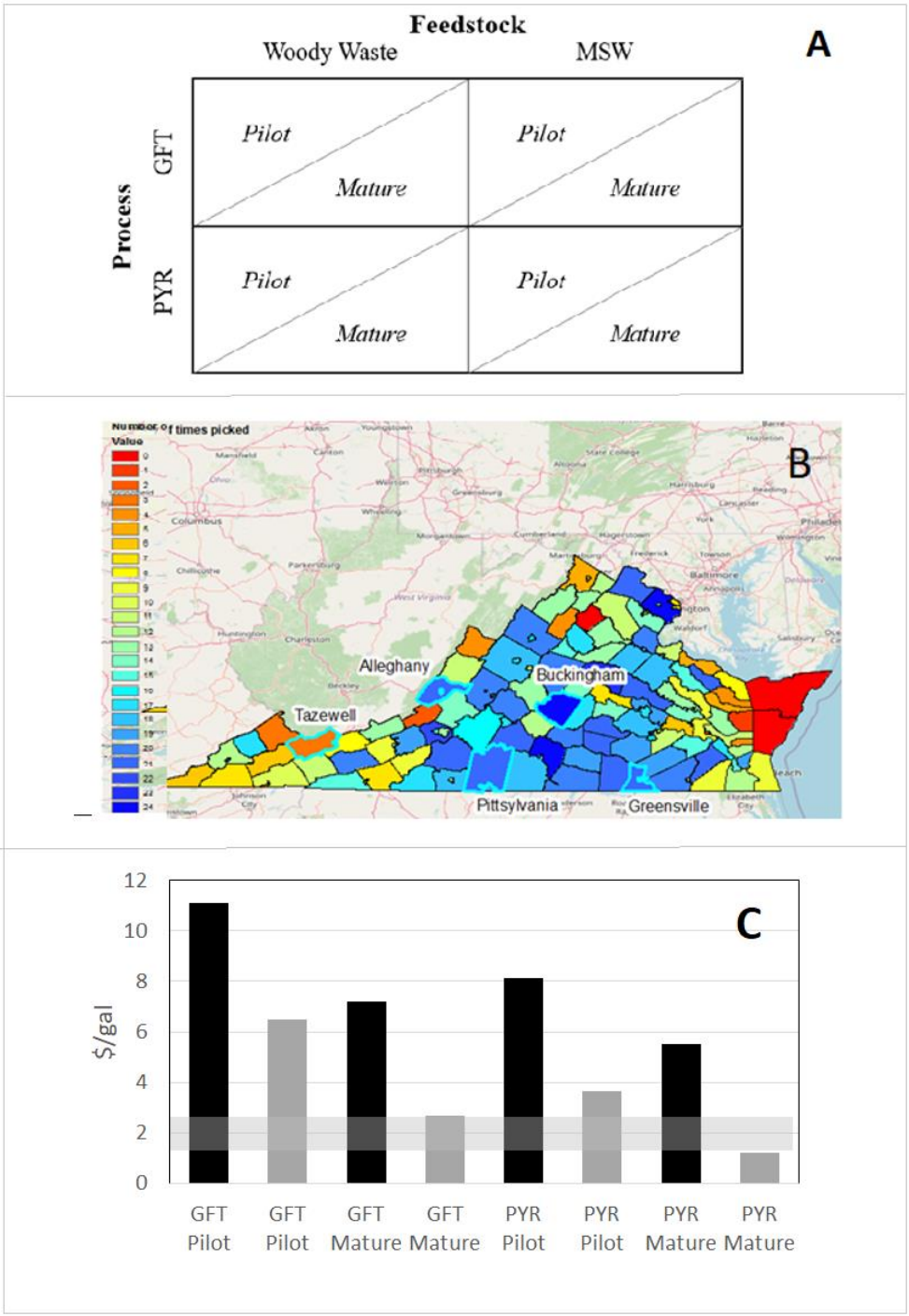

Figure 5. *4.A (upper): the set of hypothetical SAF modeled production pathways; 5.B (middle): results from the location (county) priority analysis – whereby labeled/dark blue counties offer highest potential for SAF production (including Tazewell, which had been identified in a previous analysis conducted by the University of Tennessee); and 5.C (lower): estimated SAF production costs ($/gal) relative to historical average cost for conventional jet fuel (horizontal bar) – dark black and gray bars correspond to estimated SAF costs with and without accounting for current federal incentives, respectively. For additional details, see Davis et al. (2024).*

SAF is not currently being produced in Virginia. However, Phase II modeling attempted to quantify what amount of SAF could be produced per year from woody waste feedstocks (i.e., forest residues, primary mill waste, secondary mill waste, and urban wood debris). Results are summarized in **Table 2.** Cost estimates in Table 2 do not account for existing federal incentives or subsidies, and volume estimates assume that all available woody waste is consumed to produce SAF. These results suggest that SAF production from woody waste feedstocks could fully satisfy historical demand at Washington Dulles International Airport assuming a 50:50 blend with fossil jet fuel. Results from **Table 2** also illustrate that production cost ($/gal) varies strongly with conversion technology (GFT vs. pyrolysis) and facility scale (tonnes/year).

