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Igniting the SAF Market in China: Policy Pathways to Scale Sustainable Aviation Fuel

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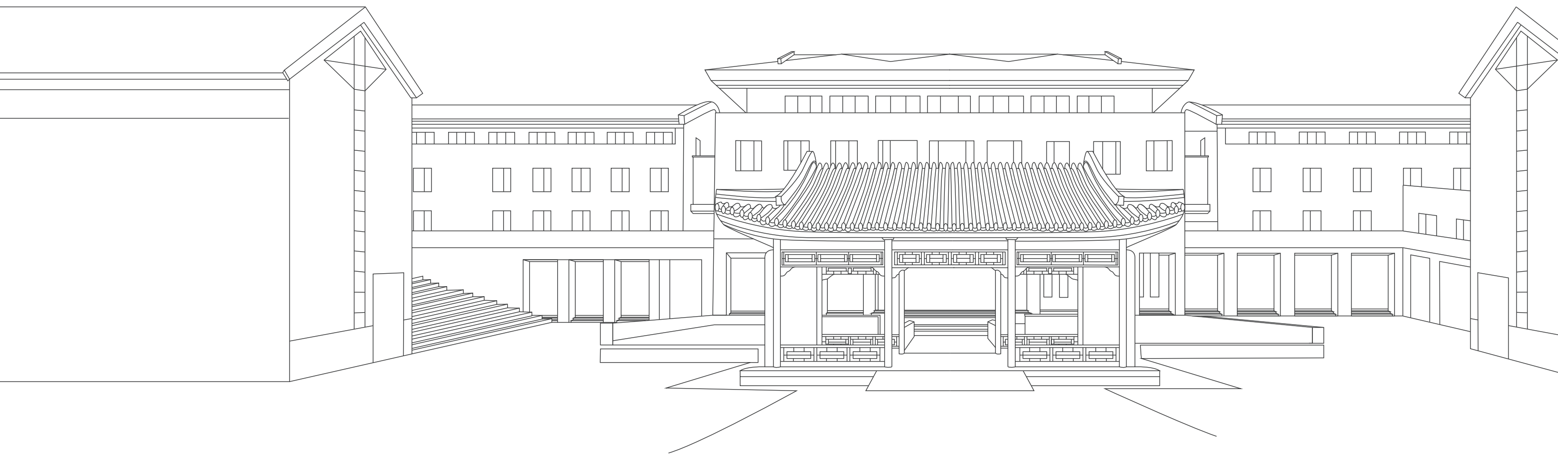

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Executive Summary

The aviation sector accounts for 2%-3% of global carbon emissions. As other sectors accelerate their low-carbon transitions, aviation's share of emissions is projected to rise significantly. Sustainable Aviation Fuel (SAF), a low-carbon alternative to conventional jet fuel, can reduce carbon emissions by up to 80% throughout its full life cycle and has become one of the key pathways for the global aviation industry to achieve carbon neutrality goals. However, the global SAF industry faces challenges such as immature technologies, limited feedstock supply, and high costs. In 2024, global SAF production was approximately 1 million tons, representing only 0.3% of jet fuel consumption, and its price was 2 to 3 times that of conventional aviation fuel.

Major economies have implemented varied policy measures to foster SAF industry growth. The European Union (EU) and the United Kingdom (UK) employ blending mandates, market mechanism and fiscal incentives, requiring aviation fuel suppliers to gradually increase the SAF blending ratios. The United States (US) emphasizes fiscal subsidies, offering tax credits to SAF producers and funding research and development. Singapore plans to introduce a dedicated SAF levy and a centralized procurement fund for SAF, alongside mandates for waste oil recycling in the food service sector and the establishment of cross-border biomass supply chains. International experiences demonstrate that leading economies leverage policy mixes to address bottlenecks in the SAF industry's early stages.

For China, accelerating SAF development is strategically vital. In terms of decarbonization, a 5% SAF blending ratio could reduce annual CO_2 emissions by 6.7 million tons, supporting China's "dual carbon" targets for 2030 and 2060. The global SAF market holds immense potential, with demand projected to exceed 360 million tons by 2050. China is advantageously positioned to capitalize on this, thanks to abundant supplies of used cooking oil, agricultural and forestry residues, and renewable energy resources, which underpin key production pathways such as Hydroprocessed Esters and Fatty Acids (HEFA), Alcohol-to-Jet (AtJ), and Power-to-Liquid (PtL). Additionally, the SAF industry can advance the circular economy by integrating renewable sectors.

However, China's SAF industry remains in its infancy, trailing global leaders. During pilot phases, the price of SAF once exceeded RMB 20,000 per ton, several times the cost of conventional jet fuel and notably higher than SAF price in EU and the US. While domestic capacity has expanded, the lack of stable demand and a market-driven pricing mechanism impedes industry development. Consequently, elevated costs and profitability challenges burden all participants across the supply chain and end-users.

Given China's strengths in SAF, policies should prioritize reducing the "price premium" over conventional jet fuel to enhance market viability. The core challenge is insufficient demand, which limits scaled production, inflates unit costs, and impedes technological advancement. Cost breakdown analysis indicates that economies of scale could yield significant long-term reductions, particularly for e-fuels (PtL pathway). Preliminary estimates suggest that once cumulative PtL-based SAF production surpasses 1.6 million tons, costs could approach those of traditional jet fuel.

Accordingly, the research team recommends demand-side interventions to ensure market uptake and enable scaled production, alongside establishing a market-based pricing mechanism to sustain the entire SAF value chain. Drawing from international best practices, we propose the following policy recommendations.

First, integrate SAF into China's 15th Five-Year Plan (2026–2030) and mandate minimum blending shares. Develop and issue the "China Sustainable Aviation Fuel Industry Development Plan (2026–2035)" with explicit blending mandates to stimulate demand. For example, a 2% mandate in 2026 would generate annual demand of approximately 800,000 tons, rising to 2.65 million tons at 5% by 2030, laying the foundation for scaled production.

Second, pass the price premium to passengers via SAF surcharges. For a 2% blending mandate, airlines would face an additional RMB 8 billion in costs based on current prices and consumption. Fully passing this to passengers equates to roughly RMB 11 per traveler—a modest burden. Design a market-based mechanism, piloting voluntary surcharges on international routes to the EU and UK, with tiers based on flight distance. To encourage participation, introduce a complementary green credits system: passengers paying the surcharge earn credits redeemable for accelerated membership upgrades, mile redemptions, or airport lounge access, fostering a cycle of "green travel, credits earned, benefits enjoyed."

Third, incorporate SAF into government green procurement system. Require civil servants and state-owned enterprise employees to pay a dedicated SAF surcharge on business flights, integrated into total costs alongside airfare and standard fees. Upgrade public procurement systems to automatically calculate and itemize this as a "SAF Green Procurement Surcharge" within travel budgets and reimbursements. This demonstrative public consumption can spur broader market demand.

Fourth, establish long-term procurement agreements and market-based pricing mechanisms. Promote direct offtake agreements between buyers and producers to secure stable pricing. To mitigate cost fluctuations (e.g., prices of used cooking oil), adopt practices like the UK's Revenue Certainty Mechanism (RCM). Longer-term, allocate a portion of carbon pricing revenues from allowance auctions to a dedicated fund subsidizing producer returns. This framework would balance cost-sharing across the value chain through transparent, stable procurement.

Fifth, enhance supply chain efficiency. Accelerate mass balance adoption to reduce costs and infrastructure retrofits. Harmonize regional tax policies to eliminate disparities. Implement phased airport upgrades, prioritizing dedicated SAF storage and refueling at sites near production facilities and major hubs, enabling efficient blending and integration with minimal specialized infrastructure.

Sixth, develop internationally aligned SAF standards and certification systems. Expedite China's domestic standards and certification frameworks, ensuring alignment with global benchmarks. Formulate rigorous quality and environmental criteria covering the full SAF lifecycle, in line with international aviation decarbonization needs. Deepen engagement with global bodies to influence standard-setting, facilitating domestic enterprises' access to international markets.

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1 Overview of the SAF Industry

1.1 Development of the SAF Industry

As a key component of the global transportation system, the aviation industry accounts for approximately 2-3% of global CO_2 emissions. With the accelerated decarbonization of other industries, the growth rate of emissions from the aviation industry is relatively more significant. In 2024, global CO_2 emissions from the aviation industry increased by approximately 5.5%, much higher than the 0.8% growth rate of global energy-related CO_2 emissions. To meet the temperature control objectives outlined in the Paris Agreement, the aviation sector must implement effective mitigation measures to curb its carbon footprint.

In 2009, the International Air Transport Association (IATA) committed to "carbon-neutral growth" for aviation, aiming to reduce the industry's overall carbon emissions by 50% by 2050 compared to 2005 levels. The International Civil Aviation Organization (ICAO) adopted the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, the world's first market-oriented emission reduction mechanism for the aviation industry. CORSIA recognizes Sustainable Aviation Fuel (SAF) as a key mitigation tool, encouraging the use of certified SAF to account for and offset a portion of emissions. According to IATA's Net Zero Roadmap[1], SAF is projected to contribute around 65% of the emission reductions needed to achieve net-zero CO_2 emissions in aviation by 2050.

SAF refers to aviation fuel that meets sustainable development standards. As a breakthrough alternative to traditional aviation fuel, it aims to reduce the industry's environmental impact[2]. SAF is typically derived from renewable resources or waste, such as used cooking oils and fats, municipal solid waste, agricultural and forestry residues, and non-food crops grown on marginal lands. Additionally, SAF can be produced synthetically by directly capturing CO_2 from the air. Compared with traditional aviation fuel, SAF can significantly reduce CO_2 emissions throughout its life cycle. Using different production technologies, the net CO_2 emissions of SAF can be reduced by 70%-100%.

1. https://www.iata.org/en/pressroom/2023-releases/2023-06-04-03/

2. https://www.sigmaearth.com/zh-CN/%E4%BB%80%E4%B9%88%E6%98%AF%E5%8F%AF%E6%8C%81%E7%BB%AD%E8%88%AA%E7%A9%BA%E7%87%83%E6%96%99-saf

ICAO has promoted the establishment of an SAF sustainability certification system. For SAF to be recognized as "sustainable," in addition to its emission reduction effects, it must meet several characteristics: its raw materials do not compete with food crops, do not lead to overuse of resources (water or land), and do not exacerbate environmental challenges such as deforestation and soil degradation. Moreover, in addition to reducing greenhouse gas (GHG) emissions, the chemical properties of SAF are similar to conventional aviation kerosene, allowing it to be directly mixed with existing aviation fuel without modifying aircraft engines. This enables SAF to be quickly applied in the existing air transportation system. In April 2025, IATA officially launched the SAF Registration System, establishing a globally unified accounting framework and transparent tracking mechanism to ensure that the emission reductions of SAF can be authoritatively calculated and avoid double counting, thereby accelerating the adoption of sustainable aviation fuel in the aviation industry.

Therefore, as an effective emission reduction tool and an industry with potential huge market, SAF has attracted widespread attention from the international community.

1.2 Overview of the SAF Market

Data released by IATA[3] shows that global SAF production in 2024 was approximately 1 million tons, accounting for 0.3% of global jet fuel production and double the 2023 production of 500,000 tons. Currently, SAF consumers are mainly concentrated in Europe and North America. According to CORSIA SAF offtake agreement data released by ICAO[4], North American airlines represented by United Airlines, Southwest Airlines, and Delta in the US, and European airlines such as Lufthansa and Air France-KLM, lead in SAF offtake volume. On the SAF supply side, there is also a distinct regional distribution pattern. North American producers represented by Gevo, Fulcrum BioEnergy, and Alder Fuels in the US dominate, while European supply is mainly led by energy giants such as Shell (Netherlands) and Neste (Finland).

Currently, the price of SAF remains relatively high compared to traditional aviation fuel. According to the 2024 Aviation Fuel Reference Price Report released by the European Union Aviation Safety Agency (EASA)[5], the average market price of traditional aviation kerosene in the EU in 2024 was €734/ton, while the average price of Hydroprocessed Esters and Fatty Acids (HEFA) SAF—the most mature SAF technology—was still as high as €2,085/ton, approximately 2.7 times the price of traditional aviation kerosene. According to data released by Argus Media[6],

3. https://www.iata.org/en/pressroom/2024-releases/
4. https://www.icao.int/SAF/saf-offtake-agreements
5. https://stillwaterassociates.com/sky-high-cost-of-compliance-eus-saf-mandate-prices-unveiled/?cn-reloaded=1
6. https://www.airlines.org/dataset/saf-vs-jet-fuel-comparison/#jet-fuel-prices

an energy and commodity market information provider, the price of SAF in the Los Angeles area of the US is also more than twice that of traditional aviation kerosene. This significant price difference highlights the economic challenges faced in the promotion and application of sustainable aviation fuel.

Box 1: Key SAF Technological Pathways and Prospects

In recent years, significant progress has been made in SAF production technologies. Currently, 11 technical routes have been certified by international standardization organizations (such as the Aviation Turbine Fuel Standard Specification ASTM D7566). The production pathways that have received more attention include Hydroprocessed Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT) synthesis, Alcohol-to-Jet (AtJ) conversion, Methanol-to-Jet (MtJ), and Power-to-Liquid (PtL) synthetic aviation fuel technologies, as shown in Table 1.

Table 1 Key SAF Production Pathways

technology roadmap	Technology maturity	principal raw material	Emission Reduction Effect
Hydrogenated esters and fatty acids (HEFA)	High (Commercial)	Used cooking oil, animal and vegetable oil	70-90%
Fischer-Tropsch synthesis (FT)	centre	Municipal solid waste, forestry waste, industrial waste gas.	80-85%
Alcohol to aviation synthetic paraffin kerosene (AtJ)	centre	Agricultural and forestry waste is converted into ethanol and syngas.	60-80%
Methanol to jet fuel (MtJ)	Low (initial stage)	Methanol (produced by biomass gasification or renewable electricity + CO_2)	80-85%
Electricity to liquid fuel (PtL)	Low (cutting-edge technology)	Renewable energy, water and CO_2 are used to synthesize fuel through electrolysis.	90%-100%

Source: Sustainable Aviation Fuel Ready for Lift Off; Compiled by the authors

The HEFA technology has become the mainstream choice in the current market due to its high commercialization level and stable process. This technology mainly uses used cooking oil, animal fats, and other raw materials, and has achieved large-scale production under the promotion of companies such as Neste (Finland) and SkyNRG (Netherlands). However, its development still faces the challenge of limited raw material supply. The cost per ton of fuel is still 2-3 times that of traditional aviation fuel. In particular, the collection system for used cooking oil is not yet perfect, and switching to vegetable oil may trigger sustainability controversies.

At the same time, the FT synthesis technology is gradually moving towards commercialization. This technology can produce synthetic fuels from biomass or natural gas, with the cooperation project between Enerkem (Netherlands) and Shell being a typical example. However, the FT technology requires the construction of complex and sophisticated gasification and synthesis facilities, resulting in high initial investment costs. Additionally, its complicated raw material pretreatment process limits its wider application.

