SUSTAINABLE AVIATION FUTURES
NORTH AMERICA

North America's Sustainable Aviation Fuels (SAF) Landscape

Intelligence Report

CONTENT

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This document is offered ahead of the Sustainable Aviation Futures North America congress, where many of the themes will be covered in greater detail by world-leading experts. The event is taking place in San Francisco from 8-9 December and more details can be found at www.safcongressna.com

INTRODUCTION

The sustainable aviation fuel landscape is changing rapidly, and announcements on offtake agreements, new facilities, progress in construction, and SAF consumption are made almost daily. After slow progress over a decade, the sector's optimism is at an all-time high and not a moment too soon. The challenges faced by the industry to reach net zero by 2050 are daunting.

The passing of the Inflation Reduction Act represents a pivotal event in catalyzing SAF development in the U.S. and globally. The SAF Blenders Tax Credit (BTC) will improve the ability of SAF to compete with conventional jet fuel and renewable diesel and, and together with the Producer Tax Credit (PTC), will aid the scaling up of technologies to commercial status. The provisions have met widespread support from SAF producers in the U.S.

The U.S. further announced an ambitious strategy with the SAF Grand Challenge, targeting the production of 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050. Multiple federal government departments and agencies are jointly committed to a coordinated approach to achieve the objectives of the SAF Grand Challenge. The SAF Grand Challenge Roadmap[1] was published and identified strategies to address aspects such as feedstocks, supply chain development, and scaling up conversion technologies and policies. The SAF Grand Challenge sets a clear target and a timeline to focus the efforts of stakeholders toward a common goal.

Unlike the E.U., the U.S. approach has focused on incentives for SAF production rather than creating structural demand through mandates. Both approaches have considerable merit and will jointly contribute to the global development of SAF.

Looking further north, the newly developed Canada Clean Fuel Standard came into force on 1 July 2023, but offers limited support for SAF, allowing an opt-in of SAF to earn credits under the Act. In contrast, British Columbia has proposed the inclusion of aviation fuel into their low carbon fuels standard, combined with a volumetric mandate commencing in 2028. Consultations on this proposal have closed. The recently formed Canadian Council for Sustainable Aviation Fuel (C-SAF), a multi-stakeholder organization representing airlines, fuel producers, feedstock suppliers and many others, recently completed a roadmap for SAF in Canada[2].

1 https://www.energy.gov/sites/default/files/2022-09/beto-saf-gc-roadmap-report-sept-2022.pdf
2 https://c-saf.ca/roadmap/

SAF IN NORTH AMERICA

The last two years have seen unprecedented developments in the SAF sector. However, significant challenges exist to achieving net zero by 2050. SAF is expected to play a critical role in decarbonizing the aviation sector, and >400 million tonnes of SAF will be required by 2050. IATA projected that about 300 million litres of SAF was produced in 2022[1]. However, recent estimates from the organization indicate that 69 billion litres of total renewable fuel are expected to be produced per year by 2030, although the SAF portion is not known at this time.

In the U.S., demand for jet fuel by 2050 is projected to form a significant portion of this total at 35 billion gallons (132 billion litres). Coordinated efforts and leadership from multiple U.S. government agencies over more than a decade have been driving the sector's development.

This has culminated in the recent passing of an aggressive enabling policy, the Inflation Reduction Act, which includes a SAF Blenders Tax Credit and Producer Tax Credit, which is expected to significantly impact the commercialization of SAF. In addition, SAF credits introduced in Illinois, Washington State, and Minnesota will create a very favourable policy environment for SAF producers, while the policy in Illinois will directly benefit airlines as well.

This report looks at the SAF landscape in North America, the current and future projects under development and the policy and regulatory framework that is being put into place by government actions.

1 https://www.iata.org/en/pressroom/2022-releases/2022-12-07-01/

KEY CHALLENGES TO DELIVERING ON SAF TARGETS TO 2050

Challenge 1 - The high cost of SAF

SAF is far more expensive than conventional jet fuel, anything between 3 to 6 times more. Argus Media reported an outright price of $3,344.74/t on 27 January, 2023, which equates to a premium of around $2,330/t to the 1-27 January jet fuel average.[1]

In an industry with small profit margins and intense competition, outright purchasing of SAF by individual airlines (if volumes were available) could become an unsustainable proposition at high SAF blends, as fuel contributes about 30% to the overall cost. Bridging the price gap and creating a level playing field are, therefore, two key issues that must be addressed by policymakers.

The WEF-CST and ICF reports both indicate that production costs for all SAF technologies will remain higher than conventional jet fuel until 2050. The projected costs from the WEF-CST report are illustrated below. Despite anticipated improvements over time, production costs will likely remain higher than current conventional jet prices by 2050.

Global SAF production cost for selected technologies - Source: WEF-CST report

1 https://www.argusmedia.com/en/news/2413894-sustainable-aviation-fuel-premium-holds-steady

When will the price of SAF come down? Production costs for technologies are expected to improve over time due to learning, innovation and greater economies of scale. However, pioneer or first-of-kind facilities are expected to be about 50% more expensive to construct. Significant cost improvements will only be obtained as there is a move toward nth facilities as multiple biorefineries are established for the same technology, and a fully commercial scale is achieved.

Before a pioneer facility is built, production costs are generally underestimated, and cost improvements can only start happening once the number of facilities based on a specific technology increases from the first facility. Production costs shown in various reports are generally a reflection of nth facilities, and, as only the HEFA pathway is fully commercial, production costs of other technologies will have a level of uncertainty. Different technologies will have potential cost improvements in different areas.

For gasification and Fischer-Tropsch, a large component of the production cost is due to the significant CAPEX required, and lower cost improvements are achievable for this component. Production cost estimates for power-to-liquids (PtL) show the greatest potential for improvement over time, as the cost of hydrogen (from renewable electricity) has the most significant impact on the cost. In the case of HEFA, feedstock cost is the largest component of production costs and will therefore impact any potential cost reductions.

Bridging the price gap will rely on an enabling policy and regulatory environment. The introduction of the Inflation Reduction Act, together with other SAF-specific policies in Illinois, Washington State, and Minnesota will have a significant impact on development of SAF technologies and increased consumption of SAF. Together with low carbon fuel standards in California, Oregon and Washington (with more states set to adopt this type of policy), as well as the federal Renewable Fuel Standard, greater price parity of SAF with conventional jet fuel will be achieved.

