METHANOL INSTITUTE

METHANOL-TO-JET SAF

Policy, Technoeconomic and Commercial Outlook

January 2026

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FOREWORD

By Ben Iosefa, Chair of the Board, Methanol Institute

Aviation is one of the defining industries of our interconnected world. It supports global trade, tourism, and cultural exchange, and demand for air travel is projected to rise by 50% by 2050. Yet this growth comes with a clear challenge: how to align the sector's future with the world's climate goals.

Sustainable aviation fuels are central to this challenge. While multiple production routes are emerging, it is increasingly clear that no single pathway can meet the scale of demand. We will need a diverse set of solutions, backed by strong policies, investment, and a commercially viable business model.

Methanol has long proven its value as a versatile and scalable chemical building block, as well as a leading alternative fuel for maritime decarbonization. The experience gained from shipping, where supply chains, safety standards, and bunkering infrastructure are being developed at pace, offers valuable lessons for aviation as it prepares for the large-scale deployment of sustainable fuels.

Methanol-to-jet represents the next frontier in this journey. It builds on a mature global methanol industry that already produces more than 100 million metric tons annually, supported by extensive transport, storage, and distribution infrastructure. MTJ opens a new avenue for delivering sustainable fuels at scale and more importantly, it reflects the kind of innovation and cross-sector collaboration that will be required if aviation is to decarbonize effectively. Interest in this pathway is growing rapidly, with airlines across the globe exploring methanol-based SAF as part of their decarbonization strategies.

This report is one of the first to take a comprehensive look at methanol-to-jet, its potential, and the conditions needed for its success. It highlights both the opportunities and the challenges ahead. As the Methanol Institute, we believe this report can help inform decisions across industry, policy, and finance, and we are committed to bringing all stakeholders together to advance methanol-based solutions for aviation.

The task before us is urgent, but the opportunities are significant. Extending methanol's role in aviation is a natural progression—one that could help ensure this vital sector continues to grow in a sustainable way.

ABSTRACT

Aviation faces an urgent decarbonization challenge coupled with increasing global jet fuel demand expected to increase by 50% by 2050. Sustainable aviation fuel (SAF) is the most viable pathway to reduce emissions in the near- and medium-term, yet existing pathways are facing constraints. Innovative SAF pathways such as Methanol-to-Jet (MTJ) offers a promising alternative, building on an established global methanol industry that produces over 100 Mt annually, supported by extensive infrastructure for transport, storage and distribution.

This report provides one of the first comprehensive assessments of MTJ, examining the policy frameworks that will shape demand, technoeconomic factors that influence commercial scale up, the emerging commercial project pipeline and ASTM qualification efforts. For biomethanol-based MTJ, Argus finds production costs are among the lowest of novel SAF options, outperforming Fischer-Tropsch (FT) and advanced Alcohol-to-Jet (AtJ) routes. Even though MTJ has higher capital intensity than HEFA, this is offset by higher yields and less exposure to feedstock scarcity. Integrated MTJ plants, which share utilities and hydrogen production with methanol facilities, could approach cost parity with fossil jet fuel by 2040 under favorable policy regimes.

The ASTM qualification process is well underway, with approval achievable in the 2026-2027 timeframe, opening the door for commercialization and scale up and allowing MtJ SAF access to incentives and participation in regulatory programs in the EU, U.S. and other parts of the world. Moreover, the global pipeline for MTJ SAF projects has grown significantly, representing approximately 1.8 Mt per year of SAF production capacity as of August 2025.

EXECUTIVE SUMMARY

The aviation industry faces a critical need to reduce its greenhouse gas (GHG) emissions amid global efforts to address climate change. Although aviation accounts for just under 3% of global CO_2 emissions, it is among the fastest-growing sources and is projected to continue expanding, with global jet fuel demand expected to increase 50% by 2050. Given the long design life of aircraft, limited electrification potential for long-haul flights and infrastructure inertia, sustainable aviation fuel (SAF) has emerged as the primary solution to reduce aviation emissions in the near- and medium-term.

SAF refers to non-petroleum-based jet fuel that can be blended with conventional jet fuel and used in existing aircraft and fueling infrastructure without modification. Depending on how the fuel is produced and from what feedstocks, SAF can reduce lifecycle CO_2 emissions by more than 50%, and in some cases up to 100%, compared to conventional jet fuel. As regulatory frameworks solidify and commercial-scale production ramps up, SAF is expected to play an important role in reducing the climate impact of global aviation. Despite accounting for less than 1% of global jet fuel consumption today, SAF production is projected to scale rapidly over the coming decades, supported by a combination of policy mandates, investment incentives and private-sector commitments.

As global demand for jet fuel rises and the industry faces tightening carbon reduction mandates, the limitations of existing SAF pathways, such as feedstock constraints and scalability, have become more apparent. Without innovative SAF pathways, such as methanol-to-jet (MTJ), the aviation industry will fall short of meeting SAF requirements in the EU and other countries, putting decarbonization goals for aviation at risk. Very little public analysis exists on the MTJ pathway today, making this report one of the first comprehensive assessments of its costs, benefits and commercial outlook.

Report Overview & Key Findings

This report provides the current state of play for MTJ and explores the technology itself, current policies that impact MTJ SAF, technoeconomic considerations and commercial development status. To fully understand the opportunity and roadmap ahead for MTJ, this report explores the pathway in detail, assessing:

- **Chapter 1:** Introduction and context for the MTJ pathway.
- **Chapter 2:** Relevant policies that impact SAF and MTJ.
- **Chapter 3:** Technoeconomic considerations and analysis for MTJ.
- **Chapter 4:** Commercial development of MTJ, including pathway approval under relevant ASTM standards.
- **Chapter 5:** Recommendations for policymakers and stakeholders to consider.

In the backdrop of the urgent need to decarbonize the aviation sector, and in the midst of future increases in fuel demand, the MTJ SAF pathway is discussed in more detail in Chapter 1. In summary, with aviation fuel demand projected by Argus to rise from 330 Mt in 2019 to over 500 Mt by 2050, efficiency gains and existing SAF pathways cannot meet the gap. Even if existing SAF pathways such as HEFA, ATJ and FT ramp up, they cannot meet projected SAF demand alone at nearly 60 Mt by 2050, according to Argus. Innovative SAF pathways such as MTJ will be needed to deliver scalable volumes alongside HEFA, ATJ and FT.

In addition, MTJ is capable of delivering deep lifecycle GHG reductions, estimated between 70% and 90% when renewable methanol is used. The MTJ process leverages existing chemical conversion technologies, such as the methanol-to-olefins (MTO) platform, which are already commercialized and scalable. Methanol as a feedstock is highly versatile and can be derived from a range of sources, including biogenic waste, biomass gasification and synthetic production using captured CO_2 and renewable hydrogen.

Chapter 2 provides a comprehensive overview of the policy and regulatory landscape shaping SAF markets. It identifies the key regional and international policies that support SAF deployment, including the EU's ReFuelEU Aviation Regulation, Renewable Energy Directive (RED), U.S. initiatives under the Inflation Reduction Act (IRA) and Bipartisan Infrastructure Law (BIL) and other global policies. In addition, it discusses the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) developed by the International Civil Aviation Organization (ICAO).

In the EU, the ReFuelEU Aviation Regulation requires that by 2030 at least 6% of jet fuel be SAF, with a 1.2% sub-mandate for RFNBOs like e-MTJ. By 2050, the mandate increases to 70% SAF, including 35% RFNBOs. These estimates show how fast SAF volumes, and innovative SAF pathways such as MTJ, must scale to meet policy targets. Timely development of MTJ-compatible policy frameworks will be critical to unlocking investment and scale.

Chapter 3 examines the technoeconomic considerations that will shape MTJ's commercial trajectory. From a feedstock perspective, methanol is already produced at global scale, with more than 100 Mt traded annually through established infrastructure of tankers, rail, barges, pipelines, and port storage. This existing network gives MTJ a deployment advantage over SAF pathways requiring new infrastructure. Integrated MTJ projects can co-locate with methanol plants, CO_2 sources, or ports to cut capital costs and simplify permitting, while also lowering costs by sharing utilities, hydrogen production, and methanol logistics. Many of these projects are designed with surplus methanol capacity for maritime use, creating additional revenue streams and resilience against SAF market volatility.

Argus assessed costs for both standalone and integrated MTJ facilities and compared them with other SAF pathways. For biomethanol-based MTJ, Argus finds production costs are among the lowest of novel SAF options, outperforming Fischer-Tropsch (FT) and advanced Alcohol-to-Jet (AtJ) routes. Even though MTJ has higher capital intensity than HEFA, this is offset by higher yields and less exposure to feedstock scarcity. Argus estimates average 2024 production costs for bio-based SAF at around $2,200 per ton, compared to roughly $8,100 per ton for e-SAF (whether MTJ or FT routes). By 2040, integrated biomethanol-MTJ plants could approach production cost parity with fossil jet fuel under favorable policy regimes. Argus also highlights the importance of byproduct economics: MTJ primarily yields naphtha, while FT produces diesel and naphtha, making FT-based e-SAF somewhat more favorable in their cost scenarios.

Chapter 4 documents the progress toward commercializing MTJ and securing ASTM qualification, a prerequisite for blending with conventional jet fuel. The qualification process is well underway, with approval achievable in the 2026-2027 timeframe, opening the door for commercialization and scale up and allowing MtJ SAF access to incentives and participation in regulatory programs in the EU, U.S. and other parts of the world. Several leading technology developers including ExxonMobil, Honeywell UOP and Topsoe are pursuing MTJ process development, while project developers are undergoing commercial-scale planning.

According to GENA Solutions, the global pipeline for MTJ SAF projects has grown significantly, representing approximately 1.8 Mt per year of SAF production capacity as of August 2025. These projects are located in Europe and Asia, and most are at the feasibility or pre-feasibility stage.

A notable feature of the current MTJ project landscape is the preference for vertically integrated production models. In fact, approximately 74% of the methanol feedstock required, equating to nearly 4.8 Mt annually, is planned for captive production at integrated facilities. This model builds on a broader trend in methanol production, where integration with downstream derivative facilities is already widespread (e.g., in coal-to-olefins complexes in China).

Finally, the trajectory of renewable and low-carbon methanol capacity is central to scaling MTJ-derived SAF. Recent data from GENA Solutions' project pipeline now includes 134 e-methanol plants and projects with a combined capacity of 23.4 Mt, 104 biomethanol projects totaling 18.5 Mt, and 17 low-carbon methanol projects totaling 10.1 Mt. Together, these represent nearly 52 Mt of announced capacity by 2030.

Chapter 5 concludes this report with targeted recommendations to accelerate MTJ deployment that include the following:

- Provide regulatory clarity and establish predictable, long-term policy frameworks.
- Consider the use of financial tools that help close the cost gap.
- Improve and harmonize international sustainability certification standards.
- Encourage infrastructure integration and project layouts that reduce cost.
- Ensure continuity of EU SAF allowance program.
- Recognize the full environmental benefits of MTJ SAF.

Implementation of these recommendations would help establish the policy certainty and supportive market conditions required for MTJ (and other SAF pathways) to scale commercially.

Acknowledgements

This report was prepared by the Methanol Institute (MI) under the guidance of its Board of Directors. The lead authors were Laurent Donceel (aviation and SAF expert), Tammy Klein (Transport and Energy Strategies), and Juan Pablo Castillo, Chris Hairel, and Heng Zeng (Argus Media Consulting).

Project management was led by Kai Zhao (Methanol Institute), whose coordination and oversight were essential to the successful completion of this report.

The report benefitted from the valuable review and contributions of external experts: Vitalii Protasov (Gena Solutions), George Andrush (Nacero), Andrew Fenwick (Haldor Topsoe), Leigh Abrams (Honeywell UOP), Mark Rumizen (Air Company), Emeric Sarron (Carbon Recycling International), Audur Baldvinsdottir (IðunnH2), and Aviation Initiative for Renewable Energy in Germany (Aireg).

Further input was provided by the Road and Aviation Working Group under MI's Fuels Committee, including Jennifer Hoppe (Proman) and Neha Vijh (Johnson Matthey).

The Methanol Institute would also like to acknowledge the leadership and guidance of CEO Alexander Döll during the development of this report.

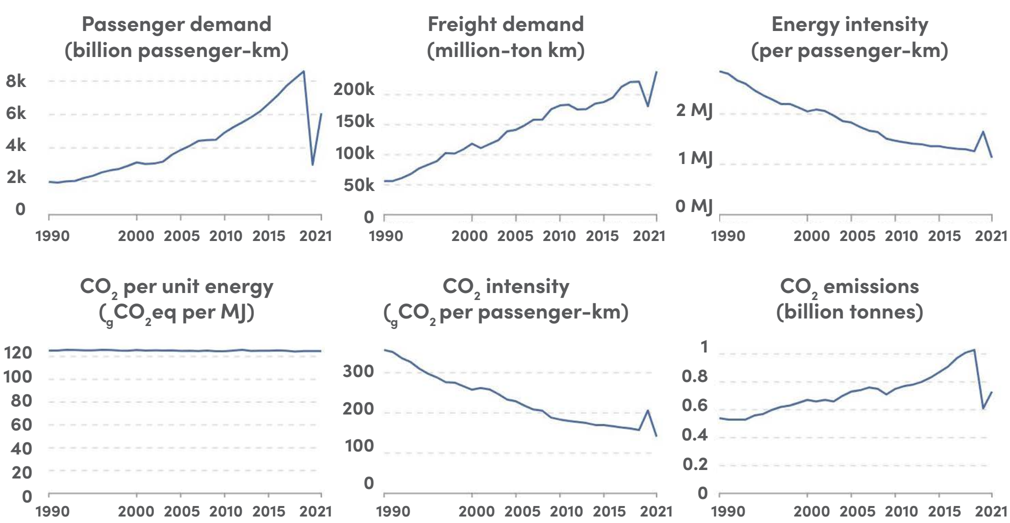
Editorial and communications support were provided by Aria Koutra (Methanol Institute).

CHAPTER 1: INTRODUCTION AND CONTEXT FOR MTJ SAF

Aviation's contribution to climate change has increased markedly over time. Global CO_2 emissions from the sector have quadrupled since the mid-1960s and exceeded one billion tonnes in 2018. Aircraft have become significantly more fuel efficient, and modern planes use less fuel per passenger-kilometer than in the past. However, the carbon intensity (CI) of jet fuel has remained essentially unchanged, meaning that efficiency improvements have not offset the rapid growth in air traffic.

As a result, overall emissions have continued to rise. Today, aviation accounts for about 2.5 percent of global CO_2 emissions, and its total contribution to warming is estimated at closer to 4 percent when non-CO_2 effects are included. This combination of rising demand, limited progress in decarbonizing the fuel mix and disproportionate climate impact makes aviation a critical focus for decarbonization efforts. Figure 1.1 illustrates historical trends in aviation demand, fuel efficiency, and CO_2 emissions, showing that while passenger and freight demand have risen sharply, improvements in energy intensity have been offset by the fact that the CI of jet fuel itself has remained essentially unchanged.

Figure 1.1: Global Aviation Demand, Energy Efficiency and CO_2 Emissions, 1990-2021



Source: Bergero et al, 2023

SAFs are one of the few viable near- to medium-term options to curb these emissions, noted in the figure above, especially for long-haul flights. SAF refers to non-petroleum-based jet fuel that can be blended with conventional jet fuel and used in existing aircraft and fueling infrastructure without modification, referred to as a "drop-in fuel". Depending on how the fuel is produced and from what feedstocks, SAF can reduce lifecycle CO_2 emissions by more than 50%, and in some cases up to 100%, compared to conventional jet fuel. As regulatory frameworks solidify and commercial-scale production ramps up, SAF will play a leading role in reducing the climate impact of global aviation.

The push to commercialize SAF began in earnest in the mid-2000s. Early test flights and demonstration projects paved the way for the development of internationally recognized fuel standards, most notably ASTM D7566, which provides the framework for approving synthetic and alternative jet fuels (see Chapter 4). The adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) framework by International Civil Aviation Organization (ICAO) in 2016 provided a formal global structure for addressing aviation emissions. CORSIA allows airlines to reduce their emissions obligations through the use of approved SAF, incentivizing investment and uptake (see Chapter 2).

Since then, the role of SAF has become even more prominent. The aviation industry has committed to reaching net-zero carbon emissions by 2050, with SAF identified as a critical enabler of that goal. The International Air Transport Association (IATA) has estimated that SAF could deliver roughly 65% of the sector's emissions reductions required to meet that target. Moreover, airlines, aircraft manufacturers, and fuel producers have responded by beginning to increase SAF procurement, forming consortia and launching commercial-scale production projects.

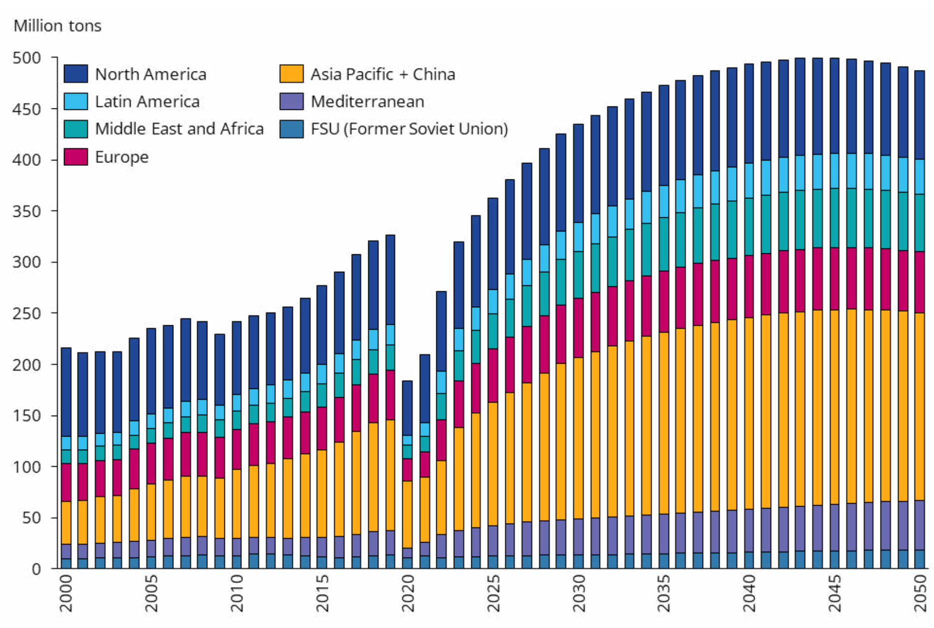
Despite accounting for less than 1% of global jet fuel consumption today, SAF production is projected to scale rapidly over the coming decades, supported by a combination of policy mandates, investment incentives and private-sector commitments. This growth is occurring against the backdrop of a steadily increasing demand for air travel and, consequently jet fuel, placing additional pressure on the aviation sector to decarbonize.