The MtJ,AtJ technologies are still in the demonstration or early promotion stage. In the MtJ technology, the core raw material is green methanol, which is mainly produced by synthesizing green hydrogen (obtained through water electrolysis) or via biomass gasification/fermentation. However, the cost of green methanol remains high, and commercialization has not yet been achieved. The AtJ technology uses ethanol as the raw material. While grain-based ethanol faces sustainability issues, non-grain ethanol production technologies (such as straw conversion) are relatively mature. However, the cost of raw material collection and pretreatment accounts for a relatively high proportion, and ethanol production from industrial waste gas through gas fermentation or catalytic conversion is still in the demonstration stage. Overall, both MtJ and AtJ technologies face commercialization bottlenecks such as high raw material costs and the need for process optimization.

The PtL technology has the most long-term potential. It produces fuel by combining green hydrogen (generated from green electricity) with CO_2, hence it is also known as e-fuel technology. Its life-cycle carbon savings can reach over 90%. Theoretically, since electricity and CO_2 are not limited by raw material availability, the supply potential of e-fuel is much higher than that of other SAF types. However, its current production cost makes commercialization difficult, with the energy consumption of electrolytic hydrogen production and carbon capture accounting for more than 70% of the total cost. Restricted by bottlenecks such as high green electricity costs and high energy consumption in carbon capture, only a few demonstration projects are in operation worldwide.

Overall, the SAF industry is still in the stage of exploring diversified technologies, with each pathway having its own advantages and disadvantages. In the short term, HEFA and FT technologies will continue to support market growth, and their unit costs are decreasing at an annual rate of 5-8% with the expansion of production scale. Emerging technologies such as MtJ, AtJ, and PtL need to make breakthroughs in cost reduction and efficiency improvement.

The high price of SAF is mainly due to insufficient technological maturity, limited feedstock supply, and imperfect supply chains. First, although SAF technology is constantly developing, compared with conventional aviation fuel, its production technology is not yet perfect, and production efficiency is relatively low, resulting in high unit production costs. For example, according to the 2024 Aviation Fuel Reference Price Report released by the EASA, the cost of producing SAF using PtL technology is 10.1 times that of conventional jet fuel[7]. Second, SAF production relies on specific feedstocks, and the supply of these feedstocks is often limited. Taking the currently commercialized SAF production technology - the HEFA process - as an example, this process mainly takes used cooking oil (UCO) as the raw material and converts it into SAF through high-pressure and high-temperature hydroprocessing. Its output accounts for more than 90% of the global SAF market[8]. However, the total amount of UCO feedstock is limited. According to Argus statistics, the globally available UCO in 2024 was approximately 8.9 million tons, with a collection rate of only 57%. In addition to limited supply, some feedstocks (such as UCO) are also widely used in other industries, which makes the SAF industry face competitive pressure in feedstock procurement and further increases production costs. Third, the SAF supply chain is not yet perfect. There are problems in various links, from feedstock procurement and transportation to production, storage, and distribution. Currently, SAF production facilities are relatively few and not widely distributed, leading to high transportation and distribution costs. At the same time, SAF has higher requirements for transportation and storage equipment, and also involves the cost of equipment modification and upgrading. All these factors have pushed up the total cost of SAF.

7. https://stillwaterassociates.com/sky-high-cost-of-compliance-eus-saf-mandate-prices-unveiled/?cn-reloaded=1
8. https://finance.sina.com.cn/stock/relnews/cn/2025-05-20/doc-inexfkuw1209756.shtml?

2 Policies to Support the SAF Industry: International Experiences

2.1 European Union

The European Union (EU) takes a leading position in the global development of the SAF industry. To promote the development of SAF, the EU has established a systematic policy framework, aiming to accelerate the market application and promotion of SAF through multiple supports such as legislative mandates, market mechanisms, and fiscal incentives.

The EU's SAF policies are mainly implemented based on the Renewable Energy Directive (RED) and the ReFuelEU Aviation Regulation. As a guiding document for the development of renewable energy in the EU, the RED covers the entire transportation sector. The RED sets binding renewable energy targets within the EU. From RED I in 2009 to RED II in 2018, and then to RED III in 2023, the incentives and requirements for SAF have been gradually strengthened. The RED III Directive is a decisive step for the EU to integrate SAF into its energy framework[9]. This directive sets specific targets for advanced biofuels and non-biological renewable fuels, requiring that the combined share of advanced biofuels and non-biological renewable fuels in the renewable energy supply of the transportation sector should be no less than 5.5%.

The ReFuelEU Aviation Regulation is a key legislation for the EU to achieve the goal of aviation decarbonization. The regulation was adopted in 2023, and most of its provisions came into effect on January 1, 2024. The regulation requires aviation fuel suppliers[10] to gradually increase the blending mandate of SAF in aircraft fuel at EU airports, from 2% in 2025 to 70% in 2050[11]. It also sets specific sub-targets for e-SAF (electrified Sustainable Aviation Fuel), which will gradually increase from 0.7% in 2030 to 35% in 2050. According to the regulation, SAF must meet the sustainability and emission reduction standards specified in the RED. Acceptable sources of SAF include advanced biofuels, synthetic fuels derived from renewable hydrogen,

9. https://sustainablefutures.linklaters.com/post/102ipy5/european-renewable-energy-directive-red-iii-updated-ambitious-targets-to-boost

10. Aviation fuel suppliers are enterprises that are specialized in the procurement, storage, transportation and refueling services of aviation fuel. For example, in China, China Aviation Oil Group Co., Ltd. (AVIC Oil) undertakes this role.

11. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:4714799#:~:text=Aircraft%20operators%20departing%20from%20EU,For%20further%20information%2C%20see

and recycled carbon aviation fuels. For flights departing from EU airports, regardless of whether the destination is within the EU or not, the ReFuelEU Aviation Regulation requires that more than 90% of the annual aviation fuel must be uplifted within the EU. Different from the RED, the ReFuelEU Aviation Regulation is directly applicable in all member states without the need for conversion into national laws, ensuring the uniformity and immediacy of the policy. The ReFuelEU Aviation Regulation establishes a strict enforcement mechanism, requiring EU airport operators to facilitate the use of SAF, and mandating aviation fuel suppliers, airports, and aircraft operators to systematically collect and report data to ensure compliance with the regulatory requirements of the EASA and national competent authorities. High fines are imposed on non-compliant suppliers and airlines. For example, the fine for aviation fuel suppliers is twice the price difference between SAF and conventional jet fuel multiplied by the non-compliant quantity. This legislation not only provides a clear roadmap for the market development of SAF but also ensures the implementation of the policy through strict enforcement mechanisms and penalty measures.

In addition, the EU provides a flexibility mechanism for aviation fuel suppliers. During the period from 2025 to 2034, they are allowed to meet the minimum SAF blending mandate requirement through a weighted average of the aviation fuel supplied at all EU airports. This is because SAF production capacity is currently only distributed in some regions, and the distance between production areas and airports may be relatively long. If blending is required at each airport, it will result in excessively high long-distance transportation costs. The core of the flexibility mechanism is that suppliers do not need to meet the minimum blending mandate at each individual airport but can conduct a comprehensive calculation across the entire EU to ensure that the overall ratio meets the regulatory requirements. For example, if a supplier blends a higher proportion of SAF in the aviation fuel supplied at one airport and a lower proportion or no SAF at another airport, as long as the overall weighted average meets the minimum ratio required by the regulation, it is considered compliant. This allows aviation fuel suppliers to flexibly arrange the supply of SAF according to their own production capacity and market conditions, thereby optimizing resource allocation and providing the SAF industry with sufficient time to expand production and enhance supply capacity. The flexibility mechanism will be terminated in 2035, after which aviation fuel suppliers must meet the SAF blending mandate requirement at each individual EU airport.

The EU Emissions Trading System (EU ETS) has included the aviation industry in its scope since 2012, requiring all airlines operating within the EU (including flights within the European Economic Area) to pay for their carbon emissions. To promote the application of SAF, the EU ETS has set up dual incentives: on the one hand, the use of SAF can enjoy zero-emission quota recognition, directly reducing the compliance costs of operators; on the other hand, the system has specially established a 20 million ton quota SAF incentive mechanism, which dynamically allocates quotas according to the actual proportion of SAF used by operators, effectively narrowing the price difference between SAF and conventional jet fuel through market-oriented means.

To reduce the high cost of SAF and promote its market application, the EU supports SAF technological innovation through a variety of fiscal incentive mechanisms. For example, the EU provides funding support for the research, development, and deployment of SAF through Horizon Europe, the Innovation Fund, and the InvestEU Program. Among them, the Innovation Fund awarded a grant of 167 million euros to the Swedish Biorefinery Östrand project for the development of the world's first large-scale bio-refinery dedicated to the production of renewable SAF. The EU also provided a 40-million-euro risk loan through the European Investment Bank (EIB) under the InvestEU Program to support the INERATEC synthetic fuel production facility in Frankfurt. At the same time, the EU has revised the Energy Taxation Directive to tax aviation fuel but provide tax incentives for SAF, further enhancing the market competitiveness of SAF.

In addition, to accelerate the promotion and application of SAF technology, the EU has established an SAF Clearing House, which is specifically responsible for the certification and approval of new technologies and promoting the market access of SAF. In addition, the establishment of a unified environmental label has increased the transparency of aircraft carbon emissions, helping consumers choose low-carbon flights and promoting airlines to increase the use of SAF.

The EU has an SAF production capacity of approximately 1.2 million tons, mainly distributed in Sweden, France, and the Netherlands. The EU requires that SAF must meet the sustainability standards of RED III, including a minimum 70% reduction in life-cycle GHG emissions and restrictions on feedstock sources, such as prohibiting the use of food crops and feedstocks with high land-use change risks. SAF production in the EU is mainly focused on traditional biomass-based fuels, such as the HEFA production pathway, while the production of e-SAF, which is more sustainable and scalable, is still in the pilot stage.

In 2024, the average price of SAF derived from biofuels, advanced biofuels, and recycled carbon biofuels in the EU was €2,085/ton, the reference price of e-SAF was approximately €7,695/ton, while that of conventional aviation fuel was only €734/ton. According to data released by S&P, with the gradual increase in blending mandates, the minimum SAF blending rate for EU flights will need to reach 2% in 2025, which means that SAF consumption will increase significantly to

1.9 million tons[12]. Considering the possible shutdowns of SAF plants, the European market may face a SAF demand gap of nearly 9 million tons in 2025.

However, despite the EU providing a clear framework and incentive mechanisms for the development of SAF through policies such as the ReFuelEU Aviation Regulation, the EU SAF market still faces challenges such as high costs, insufficient supply, and weak policy implementation. For example, the current production of e-SAF is mainly dominated by small refineries and start-ups, which lack the capital and technical capabilities for large-scale production, while traditional energy companies have insufficient investment in SAF. In 2024, major energy companies such as BP, Shell, and Uniper successively postponed or reduced their SAF production plans. Due to the high cost and insufficient supply of SAF, many airlines have expressed concerns or even opposition to the EU's SAF mandate. In March 2025, 17 major European airlines represented by Lufthansa, Ryanair, and Air France-KLM issued a joint statement calling on the EU to re-evaluate and relax its mandatory SAF regulations. In addition, the penalty mechanism of the ReFuelEU Aviation Regulation for airport aviation fuel suppliers that fail to meet the blending mandate is directly linked to the cost of SAF, and the cost of SAF is highly volatile due to potential supply shortages, which may cause financial pressure on SAF suppliers.

2.2 United Kingdom

The United Kingdom (UK) has adopted a mandatory policy framework similar to that of the EU to promote the development of the SAF industry and advance the decarbonization process of the aviation industry. According to relevant UK regulations[13], starting from 2025, aviation fuel supplied at UK airports must contain at least 2% SAF. This ratio will increase to 10% by 2030 and further to 22% by 2040. In addition, the UK has also set sub-targets for e-SAF, requiring that aviation fuel must contain 0.2% e-SAF starting from 2028, which will increase to 0.5% by 2030 and 3.5% by 2040. In promoting the development of SAF, the UK also faces challenges such as high costs and insufficient supply. Currently, the UK has only one commercial-scale SAF production facility, and its capacity expansion plans for the next five years are still in the testing phase. To ensure the implementation of the regulations, the UK has also set up penalty provisions. If aviation fuel suppliers fail to meet the blending mandate for SAF or e-SAF, they will face fines. The UK's fine provisions introduce a buy-out mechanism. Specifically, suppliers who fail to meet their SAF obligations are required to pay a fine of 4.70 pounds per liter (approximately

12. https://www.spglobal.com/commodity-insights/en/news-research/latest-news/refined-products/052825-eu-policy-stifles-short-term-saf-supply-growth-omv

13. https://www.gov.uk/government/collections/sustainable-aviation-fuel-saf-mandate

7,000 euros per ton), which is obviously higher than the cost of directly purchasing SAF to meet the requirements, thereby forcing suppliers to meet the blending mandate.

To support the production and application of SAF, the UK has also introduced a series of supporting measures. The UK Emissions Trading System (UK ETS) is one of the important tools to promote the use of SAF. Under this system, there is no geographical restriction on the SAF purchased by aviation operators. As long as it meets the compliance conditions set by the UK ETS, regardless of its origin, it can enjoy quota reduction incentives based on emission reductions, that is, the emission reductions generated by SAF can offset part of the carbon emission quota surrender obligations. In addition, the UK government supports the development of SAF through various fiscal incentive measures. For example, it has established a 165 million pound "Advanced Fuels Fund" to fund the construction of SAF plants and technological research and development[14]. The government has announced an additional 4 million pounds (approximately 4.75 million euros) in funding to support the testing and certification of SAF technology[15].

To address the high costs and market uncertainties faced by SAF production, the UK has launched the Revenue Certainty Mechanism (RCM). The core goal of the RCM is to ensure that SAF production projects built and operated in the UK can obtain stable income despite fluctuations in market prices. Specifically, SAF producers will sign Contracts for Difference (CfD) with counterparties designated by the government. If the market price is lower than the set strike price, the government will compensate for the price difference; if the market price is higher than the strike price, the producer will return the excess revenue to the government. The RCM is funded by a variable tax imposed on conventional aviation fuel suppliers, with the tax rate adjusted dynamically based on the price difference between SAF and conventional fuel. This mechanism prioritizes supporting SAF projects using non-HEFA technologies, such as synthetic fuels and advanced biofuels, to promote technological innovation. Legislation related to the RCM is currently in progress and is expected to be completed by the end of 2026[16].