Challenge 2 - Low availability of SAF

The demand for SAF is enormous, and over 40 billion litres in offtake agreements have been signed to date, according to the ICAO SAF Tracker (July 2023)[1]. From current production volumes of less than 0.1% of total jet fuel demand, availability is the biggest constraint to greater consumption of SAF at present. While numerous facilities are under construction, ramping up to full commercial scale with multiple facilities for each technology pathway will take time and SAF availability will remain limited compared to demand in the short-to-medium term.

Challenge 3 - Slow scale-up of SAF technologies

More technologies at a commercial scale are required if we are to build 5,000-7,000 refineries by 2050. The HEFA technology is currently the only fully commercial pathway with multiple facilities operating globally, although most of these facilities currently only produce renewable diesel and not SAF.

Co-processing of fats and oils for SAF production has also reached commercial scale in the past year. However, only European refineries are currently delivering commercial SAF volumes by this method. Co-processing presents the most rapid potential for scale-up as limited infrastructure is required while downstream supply chains are already in place. An ASTM committee is considering expanding the maximum 5% co-processing limit to 30% renewable feed and this could have a significant impact on the expansion of co-processing for SAF production.

Of the other technologies, the first refinery based on gasification and Fischer-Tropsch, Fulcrum Bioenergy, was recently completed and commissioned and produced its first syncrude product from municipal solid waste. In February, 2023, the first batch of syncrude was sent for upgrading to the Marathon petroleum refinery where SAF will be produced through a co-processing approach.[2] However, the Red Rock Biofuels project went into foreclosure in February 2023. The commercialization of this key technology is critical for delivering significant volumes of SAF in the future.

The first Lanzajet AtJ facility (Freedom Pines, Georgia) is expected to be completed in 2023, and the company has announced multiple additional facilities in North America, Europe, and Japan. Gevo's Net Zero project is currently under construction and poised to deliver isobutanol-to-jet volumes in the near term.

1 https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx
2 https://www.fulcrum-bioenergy.com/news-resources/first-fuel-railcar

Other technologies, such as pyrolysis and hydrothermal liquefaction with the upgrading of bio-oils/biocrudes, are still at lower levels of technology readiness. The company Alder Fuels propose to use a type of pyrolysis technology for SAF production and signed a significant offtake agreement with United Airlines. However, the process is still being commercialized, and this pathway is not currently ASTM-approved.

Technology progression for biofuels from one TRL level to the next can take a few years, in addition to time for the commissioning and ramp-up of a newly constructed facility before it reaches full capacity. The rate of technology commercialization and scale-up will play a significant role in the overall expansion and commercialization of SAF production.

Challenge 4 - Long-term policy stability

The high cost of SAF compared with conventional jet fuel in the mid to long-term means that SAF development will likely be very limited without policy support. Ambitious and stable policies are required to develop and commercialize new SAF technologies.

Policies that have enabled the development of the biofuel sector have focused on both supply and demand side policies, and the creation of volumetric mandates for bioethanol and biodiesel blending has been at the core of such policies. While this is the approach used in the E.U., policies in the U.S. have avoided mandates and focused on incentive-based policies linked to the carbon intensity of fuels. This is reflected in the SAF BTC and PTC in the Inflation Reduction Act, and the SAF policies in Illinois, Washington State and Minnesota, and in the inclusion of SAF in low carbon fuel standards such as California through an opt-in approach rather than setting an obligation for the aviation fuel pool.

IATA has been critical of a mandate-only approach, indicating that a mandate must be accompanied by measures to reduce the price gap between SAF and conventional jet fuel. As stated by IATA, "while a mandate does provide a clear demand signal which can be important for new production business cases, it rarely delivers the optimal economic outcome, typically resulting in higher prices and imposing a dead-weight loss on consumers."

A primary role of any policy must be mitigation of investment risk for the project's duration. According to the ICF report, 5,000-7,000 refineries will be required globally by 2050 to meet the industry's net zero commitments and require USD$1,080-$1,450 billion in investment. The investment cost for SAF facilities is generally much higher than for first-generation biofuels such as bioethanol and biodiesel, which must be reflected in higher capital support and loan guarantees.

A key policy challenge that is often highlighted is the inability of SAF to compete with renewable diesel. In the US RFS, renewable diesel earns 1.7 RINs while SAF only earns 1.6, which makes SAF uncompetitive against renewable diesel and favours the production of renewable diesel rather than SAF. During the production of renewable diesel from lipids, the main product is diesel, but at least 15% of the hydrocarbon molecules are in the jet range and can be separated as SAF. While there are multiple renewable diesel facilities worldwide, the majority have only been producing renewable diesel and not SAF as, in many jurisdictions, incentives only apply to renewable diesel and not SAF. It has, therefore, historically been more economically beneficial for companies to only produce renewable diesel.

Where incentives are available to both SAF and renewable diesel, the difference in energy content means that it is still more lucrative for fuel producers to target only renewable diesel.

The introduction of an energy multiplier has been proposed as an effective policy to overcome this imbalance and allocates a higher incentive to SAF compared to renewable diesel, allowing SAF to compete effectively with renewable diesel. The structure of the SAF BTC and PTC achieves a levelling between SAF and renewable diesel. Renewable diesel is currently able to earn a blenders tax credit of $1 per gallon, while the SAF BTC amounts to $1.25 per gallon, potentially increasing to $1.75 per gallon. This could have a significant impact to encourage renewable diesel producers to produce a SAF fraction, and even to maximise SAF production.