Demand for Liquid Aviation Fuel Will Increase Over the Next Decade

Prior to the pandemic, global jet fuel consumption was about 326 Mt (million tons) with projections indicating clear growth to about 487 Mt by 2050, before dropping to less than 200 Mt in 2020. Fast forward to today, jet fuel demand is well above pre-pandemic levels and expected to grow from 350 Mt in 2024 to 500 Mt by 2040-2045, shown in Figure 1.2.

As global economic conditions improve, the demand for air travel rises, leading to increased jet fuel consumption. Global demand growth is driven by Asia/Pacific, where the needs of a growing population lead to an increase in passenger and cargo flights. Meanwhile, North America and Europe represent a firm baseline for jet fuel demand albeit with a less accelerated growth rate.

Figure 1.2: Global Jet Fuel Demand, 2000-2050

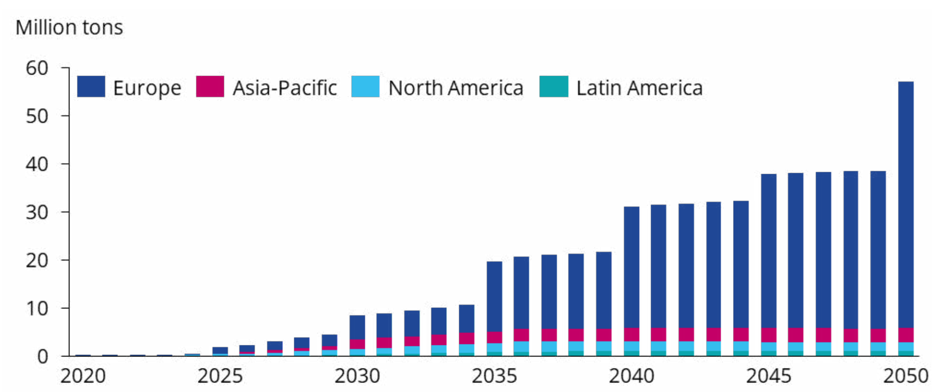


Source: Argus Media Consulting, June 2025

In line with jet fuel growth, Argus estimates SAF demand to grow from 0.5 Mt in 2025 to nearly 60 Mt by 2050 (Figure 1.3), supported by global decarbonization commitments in the aviation industry as the public sector constantly pushes for more sustainable practices across the board.

While fuel efficiency gains from improvements in engine design and air operations will help offset the expected increase in fuel demand for air travel through new engine designs, lighter weight materials, and the retirement of older models, the industry will still rely on the widespread adoption of SAF to achieve net emissions reductions across the sector. This reality has accelerated interest in SAF platforms such as MTJ, which can complement existing pathways and expand production capacity across regions and feedstocks.

Figure 1.3: Global SAF demand, 2020-2050



Source: Argus Media Consulting, June 2025

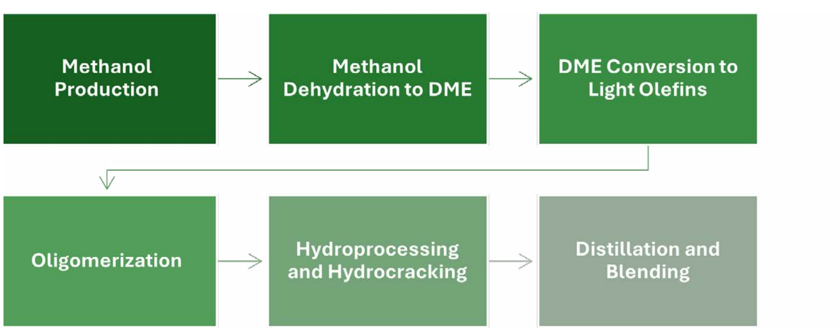
Why MTJ? An Overview of the MTJ SAF Pathway

As global demand for jet fuel rises and the industry faces tightening carbon reduction mandates, the limitations of existing SAF pathways, such as feedstock constraints and scalability, have become more apparent. Meeting long-term net-zero goals and increased demand will require a range of solutions that are both technologically robust and economically viable on a commercial scale. Among these, the MTJ pathway has emerged as a promising addition to the SAF landscape, offering feedstock diversity, process flexibility, and strong integration potential with existing methanol and olefin infrastructure.

MTJ through MTO is based on an already commercialized production process. Developed in the late 20th century, MTO was originally designed to address growing demand for light olefins in the petrochemical sector. By the early 2000s, MTO gained traction in China as a way to utilize domestically produced coal-derived methanol to manufacture ethylene and propylene that are key building blocks for plastics and other materials. Today, China hosts more than 30 commercial-scale MTO facilities, representing tens of millions of tonnes per year of installed capacity.

The MTO process begins with methanol production from a wide range of sources, including biomass, biomethane, or CO_2-derived e-methanol. In commercial practice, methanol is typically dehydrated to form dimethyl ether (DME) and then converted to light olefins within the same reactor/catalyst system, often using zeolite catalysts such as ZSM-5 at high temperatures (400-500°C). For MTJ, these olefins are subsequently oligomerized into longer-chain hydrocarbons (C8-C16), which fall within the jet fuel range. Hydroprocessing, comprising hydrogenation and hydrocracking, saturates these hydrocarbons and tailors their properties to meet jet fuel specifications. Figure 1.4 summarizes the MTJ production process in which an intermediate step is MTO.

Figure 1.4: MTJ Production Process Summary



Source: Compiled by Transport Energy Strategies, June 2025

From a readiness standpoint, MTJ using the MTO process offers several advantages. The pathway is feedstock-flexible as methanol can be derived from fossil, biogenic or renewable carbon sources. Through MTO it leverages a commercially mature technology widely used in the chemicals sector, supporting scalability and can be adapted from petrochemical production to fuel generation. However, technical challenges remain. Catalyst optimization is needed to improve olefin oligomerization while minimizing byproducts like methane or coke. Ensuring high selectivity toward jet-range hydrocarbons without excessive material or energy losses is also key. The process's energy intensity is another hurdle, though this can be addressed through strategies such as renewable electricity use and integrated heat recovery.

As a pathway, MTJ via MTO offers a promising combination of technological maturity, decarbonization potential and compatibility with existing infrastructure, particularly for regions with methanol production experience or abundant renewable power.

Variants and Extensions of the MTO-MTJ Platform for SAF

While MTO forms the foundation for most MTJ pathways, several closely related variations are under development. These share common chemistry but differ in catalyst configurations, process conditions or upstream methanol production, and each offers distinct opportunities and challenges for SAF deployment. For example, MTJ via e-fuels refers to using methanol produced from captured CO_2 and green hydrogen (e-methanol) as the feedstock for MTJ-based SAF production.

The final product can be a Synthetic Paraffinic Kerosene (SPK) or a Synthetic Cycloparaffinic Kerosene with Aromatics (CKA), depending on the technology. The MTJ SAF can then be blended with conventional jet fuel to result in a drop-in fuel. SPK is a paraffinic product with no aromatics that, in the case of methanol feedstock, is not yet ASTM-qualified but is analogous to approved ATJ-ethanol and ATJ-isobutanol pathways. CKA, also undergoing qualification within ASTM, is an emerging variant that incorporates cycloparaffins and controlled aromatics to better match the density and seal-swell properties of petroleum jet fuel.

The downstream conversion steps are identical to conventional MTO processes, but this pathway provides deep decarbonization potential. When powered by renewable electricity, MTO via e-fuels can achieve very low lifecycle emissions, making it one of the most promising options for aviation decarbonization. The primary current challenges are the significant renewable electricity requirements cost as well as the costs for green hydrogen production and CO_2 capture, which depend on continued progress in renewable energy deployment.

The ATJ pathway, traditionally associated with ethanol or butanol, could also use methanol as the feedstock once ASTM qualification is achieved. Under the D7566 Annex 5 variation, methanol would follow the standard ATJ steps of dehydration, oligomerization, and hydrogenation. In principle, a D7566 Annex 8 variation (discussed further in Chapter 4) could process methanol through two subprocesses. The first subprocess would involve dehydration, oligomerization, and hydrogenation, which are steps similar to the MTJ pathway. The second subprocess would involve dehydration, aromatization, hydrogenation, and fractionation. The final Annex 8 ATJ product would be the combined output of both subprocesses.

ATJ via methanol benefits from methanol's broad feedstock flexibility, including renewable biomass, biogenic waste, biomethane and captured CO_2. When powered by renewable energy and using low-carbon methanol, the process could achieve lifecycle GHG reductions of up to 85% compared to conventional jet fuel. Several pilot projects and test flights are advancing this pathway toward ASTM approval.

Methanol-to-Gasoline (MTG) is a proven technology originally developed for converting methanol into gasoline-range hydrocarbons, while MTO was developed to produce light olefins such as ethylene and propylene for petrochemicals. Both share common steps, methanol dehydration to DME and olefins, but diverge in catalysts, reactor design and intended product slates. With modifications, MTG can be adapted to yield jet fuel-range hydrocarbons, but this requires additional refining steps to isolate jet fractions. By contrast, MTO-based routes more naturally align with jet production since they already emphasize olefin intermediates that can be oligomerized and hydroprocessed into C8-C16 hydrocarbons.

Ultimately, MTJ pathways represent variations on a common platform for converting methanol into jet fuel rather than entirely unrelated processes. The upstream configurations such as MTO, ATJ-like routes, or MTG adapted for jet, differ in catalysts, reactor design, and operating conditions. However, they all converge on similar downstream chemistry of oligomerization, hydrogenation, and refining to produce jet-range hydrocarbons. By contrast, whether the methanol itself is produced as biomethanol or e-methanol has no effect on the MTJ chemistry once methanol is available, unless explicitly integrated with hydrogen co-supply from electrolysis.

CHAPTER 2: SAF POLICY FRAMEWORKS

Introduction

Over the past few years, the global SAF policy and regulatory landscape has developed significant momentum by developing the necessary policy foundations for long-term investment security in SAF. For example, the EU adopted the ReFuelEU Aviation regulation, and the U.S. launched its SAF Grand Challenge. ICAO adopted its so-called long-term aspirational goal (LTAG) of net-zero CO_2 emissions by 2050 based on a detailed assessment of measures which include a strong reliance on SAF, following in late 2023 by the CAAF/3 agreement. This chapter provides an overview of these and other policies that impact SAF as well as the MTJ pathway.

Policy Frameworks in Europe

The European Union has established one of the most comprehensive policy frameworks in the world to accelerate the deployment of SAF as part of its broader climate and energy goals. With binding emissions targets under the European Climate Law and a commitment to net-zero emissions by 2050, the EU is leveraging a suite of legislative instruments to drive SAF adoption and decarbonize the aviation sector. These measures are reinforced by complementary financial and regulatory tools, many of which have direct implications for MTJ fuels and other renewable fuels of non-biological origin (RFNBOs).

Renewable Energy Directive

The Renewable Energy Directive (RED) increases the demand for sustainable fuels through sector specific targets for industry and transport. The RED also determines the criteria fuels need to meet to be considered synthetic fuels, referred to as renewable fuels of non-biological origins (RFNBOs), advanced and other biofuels. Under REDII (of 2018) legislation, Member States can count SAF toward the achievement of their national renewable energy targets on the condition that they comply with the sustainability criteria listed in the Directive (see section below). The revised RED III (of 2023) gives Member States two options for targets to increase renewable energy in the transport sector. They can either opt for:

- A binding target of 14.5% GHG intensity reduction in the sector by 2030 using renewable sources or,
- A binding share of at least 29% of renewables within the final consumption of energy in the sector by 2030.

In addition, RED III establishes a binding combined sub-target of 5.5% for advanced biofuels and RFNBOs in the transport sector by 2030, of which at least 1 percentage point must be RFNBOs. To facilitate compliance, the Directive introduces mandatory multipliers so that the energy content of RFNBOs is counted at more than its actual value. Specifically, RFNBOs supplied to transport generally receive a 2x multiplier, while those supplied to aviation and maritime receive an additional 1.5x multiplier. Taken together, this means RFNBOs used in aviation or maritime are credited as 3x their actual energy content toward the 2030 sub-targets.

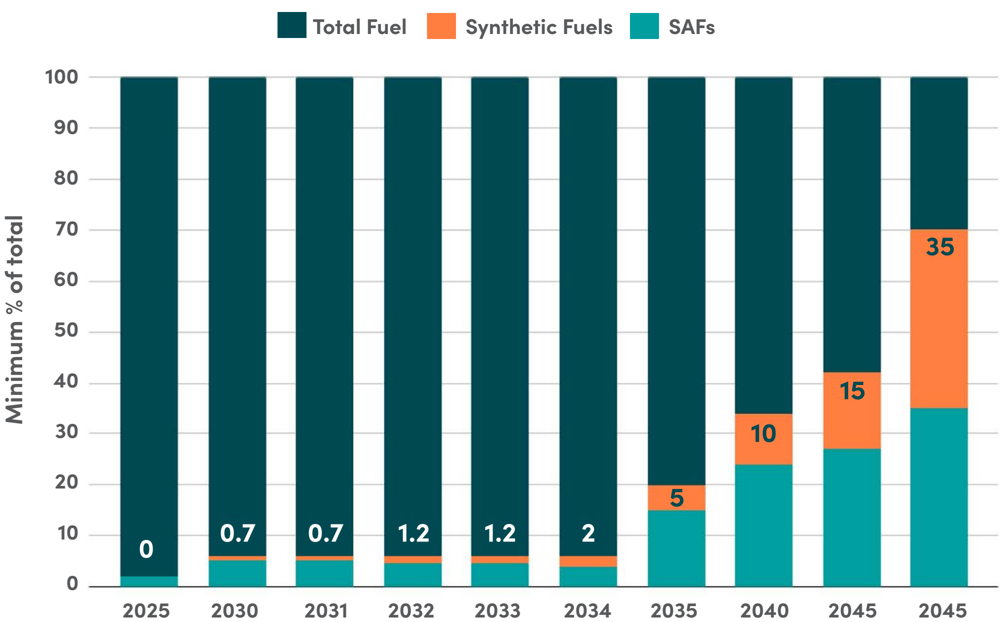
Rules for the production of RFNBO are highly complex. The GHG savings of synthetic aviation fuels must be at least 70% compared to a fossil comparator of 94 gCO_2eq/MJ. Two delegated acts define the production requirements for RFNBO, i.e., green hydrogen and derivative fuels such as e-methanol or e-kerosene. They apply equally to production projects located in the EU as well as export projects selling to the EU. Given the need for massive quantities of imported RFNBO as well as new domestic EU production, this definition in the delegated acts are essential in the shaping of the future European and global hydrogen and low-carbon fuels industry, including aviation fuels in the MTJ pathway.

A so-called Additionality Delegated Act sets out the conditions that must be met for the supply of electricity from Renewable Energy Sources (RES) to green hydrogen production facilities to qualify as fully renewable. This then allows the hydrogen or derivative product to be certified as RFNBO under the RED. The second Delegated Act and accompanying Annex define the GHG emissions methodology for the calculation of the lifecycle GHG footprint of green hydrogen and derivatives. To meet this GHG emissions limit, the green hydrogen or derivative must have a carbon footprint below (approximately) 3.38kg CO_2e/kg on a well-to-wheel basis (i.e., including emissions associated with transporting the molecule to the end-customer).

ReFuelEU Aviation Regulation

This Regulation sets obligations for all fuel suppliers to gradually increase the share of advanced biofuels and synthetic aviation fuels in the fuel supplied at EU airports. To achieve this mandate, approximately 2.3 Mt of SAF will be required by 2030, of which 0.7% will need to be RFNBO, representing an estimated 0.6 Mt per annum, rising to 0.8 Mt by 2034. Overall, depending on traffic growth, the mandated volumes of RFNBO would increase to 21.75 Mt by 2050, or 35% of the future jet fuel consumption at EU airports.

Figure 2.1: SAF Mandate Percentages under ReFuelEU Aviation



Source: Climatecatalyst as adapted from EU legislation, 2023

The Regulation sets financial penalties for fuel suppliers and aircraft operators in case they fail to comply with the obligations. Different from a buy-out price in which you can buy yourself out of the obligation as a fuel supplier, suppliers[1] and aircraft operators under ReFuelEU are faced with a penalty but still need to make up for their non-compliance in the following year. Income from penalties are required to be earmarked for funds that support SAF projects.

[1] Failing to comply with the minimum shares of SAF means fuel suppliers are liable to pay a fine of at least twice the difference between the price of conventional aviation fuel and SAF in that year. The European Aviation Safety Agency (EASA) is tasked with collecting market intelligence on SAF pricing every year. Example: Jet-A1 price €600/mt. SAF €3,400/mt. Difference multiplied by two is €5,600.