2.3 United States

As the world's largest aviation market, the United States (US) has one of the most extensive aviation networks in the world, with a per capita number of flights far exceeding that of any other country or region. GHG emissions from the aviation industry account for approximately 3% of total U.S. GHG emissions and are expected to "grow rapidly year-on-year." To reduce

14. https://ethanolproducer.com/articles/uk-sets-10-saf-goal-launches-l165-advanced-fuels-fund-19449
15. https://network.efwconference.com/posts/government-announces-new-saf-measures-to-support-green-aviation
16. https://www.gov.uk/government/consultations/sustainable-aviation-fuels-revenue-certainty-mechanism-revenue-certainty-options

carbon emissions from the aviation industry, the U.S. government has adopted a series of policy support measures. At the United Nations Climate Conference held in November 2021, the U.S. Federal Aviation Administration (FAA) released the "Aviation Climate Action Plan," which clearly outlines key action directions such as promoting SAF, developing new aircraft and engine technologies, and strengthening policy and regulatory guidance, aiming to help the U.S. aviation industry achieve the goal of net-zero GHG emissions by 2050. In 2022, the U.S. government launched the "SAF Grand Challenge Roadmap,"[17] with the goal of achieving domestic SAF annual production of 3 billion gallons (nearly 9 million tons) by 2030 and meeting 100% of the fuel demand of the U.S. aviation industry by 2050. In December 2024, the U.S. Department of Transportation updated its national action plan "U.S. Aviation Climate Action Plan 2024" to ICAO, identifying SAF as the core pathway for the aviation industry to achieve net-zero emissions by 2050.

Unlike the EU, which promotes SAF through policies such as blending mandate and carbon markets, the United States mainly encourages the production, research and development, and market promotion of SAF through subsidies.

First, tax credits are a key support measure. The Inflation Reduction Act (IRA) provides tax credits of up to $1.75/gallon[18] for SAF producers, valid until 2027. Specifically, if SAF achieves a 50% reduction in GHG emissions, producers can receive a basic credit of $1.25/gallon; for each additional percentage point of emission reduction, an additional subsidy of $0.01/gallon can be obtained, with a maximum of $0.50. Section 40B of the Internal Revenue Code also provides tax credits for qualified SAF blends, requiring a minimum 50% reduction in life-cycle GHG emissions. Although the Trump administration has repealed most of the clean energy programs in the IRA, the One, Big, Beautiful Bill[19] strongly promoted by it has retained and adjusted the tax credit provisions for SAF, extending the SAF production tax credit policy from 2027 to 2031, with the credit amount starting at 35 cents per gallon and up to $1.75 per gallon. If the relevant provisions of this bill are fully implemented, it will strongly support the goals of reaching SAF production of 3 billion gallons (approximately 8.77 million tons) by 2030 and 35 billion gallons (approximately 102 million tons) by 2050. The achievement of this goal will bring huge market demand to the SAF industry and also promote the innovation and progress of related technologies. However, the bill also sets restrictions on the participation of foreign entities in

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

18. Volume unit, 1 gallon is 3.78541 liters, according to IATA, 1 ton of SAF = 342.2 gallons of SAF

19. On July 4, 2025, U.S. President Donald Trump signed the much-anticipated "Big and Beautiful" tax and spending bill. The legislation introduced significant energy policy measures, with provisions on Sustainable Aviation Fuel (SAF) drawing particular attention from the industry. From an industrial perspective, SAF production relies on biomass feedstocks such as corn and used cooking oils, creating new economic growth opportunities for agricultural states while driving technological upgrades and transformation in traditional oil refining enterprises.

SAF projects, requiring the localization of feedstocks and production technologies, which may have a certain impact on international cooperation and supply chains.

Second, the U.S. federal government promotes the technological progress of SAF through research and innovation funding. The U.S. Department of Energy has launched various research projects on SAF preparation processes to provide technical development support for producers and provide financial guarantees through the Loan Programs Office to reduce the financing risks and loan interest rates of SAF production projects. The U.S. Department of Agriculture also supports the transformation and upgrading of SAF production facilities and the expansion of production scale through loan guarantees and financial assistance.

Finally, the policies of some state governments also provide additional support for the development of SAF. For example, California's Low Carbon Fuel Standard brings additional economic benefits to SAF producers through a carbon credit trading mechanism; Oregon combines mandatory carbon intensity targets with market-oriented credit trading, essentially endowing low-carbon fuels (such as SAF) with carbon emission reduction premiums to reduce their market cost disadvantages. The state of Illinois in the United States is also actively promoting the application and development of SAF. It has implemented the Sustainable Aviation Fuel Purchase Credit policy from July 1, 2023, to the end of 2032. According to this policy, airlines can receive a tax credit of $1.5 for each gallon (approximately 3.8 liters) of SAF purchased or used within the state of Illinois[20]. These mechanisms not only directly stimulate SAF production but also promote the transformation of the aviation fuel structure towards low carbon, becoming a core model of U.S. state-level SAF policies.

Currently, the United States leads the world in technological innovation, feedstock diversification, and capacity expansion of SAF, with the most diverse technical routes put into production. Its relevant certification standards (such as the ASTM D7566) have considerable influence on the formulation of SAF standards by ICAO.

In terms of technology, the United States leads in a variety of production routes. SAF production in the United States mainly relies on biomass feedstocks, including corn, sugarcane, vegetable oil, fats, and greases. Some projects have also begun to explore the use of sustainable feedstocks such as agricultural waste and algae to produce SAF. Unlike the EU, U.S. policies allow the use of food crops (such as corn and sugarcane) as feedstocks for SAF production, so the United States is at the international forefront in AtJ technology. In addition, the United States also widely adopts HEFA and FT synthesis processes. HEFA is currently the only mature route

20. https://tax.illinois.gov/research/news/fy-2023-23--new-sustainable-aviation-fuel-purchase-credit-enacte.html

that has achieved commercialization, while FT synthesis and AtJ are expected to gradually move out of the demonstration stage and enter commercial operation. Furthermore, the Roadrunner project in Texas, which uses green hydrogen and captured CO_2 to produce e-SAF, has a demonstration effect.

The United States has also made strict distinctions in the sustainability certification of SAF feedstocks to avoid international controversies. To balance environmental protection goals with international trade relations and reduce policy resistance, the United States has established a hierarchical certification system centered on carbon emission intensity through policy frameworks such as the Renewable Fuel Standard and the Sustainable Aviation Fuel Grand Challenge. This system prioritizes supporting non-food feedstocks such as used cooking oils and agricultural and forestry residues, endowing them with the highest tax credits and exempting them from additional certification requirements; it allows conditional access to food-based feedstocks such as corn, which must reduce their carbon footprint through climate-smart agriculture practices (such as no-till farming and cover crops) otherwise they cannot obtain subsidies; at the same time, it systematically excludes high-risk feedstocks involving deforestation (such as certain palm oil-derived fuels).

According to information released by the U.S. Energy Information Administration in May 2025, U.S. SAF production nearly doubled from December 2024 to February 2025, currently reaching approximately 30,000 barrels per day (1.4 million tons per year), and is expected to continue to grow in 2025[21]. According to the latest aviation fuel price data (June 2025) for the Los Angeles area in the United States released by Argus[22], the current market shows a significant price difference pattern: the spot average price of conventional aviation fuel is $2.27/gallon (approximately $776/ton), while the price of SAF before subsidies is $4.78/gallon (approximately $1,636/ton). It is worth noting that after enjoying policy subsidies such as IRA tax credits, the actual landing price of SAF drops to $4.5/gallon (approximately $1,540/ton), a decrease of approximately 5.9% compared with before subsidies, but still a 98% premium over conventional jet fuel.

Some SAF produced in the United States may be exported to other countries to meet the blending mandate of the importing countries. For example, Japan's demand for SAF is increasing, and it may import some SAF produced in the United States. In addition, a small amount of SAF that meets EU regulations may be exported to Europe. However, the market penetration of SAF still faces cost challenges, and it is still necessary to promote technological

21. https://enerknol.com/u-s-sustainable-aviation-fuel-production-surges-with-new-capacity-additions-eia/

22. https://www.airlines.org/dataset/sustainable-aviation-fuel-price-comparison/#jet-fuel-prices.

innovation and overcome cost barriers to further expand market applications.

2.4 Singapore

Singapore is a core hub for cross-border flights. Singapore Airlines Group, the core pillar of Singapore's aviation industry, has carbon emission performance that serves as a key indicator for measuring the environmental impact of the country's aviation industry. In the 2024/25 fiscal year, the group's total emissions increased from 18.8 million tons of CO_2 equivalent to 21.4 million tons, an increase of more than 13%. To address the issue of carbon emissions from the aviation industry, the Civil Aviation Authority of Singapore (CAAS) released the "Singapore Sustainable Air Hub Blueprint" (referred to as the Blueprint) in February 2024, setting medium- and long-term goals for carbon emission reduction in the domestic and international aviation sectors. The Blueprint plans to reduce domestic emissions from airport operations by 20% by 2030 compared with 2019; and achieve net-zero emissions in domestic and international aviation by 2050.

SAF is considered a key pathway to achieve the goals of the Blueprint. To achieve the goal of net-zero emissions by 2050, SAF is expected to contribute approximately 65% of the carbon emission reductions in the aviation industry. To this end, Singapore has set phased SAF usage targets: starting from 2026, all flights departing from Singapore must use SAF, with an initial target of SAF accounting for 1% of the total aviation fuel, and plans to increase the ratio to 3%-5% by 2030. In addition to this mandatory requirement, Singapore has also taken a series of measures to address the high cost of SAF and jointly promote the use of SAF.

Singapore is the first country in the world to ensure the use of SAF through a universal surcharge. Singapore plans to implement a mandatory SAF levy starting from 2026, requiring all departing flights to use SAF, and share the cost through a fixed levy model: the CAAS pre-sets the levy standard based on the 1% SAF usage target and estimated price in 2026 (for example, short-haul economy class flights (such as Singapore-Bangkok) require a payment of SGD 3, long-haul economy class flights (such as Singapore-London) require a payment of SGD 16, and business class/first class levies are higher). The levy revenue is centrally used to purchase SAF. This mechanism integrates demand through unified procurement to reduce unit costs, and the levy amount is fixed and not affected by market price fluctuations; the actual procurement volume is dynamically adjusted based on the total levy amount and real-time SAF prices. This design distributes the SAF premium to passengers, avoiding airlines from bearing the cost pressure alone, while providing stable cost expectations and balancing emission reduction goals with the competitiveness of the aviation hub.

Singapore is actively improving the SAF supply chain system. The government mandates the catering industry to participate in the recycling of used cooking oil and sets up special subsidies to encourage recycling. At the same time, it cooperates with countries such as Australia to develop cross-border supply chains for biomass feedstocks, promoting the application of renewable feedstocks such as used cooking oil and biomass in SAF production. In addition, Singapore provides tax relief and financial support through the "Aviation Sustainability Program" to reduce the production costs of local SAF enterprises. Neste, a world-leading sustainable fuel producer, completed the expansion of its Tuas refinery in Singapore in 2023, increasing its annual SAF production capacity to 1 million tons[23], making Singapore as one of the world's largest SAF production bases. In addition, Singapore Airlines Group has signed long-term procurement agreements with enterprises such as Neste to purchase SAF that meets international standards from local refineries, further strengthening supply chain resilience and promoting the construction of a local SAF ecosystem.

2.5 Summary and Insights of Policy Tools

Based on the above discussion and international literature (WEF, 2021), Table 2 summarizes the international policies supporting the development of the SAF market. The policies are divided into three categories: supply-side measures, demand-side measures, and supporting measures. Supply-side measures increase the production capacity and feedstock supply of SAF, reduce production costs, and thus ensure the stable supply of SAF through policy support and technological research and development. Demand-side measures stimulate the demand for SAF from airlines and consumers by reducing the cost of using SAF or increasing the cost of conventional aviation fuel through policy incentives and market mechanisms. Supporting measures eliminate obstacles to the large-scale development of SAF by optimizing the industrial chain and establishing a standard certification system.

23. https://www.neste.com/en-us/news-and-insights/renewable-solutions/singapore-refinery-expansion

Table 2 Policy Tools Supporting the Development of the SAF Market

Policy Type	Policy Name	Policy Description	Typical Examples
Supply-side	Establishment of Innovation Funds or Financing Options	Support the R&D of early-stage SAF production pathways	EU, US, UK
	CfD Mechanism	Reduce the price difference between SAF and conventional jet fuel	UK (to be implemented)
	Provision of Capital Grants and Low-Interest Loans	Attract private investment for the construction and operation of SAF production facilities	US (Oregon)
	Promotion of RD&D	Enhance the efficiency of the SAF production process and reduce manufacturing costs	US
	Priority Supply of SAF Feedstocks and Optimization of Fuel Plant Production	Encourage the conversion of existing renewable fuel production to SAF	US
	Tax Exemptions	Encourage the use of locally and regionally produced sustainable feedstocks	US
Demand-side	Establishment of SAF Blending Mandates	Gradually increase the share of SAF in the jet fuel market	EU, UK, Singapore
	Provision of Direct Tax Incentives	Reduce the cost difference for SAF buyers	US
	Imposition of SAF Dedicated Levies	Fund SAF procurement and improve consumer transparency	Singapore
	Introduction of Domestic Carbon Pricing or Carbon Trading Mechanisms	Price the emissions of fossil fuels and encourage the use of low-carbon alternatives	EU, UK
Supporting	SAF Supply Flexibility Mechanism	Allow suppliers to meet the overall blending requirement through cross-regional weighted average, reducing initial compliance costs	EU
	Feedstock Guarantee Mechanism	Mandate the recycling of key feedstocks or develop cross-border supply chains	Singapore
	Establishment of Standard Systems	Formulate and enforce strict sustainability standards and promote international mutual recognition	EU, US

Source: WEF(2021)*Clean Skies for Tomorrow: Sustainable Aviation Fuel Policy Toolkit;* Compiled by the authors.

The implementation of these policies not only provides a clear direction and strong support for the market application and promotion of SAF but also provides rich experience for other countries and regions.

1. Demand-side Pull: Clear Mandatory Targets and Sharing Mechanisms Promote Market Expansion. Setting clear and phased mandatory SAF blending targets and providing stable demand expectations is a common practice in major economies. The EU, UK, and Singapore have all established phased SAF usage obligations through legislation. This mandatory requirement provides a clear long-term roadmap for the market and ensures policy implementation through strict enforcement mechanisms. In addition, Singapore provides financial support for SAF procurement by imposing a SAF levy, and this cost-sharing mechanism distributes the cost of SAF across the entire aviation industry chain and end consumers, avoiding airlines from bearing excessive burdens due to the high price of SAF.

2. Supply-side Drive: Fiscal Incentives and Technological Innovation are the Core of Cost Reduction and Efficiency Improvement. Fiscal incentive measures play an important role in reducing the production cost of SAF and enhancing its market competitiveness. The EU provides funding for SAF R&D and deployment through Horizon Europe, the Innovation Fund (e.g., granting 167 million euros to the Swedish Biorefinery Östrand project), and the InvestEU Program (e.g., supporting the German INERATEC project with 70 million euros); the Biden administration of the United States provides tax credits of up to $1.75 per gallon for SAF producers through the IRA and supports technological development and facility upgrading through loan guarantees from the Department of Energy and the Department of Agriculture; the UK also plans to launch the RCM, which may ensure that SAF producers obtain stable income amid market price fluctuations through CfD.