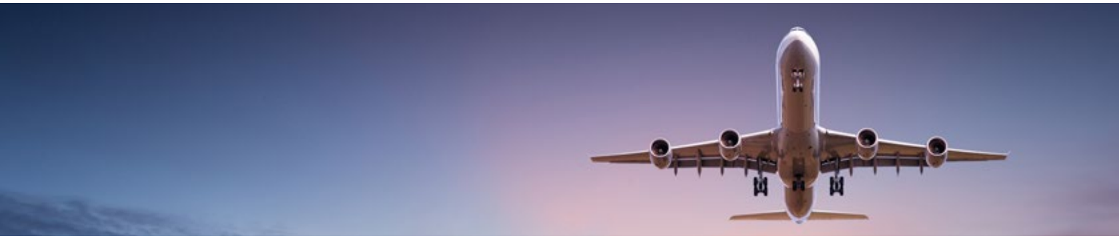
Additional policies that are needed are grants and funding for RD&D of technologies that are still under development. The U.S. has made long-term funding investments in research through national laboratories, such as the National Renewable Energy Laboratories and the Pacific Northwest National Laboratories, and organizations such as ASCENT. The Inflation Reduction Act also includes funding for competitive grants for the construction of facilities. The grant program under the IRA, termed Fueling Aviation's Sustainable Transition (FAST), has two elements focused on SAF, FAST-SAF, and elements focused on lower mission aviation technologies, FAST-Tech[1].

1 https://www.transportation.gov/sites/dot.gov/files/2022-12/IRA-Section-40007-FAST-Program-Briefing.pdf

Large grants (Tier I) are available for infrastructure for production of SAF, while smaller grant awards are available for establishing regional supply chains that would enhance existing jet fuel transportation and logistics networks to supply airports with SAF, e.g. installing blending facilities where unblended SAF can be delivered, stored and blended, and upgrade existing facilities for SAF production, delivery, and storage.

Grants are also available for installation of distillation columns at renewable diesel facilities to enable SAF production, and installation of ethanol-to-jet conversion equipment at existing ethanol production facilities.

In addition, as discussed below, the development of feedstocks with improved sustainability and carbon intensity must be addressed in order to supply future expected SAF volumes, which the U.S. has addressed through programs in the U.S. Department of Agriculture, e.g. the Farm-to-Fly program. The SAF Grand Challenge Roadmap.



Challenge 5 - Availability of low carbon intensity feedstocks at scale

Availability of sufficient, low carbon intensity and sustainable feedstocks will be critical if projected volumes of SAF are to be produced by 2050. The immediate challenge is the availability of fats, oils and greases (FOGs) for the HEFA pathway, as well as for co-processing.

Most of the SAF that will be produced up to 2030 will be using this technology. In addition, co-processing is taking off, and the current co-processing blend level limit is expected to be increased from 5% to 30%. All co-processing is currently based on FOGs, and at the large scale of petroleum refineries, even 5% can amount to significant volumes of feedstocks needed.

Low carbon intensity, sustainable FOGs, such as waste oils and fats (used cooking oil and tallow) is in great demand, but these will have limited global availability, estimated at about 40 million tonnes per year.

These feedstock volumes are relatively static, unlike vegetable oils, where harvest yields can be improved. Importantly, there is intense competition for these feedstocks from the road transportation sector for the production of biodiesel and renewable diesel. Biodiesel mandates are in operation worldwide in dozens of countries, while renewable diesel demand is growing at a rapid pace. Competition with the road sectors will impact the availability of feedstocks for SAF.

Non-edible oil crops are generally included in feedstock estimations as a sustainable alternative to vegetable oils. While several of these alternative crops are still under development, they must reach full commercialization and their associated supply chains established to support the SAF sector. Policy measures to support the development and commercialization of alternative oil crops may be necessary to deliver the significant volumes needed.

The SAF Grand Challenge roadmap has a goal to increase the supply of sustainable lipid feedstocks to support SAF production and the US Department of Agriculture (USDA) aims to work with farmers to develop and improve the supply of sustainable oilseed through research and development and support pilot trials for emerging oilseed crops. The USDA recently approved crop insurance for camelina and this will have an impact on the commercial expansion of this oilseed crop[1].

The other feedstock availability challenge is the source of low-carbon-intensity alcohol intermediates for the AtJ process. Alcohol production from advanced feedstocks such as agricultural residues is not fully commercial, and the long-term challenges faced by the cellulosic ethanol sector are well-documented. Significant volumes of such advanced ethanol are not available. In the U.S., advanced ethanol is mainly produced at a small scale in bolt-on, generation 1.5 facilities based on corn fiber.

Commercial efforts for cellulosic ethanol production have been successful to some extent in Brazil based on bagasse. More recently, cellulosic ethanol production is experiencing renewed interest with the opening of the Clariant facility in Romania, and the Indian Oil project at Panipat, Haryana based on the Praj technology. But more extensive commercial facilities will be needed to supply the AtJ SAF pathway.

The initial strategy for scaling up the AtJ pathway in the U.S. is based on the diversion of corn ethanol into SAF, combined with strategies to improve sustainability and reduce the carbon intensity of the ethanol. But large-scale commercial production of advanced ethanol and butanol will be critical to delivering the low-term low carbon intensity AtJ-SPK volumes needed.

1 https://biodieselmagazine.com/articles/2518791/usda-expands-crop-insurance-for-camelina

PROJECT DEVELOPMENT AND FUEL PRODUCER LANDSCAPE

Technology trends

In the U.S. and worldwide, a significant number of new HEFA facilities have been announced or are coming online. Multiple HEFA facilities are based on refinery conversions switching from crude oil refining to renewable diesel and SAF from oils and fats. Most HEFA facilities worldwide have only produced renewable diesel due to favourable policies offering an economic benefit for renewable diesel. With additional infrastructure and processing steps, every HEFA refinery can produce a SAF fraction, potentially delivering over 1 billion litres in the short term.

However, policy drivers will determine whether it is economically beneficial for facilities to produce both renewable diesel and SAF. Where SAF production becomes economically favourable, the SAF fraction from these facilities could potentially be increased to become the major product, and policy will be the driving force in this decision. The SAF Blenders Tax Credit will improve the competitive advantage of SAF against renewable diesel and may result in renewable diesel facilities investing in SAF production.

Some current and announced facilities plan to use soybean oil or canola as a feedstock and the cost of the feedstocks will have an impact on the economics of a facility while potentially limiting the carbon intensity of the SAF. Based on CORSIA default CI scores, SAF based on soybean oil and canola oil has CI scores of 64.9 and 71.5 gCO2e/M.J., respectively, therefore not achieving a 50% reduction in CI to be eligible for the SAF BTC, unless measures are taken to reduce the CI score.