Under ReFuelEU, SAF are certified by Sustainability Certification Schemes against criteria defined at EU level in the RED and at global level in the CORSIA framework. In the European context, SAF is defined in Article 3(7) of the Regulation, covering drop-in aviation fuels compliant with the RED sustainability criteria:

- **Synthetic aviation fuels from renewable hydrogen and captured carbon** (in the meaning of Article 2(36) of RED and limited to liquid drop-in fuels only); Once approved and certified, the e-SAF under a potential future MTJ pathway would fall under the definition of RFNBO.
- **Advanced biofuels from waste and residues** notably (produced from feedstock listed in Part A of Annex IX, in the meaning of Article 2(34) of RED).
- **Biofuels produced from oils and fats** (such as from feedstock listed in Part B of Annex IX, in the meaning of Article 2(33) of RED).
- **Recycled carbon fuels** in the meaning of Article 2(33) of RED.

Aviation fuel suppliers may also decide to comply with the minimum shares by using:

- Renewable hydrogen for aviation as defined in Article 3(16) of ReFuelEU Aviation[2];
- Synthetic low-carbon fuels and low-carbon hydrogen produced from non-fossil sources, and meeting a lifecycle emissions savings threshold of 70%[3].

It is important to keep in mind the heterogeneous definition of what constitutes a SAF, with legislators and regulations diverging in certain aspects. The table below summarizes the major differences between the European (RED) and other parts of the world (CORSIA Sustainability Criteria for CORSIA eligible fuels) definitions. (CORSIA is discussed further below.)

Table 2.1: Comparative Analysis of CORSIA Sustainability Criteria and REDII Definition

SCHEME	SUSTAINABILITY CRITERIA
Renewable Energy Directive (RED II) (2018), Article 29	**GHG reductions –** GHG emissions on a lifecycle basis from biofuels must be lower than from the fossil fuel they replace (fossil fuel baseline = 94 g CO_2e/MJ): at least 50% lower for installations older than 5 October 2015, 60% lower for installations after that date and 65% lower for biofuels produced in installations starting operation after 2021. For renewable fuels of non-biological origin the savings shall be at least 70%. **Land use change –** Carbon stock and biodiversity: raw materials for biofuels production cannot be sourced from land with high biodiversity or high carbon stock (i.e., primary and protected forests, highly biodiverse grassland, wetlands and peatlands). Other sustainability issues covered by the reporting obligation are set out in the Governance regulation and can be covered by certification schemes on a voluntary basis. ReFuelEU Aviation further restricts the RED II criteria by only allowing fuels made from feedstock listed in Annex IX.

Source: Climatecatalyst as adapted from EU legislation, 2023

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[2] Hydrogen or liquid fuel complying with the RED II RNFBO criteria (e-fuels), the energy content of which is derived from renewable resources.

[3] Championed by France, these are fuels made with non-fossil, non-renewable energy, thereby indirectly referring to nuclear power. The Low Carbon Hydrogen Delegated Act presented in July 2025, establishes the methodology for calculating GHG emissions savings from these low-carbon hydrogen and fuels.

SCHEME	SUSTAINABILITY CRITERIA
CORSIA Sustainability Criteria for CORSIA Eligible Fuels (November 2021)	**GHG reductions –** CORSIA eligible fuel / SAF will achieve net GHG emissions reductions of at least 10% compared to the baseline life-cycle emissions values for aviation fuel on a lifecycle basis (fossil fuel baseline = 89 g CO_2e/MJ). **Land use change –** CORSIA eligible fuel / SAF will not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks. For batches produced on or after 1 January 2024, additional criteria are applicable and are addressing the following themes: Water, soil, air, conservation (biodiversity), waste and chemicals, human and labor rights, land use rights and land use, water use rights, local and social development, food security.

Source: EAER 2023

Note that ReFuelEU Aviation Regulation allows aircraft operators to claim once (and once only) in a separate GHG scheme ("a scheme granting benefits to aircraft operators for the use of sustainable aviation fuels"), e.g. SAF reported under ReFuelEU Aviation can be claimed under EU ETS, and possibly under CORSIA (see section on CORSIA).

Emissions Trading System

While not directly dealing with SAF and e-fuels, the Emissions Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM) increase costs for GHG-emitting economic activities, thereby making renewable fuels a more cost-competitive alternative. The ETS provides an incentive for aircraft operators to use SAF certified as compliant with the sustainability framework of the RED, by attributing them "zero emissions" under the scheme[4]. Airlines do not have to surrender emissions allowances when SAF is used instead of fossil jet fuel, also referred to as the "zero-rating" of aviation fuels.

From January 1, 2024 to December 31, 2030, 20 million allowances from the ETS have been reserved to finance SAF use by ETS-eligible aircraft operators. The Fuels Eligible under ETS 'FEETS' apply to flights covered by the EU carbon price (intra-EU flights), representing about 40% of total aviation fuel use in the EU.

This "SAF allowances" scheme reduces the price difference between SAF and conventional Jet Fuel. There are 20 million EU ETS allowances available, supporting up to 100% level for cost difference (define) for eligible fuels (define) uplifted from January 1, 2024. This represents a subsidy of approximately €1.5billion. Financial support equals the price of eligible fuel minus the combined cost of fossil kerosene, ETS price, and any additional charges.

SAF allowances are allocated to cover different parts of the price differential, depending on the type of fuel used and where it is used. In the case of RFNBO, 95% of the price gap would be covered (compared, for example, to 70% for advanced biofuels and renewable hydrogen or 50% in the case of SAF made from UCO or animal fats).

[4] Since 1 metric ton of jet fuel produces 3.16 metric tonnes of CO2, at a theoretical price of €100/t CO2, the ETS provides a €316/t fuel incentive to uplift SAF. Default emission factor for Jet A fuel = 3,16 t CO2 / t fuel

ETS Innovation Fund

The Fund will provide around €40 billion over 2021-2030 for the commercial demonstration of innovative low-carbon technologies. Projects are assessed based on their potential to reduce GHG emissions, degree of innovation, maturity, replicability and cost efficiency. The Fund can cover up to 60% of a project's costs. Funding occurs through Grants and Actions towards deployment of net zero and innovative technologies. This can be in the form of support to manufacturing, production and use in energy intensive industries, renewables, energy storage, carbon capture use and storage, net-zero mobility and buildings. The Innovation Fund can contribute to aviation sustainability funding for projects in the EU/EEA.

Carbon Border Adjustment Mechanism

The Carbon Border Adjustment Mechanism (CBAM) imposes a levy on certain emission-intensive imports into the EU. This may impact hydrogen imports and the RFNBO import prices. Given the challenges of transporting liquid hydrogen, synthetic ammonia is one of the most likely derivatives of hydrogen for transporting the commodity over long distances. As with hydrogen, ammonia falls within the scope of CBAM, contrary to other imported hydrogen derivatives, such as green methanol or other e-fuels or synthetic gases. It is possible that the scope of CBAM will be extended to cover other hydrogen derivatives in the coming years.

Hydrogen Bank

The European Hydrogen Bank auction is a call awarded based on a competitive bidding procedure on price and subject to specific conditions (e.g., auction terms and conditions, fair bid conditions, completion guarantee, etc.). The following activities can be funded: Installation of new RFNBO hydrogen capacity as well as the verified and certified production of RFNBO hydrogen from those installations for a period of up to 10 years. In May 2025, a second auction allocated €992 million for hydrogen in sectors such as transportation, the chemical industry, or the production of methanol and ammonia. A third European Hydrogen Bank auction is planned for end 2025 with a budget of up to €1 billion.

Connecting Europe Facility

The Connecting Europe Facility (CEF) contributes to the EU goal of climate related spending and decarbonizing transport managed by European Climate, Infrastructure and Environment Executive Agency (CINEA). CEF 2021-2027 will contribute to co-financing climate and mobility projects with a budget of €25.51 billion.

European Taxation Directive

Under the European Taxation Directive (ETD), jet fuel is not subject to any taxation, which keeps its price low in comparison to SAF or eSAF. There is also potential for tax exemptions for SAF under Energy Taxation Directive proposals, the value of which could increase[5].

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[5] EC proposal for a Review of the Energy Taxation Directive. See here

Policy Frameworks in the United States

The U.S. is advancing SAF deployment through a mix of incentives and strategic initiatives. Key federal measures, including the Inflation Reduction Act's (IRA) SAF tax credit and the Bipartisan Infrastructure Law (BIL), provide funding and support for SAF production and infrastructure. The SAF Grand Challenge further targets 3 billion gallons of annual production by 2030. While regulatory mandates are still evolving, this policy environment is expected to offer opportunities for MTJ SAF.

Bipartisan Infrastructure Law

The BIL aimed to ensure a durable and equitable economic recovery post Covid and following other emergency response policies, in particular the American Rescue Plan of 2020. The BIL provided funding for both clean hydrogen and SAF demonstration projects. It also set aside funds to improve fuel infrastructure, including blending, storage, and distribution capacity for SAF.

Under BIL, US$8 billion had been committed to create eight regional hydrogen hubs, formally known as Regional Clean Hydrogen Hubs (H_2 Hubs). These were large-scale, competitively selected public-private partnerships designed to create networks of hydrogen producers, infrastructure developers, and end-users located within a specific geographic region. To date, only three hubs (California (ARCHES), Pacific Northwest (PNWH2) and Appalachia (ARCH2) have advanced to Phase 1 with initial planning grants of about $30 million each, while proposals have surfaced to cut federal support for four of the seven announced hubs.

BIL's infrastructure focus also laid the groundwork for subsequent programs like the Fueling Aviation's Sustainable Transition: Sustainable Aviation Fuels (FAST-SAF) initiative, launched by the Federal Aviation Administration (FAA) in 2023. The program completed its first funding round in August 2024, awarding roughly US$244.5 million across 22 projects. The grants were split between Tier 1 planning efforts and Tier 2 infrastructure build-outs, covering blending, storage, distribution, and regional supply chain assessments. In addition to federal dollars, the awards leveraged more than $80 million in private co-investment, reflecting strong industry buy-in. These projects are spread across airports, producers, and logistics providers, with the aim of directly addressing the infrastructure gap that remains one of the largest barriers to SAF scale-up.

The Inflation Reduction Act

The Inflation Reduction Act (IRA) established a comprehensive package of tax credits, grants, and loan programs aimed at accelerating the deployment of low-carbon energy technologies and decarbonizing key sectors of the U.S. economy. Although designed as a 10-year framework, implementation has relied on a series of IRS rulemakings and guidance documents, many of which are still unfolding. Among its most impactful provisions are changes to the federal tax code that directly support the production and use of SAF through performance-based incentives:

- Section 45Z Clean Fuel Production Credit (2025-2029): This credit is technology-neutral and emissions-based, rewarding producers (not blenders) of low-carbon fuels[6]. It was extended under the July 2025 One Big Beautiful Bill Act (OBBBA) through December 31, 2029. For SAF produced after December 31, 2025, the credit was reduced to a maximum of US$1.00 per gallon, with the precise value tied to lifecycle CI relative to a baseline of 50 kg CO_2e/MMBtu. To qualify, production facilities must meet prevailing wage and registered apprenticeship requirements. The OBBBA also narrowed eligibility by excluding fuels made from feedstocks sourced outside the United States, Mexico, or Canada, and by prohibiting foreign or foreign-influenced entities from claiming the credit.

- Section 45V Clean Hydrogen Production Credit (2025 onward): Provides a per-kilogram credit for clean hydrogen, with values ranging up to US$3.00/kg for the lowest-carbon pathways when prevailing wage and apprenticeship requirements are met. The credit is available for 10 years from the facility's placed-in-service date, but the July 2025 One Big Beautiful Bill Act (OBBA) shortened the window to begin construction: Facilities must now start construction by December 31, 2027 (instead of 2032). The provision indirectly supports SAF by lowering the cost of hydrogen used in PtL fuels such as e-kerosene and e-methanol, provided the hydrogen is produced with very low lifecycle emissions.

SAF Grand Challenge

Launched in 2021, the U.S. SAF Grand Challenge remains the federal government's flagship strategy for scaling sustainable aviation fuel. Its core goals are to enable the production of 3 billion gallons of SAF per year by 2030 and to scale to 35 billion gallons by 2050, enough to meet projected U.S. aviation fuel demand with at least a 50% lifecycle GHG reduction. The initiative is coordinated through a Memorandum of Understanding between DOE, DOT, and USDA, providing a whole-of-government framework for research, policy alignment, and stakeholder engagement.

To support these targets, the federal agencies released a SAF Grand Challenge Roadmap in 2022, which identified key strategies to overcome barriers across the supply chain: scaling sustainable feedstock availability, accelerating technology commercialization, expanding blending and distribution infrastructure, lowering production costs through R&D and loan guarantees, and ensuring environmental integrity through robust lifecycle methodologies and safeguards.

In January 2025, the agencies published the first Progress Report (2021–2024) and launched a Metrics Dashboard to track production, emissions impacts, planned capacity, and R&D activity. While production rose from 5 million gallons in 2021 to 93 million gallons by late 2024, it is not clear whether the program will retain strong political backing under the Trump Administration.

Importantly, the SAF Grand Challenge is not a funding program but a strategic framework to align federal investments under the BIL, IRA, and DOE's Bioenergy Technologies Office (BETO). It also provides a platform for stakeholder engagement and policy coordination, even as its future direction depends on administrative priorities.

[6] The IRA also provided an earlier incentive under Section 40B, the SAF Blender's Credit (2023–2024). It offered $1.25/gal for SAF achieving at least a 50% lifecycle GHG reduction versus petroleum jet fuel, with an additional $0.01/gal for each percentage point above 50%, up to $1.75/gal. Fuels had to meet ICAO CORSIA or EPA RFS thresholds. Intended as a bridge to Section 45Z, this credit will expire September 30, 2025.

The Renewable Fuel Standard

The BIL and IRA build on a foundation of long-standing federal and state-level policies that have supported the development and use of renewable fuels in the transportation sector. Chief among these is the Renewable Fuel Standard (RFS), the primary federal regulatory program that mandates the blending of renewable fuels into the U.S. transportation fuel supply. Administered by the U.S. Environmental Protection Agency (EPA), the RFS establishes annual volume requirements for various categories of renewable fuels, including advanced biofuels and cellulosic fuels, based on their lifecycle GHG emission reductions.

Although the RFS was originally designed for on-road fuels, the EPA finalized a rule in 2023 allowing SAF to generate Renewable Identification Numbers (RINs), or credits, under certain RFS categories, provided the SAF is used in jet fuel applications and meets the applicable lifecycle GHG thresholds. SAF pathways must reduce GHG emissions by at least 50% compared to petroleum jet fuel and must be approved by the EPA based on a detailed feedstock and process-specific lifecycle analysis.

Fuel producers and obligated parties that fail to meet their annual RFS obligations may face significant civil penalties, historically up to US$37,500 per day per violation (adjusted for inflation), in addition to any economic benefit gained through noncompliance. These enforcement provisions create strong financial incentives for compliance and help ensure that SAF producers who meet the regulatory requirements can access a market supported by binding volume mandates.

U.S. State Clean Fuel Standards and Incentives

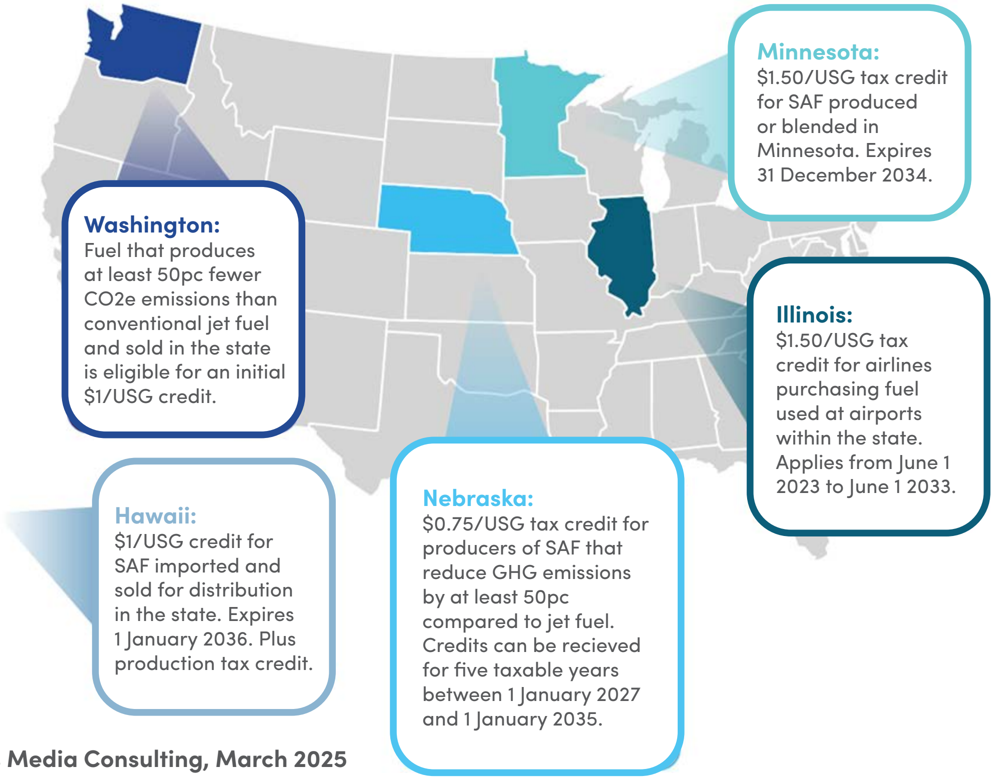
California's Low Carbon Fuel Standard (LCFS) is a market-based regulation designed to reduce the life-cycle CI of transportation fuels used in the state. Established in 2011 and administered by the California Air Resources Board (CARB), the LCFS sets declining annual CI targets for the overall fuel pool, with the aim of achieving a 20% reduction by 2030 compared to a 2010 baseline. Regulated entities generate credits when they supply fuels below the CI target and incur deficits when their fuels exceed it. These credits can be traded, creating a flexible compliance market that incentivizes the production and use of cleaner fuels such as renewable diesel, electricity, and hydrogen. Although SAF is not currently subject to a compliance obligation under the LCFS, it is eligible to opt in and generate credits when used in California and when it meets CARB-approved CI thresholds.