Table 2. *SAF production projections for individual pilot production facilities processing woody waste feedstocks via GFT or pyrolysis. Volume projections are expressed relative to historical fossil jet fuel demand per year at IAD. Volumes represent unblended SAF.*

Production Facility (Type, Size, Number)	SAF Production Cost ($/gal) [without incentives]	% IAD Demand Offset [Unblended]
GFT, 1 M tonne/year PILOT (per individual)	$11.11	7%
GFT, 1 M tonne/year MATURE (network, n = 8 plants)	$7.21	55%
Pyrolysis, 1 M tonne/year PILOT (per individual)	$8.16	8%
Pyrolysis, 1 M tonne/year MATURE (network, n = 8 plants)	$5.54	65%

Modeling results suggest that SAF produced in Virginia will require local incentives to be cost-competitive with fossil fuels. Location of production facility (by county) influences economic and environmental metrics to some degree but not nearly as much as facility size (tonnes/year). Also, different formats of financial incentives (i.e., tax credits, loan forgiveness, etc.) offer markedly different reductions in SAF production cost. As of 2023, Tazewell has an "A rating" for from the Bioeconomy Development Opportunity Zone Initiative (BDOZ Initiative, 2023). This designation signifies that the region has feedstock (hardwood forest residues) in sufficient quantities and prices to support large biomass-based projects (BDOZ Initiative, 2023).

The promising results from Phase II modeling and analyses conducted by other entities (e.g., the University of Tennessee) illustrate the potential for establishing SAF supply chains in Virginia. The results also affirmed findings from a federally funded study led by the University of Tennessee [UT, n.d.], which highlighted the region centered in Tazewell, Virginia as an especially promising location for SAF production from woody waste feedstocks.

Following completion of the Phase II study, the Virginia SAF coalition produced a final report and published the results in a peer-reviewed journal article (Davis et al, 2024). The coalition also convened several working sessions for relevant stakeholders. They hosted FAA's Energy Division Manager and representatives of the Tobacco Commission, in Charlottesville in March 2024. They briefed the CAAFI membership via an invited webinar in June 2024 and sent a

representative to the CAAFI conference in September 2024. The conference was an excellent opportunity to hear about recent SAF-related activities and initiatives underway in various states.

3.2 Recent Activity – FAA FAST-SAF Tier 1 Award

In late 2024, the Virginia SAF coalition was selected to receive approximately $205,000 from FAA's FAST-SAF Tier 1 grant program. UVA is the lead institution on this award. The Virginia team is one of seven entities receiving Tier 1 funding, which focuses on supply chain/logistics studies (FAA, 2024).

The Virginia team's FAA-funded research will have two primary goals: 1) refinement of existing SAF supply chain models, and 2) continued networking with relevant stakeholders across all stages of the SAF life cycle, especially transport, blending, and storage. Specific questions of interest are summarized below, as grouped by SAF life cycle stage.

Feedstock and Conversion Logistics

- What is the optimal number and locations of feedstock depots; do performance metrics adequately capture feedstock pre-processing specifications?

- To what extent do specific locations within high-priority counties have access to low-cost utilities (e.g., natural gas, electricity, cooling water, hydrogen)?

SAF Transport Logistics

- It is of interest to position SAF production facilities in areas that offer easy insertion to the Colonial pipeline, while also balancing trucked transport of feedstock and other inputs. Although previous results were not sensitive to pipeline adjacency, regional stakeholders are strongly interested in using the pipeline to avoid adding significant truck traffic on Virginia roadways. Therefore, what specific location options exist for siting of SAF production facilities in counties with pipeline access?

- What are the perspectives of the Colonial pipeline operators, and what are estimated SAF transport volumes and costs based on blending and other logistics?

Blending and Storage Logistics

- SAF storage is made easier after blending with fossil-derived jet fuel A, which will influence optimized siting of production and storage nodes within the supply chain network. It is therefore of interest to explore various permutations of blending, transport, and storage networks, with consideration of pipeline juncture locations.

- Transport mode will strongly influence the optimization of blending and storage logistics; therefore, modeling of these components must proceed in concert with assessment of possible SAF transport options. Therefore, what is optimized network for supply chain once the modeling for system components has been updated?

In addition to the UVA-led award, one other Virginia entity was also selected to receive funding from the FAST-SAF program. The Boeing Company, operating out of Fairfax, VA, received a Tier 1 award of approximately $2.6 million. They will work on development of a method to improve measurement of fuel quantity in an aircraft fuel tank and increase the accuracy of fuel load calculations (FAA, 2024).