Co-processing for SAF production, based on simultaneous processing of fats and oils with crude oils, is taking place at multiple refineries in the E.U. In the U.S., Chevron has announced the production of SAF by co-processing at their El Segundo refinery.

The current 5% blend insertion limit for co-processing of oils and fats under ASTM D1655 is under consideration for an increase to 30% and this will likely be approved in the near term. This can have a rapid impact on SAF availability but will place pressure on overall feedstock availability.

The production of SAF through the Alcohol-to-jet pathway is rapidly reaching a commercial level, with the first pioneer facilities for the ethanol-to-jet and isobutanol-to-jet pathways under construction. The Lanzajet Freedom Pines Project is expected to be completed in 2023. The Lanzajet process can use any source of ethanol, while Gevo produces its own isobutanol through patented technology. Gevo currently produces isobutanol from inedible corn at its Luverne facility but has a targeted approach to reaching net zero CI through steps such as renewable energy and working with farmers to adopt no-till farming practices to reduce emissions in the life cycle of the fuel. The Gevo facility in Luverne is based on the conversion of an ethanol facility, and this could provide a low-cost CAPEX route to commercial-scale production.

Ethanol and isobutanol are currently the only alcohols approved under ASTM D7566 for SAF production, but n-butanol and methanol alcohols could likely become alternative alcohols for SAF production in the future.

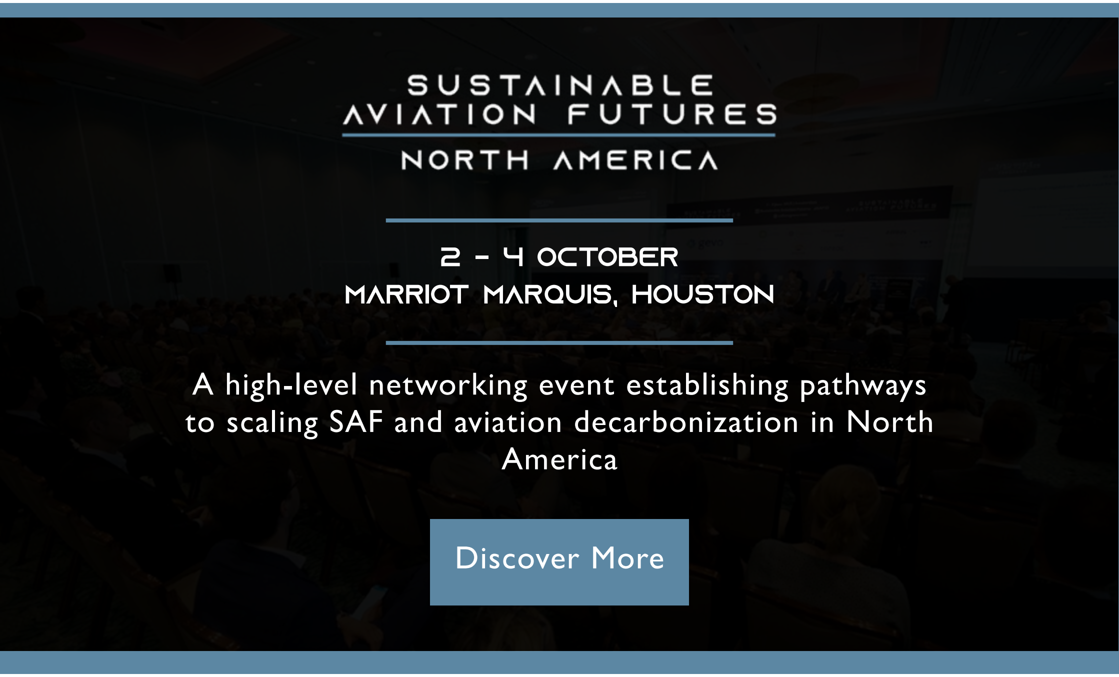
The gasification with Fischer-Tropsch (F.T.) synthesis pathway has shown slow progress to commercial scale. The Fulcrum Bioenergy facility in Sierra, based on municipal solid waste as a feedstock, was completed in 2022, but construction on the Red Rock Biofuel facility, based on woody biomass, has stalled. MSW, as a negative cost feedstock, can reduce the production cost of SAF via this pathway, but the carbon intensity is only determined based on the biogenic content of the waste. MSW has high levels of contaminants, and the syngas cleanup before F.T. is a critical step in the process. Fulcrum has announced the production of syngas as the facility is being commissioned, a positive step toward hydrocarbon production.

Once F.T. liquid hydrocarbons have been synthesized, they still require upgrading into finished SAF and Fulcrum will be using a co-processing approach to upgrading which is currently approved under ASTM D1655 at 5% insertion blends.

The other company in this space, Velocys, has announced several SAF facilities based on gasification and Fischer-Tropsch using a distinct, proprietary F.T. synthesis technology. The success of these initial facilities, all using different gasification and F.T. technologies, will be critical for this technology to progress from pioneer facilities into full commercial status.

Direct thermochemical liquefaction technologies include fast pyrolysis and hydrothermal liquefaction with the upgrading of liquid intermediates into finished fuels. The critical step in this process is upgrading, which is still at a relatively low technology readiness level.

Alder Fuels technology is based on a type of pyrolysis. Although the company has signed large SAF offtake agreements, it is still at a pre-pilot scale and will likely take a number of years to develop. Hydrothermal liquefaction has been extensively investigated for U.S. SAF production at research facilities such as the Pacific Northwest National Laboratories (PNNL) and based on wet feedstocks such as sludge. However, these technologies are not currently ASTM certified for use in jet engines.



Key producers of renewable diesel and SAF in the U.S.

The SAF landscape is rapidly changing and new facilities are announced on a regular basis. The table below shows a list of facilities that are currently in operation, under construction, or planned. All renewable diesel (HDRD, HEFA, HVO) facilities have also been included, as these facilities could potentially switch part of their product slate to SAF[1].