Building on this foundation, CARB and Airlines for America (A4A), representing major U.S. air carriers, announced a landmark partnership in October 2024 to accelerate the adoption of SAF in California. Under this agreement, CARB and the airlines committed to working together to increase SAF supply to 200 million gallons annually by 2035, covering roughly 40% of California's intrastate jet fuel demand. The agreement established a dedicated working group to address permitting, supply chain challenges and policy alignment.

Oregon and Washington have both adopted Clean Fuel Standard (CFS) programs modeled on California's LCFS, and each allows SAF to participate on an opt-in basis. Oregon's Clean Fuels Program, implemented in 2016, sets annual CI reduction targets with a goal of reducing average CI by 20% by 2030 and 37% by 2035 from a 2015 baseline. Similarly, Washington's CFS, which took effect in January 2023, targets a 20% CI reduction by 2034 from 2017 levels. Washington law was updated in 2023 to require the Department of Ecology to establish clear procedures for SAF producers to apply for CI certification and generate credits.

Other states have enacted incentives to support SAF uptake, shown in the figure below.

Figure 2.2: State Incentives to Support SAF Uptake



Source: Argus Media Consulting, March 2025

SAF Policies in Other Countries

In addition to EU-level policy, several European countries have implemented or are developing national measures to support SAF. Sweden established a regulation for annual GHG reduction obligations from jet fuel suppliers, requiring blend ratios to rise from 1% in 2021 to 30% in 2030. A national industry roadmap under Sweden's Fossil Free initiative also supports fossil-free aviation. France launched its roadmap in 2019 and introduced a 1% SAF blending obligation in 2022, with targets increasing to 2% in 2025 and 5% in 2030. Germany is emphasizing PtL fuels under its National Hydrogen Strategy, aiming for 200,000 tonnes of production by 2030. The Netherlands is considering a 14% SAF target by 2030, with full fossil jet fuel replacement by 2050. Switzerland will apply the ReFuelEU legislation as of 2026.

Other European countries are moving in parallel. For example, Norway introduced a 0.5% SAF blending mandate in 2020, with plans to scale over time. The UK's SAF mandate has been implemented in early 2025, starting at 2% and ramping up to 10% by 2030 and 22% by 2040. A PtL sub-mandate begins in 2028, rising to 3.5% by 2040. Starting in 2027, the government will introduce a progressive cap to reduce reliance on HEFA. The cap declines annually to about 92% in 2027, 88% in 2028, 80% in 2029 and roughly 75% in 2030 (equivalent to about 71% of total SAF demand). By 2040, HEFA is limited to just 35% of the SAF obligation. The UK has also developed a Revenue Certainty Mechanism (RCM) to reduce investor risk in emerging SAF technologies, with final details expected in 2026. A buy-out mechanism has been included to provide compliance flexibility, with a set price of £6,250 per tonne for RFNBOs.

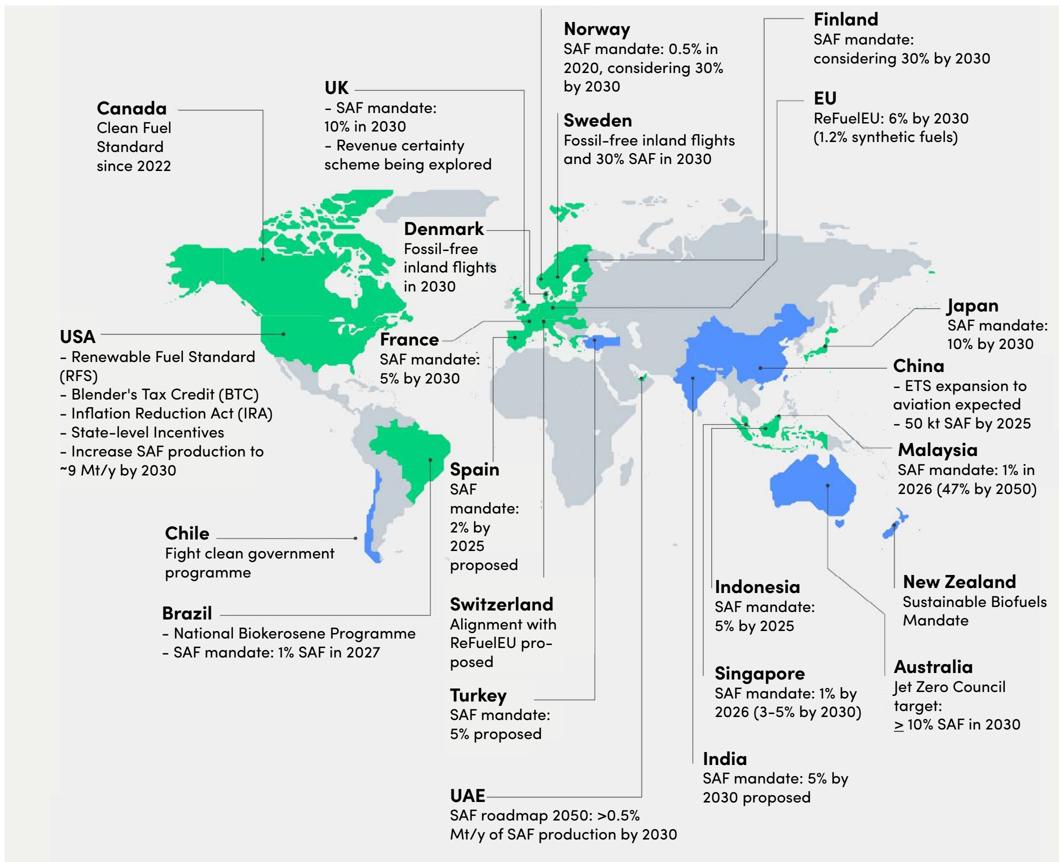
Beyond Europe, a number of other countries are pursuing SAF initiatives, shown in the figure below. South Korea, Japan, Turkey, Singapore, Brazil and New Zealand have announced varying levels of SAF policy support. Notably, China is considering an aviation blending mandate, which could tighten global markets for feedstocks such as used cooking oil (UCO). Increased demand could drive up HEFA feedstock prices, impacting SAF availability and potentially shifting the balance toward RFNBO production pathways.

Figure 2.3: Global Development of SAF Policies

Source: World Economic Forum, March 2024

Adopted

In Development



ICAO's Long-Term Global Aspirational Goal (LTAG) for International Aviation of Net-Zero Carbon Emissions By 2050

Long Term Aspirational Goal and Third Conference on Aviation Alternative Fuels

In November 2023, the ICAO's Third Conference on Aviation Alternative Fuels (CAAF/3) adopted a Global Framework for SAF, LCAF and Other Aviation Cleaner Energies. CAAF/3 includes a 5% emission reduction target by 2030 through the use of cleaner energy sources. It also contains provisions to avoid double counting of emission reductions derived from the use of cleaner energies. Assuming SAF GHG reductions over the lifecycle of 74%, the CAAF/3 target would require approximately a 7% global SAF share by 2030.

Within the ICAO long-term net zero 2050 aspirational goal (LTAG), several scenarios have been developed for fuels which represent varying levels of introduction of both drop-in and non-drop-in fuels that could reduce the lifecycle GHG emissions from aviation. Scenario 2 depicting "middle readiness/attainability and middle aspiration" is most commonly seen as the most realistic. Scenario 2 assumes that the global policy framework incentivizes SAF in the same manner as road transport, favoring SAF types with the best carbon abatement costs. The SAF uptake estimated under Scenario 2 for a middle traffic forecast results in 20 Mt of SAF by 2030, 200 Mt by 2040 and 415 Mt by 2050, resulting in 5% SAF uptake by 2030, 44% in 2040 and 72% in 2050. An overview of the modelling assumptions is given in _

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

In 2016, ICAO adopted CORSIA to address CO_2 emissions from international aviation. Offsetting is an action by a company or individual to compensate for their emissions by financing a reduction in emissions elsewhere. Offsetting and carbon markets are fundamental components of global, regional, and national emissions reduction policies. Offsetting requirements started in 2021. Upon completion of each three-year compliance period, aircraft operators will have to demonstrate that they have met their offsetting requirements by cancelling the appropriate number of emissions units. The offsetting requirements phase are:

- From 2021 until 2026, only flights between States that volunteer to participate in CORSIA.
- From 2027, all international flights[7].

Lifecycle fuel emissions are in scope for CORSIA. This means that SAF blending reduces replace Jet Fuel A emission's by 85-98% for flights between non-EEA countries in the years 2030 and 2050 respectively. CORSIA offers the possibility to report the used SAF in order to claim offsetting requirement reductions, on a lifecycle assessment basis, provided that the sustainability criteria for eligible fuels under CORSIA are respected.

[7] Flights to and from Least Developed Countries, Small Island Developing States, Landlocked Developing Countries and States which represented less than 0.5% of the global international revenue ton per kilometer (RTK) in 2018 will be exempt from offsetting requirements unless these States participate on a voluntary basis.

As for the EU ETS, operators could via these instruments be incentivized to use SAF to reduce emissions and thereby reduce the number of ETS allowances or CORSIA offsets that they need to purchase. Current price of a carbon credit is €6.93 per ton CO_2. Expected CORSIA carbon credit prices for 2030 are around €25.

Several analyses have indicated that the ETS itself, and to a much lesser extent CORSIA, will not alone have a significant impact on the demand for SAF due to the clear economic incentive to purchase allowances/offsets rather than use SAF as seen by the price difference between the prices for EU ETS allowances and/or CORSIA offset credits and the price difference between SAF and conventional fossil jet fuel[8].

Voluntary SAF Uptake Above Mandates

Besides the abovementioned policy framework, voluntary commitments could increase worldwide SAF uptake (e.g., Clean Skies for Tomorrow coalition with a 10% in 2030 ambition). This could create additional demand above mandates. Since such commitments are voluntary, it is very difficult to predict how much additional production capacity will be up and running based on these goals. Airlines will have to materialize their ambitions into offtake agreements with fuel producers to ensure the SAF uptake target is met. The current ambition of the Clean Skies for Tomorrow coalition does not ensure the additional SAF uptake takes place in Europe. The SAF volumes may also be purchased on the global SAF market at other airports around the world.

Certification and Qualification Requirements

Two types of certification/qualification need be considered for SAF: safety requirements established under the American Society of Testing and Materials (ASTM) and sustainability criteria, which is necessary for compliance eligibility, particularly for EU policies. Today, the main specifications for conventional civil aviation fuel are the ASTM specification D1655[9] and the UK specification DEF STAN 91-91. There are several other national and international jet fuel specifications, but as jet fuel is an internationally traded commodity these specifications are generally similar to and often follow the above requirements. ASTM specifications and pathway approval process is discussed in more detail in Chapter 4. Sustainability requirements are discussed further in the section below.

Sustainability Requirements

While airlines may use any SAF that meets the technical certification criteria detailed earlier, those certifications do not guarantee sustainability, only describing the physical properties of the fuel itself. Operators should ensure that the SAF has also been certified as sustainable. In the U.S. and EU, only certified SAF may contribute to government mandates for renewable fuel volumes or quotas.

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[8] The EU ETS and CORSIA apply different approaches in accounting for the use of SAF. Under the EU ETS airlines can apply an emissions factor of zero (European Parliament and the Council of the European Union, 2008, p. 18) for the fuel certified as of biogenic origin pursuant to RED. Under CORSIA airplane operators must compute the emission reduction achieved using SAF based on lifecycle emission factors compared to the reference emission factor for jet fuel of 89 g CO2eq/MJ (ICAO, 2018, p. 33). In both cases the reductions determined can be deduced from the requirements to surrender allowances or offsets, respectively. In other words, under the EU ETS a volume-based approach is applied to account for the use of SAF while under CORSIA an emissions-based approach is applied.

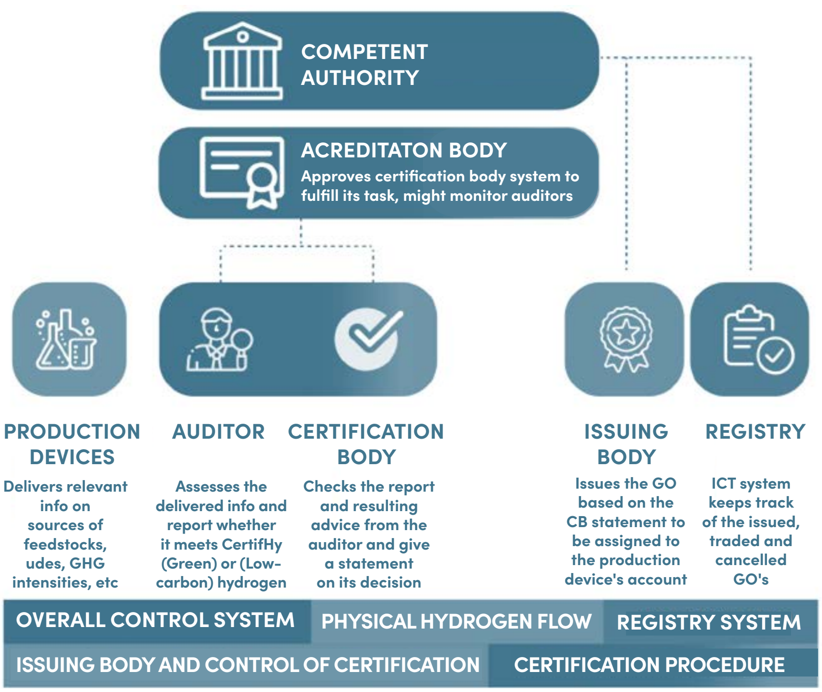
[9] Conventional jet fuel specifications. ASTM D1655 specification defines the minimum property requirements for Jet A and Jet A-1 aviation turbine fuel and lists acceptable additives for use in civil and military operated engines and aircraft.

An economic operator seeking SAF sustainability certification must first identify which scheme or schemes it would like to be certified for. Certification frameworks such as the Roundtable on Sustainable Biomaterials (RSB) or the International Sustainability & Carbon Certification (ISCC) provide guidance on core standards for voluntary markets, but also, importantly for regulatory adaptation, for ICAO CORSIA fuel standards and EU RED eligibility[10]. Organizations of the supply scheme chain of fuels can apply either a national certification scheme or a voluntary scheme approved by authorities. In essence, the sustainability provisions of the legislative framework are taken and implemented as part of a comprehensive auditing and certification framework, with the aim of it being both robust and practical in its widespread application and verification.

These certification ecosystems, involving participating operators, auditors, certification body and a sustainability certification scheme ensure the implementation of sustainability standards and requirements across the value chain including the refinery, fuel supplier and final fuel user. Fees apply to sustainability certification procedures, covering application, licensing and auditing. The operation's type and size (e.g., volumes of production, number of offices, etc.) will determine the fees.

To obtain sustainability certification, the operator needs to follow a certification approval procedure involving the selection of an auditor (certification body[11]), development of an environmental and social management plan to address the applicable certification requirement, development of a Chain of Custody procedure and performance of GHG calculation. The certification approval process is summarized in the figure below.

Figure 2.4: Certification Approval Process



Source: Certify EU

[10] The recently updated RSB Principles and Criteria guidelines will provide a detailed analysis of one of the certification frameworks most commonly used for SAF. ISCC also proposes certification depending on regulatory and customer requirements e.g. ISCC EU to ensure claiming under EU ETS, UK ETS and ReFuelEU Aviation; ISCC PLUS for voluntary and non-regulated markets and ISCC CORSIA to demonstrate compliance with the ICAO CORSIA sustainability criteria to be claimed under CORSIA and referred to in the IRS guidance for the US IRA's SAF blender's tax credit

[11] The economic operator can choose their Certification Body (CB) from a list of recognized CBs provided by ISCC (see https://www.iscc-system.org/certification/certification-process/certification-bodies/) or RSB (see https://rsb.org/certification/certification-bodies/).

In the context of ICAO CORSIA, sustainability criteria will mostly often include:

- **GHG:** SAF should generate lower carbon emissions on a lifecycle basis than its fossil alternative
- **Carbon Stock:** SAF should not be made from biomass obtained from land with high carbon stock.

In addition, ICAO CORSIA requirements would include other criteria related to:

- **Water:** Production of CORSIA SAF should maintain or enhance water quality and availability.
- **Soil:** Production of CORSIA SAFs should maintain or enhance soil health.
- **Air:** Production of CORSIA SAF should minimize negative effects on air quality.
- **Conservation:** Production of CORSIA SAF should maintain biodiversity, conservation value and ecosystem services.

There are also other criteria related to waste and chemicals, human rights, land use rights, water use rights, local development and food security. Eligibility under CORSIA guarantees the validity of the GHG reductions claims as well as claims related to other important sustainability aspects such as food security, environmental protection and human rights.

In addition to the ICAO CORSIA criteria, EU RED fuel certification will ensure compliance with ETS, ReFuelEU, RED and other EU-led support mechanisms. EU RED certification tools describe how to produce SAF that guarantee compliance with the EU sustainability criteria and traceability requirements for sustainable fuels.

Both EU RED and ICAO CORSIA consider a range of different feedstocks but have differing approaches to the recognition of feedstocks under their respective frameworks. ICAO is currently working on provisions for so-called high-electricity input fuels, which would include RNFBO (CAEP Fuel Task Group[12]). On the EU front delegated acts defines the eligibility criteria.

Both RSB and ISCC are currently developing certification RFNBOs and Recycled Carbon Fuels (RCFs). Once the official recognition is in place, ISCC EU RFNBOs and RCFs certification will be applicable. In the meantime, RFNBOs/PtX can be certified under frameworks such as ISCC PLUS Financial incentives and subsidies.

[12] The FTG's work program includes assessment of new technologies for SAF production.

Introduction: Other SAF Pathways

To fully appreciate the potential of MTJ, it is important to situate it within the broader landscape of other SAF technologies. Today, several SAF pathways have been approved under ASTM D7566, including Hydroprocessed Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT) and Alcohol-to-Jet from ethanol (ATJ-EtOH).