3. Mechanism Coordination: Carbon Pricing and Flexibility Mechanisms are Important Designs to Narrow the Price Difference. Carbon markets and flexibility mechanisms play an important role in narrowing the price difference between SAF and conventional jet fuel. The EU ETS and the UK ETS have included the aviation industry in their scope. On the one hand, they price the carbon emissions generated by the combustion of conventional jet fuel, increasing its usage cost; on the other hand, they provide incentives for the use of SAF, such as the EU ETS providing zero-emission quota recognition and SAF-specific quota incentives. This dual mechanism of "increasing carbon costs & low-carbon incentives" has effectively enhanced the relative competitiveness of SAF. In addition, the initial weighted average mechanism introduced by the EU in ReFuelEU provides flexibility for suppliers, reduces compliance costs, and balances the rigidity of targets with the flexibility of implementation in policy design.

4. Supporting Measures: Supply Chains and Standard Certification are the Foundation of the Industrial Ecosystem. Stable feedstock supply, improved storage and transportation facilities, and a mutually recognized standard certification system are the basic guarantees for the sustainable development of the SAF industry. In terms of the supply chain, Singapore mandates the catering industry to participate in the recycling of used cooking oil and provides subsidies, while actively developing cross-border supply chains for biomass feedstocks (e.g., cooperating with Australia); the United States has established a hierarchical feedstock certification system centered on carbon emission intensity, prioritizing non-food feedstocks and systematically excluding high-risk feedstocks (e.g., certain palm oils); the EU requires that SAF must meet the strict sustainability standards of the RED (e.g., life-cycle emission reduction ≥ 70%, prohibiting the use of food crops and feedstocks with high ILUC risks). In terms of standard certification, the EU and the US actively lead the formulation of international standards.

5. Multi-party Collaboration: Government Guidance and Industry-Consumer Participation are Indispensable. The promotion of the SAF industry cannot be separated from the joint participation of the government, industry, and consumers. The government's top-level design and policy framework are the leading forces. At the same time, industry cooperation is crucial. For example, airlines signing long-term offtake agreements with producers (e.g., Singapore Airlines and Neste) provides stable support for SAF projects; the requirements of leading enterprises (e.g., Amazon, Apple) for low-carbon supply chains also play an important role in promoting the wide application of SAF. In addition, improving consumer awareness and guiding choices are also key. For example, the EU has established a unified environmental label to increase the transparency of aircraft carbon emissions, helping consumers choose low-carbon flights and indirectly promoting airlines to increase the use of SAF. Multi-party collaboration is an inevitable requirement for building a healthy SAF industrial ecosystem.

3 Strategic Role of Developing China’s SAF Industry

3.1 Current Status and Policy Framework

The Chinese government has identified sustainable fuels as a key development area. The "Carbon Peaking Action Plan Before 2030" issued by the State Council in 2021 first proposed "promoting the application of advanced bio-liquid fuels in the aviation sector." Although the term "SAF" was not directly used, it laid the policy foundation for industrial development. The "14th Five-Year Plan for Renewable Energy Development" in 2022 further clarified the technical pathway of "non-food biomass liquid fuels," listed bio-jet fuel as a key R&D direction, and set a quantitative target of 50,000 tons of cumulative consumption of sustainable jet fuel during the "14th Five-Year Plan" period, but there were no blending mandates. The "Catalogue for the Adjustment of Industrial Structure" released in December 2023 upgraded the policy level, listing the collection, storage, and transportation technology of SAF feedstocks and the development and application of production processes in the encouragement category, strengthening support for the industrial chain. In October 2024, six departments including the National Development and Reform Commission jointly issued the "Guiding Opinions on Vigorously Implementing the Renewable Energy Replacement Action," in which SAF was clearly identified as a key development area.

China officially launched SAF refueling pilots in 2024. In September 2024, the National Development and Reform Commission and the Civil Aviation Administration of China (CAAC) launched the first phase of the SAF application pilot. Air China, China Eastern Airlines, and China Southern Airlines refueled SAF on 12 flights departing from Beijing Daxing, Chengdu Shuangliu, Zhengzhou Xinzheng, and Ningbo Lishe airports, marking the entry of China's domestic SAF industry into the early stage of commercialization. The second phase started on March 19, 2025, and all domestic flights departing from the above four airports will regularly refuel with a 1% blended SAF.

Box 2: Current State of SAF Technology Development in China

Although the 14th Five-Year Plan set a consumption target of 50,000 tons, by 2024, domestic SAF consumption was less than 5,000 tons, accounting for only 0.013% of total jet fuel consumption, mainly used in international cargo flights and four pilot airports. Restricted by insufficient demand, feedstock supply bottlenecks (scattered UCO resources and imperfect recycling systems), and insufficient technological maturity, the price of SAF is relatively high at this stage. In terms of technical pathways, China's SAF industry has laid out production capacity covering major technical routes such as HEFA, FT, AtJ, and PtL. Among them, the HEFA technical route, as the most mature process currently, has formed large-scale production capacity in China. Sinopec Zhenhai Refining & Chemical Co., Ltd. built a 100,000-ton/year SAF production facility in 2022, using UCO as raw material and has passed international sustainability certification (Roundtable on Sustainable Biomaterials, RSB). However, due to the limited supply of UCO resources,SAF produced by the HEFA process is insufficient to meet future demand.

In terms of AtJ technology, Shougang Langze, by introducing microbial catalytic technology from LanzaTech's laboratory, built the world's first 45,000-ton commercial fuel ethanol production facility. Relying on LanzaTech's authorized synthetic biological strains and international patent system, it passed the EU CORSIA certification in 2023 and became the only supplier of industrial exhaust gas-derived SAF raw materials in the Asia-Pacific region that has obtained this qualification[24]. China's industrialization process in the field of green methanol has laid the foundation for the preparation of SAF using the MtJ technical route. By April 2025, the total capacity of domestic green methanol projects that have been put into production and are under construction has exceeded 5 million tons[25], and the planned capacity is even more than 50 million tons. This huge supply system can provide raw material guarantees for the large-scale application of MtJ jet fuel technology.

The long-term technical direction is e-SAF, that is, synthetic fuel driven by renewable energy, whose raw materials are green hydrogen (produced by water electrolysis) and CO_2 (from industrial emissions or direct air capture). PtL covers all technical routes of "green electricity → green hydrogen → liquid fuel," and e-SAF is the specific application of PtL technology in the field of aviation fuel. The PtL technology developed by Tsinghua University has been applied in the 10,000-ton/year PtL demonstration project built by State

24. http://www.csteelnews.com/qypd/qydt/201912/t20191209_21856.html
25. https://www.toutiao.com/article/7497871760029778468/

Power Investment Corporation in Xinjiang[26]. This project focuses on wind power coupled with alkaline electrolysis water for hydrogen production, combines hydrogen with CO_2, and produces synthetic jet fuel through animproved FT synthesis process. The key technologies and equipment used are fully independent[27].

3.2 Why China Needs to Further Develop the SAF Industry

3.2.1 Achieving "Dual Carbon Goals"

From the perspective of domestic carbon emission status, China's aviation industry is showing a rapid growth trend. According to the 2025 National Civil Aviation Work Conference[28], the total turnover of air transport in 2024 increased by 14.8% compared with 2019, and carbon emissions reached 129 million tons. Although the current carbon emissions of the aviation industry account for only 1% of the country's total carbon emissions and 10% of the transportation industry, this proportion is expected to increase with the manifestation of emission reduction effects in other key fields. It is expected that by 2030, China's aviation fuel consumption will increase from 40 million tons in 2024 to 53 million tons, and carbon emissions from the aviation industry will further increase to 167 million tons. CO_2 generated by jet fuel combustion accounts for 75%-80% of the total carbon emissions of the aviation industry, making it the absolute main source of emissions. If China's SAF blending ratio reaches 5% by 2030, according to the calculation guidelines of the ICAO, each ton of conventional jet fuel emits 3.157 tons of CO_2 when burned. Calculated based on an 80% emission reduction by SAF, the annual emission reduction can reach 6.7 million tons of CO_2, which will provide important support for achieving the 2030-2060 goals.

3.2.2 Adapting to the Shifting International Policy Landscape and Global Demand

From the perspective of the evolution of international policies, the global aviation emission reduction regulatory system is accelerating its improvement. A series of policies are profoundly reshaping the global aviation fuel market pattern, making SAF production capacity and technology the core competitiveness in the future. Therefore, accelerating the development of the domestic SAF industry is not only an urgent need to cope with international

26. https://m.ofweek.com/hydrogen/2024-06/ART-180826-8420-30637118.html
27. https://finance.sina.com.cn/wm/2024-09-23/doc-incqeerm5072070.shtml
28. https://www.toutiao.com/article/7457900969234301481/?upstream_biz=doubao&source=m_redirect

emission reduction compliance pressures but also a strategic choice to enhance the global competitiveness of China's aviation industry.

The CORSIA mechanism led by the ICAO has established a mandatory emission reduction framework. Starting from 2027, the CORSIA plan will enter the mandatory compliance stage. Airlines from participating countries that fail to meet the exemption conditions[29] will need to comply with carbon emission restrictions to ensure that carbon emissions from the aviation industry do not grow indefinitely. This goal needs to be achieved by using sustainable aviation fuel or purchasing certified carbon credits. Moreover, CORSIA encourages the use of SAF by clarifying the calculation rules for SAF emission reductions and establishing a SAF carbon credit trading mechanism.

The EU and UK have successively introduced strict policies. Currently, when Chinese airlines operate routes to the EU or the UK, flights departing from local airports must use jet fuel that meets the SAF blending mandates. In addition, flights departing from UK airports need to fulfill additional carbon market compliance obligations, including submitting emission data, surrendering quotas, or using SAF to offset part of the emissions. Therefore, even if China does not join CORSIA for the time being, as the world's second-largest aviation market, the international routes of Chinese airlines still face constraints from carbon markets and reward/punishment mechanisms related to SAF use in other countries and regions.

In addition to the impact of international aviation policies, changes in market demand have also put forward higher requirements for the sustainability of future air transportation. The rapid development of cross-border e-commerce and high-end manufacturing is driving the continuous growth of demand. Leading enterprises represented by Amazon, Apple, and Alibaba are taking SAF procurement as the core link of their supply chain emission reduction strategies. This trend is mainly driven by increasingly strict ESG (Environmental, Social, and Governance) disclosure requirements, which have prompted enterprises to take more active emission reduction actions. For example, Amazon has committed to achieving net-zero emissions by 2040 and is promoting the use of SAF through various measures, including cooperating with industrial chain partners to increase the proportion of SAF used. This supply chain emission reduction model led by leading enterprises is becoming a new driving force for the development of the SAF market.

3.2.3 Cultivating New Export Growth Points

Currently, the global production of sustainable aviation fuel is still in its infancy, with its quantity

29. The exempted countries fall into two categories: 1. Special Conditions Countries: Least Developed Countries (LDCs), Small Island Developing States (SIDS), and Landlocked Developing Countries (LLDCs); 2. Low Activity Countries: Those with International Air Transport Revenue Ton-Kilometers (RTKs) below 0.5% in 2018.

accounting for less than 1% of the total consumption of traditional aviation fuel, leaving huge room for growth. The IATA predicts that to achieve net-zero emissions by 2050, the global annual demand for SAF will exceed 360 million tons (assuming 65% of emission reductions are achieved through the use of SAF). The "SAF Grand Challenge Roadmap" in the United States sets a production capacity target of approximately 110 million tons by 2050. Even when combined with the planned production capacity of the EU, the Middle East, and other key regions, there will still be a significant global supply gap. This huge market space provides important opportunities for China's SAF industry.

China's advantages in developing the SAF industry are reflected not only in the market demand level but also in multiple dimensions such as industrial foundation and resource reserves. For the currently commercialized HEFA process, China has significant resource endowment advantages in UCO, the core raw material for producing SAF using this process, but these advantages have not been fully utilized. As the world's largest consumer of edible oil, China's theoretical annual UCO production exceeds 11 million tons, accounting for 30% of the global total[30]. In 2024, China's UCO exports reached 2.95 million tons, of which 1.27 million tons were exported to the United States (accounting for 43%). However, the "Clean Fuel Production Credit Guidelines" (Section 45Z) released by the United States in January 2024 clearly excludes imported UCO from the scope of the 45Z tax credit policy. This policy change has forced China's UCO exports to face transformation. In contrast, China canceled the export tax rebate for UCO in December 2024. By converting UCO into high-value-added SAF products, China can achieve industrial upgrading from exporting primary raw materials to exporting high-value products. If measures such as improving the recycling system and strengthening policy guidance are taken to increase the annual collection of UCO to 6 million tons (a collection rate of approximately 55%), according to the 70% output rate of the HEFA process, 4.2 million tons of SAF can be produced annually. This production scale is equivalent to 10.5% of China's total aviation fuel consumption in 2024 (approximately 40 million tons), and can create an annual output value of approximately 70 billion yuan (calculated based on the 2024 EU SAF average price of 2,085 euros/ton), with a corresponding emission reduction of 10.6 million tons, fully demonstrating the significant dual economic and environmental benefits of the SAF industry.

China also has significant resource advantages in other technical routes. For example, the AtJ route requires a large amount of non-food biomass resources, and China is rich in agricultural and forestry waste resources. According to the "National Crop Straw Comprehensive Utilization Report" released by the Ministry of Agriculture and Rural Affairs of China, the theoretical

30. https://xueqiu.com/4751461282/314526904?md5__1038=n4%2BxnD9iYQqxg7DBDBqDqpDU27jFmi%2BqQ4x

resource amount of crop straw in China is 977 million tons, and the collectible resource amount is 737 million tons[31]. In addition, there are sufficient non-food biomass resources such as corn cobs and sugarcane bagasse. Potential energy crops (such as giant reed and castor) can be converted into bio-aviation fuel and can be grown on saline-alkali land without affecting the country's food production. The PtL path requires large-scale green hydrogen. In terms of renewable energy supply, by the end of 2024, China's total installed capacity of wind power and solar power exceeded 1.4 billion kilowatts, accounting for 42.1% of the country's total installed power capacity[32]. China's "Three North" regions (Northeast, North, and Northwest China) are rich in wind and solar resources, which is conducive to the continuous reduction of electricity costs per kilowatt-hour, even lower than the level of thermal power generation, providing sufficient green electricity guarantees for PtL technology. The large-scale development of the PtL path is inseparable from the support of a stable carbon source. As an industrial country with annual carbon emissions exceeding 1 billion tons, China has a solid foundation in the field of Carbon Capture, Utilization, and Storage (CCUS). According to the "China Carbon Capture, Utilization, and Storage Progress Series Report 2025", as of July 2024, the number of CCUS projects in operation in China has reached approximately 120, with an annual capture capacity of 6 million tons, and this capacity is expected to continue to increase significantly in future plans. In terms of the development of Direct Air Carbon Capture (DAC) technology, some projects have achieved initial results. For example, China Energy Engineering Group, in collaboration with Shanghai Jiao Tong University, has built a 600-ton/year CO_2 direct air capture device and successfully passed the full-load reliability test of the 100-ton module[33].

In April 2025, a breakthrough in export policies injected new momentum into the market - Lianyungang was approved as an SAF export pilot zone, and Zhejiang Jia'ao became the first domestic enterprise to enter the "exporter whitelist", with its 372,400-ton production capacity verified and obtaining export approval[34]. This means that leading enterprises can participate in the international carbon reduction market with the verified production capacity as the upper limit, referring to the traditional aviation fuel export model (customs code HS 2710191). This institutional breakthrough is expected to accelerate the release of SAF production capacity, alleviate the pressure of domestic supply-demand imbalance, and effectively connect with international demand.