Table of main producers of renewable diesel and SAF in the U.S. (in operation and planned/announced)[2]

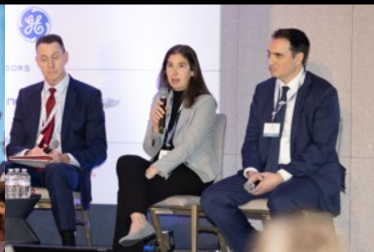
Company	Technology pathway	Capacity (MGPY) (Total Fuel, not total SAF)
Aemetis	HEFA	90
Alder	Pyrolysis	150
BP (Cherry Point)	HEFA	109
Chevron/REG	HEFA	340
CVR Coffeyville, Wynnewood	HEFA	200
DG Fuels	Gasification/FT	302
Diamond Green Diesel	HEFA	1200
Emerald	HEFA	100
ENGlobal	Various (HVO, gasification)	200
Fulcrum	Gasification/F.T.	40
Gevo	Isobutanol-to-jet	65
Global Clean Energy	HEFA	230
Gron Fuels	HEFA	996
Heartwell Renewables	HEFA	75
HIF Global	eFuels	168.6
HOBO	HEFA	120

1 https://www.biofuelsdigest.com/bdigest/2023/07/03/the-digests-2023-multi-slide-guide-to-the-state-of-saf/3/
2 Table independently verified and prepared by SvD Consulting

Table of main producers of renewable diesel and SAF in the U.S. (in operation and planned/announced)[1]

Company	Technology pathway	Capacity (MGPY) (Total Fuel, not total SAF)
HollyFrontier	HEFA	200
Indaba	HEFA	100
Infinium eFuels	eFuels	7.2
Lanzajet (Freedom Pines)	Ethanol-to-jet	10
Marathon	HEFA	1605
Montana Renewables	HEFA	150
Nacero Texas	Methanol-to-jet (from RNG)	1073
New Rise Renewables	HEFA	44
Next Renewable Fuels Inc.	HEFA	766.5
Northwest Advanced Bio-fuels	gasification	64
Phillips 66 (San Francisco)	HEFA	290
Raven SR	Fischer-Tropsch	60
Readifuels	Catalytic hydrothermolysis	24
SkyNRG Americas	Fischer-Tropsch	27
USA Bioenergy	Gasification/FT	100
Velocys (Bayou Fuels)	Gasification/F.T.	20
Vertex Energy	HEFA	200
Viking Energy	HEFA	43
World Energy	HEFA	1000

1 Table independently verified and prepared by SvD Consulting



Proposed facilities in Canada

Canada has no current SAF production, although a number of emerging companies have announced that they plan to produce SAF. However, the Inflation Reduction Act in the U.S. may draw investment away from Canada, as outlined in the Canadian media.

According to a recent report, the Canadian Fuels Association considers the IRA a "game changer". It says that investors are re-evaluating plans for $8 billion worth of proposed projects in Canada for renewable diesel, SAF and other biofuels[1]. In March, the Parkland Corporation announced that it was cancelling plans for a renewable diesel facility in Burnaby, BC. Other companies, such as Arbios Tech, are also considering relocating facilities in the U.S. to take advantage of the favourable policy environment, according to a recent report[2].

While several projects for renewable diesel facilities based on the hydrotreatment of oils and fats are planned in Canada, the impact of the IRA may still be felt. Refuel YYZ is planning a production facility in Southern Ontario producing renewable diesel and SAF from waste fats, oils and greases, and non-edible crop oils. Braya Renewables in Newfoundland, a conversion of the Come by Chance refinery, plan to produce renewable diesel and SAF from the hydrotreatment of oils. Two other refinery repurposing projects have been announced.

Tidewater Midstream and Infrastructure Ltd. is a conversion of the Husky Refinery in Prince George, British Columbia, and construction was completed in June 2023. Imperial is repurposing the Strathcona refinery in Edmonton to use canola, soy or sunflower oils in combination with hydrogen produced from natural gas and carbon sequestration to make renewable diesel and, potentially, SAF. Federated Co-operatives Ltd plans to build a $2 renewable diesel fuel and canola-crushing facility in Regina, Saskatchewan. At this stage, they have not made an announcement of any intention to produce SAF.

1 https://www.westerninvestor.com/alberta/canadas-renewable-fuel-industry-will-be-unviable-after-us-move-6730569
2 https://www.reuters.com/sustainability/rich-us-subsidies-may-hobble-canadas-clean-fuel-efforts-2023-06-12/; https://www.cbc.ca/news/canada/calgary/canada-biofuel-production-us-ira-1.6903008

In December 2020, Enerkem announced the construction of a CAD$875 million biofuels plant in Varennes, Quebec. Enerkem will partner with a group including Shell as the lead investor, Suncor and Proman, Hydro-Québec and Varennes Carbon Recycling (VCR) to make biofuels and renewable chemicals from non-recyclable residual materials as well as wood waste. According to the company website, the commissioning of the first phase is scheduled for 2025[1].

Arbios Tech was formed as a joint venture between Licella, an Australian company using hydrothermal liquefaction technology, and Canfor, an integrated forest products company. Using hydrothermal liquefaction technology based on Licella's CAT-HTR process, their long-term plans include the production of SAF.

Parkland Refining Ltd, based in Burnaby, British Columbia, have been routinely co-processing lipids for a number of years and, in May 2022, announced the development of a freestanding renewable diesel facility at the existing refinery (subsequently cancelled).

Four companies participated in the recent "Sky's the Limit" challenge that was facilitated by Natural Resources Canada, including Enerkem (gasification of forest biomass, final winner), Carbon Engineering (PtL with DAC), SAF+ Consortium (PtL with point-source capture), and Forge Hydrocarbons Corporation (proprietary lipids-to-hydrocarbons).

1 https://enerkem.com/company/facilities-projects/

REGULATORY AND POLICY LANDSCAPE IN THE USA AND CANADA

Inflation Reduction Act (USA)

The Inflation Reduction Act has already had a significant impact on the SAF sector in the U.S. The legislation was passed in August 2022 and included a new SAF Blenders Tax Credit (BTC) to support the sale and use of SAF. The BTC provides an economic incentive that will help to bridge the price gap between conventional jet fuel and SAF. Importantly, the tax credit is dependent on SAF providing a minimum of 50% emissions reductions while also driving companies to pursue further improvements in carbon intensity through an additional 1 cent per gallon for each percentage point of increased emission reductions above 50% with a cap of $1.75 per gallon.