Each of these pathways has unique strengths and limitations in terms of cost, CI, scalability, feedstock availability and technological maturity.

These pathways are summarized in Table 3.1.

Table 3.1: Summary of Other Major SAF Pathways

SAF PATHWAY	FEEDSTOCKS	PROCESS SUMMARY	COMMERCIAL STATUS	CHALLENGES
HEFA (Hydroprocessed Esters and Fatty Acids)	Used cooking oil, tallow, vegetable oils	Liquid-based feedstocks are hydroprocessed into jet-range hydrocarbons	Most commercially mature; >10 years of deployment; >20 commercial facilities globally	• Potential feedstock constraints • Competition for the same feedstock for renewable diesel & biodiesel • Potential sustainability concerns with vegetable oil use
ATJ-EtOH (Alcohol-to-Jet from Ethanol)	Ethanol from corn, sugarcane, cellulosic biomass, energy corps	Dehydration to ethylene, followed by oligomerization and hydrogenation	Early commercial phase; LanzaJet's Freedom Pines Fuels plant in commissioning	• Costly and less efficient due to added processing • Ethanol in high demand as road fuel in countries such as the U.S. • Advanced ethanol faces cost and scalability issues • Potential sustainability concerns with corn use
ATJ-EtOH (Ethanol but also any single C2 to C5 alcohol or combination of two or more C2 to C5 alcohols)	Ethanol, butanol (isobutanol, n-butanol, sec-butanol, tert-butanol), propanol (n-propanol, isopropanol), methanol (in some variants), mixed C2-$C_5$5 alcohol steams (from biomass, industrial off-gases, or synthetic/e-routes)	Two subprocesses with following steps: a) dehydration, oligomerization, hydrogenation, and fractionation, producing a non-aromatic product stream and b) dehydration, aromatization, hydrogenation, and fractionation, producing an aromatic product stream. The final product is a blend of the non-aromatic and the aromatic streams.	Swedish Biofuels plans a 20,000 ton/ year demonstration plant expected to be commissioned in 2025	• High energy demand for conversion • Limited technology rediness compared to HEFA and ethanol-to-jet • Feedstock availability and cost (especially for advanced alcohols like butanol and mixed streams)

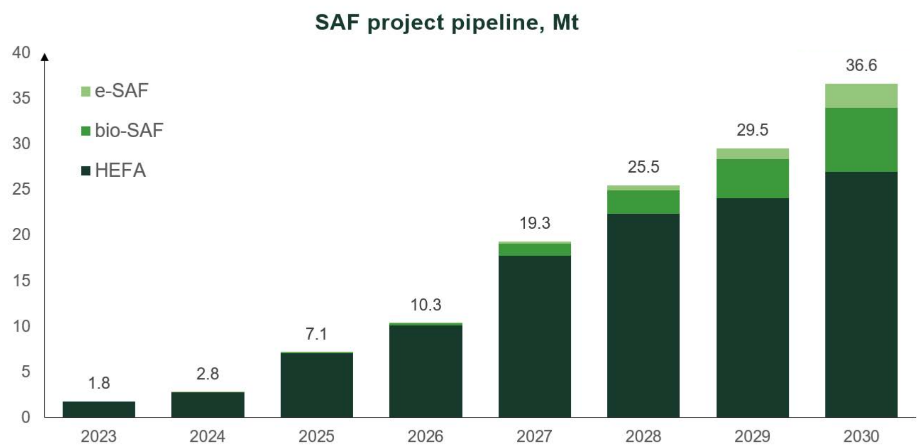
Table 3.1: Summary of Other Major SAF Pathways *Continued*

SAF PATHWAY	FEEDSTOCKS	PROCESS SUMMARY	COMMERCIAL STATUS	CHALLENGES
FT (Fischer-Tropsch)	Syngas from gasified biomass, or municipal solid waste	Upgrades syngas via FT synthesis into jet fuel	ASTM-approved and technically proven; few SAF plants in development	• High CAPEX • Complex technology, viable mainly at large scale and less suited to modular/distributed SAF deployment • Low single-pass process selectivity, resulting in a high volume of by-products
RWGS + FT (e-fuel pathway)	Captured CO_2 and green hydrogen	CO_2 converted to CO via RWGS; combined with green H_2 to form syngas; HT synthesis into liquid hydrocarbons	Experimental limited demonstration	• Requires co-location of renewable electricity, CO_2 capture, H_2 production, and the FT unit, since unlike MTJ, the process cannot be decoupled into seperate methanol and jet fuel production steps

Source: Compiled by Transport Energy Strategies citing IATA, ICAO and ASTM, September 2025

According to GENA Solutions, total SAF project pipeline capacity has reached more than 36 Mt (Mt) by 2030. Figure 3.1 summarizes the SAF project pipeline for these pathways with more detail on MTJ discussed in more depth in Chapter 4.

Figure 3.1 Overall SAF Project Pipeline



Source: GENA Solutions, Note: As of August 2025, Based on announced startup dates HEFA (Hydroprocessed Esters and Fatty Acids) refers to jet-fuel produced waste oils, fats, and vegetable oils. Bio-SAF can be produced from various biogenic feedstocks, including forestry and agricultural residues, biomethanol, and biogas (excluding the HEFA route). E-SAF is produced from CO2 and renewable hydrogen.

Technoeconomic Considerations for MTJ

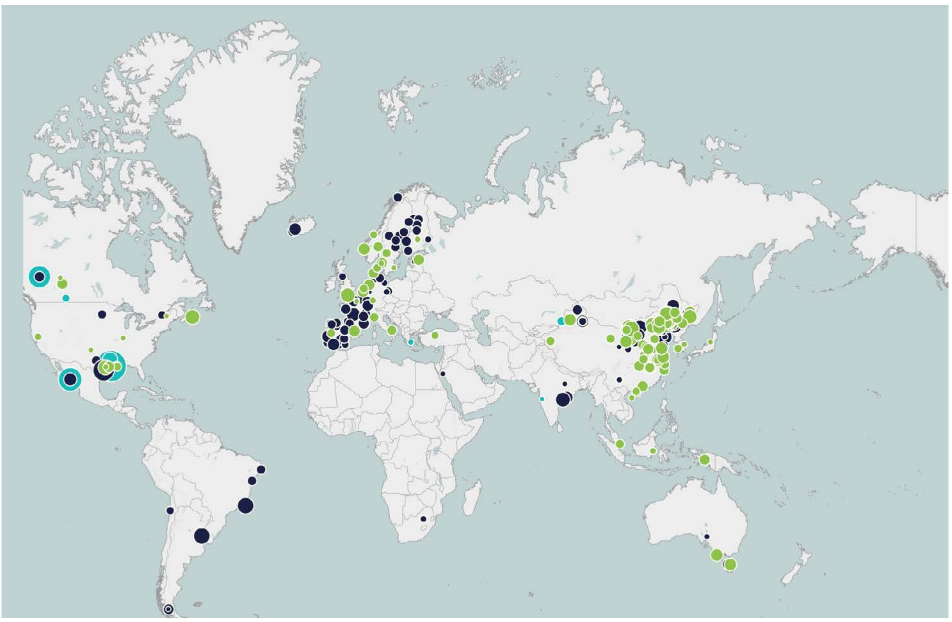
The commercial viability of MTJ SAF depends not only on its technical feasibility but also on its economic performance relative to other SAF pathways and conventional jet fuel. Technoeconomic factors include the cost and availability of methanol feedstocks, the capital intensity of conversion technologies, the efficiency and yields of different process configurations, and the degree to which projects can integrate with existing infrastructure. This section discusses these factors.

Feedstock Versatility and Process Efficiency

MTJ can use methanol produced from a wide range of carbon-containing sources, including biogenic feedstocks (e.g., landfill gas, agricultural residues, municipal solid waste) for biomethanol, industrial off-gases for low-carbon methanol, and synthetic routes that combine green hydrogen with captured CO_2 to produce e-methanol. In addition, low-carbon methanol derived from fossil feedstocks with CCS provides another pathway to reduce lifecycle emissions relative to conventional methanol. This diversity enables deployment in regions that may lack access to lipid feedstocks (HEFA) or starch/sugar crops (ATJ-EtOH).

Figure 3.2 illustrates the global distribution of announced and operating biomethanol, e-methanol, and low-carbon methanol plants. As of August 2025, the database maintained by GENA Solutions tracks 236 renewable methanol projects globally, with a total anticipated capacity of 41.9 Mt by 2030. The total projected capacity of all e-methanol projects is 23.4 Mt by 2030, while biomethanol projects account for 18.5 Mt. In addition, 17 low-carbon or "blue" methanol projects are planned, totaling 10.1 Mt of capacity by 2030. Together, renewable and low-carbon methanol projects amount to a pipeline of 51.9 Mt by 2030.

Figure 3.2: E-Methanol, Biomethanol and Low-Carbon Methanol Plants



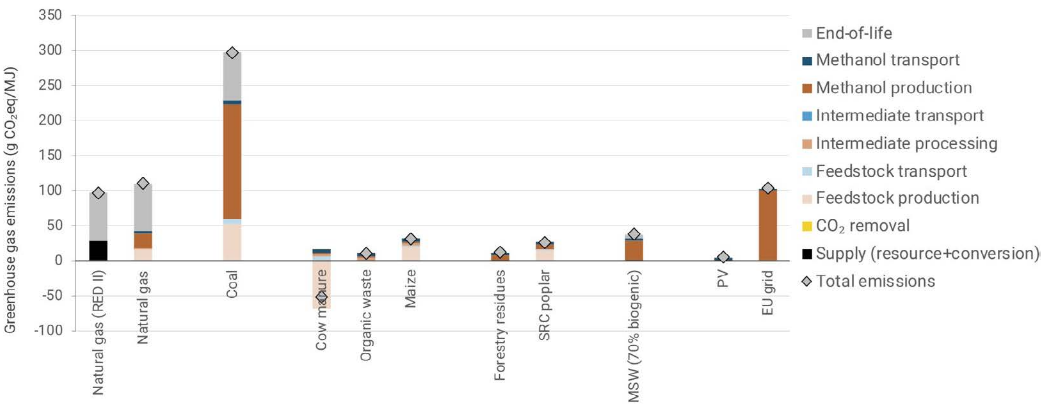
Source: Methanol Institute, 2025

The growing number of projects demonstrates the expanding supply base that MTJ may potentially draw upon, with production capacity increasingly concentrated in regions with supportive policies, renewable energy resources and/or access to industrial CO_2 streams.

Lifecycle and Carbon Intensity Performance

The lifecycle CI of MTJ fuels is highly dependent on the source of methanol. Conventional fossil methanol from natural gas generally falls in the 93–110 g CO_2e/MJ range, while coal-based methanol can be much higher, approaching 300 g CO_2e/MJ. Of course, these pathways offer little or no emissions benefit when converted to jet fuel and are not contemplated for MTJ SAF. However, low-carbon methanol produced from fossil feedstocks with CCS can significantly reduce emissions compared to conventional methanol, although the degree of reduction depends on capture rates and system boundaries. This is illustrated in Figure 3.3.

Figure 3.3: Carbon Footprint of Methanol Pathways



Source: Methanol Institute, 2022

According to a 2022 analysis conducted by Studio Gear Up, renewable methanol pathways deliver significant decarbonization potential. The analysis, using the European Commission's Renewable Energy Directive II (RED II) methodology for calculating lifecycle GHG emissions, shows that biomethanol derived from manure-based biogas can achieve net-negative lifecycle emissions (as low as -103 g CO_2e/MJ), while other biogas feedstocks typically range from 10-40 g CO_2e/MJ.

Methanol produced from wood generally falls in the 10-20 g CO_2e/MJ range, while municipal solid waste (MSW)-based methanol is more variable at 10-55 g CO_2e/MJ, depending on the fossil carbon content of the waste stream. These results highlight the heterogeneity of renewable methanol pathways, where some options exceed 100 percent emissions savings compared to fossil comparators, under the EU REDII model, while others remain closer to compliance thresholds.

E-methanol, produced from renewable hydrogen and captured CO_2, offers another very low-CI pathway. When powered by renewable electricity such as wind, solar or hydropower, e-methanol can achieve CI values as low as 4-5 g CO_2e/MJ, representing more than a 90 percent reduction compared with fossil methanol. However, if grid electricity is used, lifecycle emissions can exceed 100 g CO_2e/MJ, in some cases worse than conventional natural gas methanol.

These results highlight the strong dependence of MTJ's lifecycle performance on the choice of methanol pathway.

Scalability and Infrastructure Integration

Methanol is already produced and traded globally at scale, with over 100 Mt produced annually. It is supported by extensive infrastructure for storage, transport, and distribution, is shipped by tanker, rail, barge and pipeline and is stored in dedicated tanks and marine terminals at major industrial ports globally as shown in the figure below.

Figure 3.4: Global Methanol Fuel Availability at Ports

Source: Methanol Institute, 2025

This existing logistics network provides MTJ with a major deployment advantage over SAF pathways that require new or specialized infrastructure. MTJ SAF facilities can co-locate with methanol plants, industrial CO_2 sources, or port terminals, reducing capital costs and permitting complexity. Many integrated projects are also designed with surplus methanol capacity to serve the maritime sector, creating additional revenue opportunities and buffering against SAF market volatility. By leveraging existing infrastructure for methanol handling and distribution, MTJ projects can reduce investment needs and accelerate deployment timelines.

These results highlight the strong dependence of MTJ's lifecycle performance on the choice of methanol pathway.

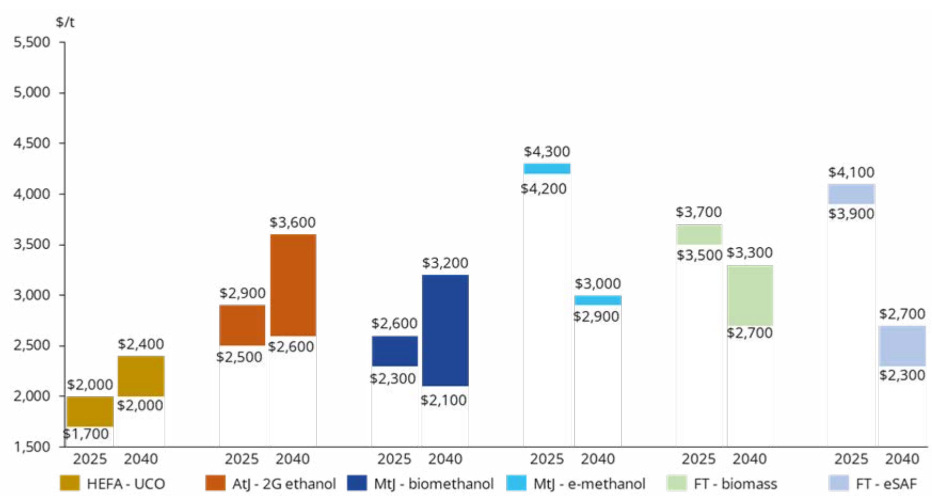
Methanol to Jet Fuel Production Cost Economics

Forecasts for Nascent MTJ Pathways Are Determined by Technological Inputs

As previously noted, several SAF pathway archetypes have emerged as viable alternatives for driving SAF production to enable meeting aviation carbon reduction targets. While SAF production pathways currently have higher costs than conventional jet fuel, continued efficiency gains, combined with government incentives such as subsidies or blending mandates, could bring SAF prices to a level at or near parity with conventional jet fuel in the market. The impact of government programs on SAF market prices is discussed in the next section and the remainder of this section discusses current and future production costs for leading SAF pathways, including MTJ.

Figure 3.5 presents an overview of the indicative SAF and e-SAF production costs through various available and emerging pathways, based on Argus's analysis. These analyses are based on data from bespoke studies developed for various market participants, literature and public information available to Argus.

Figure 3.5: Sustainable Aviation Fuel Pathways Production Costs, $/ton (2025-2040)[13]



Source: Argus Media Consulting, June 2025

HEFA-based pathways result in the lowest production costs due to the use of mature technologies where feedstocks such as tallow, used cooking oil (UCO), or vegetable seeds oils make up the majority of the production cost. This pathway is expected to remain a low-cost solution with significant CI reductions over conventional jet fuel but limited cost improvement opportunities given the technology's maturity. Moreover, Argus estimates that increasing demand and constrained UCO availability might make UCO-based SAF production slightly more expensive and limited by 2040, incentivizing producers to explore additional pathways to meet SAF demand.

[13] Argus's outcome showing FT more favorable than MTJ reflects its assumptions on byproduct yields and pricing. This should be understood as assumption-driven rather than a categorical cost advantage.

AtJ pathways using first generation ethanol (1G) have similar production costs to HEFA-based processes, but do not produce SAF with significant CI reductions compared to conventional jet fuel. Meanwhile, cellulosic or advanced ethanol (2G) pathways promise important CI reductions but current processes result in low SAF yields, leading to higher feedstock and operating costs.

Argus also analyzed the SAF production costs via the MTJ and FT pathways. [14] The MTJ pathway economics were assessed based on a standalone facility using biomethanol purchased externally at market price as feedstock. The FT pathway ranges are representative of a facility that feeds on biomass from the market for gasification.

Likewise, the indicative production costs for e-SAF were assessed under the MTJ and FT pathways. The MTJ costs ranges are representative of an integrated facility that produces green H_2 and e-Methanol on site to feed the e-SAF production process. The FT pathway figures are also indicative of an integrated facility that feeds from on-site green H_2 and CO_2 sourced from market.

The resulting cost ranges are inclusive of the different byproducts yield expected from the MTJ and FT pathways, which are deducted from the gross SAF and e-SAF production costs based on their expected market value under Argus's low and high biofuels and feedstocks price scenarios.