31. https://baijiahao.baidu.com/s?id=1779432248795497818&wfr=spider&for=pc
32. https://www.nea.gov.cn/20250121/097bfd7c1cd3498897639857d86d5dac/c.html
33. https://www.ceec.net.cn/art/2024/7/17/art_11019_2532233.html
34. https://vip.stock.finance.sina.com.cn/corp/view/vCB_AllBulletinDetail.php?id=11084336

3.2.4 Integrated Development of the SAF Industry and the New Energy Industry to Promote a Circular Economy

China's SAF industry can develop in a integrated manner with the new energy industry, providing an innovative path for solving the current problems of overcapacity and consumption of renewable energy, as well as promoting a circular economy. As the country with the largest installed capacity of renewable energy in the world, China's total installed capacity of wind power and photovoltaics has exceeded 1.4 billion kilowatts. However, limited by the grid consumption capacity, the "Three North" regions have long faced serious problems of wind and solar curtailment, with a large amount of renewable energy power unable to be effectively utilized, resulting in resource waste. The PtL technology in the SAF industry can effectively absorb this excess renewable energy power by electrolyzing water to produce green hydrogen, realizing a conversion closed-loop of "electricity - hydrogen - fuel". Taking the northwest region as an example, if the abundant wind and solar resources can be used for PtL-SAF production, it can not only improve the utilization rate of new energy and solve the problem of overcapacity in new energy but also significantly reduce the production cost of green hydrogen, opening up new value growth points for the new energy industry, while alleviating the problems of wind and solar curtailment and green electricity consumption, and realizing the coordinated development of renewable energy and the SAF industry. In addition, since the green methanol synthesis and PtL synthetic fuel processes share the green hydrogen production and carbon capture links, the SAF industry can also drive the coupled development of strategic emerging industrial chains such as bioenergy, green hydrogen, and carbon capture. This coupling effect not only improves the efficiency and sustainability of the entire energy system but also creates new development opportunities for related industries, promotes the development of a circular economy, and further promotes China's energy transformation and the construction of a green and low-carbon economy.

At the same time, the core raw material system of the SAF industry is in line with the concept of a circular economy. Traditional waste such as UCO, agricultural and forestry residues, and industrial waste gas can be recycled and used for high-value purposes through different SAF technical routes, promoting the development of a circular economy and stimulating growth in various regions. For example, if the 6 million tons of potential annual UCO in China is fully converted into SAF, it can not only solve food safety problems such as the return of gutter oil to dining tables but also create an annual output value of approximately 70 billion yuan. The large-scale utilization of agricultural and forestry residues can not only reduce pollution from open burning but also drive employment growth in rural areas, achieving a win-win situation of environmental and economic benefits. This type of industrial coupling also extends to the field of carbon cycling. Industrial waste gas from industries such as iron and steel and chemicals can be used as a carbon source for PtL technology, building a complete closed-loop of "carbon capture - fuel synthesis - aviation emission reduction". The in-depth integration across industries not only solves the problems of renewable energy consumption and traditional waste treatment but also cultivates a "green bridge" connecting new energy and the transformation of traditional energy.

3.2.5 Enhancing Discourse Power in International Aviation Governance

The global SAF industry is still in the stage of forming policies and market rules. China urgently needs to break through the pattern dominated by Europe and the United States through international standard mutual recognition and system innovation. Currently, the ASTM international standards and the RED and other standard systems of the EU have established a dual access threshold of "technical compliance - environmental compliance" and seized market share with their first-mover advantage. In 2024, global SAF production was only about 1 million tons, with production and use mainly concentrated in EU and US. Although China's CTSO-2C701A airworthiness standard has been implemented, it has not yet achieved mutual recognition with ASTM; the independently developed "Sustainability Requirements for Aviation Alternative Fuels" is still being improved, which may make it difficult for SAF produced in China to participate in the international supply chain. For example, the UK carbon market stipulates that SAF must pass a certification system recognized by RED II (such as the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB)) or UK supplementary standards to enjoy carbon quota offsets or tax reductions. This policy causes SAF under other standard systems to lose market competitiveness.

The development opportunities in the SAF market are fleeting, and the strategic window period is very urgent. The CORSIA mechanism of the ICAO will enter the mandatory implementation stage in 2027, and SAF will become the core means of carbon emission reduction in the aviation industry. If China fails to make timely arrangements, it will not only lose the leadership of this emerging market but also may be passive in the field of international air transportation.

As the world's second-largest aviation market, if China can make breakthroughs in large-scale SAF production, carbon accounting rule formulation, and standard mutual recognition, it will significantly enhance its influence and discourse power in global aviation governance. The breakthrough of the SAF industry will help China transform from a "rule acceptor" to a "rule co-shaper". The success of this transformation will directly determine the future global aviation carbon pricing power, the distribution pattern of green trade standards, and China's strategic position in the multilateral mechanism of climate governance.

3.2.6 Improving Energy Security

Traditional aviation fuel production is highly dependent on oil as the core raw material, and China's external dependence on oil resources has remained high for a long time. According to data from the National Bureau of Statistics and the General Administration of Customs, China's external dependence on crude oil remains at around 72%[35]. As a key derivative of crude oil processing, the supply chain of aviation fuel is deeply tied to the crude oil import system. Once the crude oil supply chain is interrupted due to sudden events such as international geopolitical conflicts and trade frictions, the energy security of the aviation industry will face a direct impact. Especially in the military field, any "chokepoint" risk in oil trade may pose a potential challenge to the energy security of military aviation. SAF is produced based on non-oil raw materials such as used oils and waste fats, agricultural and forestry residues, and green hydrogen, which can break the single dependence on crude oil from the source and inject diversified elements into aviation energy supply.

In conclusion, developing the SAF industry has triple values of emission reduction, economy, and strategy for China. It is a key strategic decision to achieve the "dual carbon" goals and maintain the international competitiveness of the aviation industry. In the short term, it is an urgent need to cope with international carbon barriers; in the long term, it is a key path to cultivate new productive forces and enhance global green competitiveness. China needs to coordinate policy support, technological innovation, and market mechanisms to accelerate the industrialization process of SAF and gain greater discourse power in global climate governance.

35. https://baike.baidu.com/item/%E5%8E%9F%E6%B2%B9%E5%AF%B9%E5%A4%96%E4%BE%9D%E5%AD%98%E5%BA%A6/266351

4 Challenges Facing the China's SAF Industry

4.1 Bottlenecks in the SAF Industry: Pricing Mechanism, Procurement Mechanism, and Premium Allocation Mechanism

Since China's SAF industry is still in the early stage of development, a market-oriented pricing mechanism has not yet been formed. During the pilot phase, it exhibited characteristics such as concentrated supply, a single buyer, and high prices, mainly manifested in the following three issues.

4.1.1 Lack of a Market-Oriented Pricing Mechanism

During the pilot phase, the domestic price of SAF once exceeded RMB 20,000 per ton, several times the price of traditional aviation fuel and significantly higher than the price of SAF in European and American markets during the same period. This phenomenon stems, to a certain extent, from the lack of a market-oriented pricing mechanism. On the production side, SAF during the pilot phase was mainly supplied by a few domestic enterprises, such as Sinopec Zhenhai Refining & Chemical Co., Ltd. (referred to as "Zhenhai Refining") and Henan Junheng Industrial Group Biotechnology Co., Ltd. The SAF used during the 2024 pilot phase was mainly produced by Zhenhai Refining, which adopted the HEFA technical pathway. However, due to discontinuous production, the amortization of fixed costs increased significantly, thereby pushing up the unit production cost. At the same time, due to the lack of an effective market competition mechanism, the production costs and pricing mechanism of SAF lack transparency, and airlines generally believe that there is an excessive premium on SAF.

4.1.2 Imperfect Procurement Mechanism

Similar to the procurement mechanism for traditional aviation fuel, the procurement mechanism for SAF involves China National Aviation Fuel Group Corporation purchasing SAF from production enterprises in a unified manner and then supplying it to airlines. This centralized procurement model is originally conducive to reducing the procurement cost of SAF, but in practice, due to the lack of market-oriented procurement and pricing mechanisms, this advantage has not been fully realized. As the sole intermediate supplier, CNAF needs to provide dedicated storage and transportation facilities for SAF supply. The relevant modification and construction costs are borne by CNAF and allocated to the SAF price. However, the accounting standards and allocation methods for this part of the costs are not transparent.

Meanwhile, due to the lack of continuous and stable demand, SAF procurement at this stage mainly relies on short-term orders, and there is a lack of long-term offtake agreements. This procurement model prevents the production side from obtaining clear and continuous demand signals, which in turn leads to issues such as discontinuous production and idle capacity, easily resulting in high prices.

4.1.3 Inadequate Premium Allocation Mechanism

According to the research team's survey, in the current first and second phases of domestic pilots, the premium of SAF over traditional aviation fuel is entirely borne by airlines. The cost of traditional aviation fuel usually accounts for approximately 30%-40% of an airline's total operating costs[36]. However, the price of SAF is much higher than that of traditional aviation fuel, which significantly increases the operating pressure on airlines. Against the backdrop that the civil aviation industry is still in the post-epidemic recovery stage and no targeted support policies have been introduced yet, the high cost of SAF has led airlines to generally lack the willingness to proactively purchase SAF, seriously restricting the large-scale application of SAF. The research team's survey shows that as end-users, airlines believe that the SAF premium should be shared among all parties in the industrial chain.

Overall, the current formation of SAF prices lacks a market-oriented mechanism, failing to achieve an effective balance between supply and demand. This places pressure on all parties in the supply chain and demand side, with difficulties in profitability or excessively high costs. However, promoting the development of the SAF industry cannot rely on administrative pricing and administrative interest allocation mechanisms; instead, the market mechanism should play a leading role. In fact, given China's inherent advantages in the SAF industry, the focus of policies should be on reducing the premium between SAF and traditional aviation fuel to create conditions for marketization.

4.2 Cost Forecast for Large-Scale SAF Production

As mentioned earlier, the current issue of excessively high costs (the "excessive premium") restricts the development of the SAF industry. If industrial policies can enable SAF to compete on a par with traditional aviation fuel in terms of price, and if these policies can be gradually

36. https://baike.baidu.com/item/%E9%A3%9E%E6%9C%BA%E8%BF%90%E8%90%A5%E6%88%90%E6%9C%AC/902908

phased out, then such policies are worthy of research and exploration. Although there are international reports predicting and analyzing the cost trends of SAF under different technical pathways, due to the fact that China's SAF industry is still in its infancy, there are relatively few studies on the cost and price trends of SAF targeting the Chinese market. Against this backdrop, this article analyzes the production costs of SAF under different domestic technical pathways based on the financial data of existing domestic SAF producers and the judgments of market experts, thereby determining the medium- and long-term price change trends.

Box 3: Calculation Method for the Leveled Cost of Fuel (LCOF) for SAF

The LCOF represents the average cost required to produce a unit of SAF throughout its entire life cycle:

$$LCOF_t=CapEx_t\times\theta+Opex_t+Feedstock_t-Subsidy_t \qquad (1)$$

Here, t denotes the year, CapEx stands for total capital, θ denotes the expenditure, ROI represents the return on investment, Opex indicates operating expenses, Feedstock refers to raw material costs (e.g., oils, biomass, CO_2, electricity, hydrogen), and Subsidy denotes policy subsidies. The return on investment is calculated as:

$$\theta=\frac{r(1+r)^n}{(1+r)^n-1}$$

Assuming a discount rate8%, reflecting the investment risk and capital cost of China. Assuming that the fixed asset investment of each technical path is amortized over 15 years, then $\theta=\frac{0.08(1+0.08)^{15}}{(1+0.08)^{15}-1}=0.1168$.

4.2.1 Cost Estimation for Different Technical Pathways of SAF

A typical example of the HEFA pathway is a general aviation fuel project. The first phase of this project has an investment of RMB 1.05 billion and will build a production line with an annual output of 200,000 tons of biofuels[37]. This article estimates the LCOF (as Box 3 for the calculation method) of SAF produced via China's HEFA technical pathway by referring to the financial data of this project, and the results are shown in Table 3.

37. Source: https://www.neijiang.gov.cn/njs/xmjsqk/202502/5861964d8946420b91441a609009486c.shtml.

Table 3 Description of HEFA-Related Variables and Data Sources

Item	Value	Data Source
CapEx	5,250 RMB/ton	A general aviation fuel (SAF) project
Opex	1,000 RMB/ton	Expert suggestions
Raw Material Cost (Oils and Fats)	6,175 RMB/ton	Data from Longzhong Information[38]
Hydrogen Cost	80kg/t-SAF × 34 RMB/kg	BloombergNEF; Shanghai Environment and Energy Exchange [39]
Conversion Efficiency	70%	Sichuan Tianzhou International Trade Co., Ltd[40]
LCOF	13154.78RMB/ton	Formula (1)

Note: Taking the North China market as an example, the market price of gutter oil is 5,700 RMB/ton, and the market price of swill oil is 6,650 RMB/ton, with an average of 6,175 RMB/ton. The mass conversion efficiency of the HEFA process into aviation fuel-grade hydrocarbons is generally around 70%. 80kg/t-SAF means that 80 kilograms of hydrogen are consumed to produce one ton of sustainable aviation fuel. The hydrogen price is the average of prices in the Yangtze River Delta, Tangshan, Pearl River Delta, and Henan, which is 34 RMB/kg.

In terms of AtJ projects, Shandong Hengxin Group produces non-grain ethanol on a large scale, laying the core raw material foundation for the future industrialization of AtJ fuel. This article estimates the unit cost of SAF produced via China's AtJ technical pathway by referring to the financial data of Hengxin Group, and the results are shown in Table 4.

Table 4 Description of AtJ-Related Variables and Data Sources

Item	Value	Data Source
CapEx	6,180 RMB/ton	Shandong Hengxin Group
Opex	1,300 RMB	Expert suggestions
Raw Material Cost (Ethanol)	5,482.81 RMB/ton	2025 national mainstream market average price of ethanol in China (Longzhong Information)[41]
Conversion Efficiency	48%	According to Vela-García et al. (2021), the yield of bio-jet fuel via the AtJ process can reach 48%[42]
LCOF	13444.53RMB/ton	Formula (1)

38. Source: https://www.oilchem.net/]

39. On April 28,2025, the hydrogen prices were 33.69 yuan/kg in Yangtze River Delta, 34.83 yuan/kg in Tangshan, 38.13 yuan/kg in Pearl River Delta, and 29.33 yuan/kg in Henan, https://www.cneeex.com/c/2025-04-28/496176.shtml.

40. Source: Chengdu Business Daily, https://e.cdsb.com/html/2024-11/14/content_785183.htm.

41. Longzhong Information, https://www.oilchem.net/seo-142-7.html.

42. Vela-García, N., Bolonio, D., García-Martínez, M. J., Ortega, M. F., Streitwieser, D. A., & Canoira, L. (2021). Biojet fuel production from oleaginous crop residues: thermoeconomic, life cycle and flight performance analysis. Energy Conversion and Management, 244, 114534.