Many SAF producers in the U.S. have announced extensive efforts to reduce the carbon intensity of fuels through additional investment in renewable electricity, green hydrogen, and carbon capture and storage. Linking incentives with increased carbon intensity reduction will support the higher investment costs for the additional infrastructure.

The Act also establishes a competitive grant program in support of alternative aviation and fuels. Grants will be available for projects located in the U.S. that produce, transport, blend or store SAF and will support additional infrastructure needed in the downstream supply of SAF to airports.

According to the IRA, the percentage reduction of GHG emissions must be calculated in accordance with the latest version of CORSIA, or any similar methodology under the Clean Air Act. On June 16, 2023, 16 U.S. Senators sent a letter to U.S. Treasury Secretary Janet Yellen urging the agency to adopt the U.S. Department of Energy's GREET model as the secondary methodology for calculating tax credits for sustainable aviation fuel (SAF). According to the senators, adopting GREET will dramatically enhance the effectiveness of SAF incentives to accelerate the aviation industry's decarbonization[1]. The Senators argue that GREET is more up-to-date and accurate for U.S. domestic practices. As such, it will reward farmers for climate-smart agricultural practices and introduces a market-driven approach to sustainability.

1 https://growthenergy.org/wp-content/uploads/2023/06/2023.06.16-Senate-Treasury-Letter-re-IRC-Section-40B-SAF.pdf; https://biomassmagazine.com/articles/20136/senators-to-treasury-adopt-greet-for-saf-tax-credit

The SAF Grand Challenge (USA)

The Sustainable Aviation Fuel Grand Challenge is an ambitious government-wide commitment and comprehensive strategy to produce 35 billion gallons of SAF by 2050 (enough to meet all jet fuel demand in the U.S.), with an interim target of 3 billion gallons by 2030.

It is a collaborative effort of the U.S. Department of Energy (DOE), the U.S. Department of Transportation (DOT), the U.S. Department of Agriculture (USDA), established through a Memorandum of Understanding, and other federal government agencies. The strategy's goals include scaling up new technologies to produce SAF at a commercial scale and expanding the production and use of SAF. Efforts will target reducing the cost of SAF and enhancing its sustainability.

The roadmap describes six action areas which span all activities that might impact the SAF Grand Challenge objectives of expanding SAF supply and end use, reducing the cost of SAF while enhancing the sustainability of SAF. The action areas include:

- Feedstock Innovation
- Conversion Technology Innovation
- Building Supply Chains
- Policy and Valuation Analysis
- Enabling End Use
- Communicating Progress and Building Support

Low Carbon Fuel Standard (California)

The California Low Carbon Fuel Standard (LCFS) was first implemented in 2011 to decarbonize the state by 20% in 2030. It has played a significant role in biofuel development and decarbonization of fuels while also impacting air pollution and increasing the fuel efficiency of vehicles.

In 2018, the California Air Resources Board (CARB) included alternative aviation fuels as an "opt-in", allowing these fuels to earn compliance credits in the fuel pool without incurring any debits. Credits are earned on the basis of the carbon intensity of fuels relative to a declining baseline for fossil jet fuel. The policy goes some way towards bridging the price gap between SAF and conventional jet fuel while it does not obligate its use.

However, renewable diesel is able to earn higher credits which makes SAF uncompetitive against renewable diesel and favours the production of renewable diesel rather than SAF. The incentives through the credit value of fuels in the California LCFS are stackable with incentives through the federal U.S. Renewable Fuel Standard (RFS) and federal blenders tax credits under the IRA.

New York, Vermont, Michigan, Illinois, Minnesota and New Mexico have proposed the introduction of LCFS policies but these have not been approved at this stage.

Aviation in the U.S. Renewable Fuel Standard and the role of RINs

The Renewable Fuel Standard (RFS) requires transportation fuel sold in the U.S. to contain a minimum volume of renewable fuels, Renewable Volume Obligations (RVOs), imposed on fuel refiners, blenders and importers. Renewable Identification Numbers (RINs) are used to track the compliance of obligated parties and serve as proof that they met their RVO. RINs are the system's credits and act as an incentive for fuel producers.

The U.S. Renewable Fuel Standard (RFS), while traditionally targeting road transportation, was amended to also include renewable jet fuel on an "opt-in" basis to earn RIN credits without establishing an RVO for aviation.

Under the RFS, SAF can generate 1.6 RINs per gallon, while renewable diesel earns 1.7 RINs, putting SAF at a disadvantage against renewable diesel. The stackable nature of various incentives may alleviate this disadvantage. Biodiesel and renewable diesel can currently earn a $1 per gallon blenders tax credit, while under the new Inflation Reduction Act, SAF will be able to earn between $1.25-$1.75 per gallon. This may act as a sufficient incentive for renewable diesel producers to divert some of their products into SAF.

SAF credits in Illinois, Washington State and Minnesota

In addition to the federal SAF credits under the Inflation Reduction Act, individual states have enacted policies for SAF credits.

Illinois recently enacted a SAF credit of $1.50 per gallon, which can be claimed by airlines. Airlines in Illinois will be able to claim the SAF tax credit up to a set quota dependent on the amount they spend on domestic conventional jet fuel that year. The credit applies for ten years. The Illinois SAF tax credit will effectively lower the price airlines pay for SAF used at airports in the state.

The Illinois law also caps the volume of soybean oil-derived SAF that airlines can claim credits for to 10 million gallons/yr, a measure intended to appease road transportation stakeholders concerned that the credit would lead biofuel refiners to cut back on renewable diesel production — which also uses soybean oil — and thus increase prices at the pump.

Starting in June 2028, the Illinois state tax credit will only apply to SAF derived from domestic feedstocks. This will allow SAF from Finnish producer Neste to flow into Illinois in the near term but not crowd out other domestic SAF suppliers in the future, including those in Illinois.