SAF produced via the biomethanol MTJ pathway sits amongst the least expensive of the novel SAF production pathways analyzed. The higher capital intensity and complexity when compared to HEFA or AtJ pathways is offset by the lower exposure to feedstock scarcity and higher yields. While biomethanol demand in other applications such as road and marine fuels is set to exert upward pressure on prices, widening the spread in 2040, the pathway's economics could significantly improve when assessed under the optics of an integrated facility that produces biomethanol on site as opposed to going to market. Thus, under favorable policy and market conditions, particularly in regions with strong SAF incentives, MTJ could approach parity with conventional jet fuel.

SAF produced via a FT process sits above MTJ, but its economics are expected to improve as time progresses, owing to a reduction in feedstocks and consumables costs and an anticipated increase in the market price of the saleable byproducts. Nevertheless, Argus's analysis indicates that FT-derived SAF could see an indicative cost ceiling similar to that of MTJ, whereas the lower end of the spectrum sits well above the MTJ pathway.

e-SAF stands out as the costliest alternative today, regardless of whether it is produced via the FT or MTJ pathways, mainly due to the cost of green H_2, CO_2 and renewable power. However, both routes are expected to see improved costs by 2040 as the technologies mature and become more widely adopted, improving feedstocks costs and the overall economics.

[14] MTJ and FT should be regarded as broadly comparable pathways; relative economics vary with feedstock availability, facility integration and policy support.

While Argus's analysis shows the FT pathway for e-SAF results in more favorable economics than the comparable MTJ pathway, this is largely based on byproduct yields differences for each process and their estimated market price in Argus's high and low-price scenarios. While MTJ favors SAF production, the main saleable byproduct in our analysis is naphtha; meanwhile, FT process yields a lower SAF rate, but saleable byproducts are predominantly diesel and some naphtha. Thus, these ranges are provided on an indicative basis as they are specific to these assumptions, and similar FT or MTJ processes under evaluation will encompass a different byproduct yield, quality and value.

MTJ Revenue Potential: Market Value of Production Pathways

Despite higher production costs, the aviation and biofuels industries aim to make SAF competitive with conventional jet fuel. As discussed in Chapter 2, U.S. and EU programs provide policy supports that help offset production costs and enable market pricing at or near parity. This section provides a brief discussion of policy support in the U.S. and EU for the SAF pathways discussed above.

Recall that the U.S. offers a variety of credit programs that reward the production of low-carbon fuels, particularly SAF. These include the RFS at the federal level and California's LCFS at the state level. Therefore, Argus forecasts theoretical offtake prices for SAF by stacking these credit generations on top of conventional U.S. West Coast (USWC) jet fuel price to represent revenue generation on a $/ton basis. This indicative value for SAF does not consider market dynamics that ultimately dictate the price at which SAF is traded. It should be noted that despite their higher production cost, e-fuels like e-SAF do not benefit from federal-level RINs under the current RFS framework, resulting in a lower theoretical offtake price than SAF.

The indicative prices in the EU are estimated on a credit-based approach supported by regulatory frameworks such as the ETS and REDII, discussed in Chapter 2, which provide policy support and directly influence fuel market prices. The indicative value of MTJ and FT-based SAF in the EU is based on three primary factors: the ARA fossil jet price, the biofuel premium and the energy content adjustment. This approach leverages the market price of jet fuel as a benchmark, the premium that SAF commands over the fossil alternative due to lower emissions, and the value of a higher energy content per unit of volume.

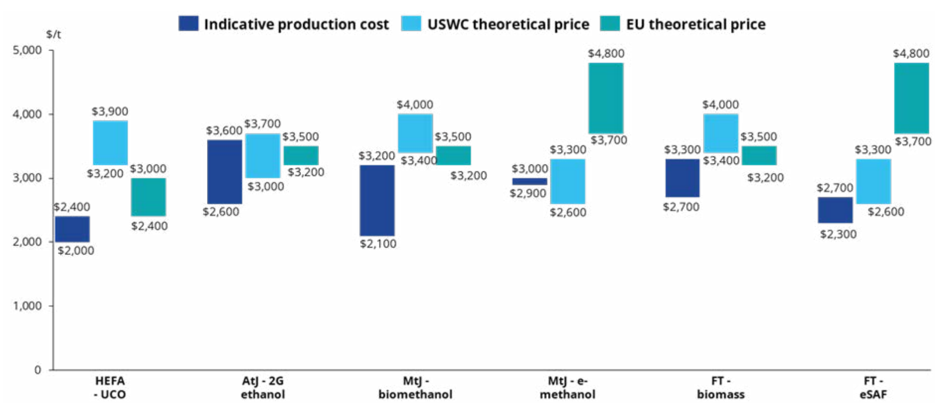
It is worth noticing that e-SAF cannot be competitively priced under this approach, as the resulting value sits well below current production cost estimates; therefore, Argus estimates the price of e-SAF based on production costs and a refiner's margin.

Additionally, the EASA has established an EU-wide buyout prices, or penalties, for non-compliance with the ReFuelEU Aviation e-SAF mandates. This buyout price is set as twice the spread between the price of fossil jet fuel and an annually defined average production cost for SAF and e-SAF. The EASA defined a 2024 guidance price for jet as $770/t, with average SAF and e-SAF production costs set at ~$2,200/t and ~$8,100/t, respectively.

The resulting buyout prices are estimated at ~$2,800/t for SAF and $14,600/t for e-SAF, which is more than enough to incentivize both suppliers and aircraft operators to meet the mandates and avoid paying 2-3 times as much. Nonetheless, it should be clarified that the buyout prices are not representative of the market prices seen today, least of all for e-SAF, which is not commercially available at scale yet.

Argus's analysis indicates that SAF and e-SAF are generally expected to be economically viable by 2040 (Figure 3.6). The deep blue bars represent the production cost ranges presented in the previous section. The pale blue bars offer an estimate of the theoretical price SAF and e-SAF could command in the USWC under Federal and State regulatory frameworks incentives. The turquoise bars represent the theoretical price range SAF and e-SAF could reach in the EU; the aforementioned buyout prices for SAF and e-SAF are not presented in this chart.

Figure 3.6: Indicative SAF Production Costs and Product Values, $/ton (2040)[15]



Source: Argus Media Consulting, June 2025

The spread in the USWC theoretical price stems from variations in the fossil fuel high- and low-price scenarios; the variations in LCFS carbon-based incentives owing to the low- and high-end CI score ranges for each pathway; and the accrual or lack of a D4 RIN for each pathway, which adversely impacts e-SAF as it does not have an accredited pathway in the U.S. RFS. Nevertheless, it is possible that a certified pathway is created for e-SAF in the future, unlocking access to RINs.

The spread in the EU indicative price is owed to the low- and high-price scenario variation for the corresponding SAF category – Part A, Part B or e-SAF, as defined by Argus's biofuels and feedstock analytics and price models.

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[15] Argus modeled bio-MTJ as a standalone facility. This likely understates the pathway's potential, since integrated configurations where methanol production is co-located with MTJ conversion can reduce logistics costs, share infrastructure, and improve overall economics.

While HEFA stands out as an economically viable SAF pathway, even today, its feedstock limitations are inevitably leading the market participants to continue pursuing alternative SAF and e-SAF production pathways.

When existing policy support is considered, MTJ and FT offer a viable SAF and e-SAF production pathways to support the decarbonization efforts of the aviation sector worldwide. The MTJ pathway with biomethanol as feedstock is expected to be a competitive solution on par with existing HEFA and AtJ (2G) pathways, even in a high-cost case. While existing policy is favorable to MTJ and some plants are being built in China, the U.S. and Europe, the MTJ process is yet to overcome some technology, optimization and scalability barriers before a generalized adoption takes place.

CHAPTER 4: COMMERCIAL DEVELOPMENT

Introduction

This chapter examines the key technical, regulatory, and market factors shaping the commercial development of MTJ. It begins with an overview of the critical role of ASTM International and the qualification processes that govern SAF adoption, with a particular focus on MTJ's progress toward inclusion in ASTM D7566. The discussion highlights why ASTM approval is essential to commercial deployment and describes the coordinated industry efforts to achieve it. The chapter then explores current MTJ project development trends and capacity projections, profiling several major MTJ technology providers alongside emerging project developers that are bringing new innovation and regional diversity to the pathway.

Developing ASTM Pathway Approval for MTJ

ASTM International is a globally recognized standards organization that develops voluntary consensus technical standards across a broad range of industries, including aviation fuel. Within the aviation sector, ASTM's role is critical. It sets detailed specifications to ensure aviation fuels are safe, reliable and compatible with existing aircraft engines and fuel-handling infrastructure.

The approval pathway for new aviation fuels is structured by two ASTM standards in particular: ASTM D4054 and ASTM D7566. ASTM D4054, Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives, defines the procedures for evaluating new aviation turbine fuels, detailing the testing protocols, data requirements and performance assessments a candidate fuel must satisfy. This comprehensive evaluation includes laboratory-scale testing, fit-for-purpose testing (e.g., compatibility with aircraft components) and full-scale engine testing.

Once a new fuel successfully completes the ASTM D4054 evaluation, it becomes eligible for inclusion under ASTM D7566, the official standard governing the specification for synthetic and renewable jet fuels. ASTM D7566, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, defines the quality and performance requirements for synthetic fuels that can be blended directly into conventional aviation fuel streams.

ASTM qualification to be included in the specification D7566 is a necessary and required step for the commercial viability and widespread adoption of MTJ SAF globally. Inclusion under ASTM D7566 is significant because fuels blended with conventional fossil-derived jet fuel Jet A or Jet A1 (defined by ASTM D1655, Standard Specification for Aviation Turbine Fuels) meeting this standard are considered "drop-in" replacements and can be used without modification to existing engines or distribution systems. Without it, MTJ would remain ineligible for blending with conventional jet fuel in commercial aviation operations.

Airlines and operators, bound by regulatory compliance and safety requirements, would be unable to use MTJ fuel in their aircraft, severely limiting its market potential and practical utility. ASTM-qualified fuels are also essential to international fuel pooling and distribution systems at airports around the world. A qualified, drop-in SAF blend can be seamlessly blended into global jet fuel supply chains and used interchangeably by multiple airlines. This capability simplifies logistics, facilitates rapid adoption, and encourages broad-based market acceptance.

Beyond operational integration, ASTM approval provides critical recognition under existing and emerging SAF mandates, regulatory frameworks and economic incentives (described in Chapters 2 and 3). Many jurisdictions, including in the U.S. and EU, base their SAF programs and incentives explicitly on ASTM-approved/qualified fuel pathways. Without inclusion in ASTM D7566, MTJ fuels would be excluded from these supportive regulatory structures, limiting commercial interest and investment in MTJ production.

Under ASTM D7566, synthetic blending components (SBC) are approved via individual annexes, each dedicated to a specific fuel production pathway. These are summarized in the table below and includes the pending MTJ pathway for comparison. The blends of SBC and conventional fossil-derived jet fuel must comply with the specifications in D7566 Table 1.

Table 4.1: Summary of ASTM-Approved SAF Pathways under ASTM D7566

FUEL PATHWAY	MAX. BLEND LIMIT	PRIMARY FEEDSTOCKS	CONVERSION PROCESS	YEAR APPROVED	ASTM ANNEX
HEFA (Hydroprocessed Esters and Fatty Acids)	50%	Biomass, natural gas, coal	FT synthesis of syngas to paraffinic hydrocarbons	2009	Annex A1
Hydroprocessed Esters & Fatty Acids SPK (HEFA-SPK)	50%	Renewable fats, oils, greases	Hydroprocessing of lipid feedstocks into paraffinic jet fuel	2011	Annex A2
Hydroprocessed Fermented Sugars to Iso-Paraffins (HFS-SIP)	10%	Sugars (fermentable biomass)	Fermentation plus hydroprocessing into synthetic iso-paraffins	2014	Annex A3
FT SPK with Aromatics (FT-SPK/A)	50%	Biomass, coal, natural gas	FT synthesis producing aromatic-containing SPK	2015	Annex A4
Alcohol-to-Jet SPK (ATJ-SPK)	50%	Ethanol or iso-butanol from biomass	Alcohol conversion to paraffinic jet hydrocarbons	2016	Annex A5
Catalytic Hydrothermolysis Jet (CHJ)	50%	Renewable fats, oils	Catalytic hydrothermolysis into jet hydrocarbons	2020	Annex A6

FUEL PATHWAY	MAX. BLEND LIMIT	PRIMARY FEEDSTOCKS	CONVERSION PROCESS	YEAR APPROVED	ASTM ANNEX
Hydroprocessed Esters & Fatty Acids with Aromatics (HC-HEFA SPK)	50%	Renewable fats, oils	Hydroprocessing with aromatization to yield aromatic-containing SPK	2023	Annex A7
Methanol-to-Jet Synthetic Paraffinic Kerosene (MTJ-SPK) (in progress)*	50%	Biomethanol, e-methanol, renewable methanol	Methanol > olefins > oligomerization > hydrogenation/ hydroprocessing to paraffinic jet fuel	~2026-2027 (projected)	Pending
Methanol-to-Jet Cycloparaffinic Kerosene with Aromatics (MTJ-CKA) (in progress)*	Anticipated 20%	Biomethanol, e-methanol, renewable methanol (various carbon sources)	Methanol > olefins > oligomerization > hydroprocessing to cycloparaffinic jet fuel with aromatics	~2026-2027 (projected)	Pending

Source: Compiled by Transport Energy Strategies citing ASTM D7566, September 2025

*** The technology developers formed a collaborative single taskforce for the approval of the MTJ pathways by ASTM. There was a parallel approval timeline for the MTJ-CKA and the MTJ-SPK products up to January 2025.**

In addition to standalone SAF production pathways, co-processing of renewable feedstocks alongside fossil petroleum is permitted under current standards, but with varying input limits. Until recently, ASTM D1655 Annex A1 limited input of esters/fatty acids or FT hydrocarbons to 5%. A higher input limit (24%) applies in some HEFA co-processing scenarios, but under existing certification rules only around 10% of a refinery's output qualifies as SAF.

ASTM periodically updates the D7566 standard and its annexes based on evolving technological developments, research findings, and stakeholder consensus.

Separately, a recent approval under the UK Defence Standard (Def Stan 91-091) raised the permitted renewable HEFA feedstock concentration in co-processed Jet A-1 fuel to 30%, up from 5%. This change applies to fuel meeting the updated Defence Standard, which is recognized globally for military and civil Jet A-1 supply, but it does not alter ASTM limits for civil aviation fuel qualification.

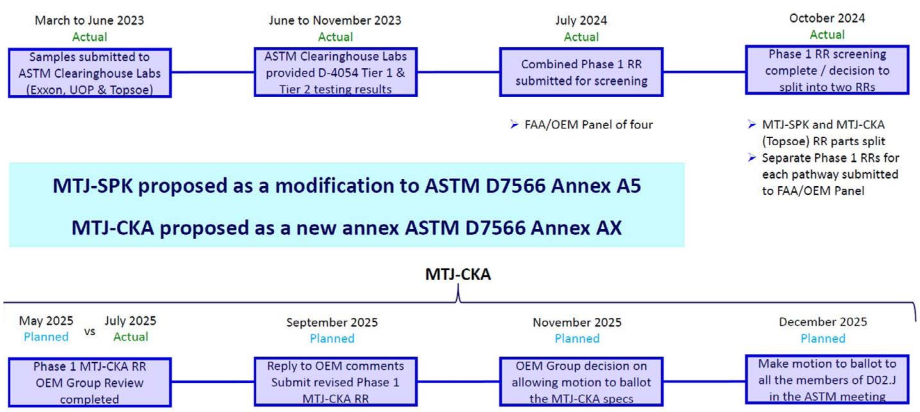
Current Efforts to Qualify MTJ Under ASTM D7566

Throughout 2023 and 2024, the Methanol-to-Jet Task Force participants from ExxonMobil, Honeywell UOP and Topsoe coordinated the production and comprehensive testing of MTJ fuel samples by key industry participants. ExxonMobil supplied approximately 200 gallons of MTJ fuel generated at pilot-scale, representing diverse process conditions and feedstock combinations. Honeywell UOP submitted a single 10-gallon sample and Topsoe submitted three samples amounting to 40 gallons. These fuel samples have undergone rigorous ASTM D4054 testing, and results from these initial testing phases have been promising. Testing indicates that MTJ blends of up to 50% with conventional Jet A or Jet A-1 fuel consistently meet critical ASTM specifications.

The MTJ-SPK fuels display negligible aromatic content, low sulfur levels, excellent thermal stability, and paraffinic profiles similar to existing ASTM-certified approved synthetic fuels. MTJ-SPK must be blended with Jet A/Jet A-1 to ensure sufficient aromatics to meet Jet A/Jet A-1 specifications. The MTJ-CKA fuels also display low sulfur levels, excellent thermal stability, density in the jet A range, excellent fluid properties, it contains monoaromatics but not naphthalenes. When MTJ-CKA is blended up to 20 vol%, the blend fulfills all specification and fit-for-purpose properties, including the cycloparaffin content. Nevertheless, all phase I and partial Tier 3 results in the ASTM qualification indicate that MTJ-CKA has the potential to be used unblended.

Given the technical progress to date, Task Force participants are optimistic about achieving timely ASTM qualification for the SPK and CKA pathways. The current trajectory suggests that comprehensive data packages including final test results, OEM endorsements and detailed fit-for-purpose evaluations could be finalized for ASTM balloting and approval in 2025. If the pace of data collection and testing remains on schedule, formal approval under ASTM D7566 is anticipated by approximately 2026-2027. The figure below provides a schematic of key milestones for both SPK and CKA in the ASTM MTJ qualification process.