3.3 Additional Proposed Research

Phase IV of the Virginia SAF coalition's work was launched in January 2025. The team will adapt and extend the existing supply chain models to include one additional SAF production platform, likely HEFA (**Table 1**). With the recent, highly publicized failures of the Fulcrum and Red Rock facilities, there is concern that the GFT process may not be fully ready for commercialization. Model refinement to add HEFA and better articulate distribution, blending, and storage stages of the SAF life cycle will proceed concurrently with consensus-building activities among stakeholders, e.g. convening digital and in-person meetings of stakeholders; organizing periodic briefings; coordinating introductions among relevant parties, etc.

With additional funding, Phase IV could also address the following questions:

- Identify the range of SAF demand in Virginia based upon current and forecast levels of air transportation activity.
- Identify what risk reduction measures or financial support mechanisms are available from the Federal Government, the Commonwealth, and private sector investment interests.
- Identify any barriers to entry, such as policy or regulatory constraints.
- Perform a detailed analysis to estimate SAF production scale, with results yielding sufficient information to inform creation of business cases in Virginia
- Quantify economic impacts and job creation potential of SAF production at various scales in Virginia.
- Provide milestones and a schedule of anticipated production and distribution activities to provide scenarios for test cases over a range of implementation strategies.

An additional tactical goal for the Virginia SAF coalition is to find one or more champions to apply for FAST-SAF Tier 2 funding and position them to be competitive for an award. Tier 2 funds can be multiple millions of dollars, to cover the cost of building relevant infrastructure for all stages of the SAF life cycle.

4.1 Strengths, Weaknesses, Opportunities and Threats for Virginia SAF (not exhaustive)

The following sub-sections summarize existing and potential strengths, weaknesses opportunities, and threats related to SAF commercialization in Virginia. These items were identified during Phases I and II of the coalition's work. As additional work is completed, the SWOT analysis will be updated and refined. However, it is currently unknown how recent changes in federal administration will affect national SAF policy.

4.1.1 Virginia SAF Strengths

- Strategic Mid-Atlantic location, world-class port and transportation infrastructure (including proposed inland port)
- (Potential) pipeline access (via Colonial) for low-cost distribution to East Coast airline hubs including Washington, Philadelphia, Newark, New York (JFK), Baltimore, and others
- Opportunity for co-product development (sustainable marine fuels)
- Availability of non-crop biomass feedstocks
- Superior system analysis capabilities and stakeholder engagement

4.1.2 Virginia SAF Weaknesses

- State topography may present cost and transportation challenges for obtaining waste feedstock
- Viability and sustainability of currently available and previously modeled conversion technologies (GFT and pyrolysis) is still largely unproven
- Pipeline integration costs may be higher than in neighboring states such as North Carolina
- Absence of existing oil refineries and other processing infrastructure for coprocessing, blending, and pipeline transport

4.1.3 Virginia SAF Opportunities

- Establish airport advocacy (e.g., at Washington Dulles International Airport) for SAF supply development, to enhance competitiveness for international traffic.
- Increase CCALS private sector engagement to engage with the Virginia Economic Development Partnership (VEDP) and private processor entities.
- Work aggressively with VEDP to prioritize sustainable liquid fuel options as means to improve Virginia competitiveness for international freight cargo
- Work with Tazewell County to understand how they plan to utilize their Ecostrat *Bioeconomy Development Opportunity (BDO) Zone* designation and leverage that effort within the FAA-FAST implementation plan.
- Capitalize on Virginia's proximity to Washington, DC to pursue other federal channels (e.g., DOE, USDA), thereby improving competitive position through leverage of FAA FAST and other programs.

- Develop relationships with Virginia's marine and military communities to identify/exploit co-production opportunities i.e., multiple fuels produced via the same process)

4.1.4 Virginia SAF Threats

- Market conditions, including prices for SAF, conventional jet fuels, and other biofuels (e.g., biodiesel produced from SAF feedstocks)
- Competing demands for waste feedstock

4.2 Recommendations

To advance SAF development, it is recommended that Virginia:

- Leverage systems analysis capabilities of CCALS and UVA as competitive advantages in attracting the participation of supply chain participants through ongoing and dedicated support and investment for their leadership, participation and retention of Virginia talent.
- Foster strong and dedicated cooperation among the Virginia Department of Energy, Virginia Department of Forestry, DOAV and CCALS in combination with the Virginia Economic Development Partnership (VEDP).
- Coordinate biomass capacity and bioeconomy planning initiatives at the state level, to understand and align SAF and other interests.
- Promote SAF development in the Commonwealth and message accordingly to increase visibility of Virginia's interest and potential in this space."
- Work with the existing SAF-coalition to convene maritime and aviation stakeholders to discuss the feasibility of co-production (i.e., multiple fuels produced via the same process), engage resources of regional planning authorities, and set goals/expectations of multiple candidate processing options. This action is intended to ensure Virginia production and logistics siting is included in the evaluations by both stakeholder groups.
- Ensure that the nexus of planned inland port facilities and access to existing pipelines from all candidate processing sites are integrated into state-wide and local economic development plans.
- Ensure that the infrastructure of future inland ports and candidate conversion sites have adequate supplies of relevant utilities to support SAF processor operations

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