There is no public information available on MtJ projects in China. This article estimates the cost of MtJ in China based on the financial data of a typical domestic green methanol-to-SAF project, and the data are shown in Table 5.

Table 5 Description of MtJ-Related Variables and Data Sources

Item	Value	Data Source
CapEx	4,800 RMB/ton	A domestic 100,000-ton/year green methanol-to-SAF project in China
Opex	1,500 RMB/ton	
Green Methanol Cost	5,500 RMB/ton	
Hydrogen Cost	225 RMB/ton SAF[43]	
Green Methanol Conversion Efficiency	34%[44]	Eyberg et al. (2024)[45]
LCOF	17,775.07 RMB/ton	Formula (1)

In terms of the PtL technical pathway, this article estimates the cost of China's PtL technical pathway based on information from the National Energy Group Hami Energy Integration Innovation Base project[46] and combined with expert suggestions, and the results are shown in Table 6.

43. The specific consumption is 225 NM^3/ton SAF (standard cubic meter), with a unit price of 1 yuan/NM^3. The unit hydrogen cost is calculated as: specific consumption × unit price = 225NM^3 × 1 yuan/NM3 =225 yuan/ton SAF.

44. The specific consumption is 2.9 tons of green alcohol per ton of SAF, resulting in a conversion efficiency of (1/2.9) × 100% ≈ 34.48%.

45. Eyberg, V., Dieterich, V., Bastek, S., Dossow, M., Spliethoff, H., & Fendt, S. (2024). Techno-economic assessment and comparison of Fischer–Tropsch and Methanol-to-Jet processes to produce sustainable aviation fuel via Power-to-Liquid. Energy Conversion and Management, 315, 118728.

46. http://www.cciac.org.cn/html/article/2024-10/27476.html

Table 6 Description of PtL-Related Variables and Data Sources

Item	Value	Data Source
CapEx	11,334 RMB/ton	National Energy Group Hami Energy Integration Innovation Base project
Opex	1,200 RMB/ton	Expert suggestions
CO_2 Cost[47]	763.25 = 4.3t-CO_2/t-SAF × 177.5 RMB/ton	BloombergNEF; Frontier and Trend Forecast of Carbon Capture Technology Development
Hydrogen Cost[48]	400kg H_2/t-SAF × 34 RMB/kg	OFweek Hydrogen Energy Network; Shanghai Environment and Energy Exchange[49]
LCOF	16887.40RMB/ton	Formula (1)

China's first FT project was announced to start in July 2025[50]. Since there is no public financial information available for the project, this article mainly draws on the cost analysis of international relevant projects from research reports by McKinsey & Company and the World Economic Forum, and the results are shown in Table 7.

Table 7 Description of FT-Related Variables and Data Sources

Item	Value	Data Source
CapEx	95,859.91 RMB/ton	World Economic Forum (2020)
Opex	2,197.92 RMB/ton = $304/ton × 7.23	
Biomass Raw Material Cost	250.26 RMB/ton = $34.61/ton × 7.23	
LCOF	13647.45RMB/ton	Formula (1)

Note: According to research reports by World Economic Forum (2020), the amortization of capital expenditure for FT in 2025 is $1,549/ton. Calculated based on a 15-year period, the total capital expenditure (CapEx) is ($1,549/ton × 7.23)/0.11683 = 95,859.91 RMB/ton. The operating cost (Opex) is $304/ton. The biomass demand is derived by reversing the average growth rate from 2030 to 2050, which is approximately $34.61/ton[51]. 1 US dollar ≈ 7.23 RMB.

47. 1 ton of SAF requires 4.3 tons of CO2 (BloombergNEF). The integrated oil displacement demonstration projects in China's coal chemical and petrochemical sectors have relatively low capture costs, ranging from 105 to 250 yuan per ton of CO2, with an average of 177.5 yuan per ton.

48. 1 ton of SAF requires 100–400 kg of hydrogen (https://m.ofweek.com/hydrogen/2024-07/ART-180826-8110-30639298.html#:~:text=03%20)

49. On April 28,2025, the hydrogen prices were 33.69 yuan/kg in Yangtze River Delta, 34.83 yuan/kg in Tangshan, 38.13 yuan/kg in Pearl River Delta, and 29.33 yuan/kg in Henan, https://www.cneeex.com/c/2025-04-28/496176.shtml.

50. https://gict-developer.com/news.aspx

51. World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020

4.2.2 Long-Term Price Forecast Based on Cost Decomposition

Based on the cost decomposition of the above technical pathways, this article predicts the price trends of various factors constituting the costs and determines the long-term cost (price) trends of SAF under different technical pathways. This article refers to the World Economic Forum's (2022) forecast of the long-term trends of the average prices of various cost components internationally to analyze the cost trends of SAF in China.

Figure 1 shows the evolution trend of the unit production cost of major SAF pathways in China from 2025 to 2050 (see the Appendix for detailed analysis). Overall, the costs of all pathways show a downward trend, but there are significant differences in the magnitude of the decline and the final cost level. Among them, the HEFA process is relatively mature currently. Due to the limited supply of raw materials, the future cost decline will be limited and will basically stabilize after 2035. The cost of the PtL pathway will decrease significantly with the substantial decline in the cost of green hydrogen, and it is expected to become the most cost-competitive technical pathway in the long term. The costs of the AtJ and MtJ pathways will also decrease to varying degrees. The overall trend indicates that the cost of SAF is expected to continue to decline with technological progress and scale expansion.

The commercial application prospect of SAF depends on whether it can reach price parity with traditional aviation kerosene. The recent price of aviation kerosene in China is approximately 5,500 RMB/ton[52], and this article assumes that the price of aviation kerosene will increase by 5% annually. Under the policy premise of achieving the carbon neutrality goal, airlines need to pay corresponding fees for their carbon emissions. Generally, one ton of traditional aviation fuel emits 3.2 tons of CO_2 when burned[53], while SAF can reduce CO_2 emissions by an average of 80% throughout its life cycle[54]. Based on the carbon price pathway under the premise of China's carbon neutrality goal[55], Figure 1 shows a comparison between the cost of traditional aviation kerosene (including carbon emission fees) and the cost of SAF. Among them, the cost of the PtL pathway will decline the most rapidly, and it is expected to reach price parity with conventional aviation fuel around 2045.

52. https://www.safetyga.com/cnaf/cnafindex.html

53. https://paper.people.com.cn/zgnyb/html/2019-05/20/content_1926237.htm

54. https://www.chinanews.com.cn/cj/2025/05-19/10418477.shtml

55. According to the forecast of Zhang Xiliang et al. (2022), the carbon price in 2030,2035,2040,2045 and 2050 is 18 US dollars, 33 US dollars, 54 US dollars, 75 US dollars and 120 US dollars respectively (assuming that the exchange rate of RMB against US dollars remains at 7.0).

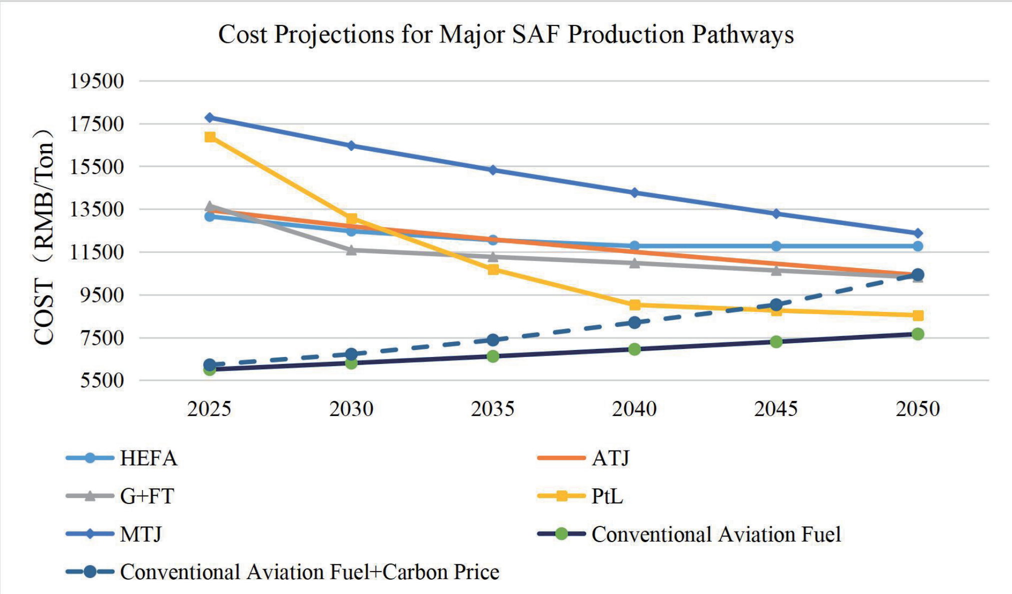

Figure 1 Forecast Trend of Unit Costs of Major SAF Pathways and Aviation Kerosene in China (2025-2050)

4.2.3 Long-Term SAF Cost Projections: Lessons from the Photovoltaic Industry

Currently, the high cost of SAF production in China is mainly due to small production volume and discontinuous production. The scale effect is of great significance in the manufacturing industry and is a key factor in reducing the average cost. An important source of the scale effect is the experience effect accumulated through production practice (i.e., the "learning-by-doing" effect). Therefore, the learning curve formula is often used for cost forecasting in fields such as renewable energy, manufacturing, and aviation fuel (Steffen et al., 2020)[56]. The formula is:

$$Cost_t=Cost_{2025}\times\left(\frac{Q_t}{Q_{2025}}\right)^{log2(1-LR)}$$

Among them, is the unit cost in year t (RMB/ton); represents the unit cost in 2025 (base year); is the cumulative output in year t; LR represents the learning rate corresponding to different technical pathways.

This section refers to the development experience of China's photovoltaic technology and sets corresponding learning rates for different technical pathways. The core driving factors for the high learning rate of photovoltaic technology include the reduction in equipment costs

56. Steffen, B., Beuse, M., Tautorat, P., & Schmidt, T. S. (2020). Experience curves for operations and maintenance costs of renewable energy technologies. Joule, 4(2), 359-375

brought about by large-scale production in China, breakthroughs in silicon material purification technology, and the improvement in efficiency driven by global market competition. According to research by Sui Lihui (2012), the learning rate of China's photovoltaic power generation costs ranged from 15% to 25% between 2005 and 2010[57]. Meanwhile, Creutzig et al. (2017) also pointed out that the dynamic relationship between cost reduction and installed capacity growth of photovoltaic technology is reflected in the fact that the cost of photovoltaic modules decreases by 22.5% every time the cumulative installed capacity doubles. This learning rate is much higher than the median level of other energy technologies (approximately 15%)[58]. Based on this, we assume that the learning rate of SAF production technology, which is most likely to replicate the cost reduction path of China's photovoltaic modules in the future, will remain at around 22.5%.

Among the five technical pathways, the PtL-based pathway is most likely to replicate the cost reduction curve of China's photovoltaic industry. This is because this pathway does not rely on the limited supply of biomass raw materials but mainly depends on the progress of the manufacturing industry and the scale effect. Based on this, this article assumes that the learning rate of the PtL pathway is similar to that of the photovoltaic industry, at 22.5%.

Both the AtJ and MtJ pathways rely on a standardized intermediate raw material—ethanol or methanol. It is assumed that the learning rates of the AtJ and MtJ pathways are set at the median level of 15% of the learning rates of other energy technologies. The other two pathways, HEFA and FT, have the lowest similarity to the photovoltaic model. The bottleneck of HEFA production costs lies not in technical equipment but in the acquisition of raw materials, so its potential is limited. The core of FT lies in large-scale, complex, and highly integrated gasifiers and Fischer-Tropsch reactors, making it a typical "heavy chemical industry" project. Therefore, it is assumed that the learning rates of the HEFA and FT pathways are relatively low, at 7% and 10% respectively.

Figure 2 shows the cost trend results under different scales and learning rates. Similar to the previous analysis, the long-term cost trends of several technical pathways are compared with the price of traditional aviation fuel (including the expected carbon price in 2030[59]). When the cumulative output of SAF reaches approximately 1.6 million tons, the costs of the PtL and AtJ pathways may approach price parity with traditional aviation fuel. In 2024, the domestic

57. Sui Lihui. Analysis of the Development Trend of China's Photovoltaic Power Generation Cost Based on the Learning Curve [J]. Hydropower Energy Science, 2012,30(06):209-211+215

58. Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. Nature Energy, 2(9), 17140

59. According to Zhang Xiliang et al. (2022), China's carbon price in 2030 is predicted to be $18 (assuming the exchange rate of RMB against the US dollar remains at 7)

consumption of aviation kerosene was 40 million tons. If the blending ratio is 1%, the annual consumption will reach 400,000 tons. This means that the cumulative consumption will reach 1.6 million tons in four years, and by then, the cumulative production scale of SAF may reach the critical point of price parity with traditional aviation fuel.

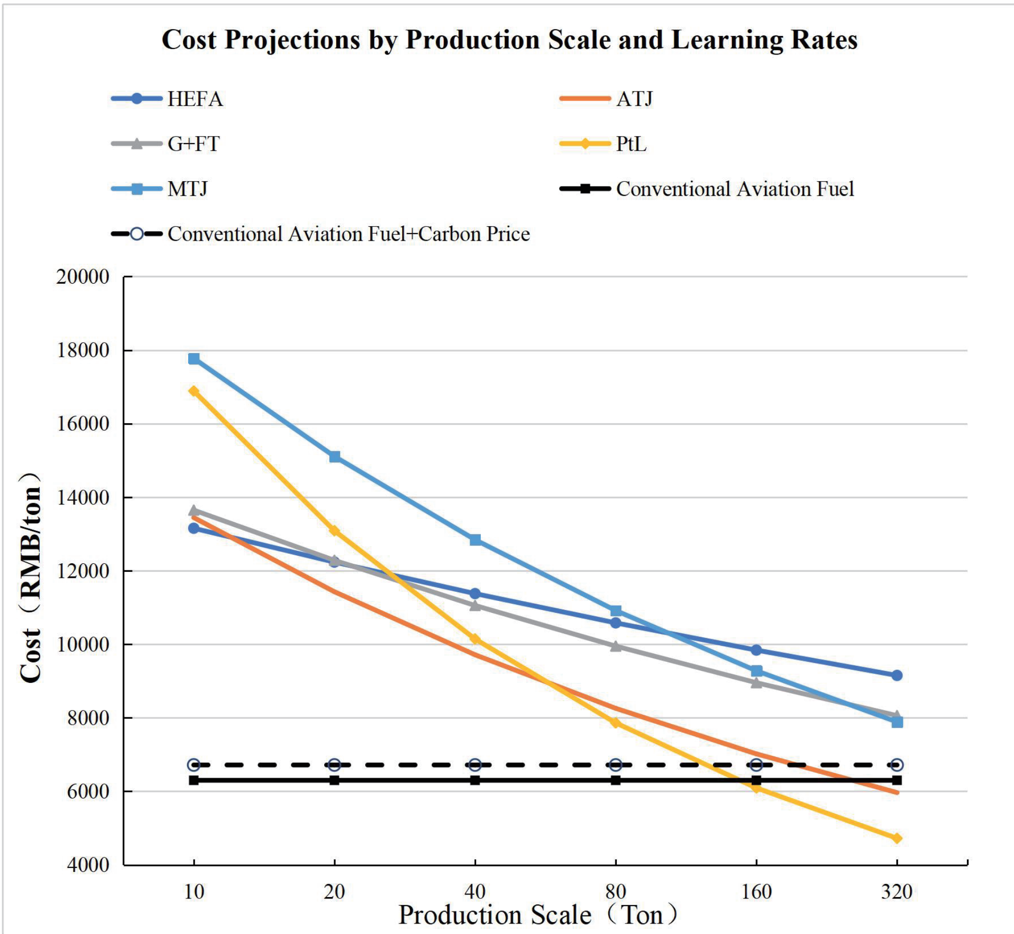

Figure 2 Cost Projections by Production Scale and Learning Rate

Note: China's carbon prices in 2030 is based on Zhang Xiliang et al. (2022).