Figure 4.1: MTJ Key Milestones in the ASTM Qualification Process



Source: Nacero, September 2025

Notes: RR = Research Report

MTJ-SPK = Methanol to Jet Synthetic Paraffinic Kerosene

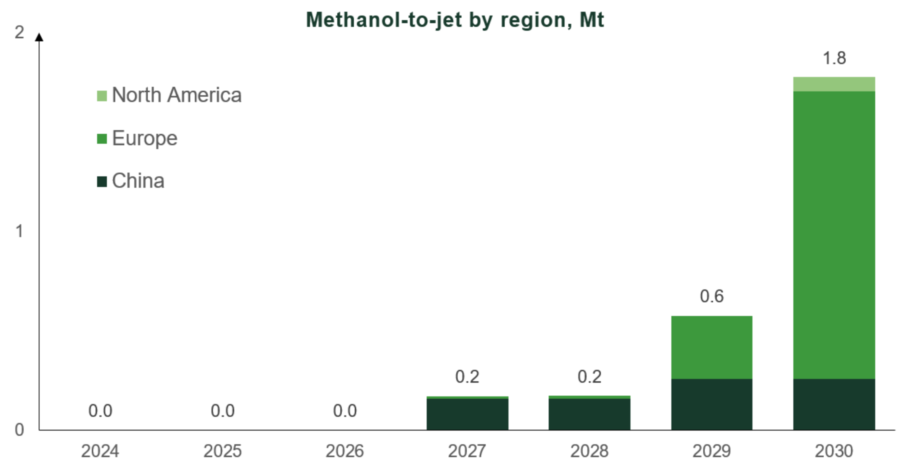
MTJ-CKA = Methanol to Jet Cycloparaffinic Kerosene with Aromatics

D02.J = ASTM Subcommittee on Aviation Fuels

Current Status and Project Development Trends for MTJ SAF

According to GENA Solutions' analysis of the sector, as of August 2025, the global pipeline for MTJ SAF projects has grown significantly, representing approximately 1.8 Mt per year of SAF production capacity. As Figure 4.2 shows, these projects are located in Europe and Asia, and most are at the feasibility or pre-feasibility stage.

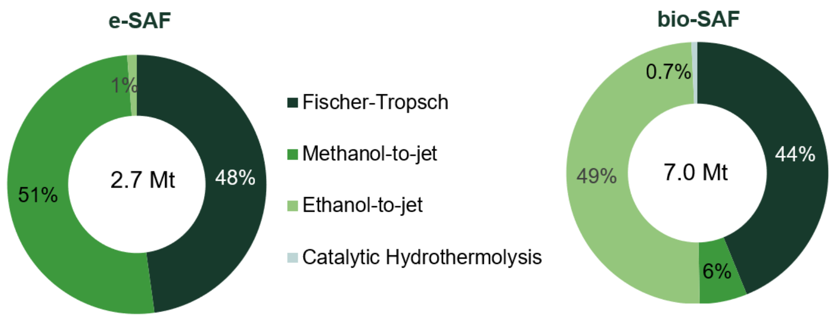
Figure 4.2: MTJ Pipeline by Region



Source: GENA Solutions, August 2025

GENA notes that among bio-based SAF projects, roughly 49% rely on ethanol-to-jet (AtJ-EtOH) technologies, 44% on FT, around 6% on MTJ and 0.7% on catalytic hydrothermolysis (or hydrothermal liquefaction). For e-SAF projects, about 51% employ MTJ, 48% use FT, and around 1% ATJ-EtOH. Within these, MTJ dominates ATJ-based e-SAF projects, whereas ethanol-to-jet is primarily used in bio-SAF ATJ projects. Figure 4.3 summarizes the bio-SAF and e-SAF project pipeline by process and expected by 2030.

Figure 4.3: Bio-SAF and e-SAF Project Pipeline by Process (2030)



Source: GENA Solutions, August 2025

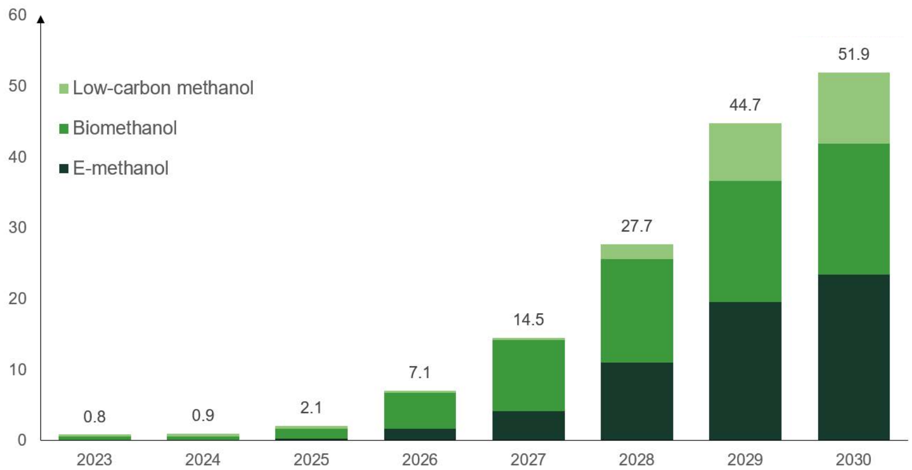
According to GENA Solutions, a notable feature of the current MTJ project landscape is the preference for vertically integrated production models, noted in Chapter 3. In fact, approximately 74% of the methanol feedstock required, equating to nearly 4.8 Mt annually, is planned for captive production at integrated facilities. This model builds on a broader trend in methanol production, where integration with downstream derivative facilities is already widespread (e.g., in coal-to-olefins complexes in China).

In the case of MTJ, integration is particularly significant because it lowers capital and operating costs for SAF by leveraging shared utilities and hydrogen production, while also reducing the risks and costs associated with external methanol logistics. Additionally, these facilities achieve enhanced operational efficiencies and lower overall risk. Several integrated projects are deliberately designing surplus methanol production capacity. This additional capacity can serve the growing maritime fuel market, providing valuable revenue diversification and an economic hedge against fluctuations in SAF demand, pricing volatility and regulatory shifts.

Capacity Growth Projections and Market Dynamics

The trajectory of renewable and low-carbon methanol capacity is central to scaling MTJ-derived SAF. Recent data from GENA Solutions (August 2025) underscores the rapid growth of project announcements worldwide. The pipeline now includes 134 e-methanol plants and projects with a combined capacity of 23.4 Mt, 104 biomethanol projects totaling 18.5 Mt, and 17 low-carbon methanol projects totaling 10.1 Mt. Together, these represent nearly 52 Mt of announced capacity by 2030. The first industrial-scale e-methanol facility in Denmark, which began operations in May 2025, marks an important commercialization milestone for power-to-methanol. Figure 4.3 summarizes GENA Solutions' August 2025 renewable and low-carbon methanol project pipeline through 2030.

Figure 4.4: Renewable and Low-Carbon Methanol Project Pipeline, Mt



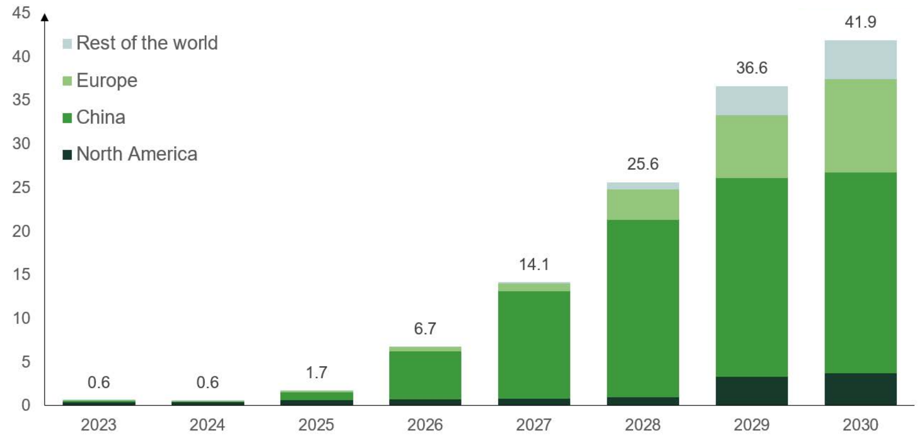
Source: GENA Solutions, August 2025

Building on these advances, GENA projects that global renewable methanol capacity could reach 8 to 14 Mt annually by 2030, depending on the scale and timing of project developments. Even in a conservative scenario accounting only for projects that have passed final investment decisions (FID), capacity is expected to reach approximately 4.4 Mt per year by the end of the decade. This trajectory significantly strengthens the supply foundation necessary for widespread MtJ deployment. The underlying drivers of this capacity expansion include:

- Commercial deployment of e-methanol, supported by declining electrolyzer costs, abundant renewable electricity, and increasing CO_2 utilization projects—evidenced by the Danish plant launch.
- Expansion of biomass gasification-based methanol, leveraging agricultural and forest residues for low-carbon methanol production in regions with strong bioenergy infrastructure.
- Hybrid production models, combining biomass-derived syngas with renewable hydrogen to optimize carbon yield and energy efficiency.

From a regional perspective, China continues to dominate the renewable methanol project pipeline, accounting for about half of announced global capacity. This includes 71% of biomethanol projects and 42% of e-methanol, according to GENA Solutions. Europe represents the second-largest share at 26%, with nearly equal weight in e-methanol (33%) and a 17% share in biomethanol. North America ranks third, representing roughly 9% of the pipeline (11% e-methanol, 7% biomethanol). The remainder of capacity is distributed across other regions. Figure 4.4 summarizes GENA Solutions' August 2025 renewable methanol project pipeline by region through 2030.

Figure 4.5: Renewable Methanol Project Pipeline by Region, Mt



Source: GENA Solutions, August 2025

GENA notes that the renewable methanol project pipeline in Latin America has been growing and now totals 2.1 Mt (as of August 2025). Four projects are based in Brazil, three in Chile, and two in Uruguay. All projects in the region are currently based on the power-to-methanol (e-fuels) pathway, accounting for about 9% of the global e-methanol project pipeline.

Projects in Latin America are well positioned to export their products to Europe, as well as use them locally for bunkering or processing into renewable chemicals and fuels, including SAF. GENA notes that considering the region's vast renewable energy and biomass resources as well as expected methanol production and delivery costs it is likely that Latin America will become the third-largest exporter of renewable methanol to the global market by 2030, after China and North America. The primary export market will be Europe.

Technological Advances and Key Industrial Players in MTJ Production

Several major technology providers are advancing MTJ fuel production by adapting established methanol conversion processes for aviation use. Each brings decades of experience in catalysis, process engineering, and fuel optimization to the development of jet-range synthetic blending components (SBC). ExxonMobil, Honeywell UOP, and Topsoe have emerged as leading industrial proponents, leveraging mature MTG-, MTO- and Topsoe Improved Gasoline Synthesis (TIGAS)-based pathways.

While all three approaches rely on the common backbone of converting methanol to olefins, followed by oligomerization and hydrogenation, they diverge in process design and product slate. ExxonMobil and Honeywell UOP are focused primarily on producing paraffinic SPK, while Topsoe's TIGAS-derived approach is being advanced toward CKA, incorporating cycloparaffins and aromatics to better match conventional jet fuel properties. These companies are pursuing tailored approaches that emphasize catalytic selectivity, carbon efficiency, and integration with renewable hydrogen and CO_2 utilization strategies. The table below briefly summarizes their core process features and commercialization efforts and described further in the subsections that follow.

Table 4.2: Leading Technology Developers Advancing MTJ Fuel Pathways

COMPANY	TECHNOLOGY BASIS	CONVERSION PROCESS BRIEF SUMMARY	COMMERCIALIZATION STATUS	KEY DIFFERENTIATORS
ExxonMobil	Adapted Methanol-to-Gasoline (MTG) process	Catalytic dehydration of methanol to olefins, oligomerization and hydrogenation to produce SPK	Pilot-scale facilities producing test fuel for ASTM qualification	Builds on decades of MTG experience; highly selective for aviation-range paraffins; targets integration with large-scale projects
Honeywell UOP	Commercial MTO	Methanol conversion to light olefins (ethylene, propylene) then oligomerization and hydrogenation	Commercially proven MTO in petrochemicals; adapted for MTJ aviation use	Extensive global MTO deployment; leverages petrochemical-scale experience to support aviation fuel qualification
Topsoe	New development to produce either CKA or SPK product	Methanol conversion to olefins, followed by oligomerization and hydrogenation to produce CKA or SPK	Pilot-scale facilities producing test fuel for ASTM qualification, adapted from commercial MTG in operation	Focused on high carbon efficiency to SAF and integration benefits with methanol production with biogenic feedstocks and green hydrogen. Leverages strong experience in MTG and methanol technology

Source: Compiled by Transport Energy Strategies, June 2025

In addition, a number of startups, including firms such as Metafuels, are developing innovative MTJ processes and pilot projects, expanding the range of technological approaches under development.

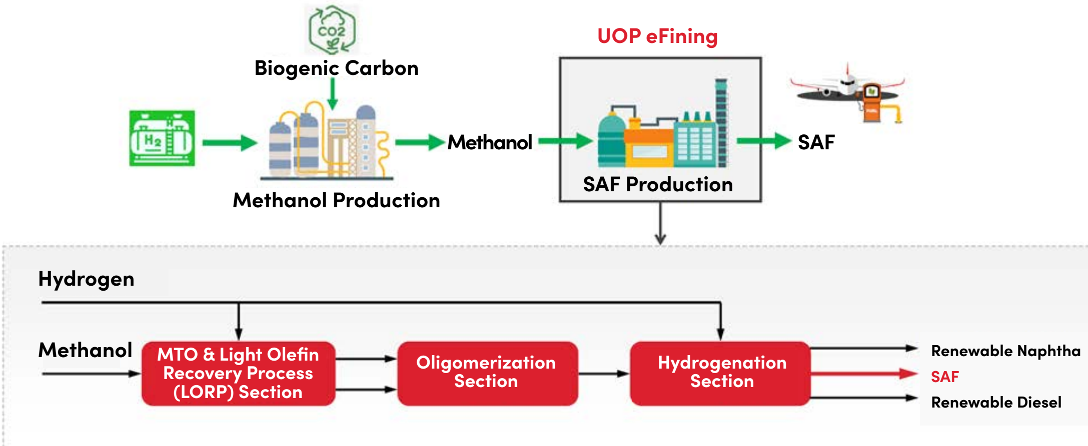
Description of the Honeywell UOP MTJ Pathway

Honeywell UOP has developed the eFining™ MTJ process, which converts renewable methanol into SPK. The process is designed to use bio-methanol derived from biomass or municipal solid waste, as well as e-methanol produced from renewable hydrogen and captured CO_2. It is highly feedstock-flexible, with the ability to process a wide range of methanol grades, from crude to refined, and tolerate moderate water content without additional capital expense.

The process begins with a MTO step, in which methanol is catalytically converted into a mixture of light olefins. This stage leverages Honeywell UOP's commercial MTO technology, which has been proven at scale. The light olefins are then directed to an oligomerization unit, where C3-C5 olefins are selectively combined into longer-chain hydrocarbons in the jet fuel boiling range.

Following oligomerization, the olefinic intermediates undergo hydrogenation to saturate double bonds and produce stable paraffins with properties aligned to aviation fuel requirements. The final step is fractionation, which separates the jet fuel product from renewable diesel, renewable naphtha and other by-products. This configuration allows operators to tune the product slate toward SAF while maintaining co-product flexibility. The process is summarized in the figure below.

Figure 4.6: UOP Fining™ MTJ Process



Source: Honeywell UOP, September 2024

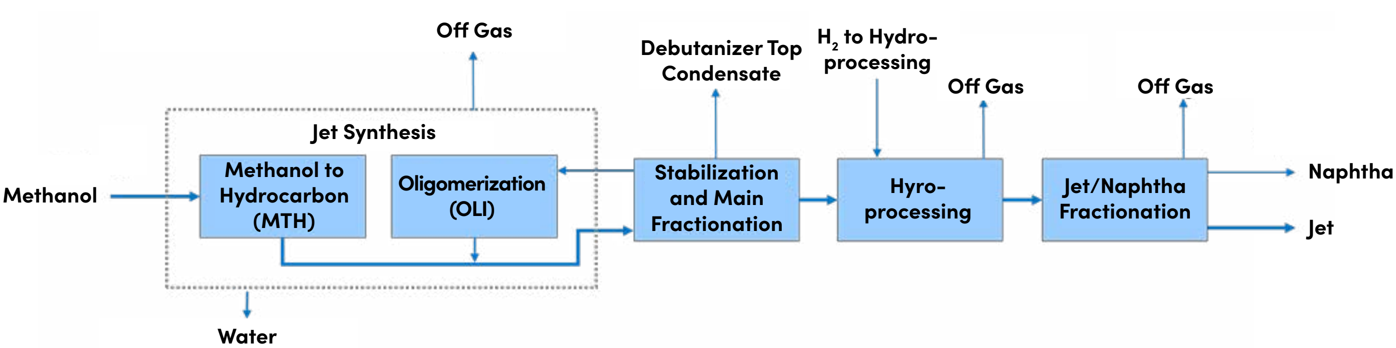
Co-location of methanol synthesis with MTJ units can further improve efficiency through shared utilities, hydrogen integration and carbon recycling.

In addition, Johnson Matthey (JM) is advancing MTJ with Honeywell UOP, combining its eMERALD™ CO_2-to-methanol technology with Honeywell's eFining™ process to improve carbon efficiency, cut costs and boost SAF yields. In parallel, it is supplying e-methanol technology to projects like ETFuels in Texas, positioning clean methanol as a key MTJ feedstock.

Description of the Topsoe MTJ Pathway

The main reaction steps involved in Topsoe MTJ process are the conversion of methanol to kerosene through dehydration, oligomerization, hydroprocessing and fractionation. The main process section of the Topsoe MTJ plant is illustrated in the block flow diagram shown in Figure 4.6.

Figure 4.7: Simplified Block Diagram of Topsoe MTJ Process



Source: Topsoe. Note: The block diagram does not show all process integrations and recycle streams.