Washington State also enacted a SAF credit that would give tax incentives to manufacture and purchase SAF. The aim is to incentivize fuel producers to build SAF production facilities in Washington State by creating a business and operations tax rate of 0.275% for the manufacture and sale of sustainable aviation fuels. The tax incentive would go into effect July 1, 2024, but only after a facility capable of producing at least 20 million gallons of alternative jet fuel is operating in Washington State. It will be applicable for 10 years. The credits are equivalent to one dollar for every gallon of alternative jet fuel, increasing depending on the reduction in emissions. For example, alternative fuel that is 50% cleaner than conventional fuel would generate a $1 credit. Fuel that is 51% cleaner would receive a $1.02 credit, increasing by each percent up to $2 per gallon.

Minnesota also enacted a Sustainable Aviation Fuel Tax Credit on March 23, 2023. S.F. 2723 establishes a refundable sustainable aviation fuel ("SAF") tax credit and related sales tax exemption for blenders and producers of sustainable aviation fuel. The Act provides a refundable income and corporate franchise tax credit equal to $1.50 per gallon of SAF produced or blended in Minnesota which will be in force until January 1, 2035. The commissioners of revenue and agriculture must prescribe the manner in which the credit will be claimed. The Act specifies that SAF is exempt from aviation gasoline and jet fuel taxes, and exempt from sales tax. Section 6 of the Act also provides a sales tax exemption for construction materials and supplies used or consumed in, and equipment incorporated into, the construction, reconstruction, or improvement of a facility that produces or blends SAF.

Canada's Clean Fuel Standard

Canada has seen major developments in the policy landscape recently with the development of a comprehensive clean fuel standard.

The Clean Fuel Regulations came into force on July 1, 2023 and will require liquid fossil fuel primary suppliers (producers and importers) to gradually reduce the carbon intensity of the gasoline and diesel that they produce and sell for use in Canada. A carbon intensity reduction requirement will start at 3.5 gCO2e/M.J., and increase by 1.5 gCO2e/M.J. each year, reaching 14 gCO2e/M.J. in 2030.

The Regulations establish a credit market, and regulated parties must create or buy credits to comply with the reduction requirements. There is no carbon intensity reduction requirement for aviation fuel, but the regulations provide an "opt-in", allowing credit creation for SAF if it is deemed a low carbon intensity fuel as per the Regulations. Whether this will promote the development of SAF remains to be seen as the SAF will not be competitive with renewable diesel as no multiplier is included. The favourable policies under the Inflation Reduction Act will likely have an impact on SAF development in Canada as it may be more favourable to invest in facilities in the U.S. to reap the benefits of the producer tax credit. Canada may also see the export of feedstocks to the U.S. as a result of the IRA.

British Columbia's Low Carbon Fuel Regulations

On a provincial level, British Columbia has operated a low carbon fuel standard since 2010, but this only applied to the gasoline and diesel fuel pools. The B.C. government announced in May 2022 that the new Low Carbon Fuels Act (LCFA) will replace the previous regulations. There are two changes worth noting; firstly, the carbon intensity reduction required is increased from 20% to 30% by 2030. Secondly, the penalty rate for non-compliance with the carbon intensity requirements of the Act is increased from CAD$200 per tonne to CAD$600 per tonne. The Act comes into force on 1 January 2024. Carbon intensities of fuels must be calculated using GHGenius as a model.

In the regulations for the New Act, the Ministry has proposed to add a renewable fuel content requirement for suppliers of fuel in the jet fuel category[1]. The Ministry intends for the jet fuel category to be subject to carbon intensity reduction requirements starting January 1, 2024, as well as renewable fuel content requirements starting January 1, 2028. This will require suppliers of jet fuel category fuel to meet increasingly stringent annual carbon intensity reduction targets. As these requirements may be met with overcompliance in the gasoline or diesel fuel categories, the Act also introduces a requirement for a minimum renewable content in the jet fuel category. Suppliers of fuel in the jet fuel category will be required to ensure that the volume of jet fuel they supply in a compliance period contains at least 1% renewable fuel content by volume starting in 2028, 2% renewable fuel content by volume in 2029, and 3% renewable fuel content by volume in 2030 and subsequent compliance periods.

The renewable fuel content requirements for the jet fuel category must be met with non-fossil-derived alternatives to jet fuel, as prescribed in the Regulation, and may not be met by over-compliance with the renewable fuel content requirements in the gasoline or diesel fuel categories.

The Ministry intends to accept as low carbon jet fuel, fuel produced from renewable feedstocks in a stand-alone facility or co-processed from renewable feedstocks in a conventional petroleum refinery, so long as the fuel meets equivalent standards to fossil-derived jet fuel for use in a jet engine.

1 https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/aviation_intentions_paper.pdf

Direct investments and offtake agreements by airlines

Airlines, through voluntary actions, have played a pivotal role in SAF development through direct investment in fuel producers and the signing of multi-year offtake agreements. Dating back to 2015, United Airlines invested $30 million in Fulcrum Bioenergy and has signed a total of six offtake agreements amounting to over 10 billion litres in volume. Other airlines have followed suit, and as of May 2023, over 40 billion litres of SAF offtake agreements have been signed by airlines, according to ICAO's offtake tracker[1].

A government-led, multi-agency, coordinated approach in the U.S. driving SAF development

The SAF industry would not be commercial today without the federal research and development policies that have been critical to deployment, particularly concerning supply chain development, testing, and technical approvals of SAF.

Various programs under the U.S. Department of Energy (DOE), the Bioenergy Technologies Office (BETO), and the U.S. Department of Agriculture have addressed aspects of research and development of SAF technologies and feedstocks. The FAA Center of Excellence for Alternative Jet Fuels and the Environment (ASCENT), the Continuous Lower Energy, Emissions & Noise (CLEEN) program, and the Commercial Aviation Alternative Fuels Initiative (CAAFI) have also been instrumental in developing the SAF industry. These activities will continue to support and drive further development and analysis of new feedstocks, technologies, and supply chains to continue to scale the industry.

The Canadian Council for Sustainable Aviation Fuels (C-SAF)

The Canadian Council for Sustainable Aviation Fuels (C-SAF) was launched in 2022 to accelerate the commercial production and use of SAF in Canada. Members include 45 stakeholders from the entire SAF value chain (airlines, suppliers, airports, OEMs, academia, and others), including about 60 airlines.