4.3 Main Challenges in Scaling SAF Production

First, insufficient policy driving force is the core bottleneck in the current development of the SAF industry. Currently, there is no clear mandatory SAF blending ratio stipulated in China. The lack of this key policy directly leads to insufficient demand for SAF. On the supply side, some enterprises have delayed investment decisions due to policy uncertainties, and some enterprises that have already put into production only maintain trial production. The early fixed investment in SAF is very high. Insufficient demand will lead to high unit costs of SAF production, and will also hinder technological progress due to the inability to achieve large-scale production, restricting the industrialization process of SAF. For example, the price of SAF used in domestic pilots in 2024 was higher than the price of similar SAF in the EU or the US. The main reason is that enterprises have discontinuous production, resulting in large amortization of fixed costs and high unit production costs. Another example is that for long-term technical pathways such as the PtL technical pathway, large-scale green hydrogen is required as a raw material, but the cost of green hydrogen production is very high; an important reason for the high cost of green hydrogen is the current lack of actual market demand. Most green hydrogen is self-produced and self-sold, and there is a lack of market transactions and effective pricing.

Since China's airlines are still in the post-epidemic recovery stage, their overall operating efficiency is not good, and they themselves have no incentive to adopt SAF, whose price is 4-5 times higher than that of ordinary fuel. The CAAC is responsible for supporting the development of the aviation industry and adopts a cautious attitude towards policies that increase the costs of airlines. Therefore, there is insufficient motivation to increase the market demand for SAF through mandatory policies.

Second, there is a lack of collaboration across the entire SAF industrial chain. Firstly, the supply of UCO raw materials relied on by the HEFA process faces bottlenecks. On the one hand, a large amount of UCO is used for export. China is the world's largest exporter of UCO, accounting for 40% of the global total UCO trade volume. On the other hand, as the world's largest consumer of edible oil, China's theoretical annual UCO production exceeds 11 million tons (accounting for 30% of the global total)[60], but the actual collection volume is only about 4 million tons, with a collection rate of less than 40%, far lower than the global average level (57%) and the recycling level of developed countries in Europe (85%). This means that China has huge room for improvement in UCO supply. Secondly, the construction cost of SAF storage and transportation infrastructure is high. The requirement for an independent storage and transportation system means that the modification of refueling equipment at a single airport requires an investment of several million yuan, which limits the promotion and application of SAF to a certain extent.

Finally, the lagging standard certification system restricts the export of China's SAF. The SAF certification system mainly includes airworthiness certification and sustainability certification, which focus on fuel performance safety and life-cycle emission reduction responsibilities respectively. The CAAC has established an SAF airworthiness standard

60. https://xueqiu.com/4751461282/314526904?md5__1038=n4%2BxnD9iYQqxg7DBDBqDqpDU27jFmi%2BqQ4x

certification system based on international mainstream standard systems, but China has not yet established an independent sustainability standard certification system. Although China has started the framework design of a sustainability standard system, for example, the CAAC released the "Sustainability Requirements for Aviation Alternative Fuels" (draft for comments) in 2023, this standard is still in the revision stage and has not been officially released or become mandatory. Currently, there is no requirement for sustainability certification for SAF used in China. Although there have been recent progress, the overall situation is still lagging: in July 2025, the SAF Center of the Second Research Institute of Civil Aviation passed the document review of the independent aviation fuel certification system and recommended the launch of a pilot sustainability certification system for SAF covering the entire chain; in August, the two industry standards for aviation fuel carbon footprint accounting led by it were released, providing standardized basis for the industry. However, among the above achievements, the core sustainability certification standard system has not yet been officially released. Currently, enterprises need to prove the emission reduction potential of SAF through international certification programs (such as ISCC, RSB) when exporting SAF, but the certification process is relatively complex and incurs certain costs. At present, domestic certification can only be carried out through cooperation with these international institutions. Therefore, China urgently needs to establish a sustainability standard system based on domestic standards and supported by international mutual recognition to promote the integration of China's SAF industry into the global decarbonization chain and enhance its competitiveness in the international market.

Overall, China's SAF industry faces multiple challenges such as insufficient policy driving force, lack of collaboration across the entire industrial chain, and lagging standard certification. In the short term, it is necessary to activate the market through policy driving; in the medium and long term, it is necessary to overcome key technologies and establish a raw material supply system, while accelerating international mutual recognition of standards to address relevant trade barriers. Only through coordinated promotion in multiple dimensions can the SAF industry achieve leapfrog development from pilot demonstration to commercial large-scale application.

5 Policy Recommendations

Currently, the SAF industry is in a critical period of development, facing the global trend of aviation industry emission reduction and the growing demand for SAF. In the global aviation field, countries are competing for technological and market discourse power. As a low-carbon aviation fuel, SAF has become an important pathway to achieve the carbon neutrality goal. Although the production cost of China's SAF industry is relatively high during the pilot phase, it has huge potential for cost reduction relying on its abundant raw material reserves, strong new energy supply capacity, and mature manufacturing foundation. However, the current core issue is insufficient market demand, which limits the continuous production of producers, leading to high unit costs and slow technological progress, making it difficult for all parties in the supply chain and demand side to profit or facing excessively high costs.

In conclusion, stable market demand is the key to promoting the large-scale development of the SAF industry. Learning from China's policy experience and lessons in the fields of the "new three" (electric vehicles, lithium batteries, and photovoltaic products), the government should prioritize ensuring market demand from the demand side. In fact, compared with supply-side subsidies, demand-side support can effectively avoid international trade disputes and potential overcapacity caused by excessive subsidies. More importantly, through the reasonable design of the "premium allocation mechanism" and a market-oriented pricing mechanism, the sustainable development of the SAF industry can be promoted.

Drawing from international best practices, we propose the following policy recommendations.

First, integrate SAF into China's 15th Five-Year Plan (2026–2030) and mandate minimum blending shares. Develop and issue the "China Sustainable Aviation Fuel Industry Development Plan (2026–2035)" with explicit blending mandates to stimulate demand. Based on the current annual consumption of aviation kerosene in China[61], if the SAF blending ratio is initially set at 2% in 2026, the annual demand for SAF will be approximately 800,000 tons; based on the forecast of China's aviation kerosene consumption in 2030[62], if the blending ratio is increased to 5% by then, the annual demand for SAF is expected to reach 2.65

61. 40 million tons/year

62. The expected annual output is 53 million tons.

million tons. This will lay a solid foundation for the large-scale production of SAF producers.

Second, pass the price premium to passengers via SAF surcharges. For a 2% blending ratio, airlines would face an additional RMB 8 billion in costs based on current prices and consumption[63]. According to the 730 million passenger trips of China's civil aviation industry in 2024[64], even if the additional RMB 8 billion cost is fully allocated to passengers, each passenger will bear RMB 11—a modest burden. Design a market-based mechanism, piloting voluntary surcharges on international routes to the EU and UK, with tiers based on flight distance. To encourage participation, introduce a complementary green credits system: passengers paying the surcharge earn credits redeemable for accelerated membership upgrades, mile redemptions, or airport lounge access, fostering a cycle of "green travel, credits earned, benefits enjoyed".

Third, incorporate SAF into government green procurement system. Require civil servants and state-owned enterprise employees to pay a dedicated SAF surcharge on business flights, integrated into total costs alongside airfare and standard fees. Upgrade public procurement systems (aka, government-authorized flight ticket booking platforms[65]) to automatically calculate and itemize this as a "SAF Green Procurement Surcharge" within travel budgets and reimbursements. This demonstrative public consumption can spur broader market demand.

Fourth, establish long-term procurement agreements and market-based pricing mechanisms. Promote direct offtake agreements between buyers and producers to secure stable prices. To mitigate cost fluctuations (e.g., prices of UCO), adopt practices like the UK's RCM. Longer-term, allocate a portion of carbon pricing revenues from allowance auctions to a dedicated fund subsidizing producer returns. This framework would balance cost-sharing across the value chain through transparent, stable procurement.

Fifth, enhance supply chain efficiency. Accelerate mass balance[66] adoption to reduce costs and infrastructure retrofits. Harmonize regional tax policies to eliminate disparities. Implement phased airport upgrades, prioritizing dedicated SAF storage and refueling at sites near production facilities and major hubs, enabling efficient blending and integration with

63. The expected annual demand for SAF is 8 million tons

64. It includes domestic routes, Hong Kong, Macao and Taiwan regions and international routes.

65. https://app.gpticket.org/login.action;jsessionid=933716DDE3195A25DFD7D117F849EA1F

66. Mass Balance is a tracking and allocation method based on the law of conservation of mass. By establishing a traceable accounting system, it ensures that the total amount of SAF in mixed production or transportation processes precisely matches environmental attributes (such as carbon reduction). For example, in SAF production, even though SAF is blended with traditional aviation fuel, mass balance certification guarantees that the proportion of sustainable components in the final SAF product aligns with the input quantities.

minimal specialized infrastructure.

Sixth, develop internationally aligned SAF standards and certification systems. Expedite China's domestic standards and certification frameworks, ensuring alignment with global benchmarks. Formulate rigorous quality and environmental criteria covering the full SAF lifecycle, in line with international aviation decarbonization needs. Deepen engagement with global bodies to influence standard-setting, facilitating domestic enterprises' access to international markets.

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Appendix: Analysis of SAF Price Trends Based on Cost Decomposition

1.HEFA

This section explores the cost of China's HEFA from 2030 to 2050 based on assumptions from McKinsey & Company and the World Economic Forum (2020)[67]. Forecasting the production cost of HEFA fuel requires comprehensively considering the long-term trends of key factors such as capital expenditure, operating costs, raw materials, and hydrogen. First, as technology becomes increasingly mature and the scale of factory construction expands, capital expenditure is expected to gradually decrease at an annual rate of approximately 0.85%. Operating costs are also expected to decrease at an annual rate of approximately 0.58%, mainly due to the promotion of automated operation and maintenance technology and the amortization of unit labor and energy costs brought about by increased production capacity. In terms of raw material costs, the price of major oil resources is expected to rise slightly at an annual rate of approximately 0.1%, reflecting relatively stable supply.

The future cost trend of hydrogen, an indispensable hydrogenation raw material in HEFA production, is particularly crucial. According to TÜV Rhineland's White Paper on the Entire Industrial Chain of Hydrogen Energy and Fuel Cells in China (2024), it is expected that by 2050, the proportion of green hydrogen produced by electrolysis using renewable energy in China will reach 70%. At the same time, the cost of hydrogen production will decrease accordingly. The forecast of China's hydrogen production cost trend shows that the cost of hydrogen production from 2021 to 2025 is 20 RMB/kg, from 2026 to 2030 it is 15 RMB/kg, from 2030 to 2035 it is 12 RMB/kg, and after 2040, the cost of green hydrogen will drop to below 10 RMB/kg. Based on the corresponding market hydrogen price of 34 RMB/kg in 2025, this report forecasts that the hydrogen price from 2026 to 2030 will be 25.5 RMB/kg, from 2030 to 2035 it will be 20.4 RMB/kg, and after 2040, the hydrogen price will be 17 RMB/kg.

67. World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2020. https://www.weforum.org/publications/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation/

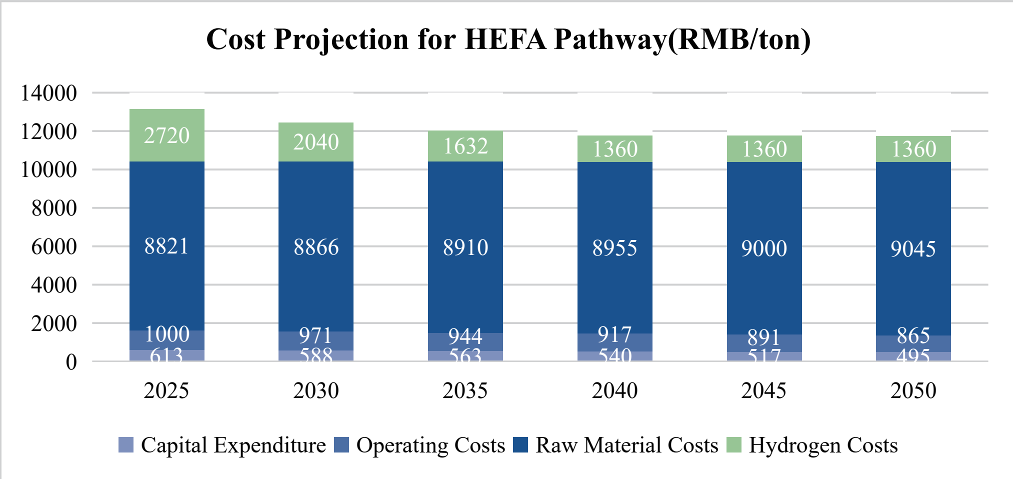

Figure 1 Cost Projection for HEFA Pathway (2025-2050)

Figure 1 shows that the unit total cost of HEFA first decreases and then stabilizes. Among them, the significant decrease in hydrogen cost is a key factor driving the reduction in total cost. It drops significantly from 2,720 RMB/ton in 2025 to 1,632 RMB/ton in 2035, and then stabilizes at 1,360 RMB/ton, with a cumulative decrease of 50.0% by 2050. At the same time, capital expenditure and operating costs also show a continuous downward trend. However, it is worth noting that the raw material cost shows a slight upward trend during this period, which partially offsets the reduction in other costs. Overall, the total cost of HEFA decreases from 13,155 RMB/ton in 2025 to 11,771 RMB/ton between 2025 and 2040, and then basically stabilizes at around 11,765 RMB/ton by 2050. Compared with 2025, the total cost in 2050 decreases by 10.6%, indicating that although there are driving forces for cost reduction, the overall decrease is limited by the increase in raw material costs.