Methanol is fed into the MTH synthesis unit, which is characterized by a setup of parallel fixed-bed downward flow reactors filled with Topsoe high performance MTH catalyst. Here, the methanol undergoes dehydration and subsequent conversion into a spectrum of hydrocarbons, ranging from C1 to C17+. The Methanol to Hydrocarbon (MTH) synthesis can also be denominated methanol dehydration and/or MTO. The resulting hydrocarbons are primarily olefinic in nature, which are the building blocks for further product upgrading. The net reaction may be expressed as:

MeOH → C1-2 + C3-4 + C5+ + H_2O + Heat

Compounds in the C3-C8 naphtha range are sent to the oligomerization (OLI) synthesis stage, allowing these components to further develop into kerosene range molecules. Similarly to the MTH synthesis, the oligomerization synthesis step utilizes a system of fixed-bed downward flow reactors filled with Topsoe oligomerization catalyst. The process operates at mild temperatures and high residence times to favor the formation of longer chain species. The end products of the synthesis steps include off gases, LPG range hydrocarbons, naphtha range hydrocarbons, with kerosene range hydrocarbons being the predominant product.

Given the highly olefinic nature of the synthesized kerosene, an additional upgrading step by hydroprocessing is required. Jet fuel properties of the product are achieved by reaction in a fixed-bed reactor in the presence of hydrogen and Topsoe TK hydroprocessing catalysts. The final step in the process involves fractionating the hydroprocessed product into the final product streams. This step also guarantees that the final kerosene product meets the required flash point.

Other separation and fractionation steps may be involved in the process that permit the removal of components generated during the process that do not participate in the synthesis reactions. The aforementioned components can be useful in process integration, production of heat or improving overall efficiencies, or alternatively sold as valuable by-products.

Project Highlights

In addition to these technology providers, a diverse array of project developers around the globe are now advancing MTJ. The table below summarizes select MTJ projects.

Table 4.3: Select Emerging MTJ Projects

COMPANY/PROJECT	TECHNOLOGY/ROUTE	PLANNED CAPACITY	LOCATION	FEEDSTOCK ENERGY SOURCE
IdunnH_2	CO^2-to-Methanol + eFining MTJ	~70,000/yr (planned)	Iceland	CO_2 + green H_2 (wind/geo)
HIF Global (Matagorda)	e-Methanol + MTJ conversion	TBD	Texas, U.S.	e-Methanol (CO_2 + green H_2, wind/solar)
Inner Mongolia Jiturai Group	MTO plant retrofit + Honeywell eFining	~100,000 t/yr	China (Inner Mongolia)	e-Methanol from CO_2 + green H_2 (wind power)
Metafuels	MTJ pilot	~12,000 liters/day	Switzerland/ Netherlands (Rotterdam)	e-Methanol
Nacero	Topsoe MTJet	World-scale RAF complex (capacity TBD, large)	U.S. (Texas)	Renewable natural gas, solar power
Ordos City MTJ Iniative	MTO-derived MTJ	TBD	China (Inner Mongolia)	Biomass + CO_2 renewable energy mix
Power2X/eFuels Rotterdam	Honeywell eFining MTJ	~250,000 t/yr	Netherlands (Rotterdam)	e-Methanol from CO_2 + green H_2
Ji Lin Kang Naier	Honeywell eFining MTJ, repurposing existing MTO facility	300,000 t/yr	China (Ji Lin City)	Outsourcing methanol
Universal Fuel Technologies (Unifuel)	Flexiforming pilot MTJ/ATJ-EtOH	Pilot scale (completed)	U.S.	Methanol, ethanol, renewable naphtha

Source: Compiled by Transport Energy Strategies, June 2025

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The preceding chapters have traced the full landscape of the MTJ pathway, from the scale of aviation's decarbonization challenge to the policies, economics and commercial progress that will determine MTJ's future. The MTJ pathway offers a promising combination of emissions reduction potential and scalability. It draws on the strength of an established global methanol industry and proven chemical platforms, giving it a foundation that other emerging SAF options may lack. The conclusions that follow distill the key insights from this report and set the stage for specific recommendations.

Chapter 1 highlighted the challenge and opportunity: Aviation's GHG emissions have continued to grow despite major efficiency improvements, because the underlying CI of jet fuel has not changed. With jet fuel demand projected to rise from 330 Mt in 2019 to over 500 Mt by 2050, the sector has limited alternatives for decarbonization. SAF is one of the few viable near- and medium-term solutions, particularly for long-haul flights where electrification is not practical. Within this context, MTJ stands out for its ability to leverage a mature chemical platform and for its feedstock flexibility.

Methanol can be produced from biomass, waste, or renewable hydrogen with captured carbon, giving MTJ multiple routes to deliver lifecycle GHG emission reductions of 70 to 90 percent.

Chapter 2 mapped the policy environment: The evolving policy landscape reflects growing global consensus on the urgent need to decarbonize aviation and the critical role SAF will play in achieving long-term climate goals. Across jurisdictions, governments are enacting mandates, creating financial incentives and building regulatory frameworks that are attempting to provide investment certainty for SAF production and use. Yet significant challenges remain. Differences in policy design, sustainability criteria and market support mechanisms may create uncertainty or fragmentation in global SAF markets. Certification systems, while essential, add layers of complexity, particularly for new production pathways like MTJ or RFNBOs. Coordinated international frameworks such as ICAO's LTAG and CORSIA alongside strong national policies, will be essential to align global ambition with practical implementation.

Chapter 3 examined technoeconomic considerations. The cost profile of MTJ is highly sensitive to feedstock type, conversion efficiency and local policy support. Renewable methanol production is expected to expand significantly, yet the economics vary by pathway. Facilities that integrate renewable hydrogen, CO_2 capture, and methanol synthesis with jet upgrading can reduce logistics costs and improve resilience. Co-production strategies that allow surplus methanol to serve maritime markets offer additional risk mitigation. The chapter underscores that MTJ can be competitive, especially where policies close the cost gap and where projects are designed with strong integration into existing infrastructure.

Chapter 4 turned to commercial development. ASTM approval is a gatekeeper for SAF pathways, and MTJ is in the midst of this process with potential qualification as early as 2026. Several technology developers, including ExxonMobil, Honeywell UOP and Topsoe, are leading pilot and demonstration efforts. Industrial consortia are validating performance and emissions outcomes, while some companies are developing MTJ projects. It draws on the strength of an established global methanol industry and proven chemical platforms.

Recommendations for Policymakers and Other Stakeholders

Unlocking the full potential of MTJ SAF hinges on aligning public policy, market incentives and infrastructure with emerging technology pathways. While MTJ is technically feasible and can deliver meaningful GHG reductions it still faces structural cost and market barriers that limit investment and commercial rollout. To address these challenges for MTJ and other SAF pathways, coordinated action from policymakers, regulators, fuel producers, investors and international bodies is essential. The following recommendations are offered for policymakers and stakeholders alike to consider.

1. Provide Regulatory Clarity and Establish Predictable, Long-Term Policy Frameworks

For MTJ and other innovative SAF pathways to become investable at scale, governments must resolve two linked challenges: whether the pathway is explicitly recognized under compliance systems, and whether those systems provide long-term durability and predictability needed to support project development. Clarity of recognition is the first hurdle. For example, in the EU, eMTJ sits within the broader category of renewable fuels of non-biological origin (RFNBOs) under RED III. While that creates a formal entry point, delegated acts impose detailed requirements for renewable hydrogen – additionality, temporal correlation, and geographic correlation – that impact methanol production. A phased or risk-based approach could give producers space to invest while still ensuring rigor over time.

In both the U.S. and other international policy frameworks, hydrogen and its derivatives such as methanol and synthetic hydrocarbons are underrepresented in aviation regulations. While the EU has integrated specific treatment of these fuels in ReFuelEU Aviation and the RED framework, the U.S. lacks comparable provisions. Other countries have no such policies at all. To unlock the full decarbonization potential of MTJ, aviation fuel policies should explicitly address RFNBO pathways, recognize their GHG performance and provide a path to regulatory approval under sustainability and eligibility schemes.

While there are binding mandates in the EU and other countries, there is no binding national SAF blending mandate in large jet fuel markets such as the U.S. Programs like the SAF Grand Challenge set aspirational goals, but they do not create guaranteed demand. Meanwhile, MTJ's eligibility under GREET modeling and IRA tax credits (e.g., Section 45Z) remains unclear, and guidance shifts create real financing risk for MTJ and all innovative SAF pathways. The result is that developers and investors cannot easily determine whether a SAF (including MTJ) project will qualify for support, or whether that support will be sufficient to help close the cost parity gap with fossil jet fuel. Other jurisdictions, from Asia-Pacific to Latin America, face their own gaps in pathway recognition, often lacking MTJ-specific provisions entirely. Aligning with ICAO's CORSIA sustainability criteria may provide a baseline, but deeper national treatment is still needed for all SAF innovative pathways.

Durability and predictability of policy frameworks once they are implemented is equally important. SAF projects take years to develop, and first-of-a-kind plants require financing structures that depend on policy support lasting through construction and well into operations. If policies change midstream, projects may not proceed. Innovative SAF pathways such as MTJ require long-term frameworks that offer long-term stability. Binding mandates, multi-year eligibility criteria under compliance schemes and assurance that credits and incentives will not be abruptly rescinded all reduce risk for project developers.

2. Consider the Use of Financial Tools That Help Close the Cost Gap

Bridging the cost gap between innovative SAF pathways and conventional jet fuel may require a portfolio of financial tools, since no single tool works across all markets or project stages. Such tools could include:

- Contracts for difference or carbon contracts for difference can underwrite price risk against fossil jet or a carbon benchmark, which is valuable in both the EU ETS context and in other jurisdictions without an economy-wide carbon price.

- Long-term offtakes from airlines and alliances may reduce volume risk. Where possible, offtakes should be bankable and aligned with compliance markets so the producer can monetize credits.

- Production tax credits and operating support can be effective in early years, provided they are stable and predictable.

- State or provincial clean fuel programs can include aviation fuels or allow opt-in participation so MTJ SAF producers can stack credits in a transparent way.

- In the EU, public finance mechanisms such as the Innovation Fund and the Hydrogen Bank can prioritize aviation-linked projects. In the U.S., DOE's Loan Programs Office, USDA energy programs and state green banks can reduce the cost of capital. Export credit agencies and multilateral banks can play the same role in emerging markets.

Moreover, while these tools are important to close the market pricing gap between fossil and alternative fuels, they do not reflect the full environmental externalities of conventional jet fuel. A robust and durable carbon price would help internalize these externalities, reinforce the market competitiveness of SAF in general and generate revenue to fund further decarbonization.

In the EU, the inclusion of aviation in the ETS has established such a price signal, though with limited direct impact on SAF uptake. In the U.S., carbon pricing remains limited and fragmented. There are several state-level low carbon/clean fuel standards programs in place, but they do not target or mandate CI reduction from jet fuel. Establishing carbon pricing mechanisms or expanding low-carbon fuel standards to include aviation fuels, paired with compliance multipliers or credit premiums for RFNBOs, could materially shift the investment calculus for SAF pathways, including MTJ.

3. Improve and Harmonize International Sustainability Certification Standards

The international nature of aviation requires alignment on sustainability definitions and lifecycle GHG accounting methods for SAF. Initiatives such as ICAO's CORSIA scheme play a central role but have limitations in terms of rigor and enforcement. Improved mutual recognition of certification frameworks between the U.S., EU and ICAO would reduce compliance costs for producers and streamline project approvals. Harmonizing accounting methodologies, especially for RFNBOs and synthetic fuels, is a necessary foundation for robust international trade in SAF.

4. Encourage Infrastructure Integration and Project Layouts That Reduce Cost

A potential advantage of MTJ compared with other SAF pathways is that it can build on the scale and infrastructure of the global methanol industry. Policymakers can lower delivered costs and improve financeability by creating frameworks that explicitly support integrated projects rather than treating each facility in isolation, which might include:

- Facilitating co-location by aligning permitting for methanol production, hydrogen electrolysis, CO_2 capture and jet fuel upgrading. Instead of requiring separate approvals for each component, integrated permitting can cut lead times and reduce transaction costs.
- Enabling reuse of infrastructure by updating safety codes and standards so that existing methanol storage, pipelines, ports, and blending systems can be adapted where appropriate. Clear regulatory guidance reduces uncertainty for developers.
- Supporting cross-sector hubs through zoning, infrastructure funding and incentives that encourage developers to design projects serving both aviation and maritime fuels. This diversification reduces project risk and makes financing easier.

Permitting frameworks should explicitly recognize the value of integrated projects. Without coordinated policies, developers must navigate multiple approval processes that may work at cross-purposes, adding cost and delay.

5. Ensure Continuity of EU SAF Allowance Program

The EU SAF allowances program, established under the revised ETS Directive, has been well received by airlines and freight operators. To strengthen its effectiveness, policymakers should consider extending the program through 2040 and making participation automatic for aircraft operators (with opt-out provisions). Longer-term certainty will encourage investment in new production capacity, while evolving the program to reward fuels with superior sustainability attributes, such as those derived from renewable methanol, will ensure alignment with climate goals.

6. Recognize the Full Environmental Benefits of MTJ SAF

Policymakers and regulators should also update their lifecycle analysis methodologies and scoring frameworks to account for the full benefits of methanol-based SAF. This includes:

- Accounting for avoided methane emissions in the case of biomethane-derived methanol.
- Including carbon removals where direct air capture or CCS is used.
- Allowing for crediting of co-products and avoided burdens, as applicable.
- Such recognition would allow MTJ to compete on a level playing field with other SAF pathways and reflect its true climate benefit.

The transition to sustainable aviation fuels is one of the most complex but essential undertakings in the global decarbonization effort. MTJ SAF offers a promising solution, one that leverages flexible feedstocks, established technologies and substantial GHG emission reduction potential. However, realizing this promise requires coordinated action across regulatory, financial and technical dimensions. The recommendations outlined in this chapter provide a roadmap for addressing structural barriers and aligning policy frameworks with the emerging capabilities of MTJ technology. With timely support, MTJ SAF can make a meaningful contribution to the aviation sector's climate goals.

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Abbreviations

1G - First generation
2G - Second generation
A4A- Airlines for America
ASTM - American Society of Testing and Materials
ATJ-SPK - Alcohol-to-Jet Synthetic Paraffinic Kerosene
BETO - Bioenergy Technologies Office
BIL - Bipartisan Infrastructure Law
CAAF/3 - Third Conference on Aviation Alternative Fuels
CARB - California Air Resources Board
CBAM - Carbon Border Adjustment Mechanism
CEF - Connecting Europe Facility
CfD - Contract for Difference
CFS - Clean Fuel Standard
CHJ - Catalytic Hydrothermolysis Jet
CI - Carbon Intensity
CINEA - Infrastructure and Environment Executive Agency
CKA - (Synthetic) Cycloparaffinic Kerosene with Aromatics
CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation
DME - Dimethyl Ether
DOE - U.S. Department of Energy
DOT - U.S. Department of Transportation
EEA - European Economic Area
EPA - U.S. Environmental Protection Agency
ETD - European Taxation Directive
ETS - Emissions Trading System
FAA - Federal Aviation Administration
FAST-SAF - Fueling Aviation's Sustainable Transition: Sustainable Aviation Fuels
FID - Final Investment Decision
FT - Fischer-Tropsch
FT-SPK/A - Fischer–Tropsch SPK with Aromatics
GHG - Greenhouse Gas
HEFA - Hydroprocessed Esters and Fatty Acids
HFS-SIP - Hydroprocessed Fermented Sugars to Synthetic Iso-Paraffins
IATA - International Air Transport Association
ICAO - International Civil Aviation Organization
IF - Innovation Fund
ILUC - Indirect Land-Use Change
IRA - Inflation Reduction Act
IRENA - International Renewable Energy Agency
IRS - Internal Revenue Service
ISCC - International Sustainability & Carbon Certification
LCFS - Low Carbon Fuel Standard
LTAG - Long-Term Aspirational Goal
MSW - Municipal Solid Waste
Mt - Million Tonnes
MTJ - Methanol-to-Jet
MTG - Methanol-to-Gasoline
MTH - Methanol-to-Hydrocarbons
MTO - Methanol-to-Olefins
OBBBA - One Big Beautiful Bill Act
RCM - Revenue Certainty Mechanism
PtL - Power-to-Liquids
PtX - Power-to-X
RCF - Recycled Carbon Fuels
RED - Renewable Energy Directive
RES - Renewable Energy Sources
RFNBO - Renewable Fuels of Non-Biological Origin
RFS - Renewable Fuel Standard
RIN - Renewable Identification Number
RSB - Roundtable on Sustainable Biomaterials
RTK - Revenue Ton Per Kilometer
RWGS - Reverse Water-Gas Shift
SAF - Sustainable Aviation Fuel
SBC - Synthetic Blending Component
SKA - Synthetic Kerosene with Aromatics
SPK - Synthetic Paraffinic Kerosene
UCO - Used Cooking Oil
USDA - U.S. Department of Agriculture
USWC - U.S. West Coast

About the Methanol Institute

The Methanol Institute (MI) is the global trade association for the methanol industry, representing leading producers, distributors, and technology companies worldwide. Founded in 1989 in Washington, D.C., MI is an international organization with offices in Washington, Beijing, Brussels, Delhi, and Singapore — connecting regions and bringing together the full methanol value chain.

As the voice of the global methanol industry, MI works with governments, international organizations, and industry partners across sectors to advance policies and collaborations that support methanol's role in the energy transition. Methanol is a versatile chemical used in countless everyday products and, when produced from renewable or low-carbon sources, a low-emission fuel that can help decarbonize hard-to-abate sectors such as shipping and aviation. Beyond these, methanol also provides solutions for cleaner power generation, fuel cells, heavy-duty road transport, and the chemical industry, as well as a wide range of other industrial applications.

Through research, advocacy, and strategic partnerships, MI accelerates the adoption of methanol solutions worldwide, helps scale low-carbon and renewable production pathways, and provides a platform for the industry to innovate, share knowledge, and deliver impact toward a sustainable energy future.

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