1 https://www.icao.int/environmental-protection/GFAAF/Pages/Offtake-Agreements.aspx

Over the past year, the C-SAF with the collaboration of its ecosystem, The Transition Accelerator, and Energy Futures Lab have worked on producing "The C-SAF Roadmap: Building a feedstocks-to-fuels SAF supply chain in Canada" through a series of workshops and extensive reviews[1].

Canada's Aviation Action Plan lays out a clear and ambitious goal that SAF should be 10% of projected Canadian jet fuel use by 2030. Based on this goal and the total market for jet fuel in Canada, C-SAF has established a target of 1 billion litres of SAF production by 2030.

FEEDSTOCK AVAILABILITY AND SUSTAINABILITY

Feedstock availability is a significant factor in the potential production of SAF and potential SAF production will be linked to the regional distribution of feedstocks. Whereas oils and fats feedstocks can be transported globally due to their high energy density, other feedstocks, such as municipal solid waste and residues, have a low energy density and cannot be transported economically over great distances. This will have an impact on the location of SAF production facilities and the likely SAF technologies that will be employed in a region.

The most recent US Billion-ton study (2016) is a seminal report on the economic availability of biomass feedstocks in the U.S., based on its regional distribution down to the county level and taking into account sustainability. The report shows that one billion tonnes of biomass feedstocks are available per year for bioenergy applications after taking into consideration competing uses such as food and feed. According to the DOE, about 645 million tonnes could support the production of 35 billion liters of SAF, which will satisfy 100% of jet fuel demand in the U.S. by 2050. The Billion-ton study 2023 update is expected to be published imminently[2].

The HEFA pathway is fully commercial and presents the lowest risk investment. Until 2030, it is likely that the majority of SAF will come from the HEFA pathway, and the biggest obstacle will become the availability of feedstock.

1 https://c-saf.ca/roadmap/
2 https://www.energy.gov/sites/default/files/2023-06/beto-01-energy-crops-saf-panel-june-2023-langholtz.pdf

Estimates for waste-based lipid feedstocks (mainly UCO and tallow) for HVO and HEFA production indicate that only about 25-30 million tonnes are available worldwide. Based on the Greenea Horizon 2030 market report, announced facilities for HVO/HEFA production by 2025 alone amount to about 30 million tonnes. Not all these facilities will use waste-based lipids, and feedstocks will include soybean oil or canola, although this will result in fuel with a higher carbon intensity and lower sustainability. In jurisdictions like the E.U., SAF produced from crops such as soybean oil will not be eligible for meeting mandate obligations, increasing the pressure on waste FOGs for SAF production in the region. In the U.S., the only feedstock that is banned for HEFA production is palm oil derivatives, and the carbon intensity of the SAF will be the main criterium to determine eligibility for the SAF BTC.

The advantage of using vegetable oils is that they have mature supply chains and are available in large quantities, while collection and supply chains for waste feedstocks such as UCO must often be established. Due to anticipated challenges with future availability, many HEFA producers are investing in feedstock suppliers such as renderers to secure future feedstock supply.

Apart from availability, the cost of feedstock can have a significant impact on SAF production. For HEFA, feedstock cost can amount to 80% of production cost. According to Greenea, UCO prices skyrocketed to $1330/tonne in December 2021, while vegetable oil prices, such as rapeseed oil, increased dramatically in 2022 and prices exceeded $2000 per tonne between April and June 2022. However, prices have dropped significantly since then. In May 2023, Argus Media reported prices for rapeseed oil between €850-890/t (~USD956-1001), UCO between €880-1028 (~USD989-1156), and tallow between €700-1276 (~USD787-1435)[1].

1 https://www.argusmedia.com/-/media/Files/sample-reports/argus-biofuels.ashx?la=ru&hash=53A787ECEC-CE3499E74D6EE109A3FD467996C208

Alternative lipid feedstocks, such as camelina, carinata, pennycress, jatropha, salicornia, and others, are in development and are expected to provide a source of low carbon intensity feedstocks for SAF production. However, greater support must be directed toward the commercialization of these feedstocks and their supply chains to achieve large-scale availability.

Feedstocks such as energy crops (e.g. miscanthus) also feature as an important component in feedstock availability assessments that can deliver negative carbon intensity SAF, but commercial-scale growth and availability are still challenging.

Apart from availability and cost, the sustainability of SAF is critical to supply real climate benefits, with feedstocks a central focus in sustainability assessment. Under current CORSIA guidelines, RSB and ISCC have been approved as sustainability certification bodies for SAF. These bodies include multiple principles and standards of sustainability into their certification process, with carbon intensity only one such measure. While a significant emphasis is placed on the carbon intensity of production pathways, overall sustainability will be essential to determine SAF eligibility. But ultimately, airlines place a premium on sustainability compliance of SAF to meet their environmental commitments.

A message from Sustainable Aviation Futures

This independently written report has been updated from its first 2022 version to present the current landscape for SAF in North America, objectively and from a technology agnostic perspective. Exciting developments in 2023 include new states offering incentives for SAF production and use, as well as taking stock of project progress 12 months on. We hope you found the content useful.

The report sought to be clear about the key challenges currently facing the sector and the progress of projects across the USA and Canada. This is not to detract away from the exciting developments that have recently been seen in aviation fuel, but so that the industry can develop the solutions needed to tackle these challenges head on to ensure SAF's continued progress.

As new technologies and feedstocks achieve commercial scale up and additional government support, SAF will hopefully become as commonplace a word as solar and wind and achieve the same economies of scale that the renewable energy industry has seen in recent times.

The growth of SAF presents an enormous opportunity for the entire industry, and important policy announcements such as the Inflation Reduction Act point towards a very positive future for the decarbonization of the aviation sector. We welcome your feedback on this report so we can adapt and build additional information for future editions.

We will discuss and uncover the challenges and opportunities in this report at the Sustainable Aviation Futures North America congress taking place in Houston from 2-4 October. The event will share perspectives from over 120 leading experts and 400 industry stakeholders, technology providers, policymakers and fuel producers during interactive panel discussions and presentations. Coupled with a dedicated networking app, the congress will be the meeting place for aviation decarbonisation and the scale up of SAF production, development, and growth.

I look forward to seeing you there.

Jamie Dowswell
Director
Sustainable Aviation Futures