2.AtJ

When forecasting the production cost of AtJ fuel, technological progress and scale effects will be the main driving factors. Based on industry development trends, the following assumptions are made for key cost items: in terms of capital expenditure, a significant decrease is expected between 2025 and 2030, with an annual decrease rate of 4.2%. This is mainly due to the rapid iteration of technology and continuous optimization of equipment in the early stage of project construction. After 2030, as technology becomes mature, the decrease rate will slow down, with an annual decrease of approximately 1%. Operating costs will maintain a stable downward trend throughout the forecast period, with an annual decrease rate of 0.8%. This improvement mainly comes from the continuous optimization of production processes and the continuous improvement of automation levels. In terms of raw material costs, the procurement price of ethanol, the main raw material, is expected to decrease at an annual rate of 1%. This is mainly due to the continuous expansion of ethanol production capacity, progress in production technology, and the overall improvement of upstream supply chain efficiency. It is worth noting that the conversion efficiency of the AtJ process will remain stable at the 2025 level of 0.48.

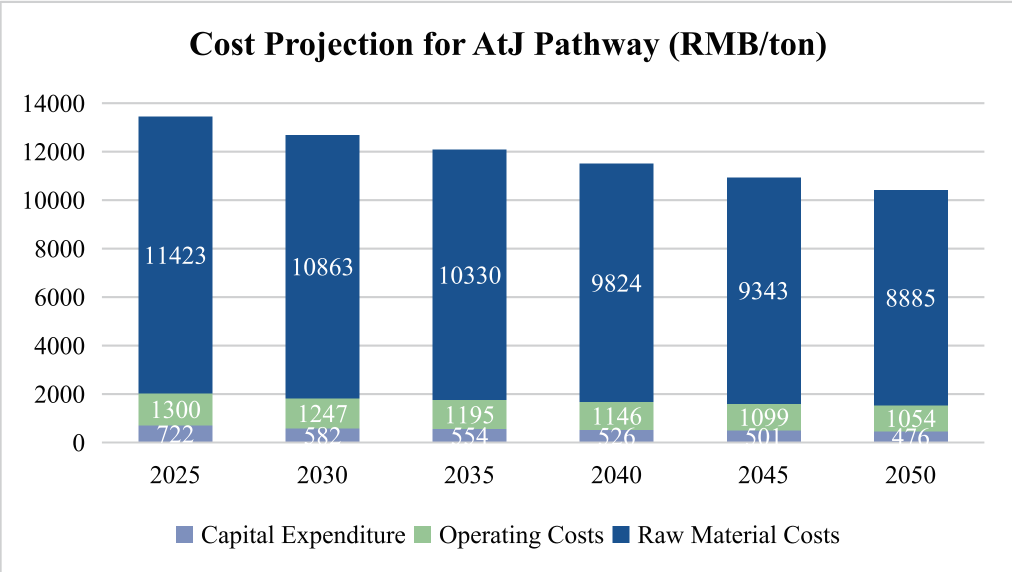

Figure 2 Cost Projection for AtJ Pathway (2025-2050)

Figure 2 shows that the unit total cost of China's AtJ shows a significant downward trend from 2025 to 2050. During this period, the reduction in raw material costs is the main driving force for the decrease in total cost, dropping significantly from 11,423 RMB/ton in 2025 to 8,885 RMB/ton in 2050, with a cumulative decrease of 22.2%. At the same time, capital expenditure also shows a significant decrease, decreasing by 34.1% in 2050 compared with 2025, from 722 RMB/ton to 476 RMB/ton, reflecting the improvement in the efficiency of fixed asset investment brought about by technological progress and scale effects. Operating costs also show a steady annual downward trend, decreasing from 1,300 RMB/ton to 1,054 RMB/ton, with a cumulative decrease of approximately 18.9%, reflecting the continuous optimization of operating efficiency. It is worth noting that the conversion efficiency of AtJ remains stable at 0.48 during this period. Combining these factors, the unit total cost of AtJ decreases significantly from 13,445 RMB/ton in 2025 to 10,415 RMB/ton in 2050, with a total decrease of 22.5% and an average annual decrease of approximately 0.90%, indicating that the production cost of AtJ will continue to be optimized over the next 25 years.

3.G+FT

The following assumptions are made regarding the trends in capital, operating, and raw material costs. Capital expenditure is expected to decrease at a compound annual rate of 4%

between 2025 and 2030, reflecting the optimization of initial technology and the improvement of infrastructure construction efficiency; from 2030 to 2050, it will slow down to a compound annual decrease of 1%, reflecting the cost stability in the mature stage. Operating costs are assumed to decrease slowly at an annual rate of 0.3%, benefiting from the optimization of operation management and the improvement of equipment efficiency. Biomass, as the main raw material, will see a continuous increase in its cost, reaching 318 RMB/ton, 484 RMB/ton, 643 RMB/ton, 723 RMB/ton, and 803 RMB/ton in 2030, 2035, 2040, 2045, and 2050 respectively.

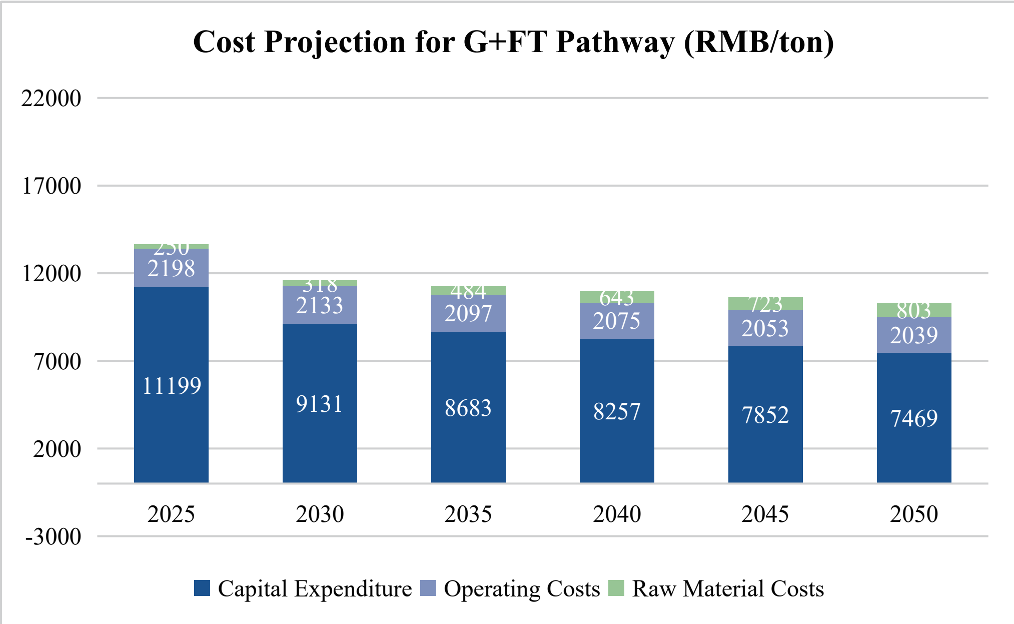

Figure 3 Cost Projection for G+FT Pathway (2025-2050)

Figure 3 shows that the reduction in capital expenditure and operating costs is the main driving force for the decrease in total cost. Specifically, capital expenditure decreases by approximately 33.31% in 2050 compared with 2025, from 11,199 RMB/ton to 7,469 RMB/ton, which is an important contributor to the decrease in total cost. Operating costs also achieve a steady decrease, decreasing from 2,198 RMB/ton in 2025 to 2,039 RMB/ton in 2050, with a cumulative decrease of 7.24%. Raw material costs show an upward trend, increasing from 250 RMB/ton in 2025 to 803 RMB/ton in 2050, with an increase of 220.7%. Affected by the comprehensive changes in various costs, the total cost of G+FT decreases from 13,647 RMB/ton in 2025 to 10,310 RMB/ton in 2050, with a cumulative decrease of 24.45% and an average annual decrease of approximately 0.98%.

4.PtL

The forecast of the production cost of PtL fuel in this article is based on the following key assumptions: in terms of capital expenditure, with the continuous maturity of technology and the advancement of large-scale production, the investment efficiency is expected to gradually improve, with an average annual decrease of 2.97% in capital expenditure. In terms of operating costs, through the continuous optimization of energy efficiency and the improvement of operation and maintenance management, the operating costs are expected to maintain an average annual decrease of 3.44%. In terms of CO_2 costs, benefiting from the progress of carbon capture technology and the improvement of the carbon trading market mechanism, the CO_2 cost is expected to decrease by 0.87% annually, thereby further reducing the overall production cost.

In terms of hydrogen costs, according to TÜV Rhineland's White Paper on the Entire Industrial Chain of Hydrogen Energy and Fuel Cells in China (2024), it is expected that by 2050, the proportion of green hydrogen produced by electrolysis using renewable energy in China will reach 70%. At the same time, the cost of hydrogen production will decrease accordingly. The forecast of China's hydrogen production cost trend shows that the cost of hydrogen production from 2021 to 2025 is 20 RMB/kg, from 2026 to 2030 it is 15 RMB/kg, from 2030 to 2035 it is 12 RMB/kg, and after 2040, the cost of green hydrogen will drop to below 10 RMB/kg. Based on the corresponding market hydrogen price of 34 RMB/kg in 2025, this report forecasts that the hydrogen price from 2026 to 2030 will be 25.5 RMB/kg, from 2030 to 2035 it will be 20.4 RMB/kg, and after 2040, the hydrogen price will be 17 RMB/kg.

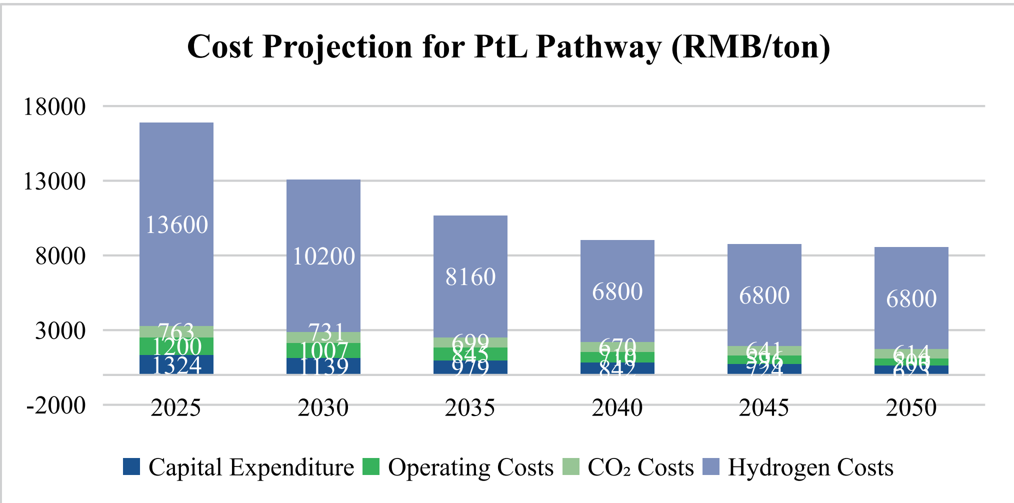

Figure 4 Cost Projection for PtL Pathway (2025-2050)

As shown in Figure 4, from 2025 to 2050, the decrease in hydrogen cost is the dominant factor driving the reduction in the total cost of PtL, dropping significantly from 13,600 RMB/ton in 2025 to 6,800 RMB/ton in 2050, with a decrease of 50%. In addition, both capital expenditure and operating costs also show significant decreases: capital expenditure decreases by approximately 53% over 25 years, from 1,324 RMB/ton to 623 RMB/ton; operating costs decrease from 1,200 RMB/ton to 500 RMB/ton, with a cumulative decrease of approximately 58.3%. The CO_2 cost decreases slightly, from 763 RMB/ton in 2025 to 614 RMB/ton in 2050, with a decrease of approximately 19.6%. Combining the changes in various costs, the total cost of PtL decreases from 16,887 RMB/ton in 2025 to 8,536 RMB/ton in 2050, with a cumulative decrease of 49.45% and an average annual decrease of approximately 1.98%. This means that with technological progress and scale effects, the production cost of PtL is expected to be significantly optimized over the next 25 years.

5.MtJ

The forecast of the production cost of MtJ fuel in this article is based on the following key assumptions: in terms of capital expenditure, it is expected to decrease by an average of 4.22% annually between 2025 and 2030, mainly due to technological improvements and scale effects; after 2030, the decrease rate will narrow to an average of 1% annually, reflecting the stable trend after technological maturity. Operating costs are expected to decrease by 0.83% annually, benefiting from continuous process optimization. The cost of methanol raw materials will decrease by 1.5% annually, which is closely related to capacity expansion and supply chain maturity. The methanol conversion efficiency will remain stable at the 2025 level of 0.35.

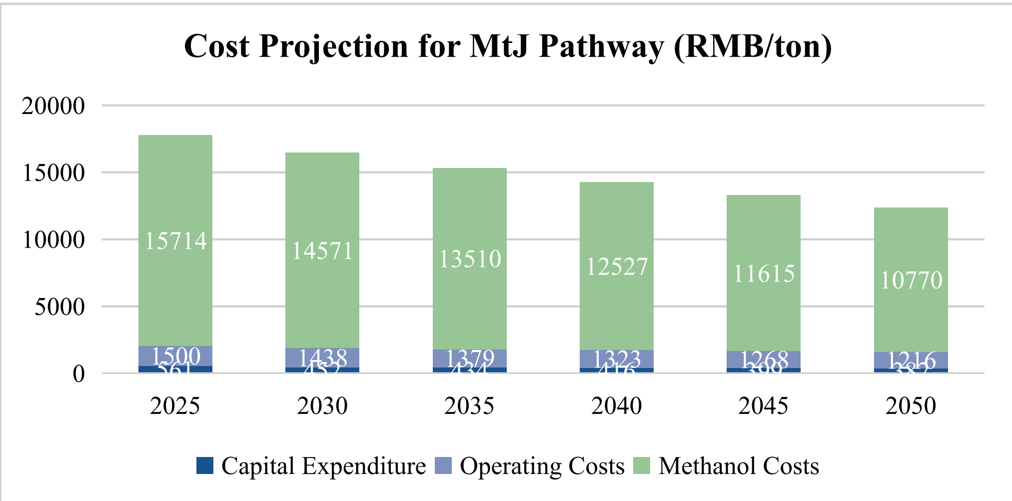

Figure 5 Cost Projection for MtJ Pathway (2025-2050)

As shown in Figure 5, from 2025 to 2050, the total cost of MtJ shows a continuous downward trend. Among them, the reduction in methanol costs is the main driving force for the decrease in total cost, dropping significantly from 15,714 RMB/ton in 2025 to 10,770 RMB/ton in 2050, with a cumulative decrease of 31.5%. At the same time, capital expenditure also shows a significant decrease, decreasing by approximately 31.8% in 2050 compared with 2025, from 561 RMB/ton to 382 RMB/ton. Operating costs also show a steady downward trend, decreasing from 1,500 RMB/ton to 1,216 RMB/ton, with a cumulative decrease of approximately 18.9%. Combining the continuous optimization of various costs, the total cost of MtJ decreases from 17,775 RMB/ton in 2025 to 12,368 RMB/ton in 2050, with a cumulative decrease of 30.4% and an average annual decrease of approximately 1.2%.

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